Harmonization of biomass resource assessments

Volume I

Best Practices and Methods Handbook

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<td>EFI - European Forest Institute</td>
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<td>SEC Biomass - Scientific Engineering Centre “Biomass”</td>
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<td>BEE</td>
<td>Biomass Energy Europe</td>
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<td>BMW</td>
<td>Biodegradable Municipal Waste</td>
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<tr>
<td>CAP</td>
<td>Common Agricultural Policy</td>
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<tr>
<td>CAPSIM</td>
<td>Common Agricultural Policy SIMulation model</td>
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<tr>
<td>CEEC</td>
<td>Central and Eastern European Countries</td>
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<tr>
<td>CEOS</td>
<td>Committee on Earth Observation Satellites</td>
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<tr>
<td>CLC</td>
<td>CORINE Land Cover</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide emission (a greenhouse gas)</td>
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<td>CORINE</td>
<td>Coordination of Information on the Environment</td>
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<tr>
<td>DBH</td>
<td>Diameter at Breast Height</td>
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<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
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<tr>
<td>DM</td>
<td>Dry matter</td>
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<td>DOM</td>
<td>Dry Organic Matter</td>
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<td>DSM</td>
<td>Digital Surface Model</td>
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<td>DTM</td>
<td>Digital Terrain Model</td>
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<td>European Commission</td>
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<td>European Environment Agency</td>
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<td>Earth Observation</td>
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<td>Statistical institute of the EU</td>
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<td>Food and Agriculture Organisation of the United Nations</td>
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<td>FAOSTAT</td>
<td>Statistical institute of the FAO</td>
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<td>FOD</td>
<td>First Order Degradation (model)</td>
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<td>FP7</td>
<td>The Seventh Framework Programme of the European Union for the funding of research and technological development in Europe</td>
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<td>GEO</td>
<td>Group on Earth Observations</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>GLC2000</td>
<td>Global Land Cover 2000</td>
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<td>GMES</td>
<td>Global Monitoring for Environment and Security</td>
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<td>GSD</td>
<td>Ground Sampling Distance</td>
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<td>Ha</td>
<td>Hectare</td>
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<td>HCV</td>
<td>High Conservation Value</td>
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<td>Higher Heating Value</td>
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<td>Integrated Assessment Model</td>
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<td>IGOL</td>
<td>Integrated Global Observation of Land</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>KNN</td>
<td>K nearest neighbours</td>
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<td>Abbreviation</td>
<td>Description</td>
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<td>LAI</td>
<td>Leaf Area Index</td>
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<td>LFG</td>
<td>Landfill gas</td>
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<tr>
<td>LHV</td>
<td>Lower heating value (also: net caloric value)</td>
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<td>LIDAR</td>
<td>Light detection and ranging</td>
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<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
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<tr>
<td>Mtoe</td>
<td>Million tonnes of oil equivalent</td>
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<td>nDSM</td>
<td>normalized DSM</td>
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<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
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<td>NLCD</td>
<td>National Land Cover Database</td>
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<td>NUTS</td>
<td>Nomenclature of Territorial Units for Statistics</td>
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<td>ODT</td>
<td>Oven Dry Tonne</td>
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<td>PEEP</td>
<td>Perspectives on European Energy Pathways (model)</td>
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<td>Radar</td>
<td>Radio detection and ranging</td>
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<td>Renewable Energy Sources</td>
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<td>RS</td>
<td>Remote Sensing</td>
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<td>SAR</td>
<td>Secondary Agricultural Residue</td>
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<td>SRC</td>
<td>Short rotation coppice</td>
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<td>SRES</td>
<td>Special Report on Emission Scenarios</td>
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<td>SWDS</td>
<td>Solid Waste Disposal Site</td>
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<tr>
<td>tce</td>
<td>Tonnes of coal equivalent</td>
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<tr>
<td>toe</td>
<td>Tonnes of oil equivalent</td>
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<tr>
<td>TOF</td>
<td>Trees Outside Forests</td>
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<tr>
<td>WP</td>
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<td>Gigagram (1000 kg)</td>
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<td>GJ</td>
<td>GigaJoule</td>
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1 Introduction

Existing biomass resource assessments use a broad variety of approaches, methodologies, assumptions and datasets that lead to different estimates of future biomass potentials. The overall objective of the Biomass Energy Europe (BEE) project is to improve the accuracy and comparability of future biomass resource assessments for energy by reducing heterogeneity of terms and definitions, increasing harmonisation of data and calculations and exchanging knowledge on methods and approaches.

1.1 Purpose and scope

This handbook has the purpose to promote harmonisation in the development of biomass resource assessments. It provides best practice methods for determination of biomass resource potentials, and gives guidance for transparent presentation of results by providing terms and definitions needed for the execution and presentation of biomass resource assessments.

Methods are provided for four categories of biomass types: (1) forest biomass, (2) energy crops, (3) agricultural residues and (4) organic waste. Furthermore, five types of methods are identified: statistical methods, spatially explicit methods, cost-supply methods, energy-economics and energy system model methods, and integrated assessments. For each of the before-mentioned biomass types, the handbook shows how these methods can be applied. Furthermore, the handbook provides a detailed overview of sustainability aspects that can be implemented in future biomass assessments.

The handbook will focus on methods that can be applied to national and European level biomass resource assessments. If data source availability allows it, the methods can be used at a more local level and outside Europe as well.

1.2 Target group

The target group consists of both the groups that prepare biomass resource assessments, like researchers and consultants, as well as their sponsors and clients that will use the results for policy making and business purposes. The methods handbook presents a variety of biomass assessments that could be used, from simple statistical approaches to advanced spatially explicit methods and more. Each method has its own merits and costs. The methods handbook seeks to provide guidance to policy makers and companies that need to specify their need for biomass resource assessments. In parallel it serves scientists and consultants in providing detailed descriptions of methods and a large selection of useful data sources for the performance of biomass resource assessments.

1.3 How to use this handbook

The handbook has multiple functions:

- The handbook can be used as a reference work on the use of terminology in the field of bioenergy resource assessments.
- The handbook provides an overview of best practice methods in the range of relatively straightforward resource-focused biomass assessments to complex integrated assessments.
- The handbook presents a detailed overview of sustainability themes, criteria and parameters that are relevant for biomass resource assessments, and shows how they can be implemented in future biomass resource assessments.
The following guidance is given on the use of this handbook:

- Chapter 2 presents the general approach of the handbook, introducing a classification of biomass types and biomass potentials, and an overview of the approaches and methods as used in this handbook.

- Biomass types are clearly divided into four categories: forestry, energy crops, agricultural residues and wastes. The methods related to these biomass categories are presented in chapters 3 to 6. This way the reader can easily switch to the methods related to the biomass types he/she is interested in. Within these chapters, generally, a further division of biomass types can be found. For instance, forest biomass can be divided in stemwood, primary forestry residues (that originate from wood harvesting) and secondary forestry residues (that originate from wood processing).

- For most biomass types the following assessment methods are described:
  - basic statistical method
  - advanced statistical method
  - basic spatially explicit method
  - advanced spatially explicit method
  - cost-supply method.

  For each biomass type, these methods are presented in separate sections which can be identified easily using the table of contents of this handbook. Each section has the same format, showing the method, data sources, remarks, advantages, disadvantages, information for estimation of future biomass potentials, sustainability aspects, key uncertainties and future research needs.

- The statistical method can be applied using statistical data only, which are usually available on national level. The spatially explicit method allows presentation of the geographic location of the biomass, at least on a regional level and often at a more detailed level.

- The direct use of remote sensing data or the use of remote sensing data derived products is necessary for spatially explicit assessments; this is shown in the sections on spatially explicit methods and is presented as a cross-sectorial issue in Annex 1.

- A distinction is made between basic methods that allow a quick estimation of biomass availability with a minimum of effort, and advanced methods that allow a more accurate but often more time-consuming estimation of biomass availability. It is recognised that both types of methods have their own merits; the selection of methods will depend on factors like the purpose of the biomass resource assessment and the time and/or financial means available. For some types of biomass the distinction between basic and advanced methods is not relevant and therefore omitted.

- The cost-supply method shows how biomass availability for energy or other purposes depends on the costs to make the biomass available. Its shows the economic/implementation potential rather than the theoretical/technical potential that is determined using the statistical and spatially explicit methods.

- Some biomass resource assessments aim to cover biomass availability in all sectors. The use of total resource assessments gives opportunity to avoid double counting and to study the interaction of biomass availability between sectors. The total resource assessments are presented as a cross-sectorial issue in Annex 1.

- The presented methods are closely linked with data sources available on European level. In this methods handbook the data sources are briefly introduced, while in the accompanying data sources handbook detailed descriptions of the used data sources can be found.

- The use of sustainability criteria for the production and use of biomass is a recent development promoted by increased environmental awareness and European and national legislation. Chapter 8 shows an overview of the political framework and a detailed set of sustainability themes, principles, criteria and parameters that could be taken into account in biomass resource assessments.

- Furthermore, chapter 8 and its accompanying annexes show to what degree the different sustainability parameters can actually be implemented in different types of biomass resource assessment methods. For instance, exclusion of Natura2000 areas requires the use of a spatially explicit method, and cannot be (easily) implemented using a statistical method.

1.4 Best practise guidelines

Based on the analysis of existing biomass resource assessments, the following best practise guidelines for the performance of biomass resource assessment have been developed:

- Describe clearly what biomass types are included in the biomass resource assessment (for suggested terminology, see section 2.1 and the first section of chapters 3 to 7).
- Indicate what type of resource potential is assessed (e.g. theoretical, technical, economic or implementation potential; see section 2.2).
- Describe the general approach (resource focused, demand driven or integrated approach) and the type of method that is used. (e.g. statistical, spatially explicit; see section 2.3).
- Describe the method followed including its main advantages and disadvantages, and indicate which sustainability criteria have been included.
- Provide detailed insight into the datasources used and pay special attention to the use of conversion units, including those for conversion from cubic meters and metric tonnes toward energy values (e.g. explicitly show which LHV values and densities have been used).
- Describe the timeframe of the resource assessment and how extrapolation to future biomass potentials has been carried out.
- Provide results not only in graphs, but also in (annexes with) detailed tables.
- Provide detailed results on country level in biomass resource assessments covering the EU.

1.5 Acknowledgements

The Best Practices and Methods Handbook and the Data Sources Handbook have been produced as part of the Biomass Energy Europe project, which is supported by the European Commission under the 7th Framework Programme (FP7) and coordinated by the Albert Ludwig-Universität Freiburg. The Best Practices and Methods Handbook (“Methods Handbook”) and Data Sources Handbook form the two main deliverables (D5.1 and D5.2) of Work Package 5 ‘Harmonisation of biomass resource assessments’ of the BEE-project. BTG Biomass Technology Group B.V. is work package leader of this work package. All BEE project participants have contributed parts to the different chapters of the Methods Handbook and Data Sources Handbooks. Below, the organisations responsible for the different chapters of the Methods Handbook are listed.

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<thead>
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<th>Responsible organisation</th>
<th>Contact person</th>
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We would like to thank those who have participated in the external review of the Methods Handbook, in particular the European Commission, Ökoinstitut, European Topic Centre on Sustainable Consumption and Production, and Deutsches BiomasseForschungsZentrum. Ms. A. Abbink (ahavertalingen@live.nl) has performed a final linguistic check of both Handbooks.
2 General approach

This chapter contains a general classification of biomass types, types of biomass potentials and types of biomass resource assessments that is applied throughout the handbook. Furthermore, a number of relevant issues like the timeframe of biomass resource assessments, current use of biomass and bioenergy, the geographical coverage of used methods, and the use of units and conversion factors are introduced in separate subsections.

2.1 Types of biomass

Biomass can be defined as ‘the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste’ (2001/77/EC 2001).

In this handbook, the different biomass types are divided into four biomass categories:
- Forest biomass and forestry residues
- Energy crops
- Agricultural residues
- Organic waste.

Forest biomass

In the context of bioenergy, forest biomass includes several types of raw woody materials derived from forests or from processing of timber that can be used for energy generation:
- Stemwood: biomass from pre-commercial and commercial thinnings and final fellings, available for energy production, including whole trees and delimbed stemwood from pre-commercial thinnings.
- Primary forestry residues: logging residues, stumps.
- Secondary forestry residues: wood processing industry by-products and residues, like sawdust & cutter chips, bark, slabs, lump wood residues, and black liquor.
- Woody biomass from short rotation plantations on forest lands.
- Trees outside of forests such as trees in settlement areas, along roads and on other infrastructural areas.

The following woody biomass types are not included as ‘forest biomass and forestry residues’:
- Woody biomass from non forest areas:
  - Short rotation coppice on agricultural and marginal land, these are covered in the energy crops chapter (chapter 4).
  - Orchards and vineyards on agricultural lands.
- Tertiary residues: recovered wood (old furniture, wood used in construction etc.), these are considered in chapter 6 on organic waste.

Energy crops

Five main types of energy crops can be distinguished, and are further classified as annual (a) and perennial (p) crops:
- Oil containing crops: like sunflower (a), rape (a), soy (a), oil palm (p), and jatropha (p).
- Sugar crops: like sugar cane (p), sugar beet (a), and sweet sorghum (a).
- Starch crops: like corn (a), wheat (a), barley (a), and cassava (a).
- Woody crops: like poplar (p), and eucalyptus (p).
- Grassy crops: like miscanthus (p), and switchgrass (p).

Part of the woody energy crops can also be considered as ‘forest biomass’. The following distinction is made: Short rotation coppice (SRC) production systems are included as energy crops, while short rotation forestry (SRF) production systems are included as forest biomass. In an SRC plantation the
trees are planted in much higher densities compared to an SRF system. After harvesting, an SRF needs to be replanted, while an SRC crop will regenerate as new growth emerges from the original stools (stumps).

**Agricultural residues**

Agricultural residues are the by-products of agricultural practice. A distinction is made between primary or harvest residues (like straw) that are produced in the fields and secondary residues from the processing of the harvested product (like bagasse, rice husks) that are produced at a processing facility. Manure is included as a separate category. By-products from further processing of agricultural products like molasses, vinasse, etc. are not included. They are regarded as residues from the food industry.

**Organic waste**

Organic waste includes biodegradable waste from households, industry and trade activities. The waste fractions covered in this handbook include biodegradable municipal waste, construction and demolition wood, and sewage sludge. Biogas from sewage treatment plants as well as landfill gas are also included in the handbook as energy carriers from organic waste.

Table 1 shows examples of biomass types that are covered in this handbook. A detailed description of each biomass type can be found in the introduction of each chapter that covers its biomass potential.

<table>
<thead>
<tr>
<th>Table 1 Biomass types covered in the handbook</th>
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<tbody>
<tr>
<td><strong>Main type</strong></td>
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<tr>
<td>Forestry</td>
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<tr>
<td>Energy crops</td>
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<td>Agricultural residues</td>
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<td></td>
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<tr>
<td>Organic waste</td>
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</tbody>
</table>

For practical reasons this Methods Handbook does not cover all possible biomass types. For instance, aquatic biomass (algae, seaweed, etc.) is not covered in this handbook, because the potential of this type of biomass is highly uncertain and data availability is scarce. Residues from the food industry are also not covered because they consist of a large variety of different biomass types (over 100), for which hardly any national or international resource assessment has been carried out so far. Peat is also excluded, since peat is not a renewable type of biomass within the timeframes relevant for climate and energy policies.
2.2 Types of biomass potentials

The type of biomass potential is an important parameter in biomass resource assessments, because it determines to a large extent the approach and methodology and thereby also the data requirements. Four types of biomass potentials are commonly distinguished:

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

Moreover, the concept of a fifth type of potential, ‘the sustainable implementation potential’, is introduced in this section.

Theoretical potential
The theoretical potential is the overall maximum amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits. The theoretical potential is usually expressed in joule primary energy, i.e. the energy contained in the raw, unprocessed biomass. Primary energy is converted into secondary energy, such as electricity and liquid and gaseous fuels. In the case of biomass from crops and forests, the theoretical potential represents the maximum productivity under theoretically optimal management taking into account limitations that result from soil, temperature, solar radiation and rainfall. In the case of residues and waste, the theoretical potentials equal the total amount that is produced.

Technical potential
The technical potential is the fraction of the theoretical potential which is available under the regarded techno-structural framework conditions with the current technological possibilities (such as harvesting techniques, infrastructure and accessibility, processing techniques). It also takes into account spatial confinements due to other land uses (food, feed and fibre production) as well as ecological (e.g. nature...
reserves) and possibly other non-technical constraints. The technical potential is usually expressed in joule primary energy, but sometimes also in secondary energy carriers.

**Economic potential**
The economic potential is the share of the technical potential which meets criteria of economic profitability within the given framework conditions. The economic potential generally refers to secondary bioenergy carriers, although sometimes also primary bioenergy is considered.

**Implementation potential**
The implementation potential is the fraction of the economic potential that can be implemented within a certain time frame and under concrete socio-political framework conditions, including economic, institutional and social constraints and policy incentives. Studies that focus on the feasibility or the economic, environmental or social impacts of bioenergy policies are also included in this type.

The classification in types of biomass potentials helps the reader to understand what information is presented. For instance, some biomass types show high technical potentials while their economic potential is rather limited due to the high costs of extraction and transport. Therefore it is recommended that the type of potential is explicitly mentioned in every biomass resource assessment. In existing resource assessments, it is often difficult to distinguish between theoretical and technical potential and between economic and implementation potential. The technical and theoretical potential and the economic and implementation potential form two pairs of potential types. However, even more important than making this distinction between four types is the provision of insight into explicit conditions and assumptions made in the assessment.

**Sustainable implementation potential**
In theory, a fifth type of potential can be distinguished, which is the sustainable implementation potential. It is not a potential on its own but rather the result of integrating environmental, economic and social sustainability criteria in biomass resource assessments. This means that sustainability criteria act like a filter on the theoretical, technical, economic and implementation potentials leading in the end to a sustainable implementation potential. Depending on the type of potential, sustainability criteria can be applied to different extents. For example, for deriving the technical potential, mainly environmental constraints and criteria are integrated that either limit the area available and/or the yield that can be achieved. Applying economic constraints and criteria leads to the economic potential and for the sustainable implementation potential, additional environmental, economic and social criteria may be integrated (see Figure 2).

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![Figure 2 The integration of sustainability criteria in biomass potential assessments](image)

There is a strong demand for inclusion of sustainability aspects in bioenergy potential. Especially after bioenergy in general and biofuels in particular have lost some of their good reputation due to the food versus fuel debate and due to an increased awareness of land use changes, both industry and politics strive for more sustainable practises. The concept of sustainable biomass contains multiple
environmental, economic and social aspects, though integrating these aspects may be complex. An overview of sustainability aspects that can be included in biomass resource assessments as well as relevant approaches and methods are presented in chapter 8, Annex 2 and Annex 3.

2.3 General approach to biomass resource assessments

Methodologies to assess biomass resources (further referred to as ‘methods’) generally use one of the following three main approaches: the resource focused approach, the demand driven approach, or the integrated approach. The general approach determines to a large extent the methodology that is used and in turn, the methodology determines to a large extent the data that are used.

![Resource focused and Demand driven](image)

**Figure 3 The classification ‘demand-driven’ and ‘resource-focused’ that is used in this study**  
**Source:** (Berndes et al. 2003)

2.3.1 Resource-focused approach

In the resource-focused approach, the bioenergy resource and the competition between different uses of the resources are investigated, i.e. the focus is on the supply of biomass for bioenergy. Resource-focused assessments typically estimate the theoretical or technical potential to produce biomass for energy, thereby usually taking into account the demand for land for food production and biomass needed for the production of food and materials. Sometimes also environmental limitations or economic criteria are included; for instance costs of stump extraction can be far too high to be seriously considered, and areas needed for the protection of biodiversity are often included as important limitation for the production of biomass energy.

Within the resource-focused approach *statistical* and *spatially explicit* methods can be distinguished.

**Statistical methods**  
Statistical methods make use of data from statistics on land use, crop yields, crop production and from forest inventories and literature. The statistical data is combined with conversion factors, like yields per ha, residue to crop factors, etc. These factors are based on expert judgement, field studies or literature review. In addition, further assumptions are made on the fraction of biomass available for energy production, taking into account biomass or land needed for other purposes.
**Spatially explicit methods**
Spatially explicit methods present data on biomass availability in a location specific, two dimensional way, for instance on maps. This makes it possible to take into account various location specific factors that affect biomass availability. Spatially explicit methods include area specific data on the availability and accessibility of agricultural land and forests in combination with calculations of the yields of energy crops and forests, based on growth models that use spatially explicit data on e.g. climate, soil type, vegetation type, and management. When statistic data are available at a detailed level (e.g. regional or municipal level), results from statistical assessments can be presented in a spatially explicit way.

### 2.3.2 Demand-driven approach

In the demand-driven approach, the competitiveness of biomass-based energy systems is compared with conventional fossil fuel based energy systems, other renewable energy systems and/or nuclear options. Alternatively, the production and use of biomass required to meet exogenous targets on bioenergy are estimated, i.e. the focus is on the biomass energy demand side. Thus, demand-driven studies typically focus on economic and implementation potentials, more than on the theoretical and technical potentials. However, some studies start with an evaluation of the feasibility of the projected use of bioenergy, by reference to other studies or by estimating the technical biomass potential.

Within the demand-driven approach, **cost supply methods** and **energy and/or economic modelling methods** can be distinguished.

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

The transportation of biomass can be a crucial factor for the economic performance. Some studies investigate this by taking into account spatially explicit data on the availability of biomass for energy, combined with data on the costs of transportation and the location of the facilities where the biomass will be converted into bioenergy. Spatially explicit data and analysis are crucial for the optimisation of biomass production chains.

**Energy and/or economic modelling methods**
Several demand driven assessments use energy-economics and energy-system models. Other (agricultural) economic models are also sometimes applied. Energy-economics and energy-system models mimic the dynamics of the demand and supply of energy, including bioenergy, by means of investigating economic and non-economic correlations.

Most energy-economics and energy-system models use scenarios, whereby typical scenario variables include the fundamental drivers of energy demand and supply, such as population growth and income growth, as well as technological developments and policy incentives. These variables are often integrated into a coherent set of scenario assumptions. Some models also include greenhouse gas and energy balances for different energy systems, which allows for the optimisation of costs towards greenhouse gas reduction or energy security targets.

An ideal agricultural economic model takes into account the effects on prices, production and markets of other crops. This allows a comparison of the net-returns of alternative options a land owner can choose from. The competition with other biomass (food, feed, timber, pulp and paper) and energy...
markets (gas, coal, oil, etc.) - determining the output prices of competing markets and products - is decisive for the economic viability of bioenergy options.

### 2.3.3 Integrated approach

In the integrated approach integrated assessment models (IAMs) are used. IAMs in the field of energy include mathematical correlations between the socio-economic drivers of economic activity and energy use. Energy output is associated with emissions and other pressure on environmental factors that might again have a feedback on productivity and supply of energy. In that way, IAMs combine information from different sectors (economic, energy, land use and climate) across various time and spatial scales. IAMs are particularly useful for the purpose of addressing policy questions, mostly by means of scenario analysis. These aspects are not all necessarily included in all IAM-biomass potential assessments, but a clear difference with other approaches/methods is that the various aspects and dimensions of bioenergy are included in an integrated manner, e.g. by combining results from different models.

IAMs are typically applied to aggregated world or continental regions or countries, depending on the resolution of data.

### 2.3.4 Overview of approaches and methods

An overview of the different combinations of approaches and methodologies to assess biomass resources (methods), and the resulting type of biomass potential is presented in Table 2.

<table>
<thead>
<tr>
<th>General approach</th>
<th>General methodology</th>
<th>Type of biomass potential</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Theoretical-technical biomass potentials</td>
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<tr>
<td></td>
<td></td>
<td>Economic-implementation biomass potentials</td>
</tr>
<tr>
<td>Resource-focused</td>
<td>Statistical methods</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Resource-focused</td>
<td>Spatially explicit methods</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Resource-focused</td>
<td>Cost-supply methods</td>
<td>No</td>
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<tr>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Demand-driven</td>
<td>Energy-economics and energy-system model</td>
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</tr>
<tr>
<td></td>
<td>methods</td>
<td>Yes</td>
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<td>(a)</td>
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<td></td>
<td>Integrated assessment model methods</td>
<td>Yes (a)</td>
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<td></td>
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</table>

* Often demand-driven cost-supply analyses start with a statistical analysis or spatially explicit analysis of technical biomass energy potentials, although this is not the key focus of these studies.
* Some demand-driven energy-economics and energy-system model analysis use the results of cost-supply analysis.
* Integrated assessments typically focus on the economic and/or implementation potential, although IAMs are also used for the theoretical and/or technical biomass energy potential.

Based on this classification of approaches, the Methods Handbook contains best practice guidance on the following methods:

- (Resource-focused) statistical methods
- (Resource-focused) spatially explicit methods
- (Demand-driven) cost-supply methods
- (Demand driven) energy and/or economic modelling methods
- Integrated assessments

The methods are presented in separate sections for each relevant type of biomass. This way each method can be found easily using the table of contents of this Handbook.
### 2.4 Basic and advanced biomass resource assessments

The degree of detail, accuracy and comparability of biomass resource assessments that can be achieved depends on the applied methods, but also on the available budget and time requirements. Depending on the wishes of the client and the purpose of the assignment or research, either a basic or advanced approach is appropriate. Therefore, in the categories *resource-focused statistical methods* and *resource-focused spatially explicit methods* a distinction is made between ‘basic’ and ‘advanced’ methods.

- The basic method provides an estimation of the bioenergy potential with limited effort and with data sources that are easily accessible. The basic method is applicable to all European countries and the use of commonly available data leads to biomass potentials that are comparable between European countries, at least within EU27.

- The advanced method represents best practice, using state of the art methods. Advanced methods generally require more data of a higher quality. The methods are applicable in all European countries, however, it depends on the availability and quality of data sources whether the methods can actually be applied in a specific country. The application of advanced methods will increase the accuracy of the biomass resource assessment on country level.

- The advanced methods could be an extension of the basic method or be based on another (more complex) approach.

For the other types of resource assessments, the demand driven cost-supply methods, demand-driven energy and/or economic modelling methods and integrated assessments, no distinction is made between ‘basic’ and ‘advanced’ methods. In general, these methods can be regarded as advanced.

### 2.5 Timeframe of biomass resource assessments

Biomass resource assessments can show snapshots of biomass potential in the past, present and as it is anticipated in the future, or can provide a more consistent view on the development of the biomass potential on a regular (yearly) base.

Resource-focused statistical and spatially explicit methods are generally focused on the determination of the *current* theoretical and/or technical potential. In fact, the reference years of the used datasets determine the (base) year for which the biomass potential is presented. However, *future* theoretic and technical biomass potentials are often presented as well, based on assumptions on the development of the resource potential, for instance by relating it to economic growth, population size, or any other relevant indicator. In demand-driven cost-supply methods and energy and/or economic modelling methods the time factor is generally already integrated in sets of assumptions called scenarios.

### 2.6 Geographical coverage

All methods discussed in this handbook are basically applicable at any geographic level, as long as sufficiently detailed data are available.

The handbook will focus on methods that can mainly be applied on national and European level biomass resource assessments. However, the presented level of detail of biomass availability can be much higher, especially when using spatially explicit methods. Generally, most methods can be applied outside Europe as well, provided that the needed datasets are available. Part of these methods might be applicable on a sub-national, regional and local level as well. Advanced methods, especially those determining the bioenergy potential of energy crops, use models on a global level since availability of especially energy crops is strongly interlinked with global food production and markets.
2.7 Total resource assessments

Total resource potentials cover the energy potential of biomass available from energy crops, forest biomass and forestry residues, agricultural residues, and organic wastes. Specific attention can be given to competition between and co-benefits from the different types of biomass. Instead of summing up the potentials separately, this approach takes interactions into account (e.g. competition over land). This way, an overestimation due to overlap of different biomass potentials can be avoided, for instance areas used for agricultural land cannot be used for forestry and vice versa.

The statistical and spatially explicit methods for the estimation of total resources will mainly be based on the separate methods presented for forestry, energy crops, agricultural and waste sectors. Total resource assessments provide opportunities especially for demand-driven and integrated assessments, since with these types of assessments, cross-sectoral economic effects can be accounted for in an optimal way. The demand-driven and integrated total resource assessments are presented in chapter 7.

2.8 Sustainability

Sustainable development is generally defined as being a ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED 1987). The concept of sustainability is commonly defined within ecological, social and economic contexts – also referred to as the ‘three pillars’ of sustainability. The three pillars are connected via feedback mechanisms, trade-offs and synergies. Because of the large range of aspects, connections and feedback mechanisms to be considered within different approaches, it is difficult to assess a single ‘sustainable bioenergy potential’. However, since the production and use of biomass for bioenergy purposes affects all dimensions of sustainability, there is a strong demand for inclusion of sustainability aspects in assessments of the different bioenergy potentials.

Based on an extensive research on current regulations, agreements, guidelines and research in the field of sustainability, a set of parameters has been defined that aims to cover sustainability as completely as possible. The following impacts are covered:

- Environmental sustainability
  - Biodiversity
  - Climate change
  - Soil (quality and quantity)
  - Water (quality and quantity)
  - Air quality
  - Resource use
- Social sustainability
  - Competition with the demand for food, feed and fibres
  - Labour conditions
- Economic sustainability
  - Bioenergy costs

Sustainability aspects can be included in biomass potential assessments to different extents depending on the type of potential to be assessed as well as on the method applied. Often, the inclusion of sustainability parameters leads to a decrease of the biomass potential: they either limit the area available (e.g. since protected areas are excluded from bioenergy production) or the yields (e.g. via extensive management methods in sensitive areas).

Within the description of biomass assessment methods for single biomass categories (chapters 3 to 7) basic sustainability aspects are included directly in the methods. Moreover, additional parameters are listed that could be included in order to obtain an even more sustainable potential. In these chapters, the focus is on simply listing relevant parameters. More detailed information can be found in chapter 8, Annex 2 and Annex 3. Chapter 8 provides a description of the theoretical background of
sustainability including the political framework, data gaps and future research needs as well as the whole set of sustainability parameters that could be included in biomass potential assessments. In the annexes, extensive background information is given on all sustainability parameters as well as detailed instruction on how to include them in the various assessment methods.

2.9 Use of units, conversion factors, etc.

The theoretical and technical biomass potentials will be expressed both as its total mass including moisture (tonnes\textsubscript{w}) and as its total net calorific content (PJ).

- Along with the mass, the average moisture content of the biomass will be expressed on a wet basis.
- The lower heating value of the biomass resource will be used to calculate the total net calorific content.
- The theoretical and technical biomass potentials will be expressed on primary energy basis (before conversion into electricity, heat or transport fuels in Joules (mainly PJ, but also TJ, GJ etc, when appropriate).

Economic and implementation potentials will be expressed as secondary energy.

- Electric energy will be expressed in TWh (or MWh, GWh, when appropriate);
- Thermal energy will be expressed in PJ (or GJ, etc);
- Biofuels for transportation purposes will be expressed as primary energy (in PJ, GJ, etc).
Forest biomass

3.1 Scope and definitions

Scope
This chapter describes methods for estimations of potentials of woody biomass derived from forests (further – woody biomass). The described methodology was developed on basis of methods of biomass assessments (e.g. (Asikainen 2008); (Ericsson and Nilsson 2006); analysed in work packages 3 and 4 of the Biomass Energy Europe project (BEE 2008), (BEE 2009). In theory, the methods are applicable also to estimate potentials of woody biomass from other wooded lands and trees outside forests (TOF), but in practice it is often not possible due to very limited data. The methods are based on information about actual or future net annual increment and fellings. Reliable forest statistic data are easily available from public sources, e.g. the Statistic Committee of the European Commission and different studies. On the contrary, availability of statistics on TOF for wide scales (e.g. at international level) is low and the data are often inaccurate due to the methods used in assessments of biomass potentials from TOF (FAO 2002).

In the context of bioenergy, forest biomass includes all kinds of woody raw materials derived from forests or from processing of timber and used for energy generation. Thereby, the term “forest biomass” covers several types of biomass:

- Stemwood: biomass from pre-commercial and commercial thinnings and final fellings, available for energy production, including whole trees and delimbed stemwood from pre-commercial thinnings.
- Primary forestry residues: logging residues, stumps.
- Secondary forestry residues: wood processing industry by-products and residues – sawdust and cutter chips, bark, slabs, lump wood residues, and black liquor.
- Woody biomass from short rotation plantations on forest lands.
- Trees outside of forests such as trees of settlement areas, along roads and on other infrastructural areas.

The following woody biomass types are not included:

- Woody biomass from non forest areas:
  - Short rotation coppice on agricultural and marginal land, these are covered in the energy crops chapter (chapter 4).
  - Orchards and vineyards on agricultural lands.
- Tertiary residues: recovered wood (old furniture, wood used in construction etc.), these are considered in chapter 6 on organic waste.

It should be noted that in contrast to stemwood and the primary forestry residues, which are in most cases domestic resources, the secondary residues can originate from processing of imported timber.

There is a difference between the total potential of wood available as energy source and additional potential of wood for energy. The difference is the volume of woody biomass that is already used as a fuel. This volume of wood cannot be considered as a resource for new bioenergy facilities being established.

The total potential of woody biomass is:

\[ TP_{FWB_{x,y}} = TP_{SW_{x,y}} + TP_{PFR_{x,y}} + TP_{SFR_{x,y}} \] (Equation 3.1.1)

Where:

- \( TP_{FWB_{x,y}} \) = total \( p \)-potential of forest woody biomass in country \( x \) in year \( y \), (m\(^3\)/year)
- \( TP_{SW_{x,y}} \) = potential of stemwood in country \( x \) in year \( y \), (m\(^3\)/year)
When determining the theoretical potential from stemwood for energy use, the amount of wood needed for material use is already deducted, as this constraint is regarded as fundamental in the forestry sector. Thus this theoretical potential can be characterised as a “complementary” theoretical potential from stemwood for energy use. Alternatively, a theoretical potential without such a constraint could also be defined. When determining economic potentials, the constraint to exclude the material use is not made when defining the upper limits of the economic models. At the same time such unconstrained potential can be regarded an overall theoretical potential considering a full implementation of a cascade use after a material use of wood (recycling where appropriate and in the end energy use).

Potentials of woody biomass can be estimated in terms of volume, mass, primary or secondary energy. Conversion factors are used to convert different measurement units (e.g. volume to primary energy). Conversion to alternative measurement units always causes uncertainties in results and should be carried out with attention to many specific aspects, e.g. type of biomass, moisture of wood, tree species, state and type of wood to energy conversion technologies etc. (Hagauer et al. 2008).

All the calculations in the first section of this chapter will use volume units, because most of forest inventory data are presented in terms of volume. The last section (3.6) will then provide information on how to perform the conversion to the energy unit GJ or PJ.

Definitions
Table 3 and Table 4 provide terms and definitions related to forest woody biomass.

<table>
<thead>
<tr>
<th>Biomass type</th>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.</td>
<td>(FAO 2006a)</td>
</tr>
<tr>
<td>Forests available for wood supply (FAWS)</td>
<td>Forest where any legal, economic or specific environmental restrictions do not have a significant impact on the supply of wood. Includes: areas where, although there are no such restrictions, harvesting is not taking place.</td>
<td>(FAO 1999)</td>
</tr>
<tr>
<td>Other wooded land</td>
<td>Land not classified as forest, spanning more than 0.5 hectares; with trees higher than 5 m and a canopy cover of 5–10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.</td>
<td>(FAO 2006a)</td>
</tr>
<tr>
<td>Trees outside forests</td>
<td>Trees outside forests (TOF) are defined by default, as all trees excluded from the definition of forest and other wooded lands. TOF are located on “other lands”, mostly on farmlands and built-up areas, both in rural and urban areas. A large number of TOF consists of planted or domesticated trees. TOF include trees in agroforestry systems, orchards and small woodlots.</td>
<td>(FAO 2000)</td>
</tr>
<tr>
<td>Woody biomass</td>
<td>The mass of the woody parts (wood, bark, branches, twigs, stumps and roots) of trees, alive and dead, shrubs and bushes, measured to a minimum diameter of 0 mm (d.b.h.). Includes: Above-stump woody biomass, and stumps and roots. Excludes: Foliage.</td>
<td></td>
</tr>
<tr>
<td>Stemwood</td>
<td>Part of tree stem from the felling cut to the tree top with the branches removed, including bark.</td>
<td></td>
</tr>
<tr>
<td>Biomass from pre-commercial thinnings</td>
<td>Stems, branches, bark, needles/leafs.</td>
<td></td>
</tr>
<tr>
<td>Logging residues</td>
<td>Woody biomass by-products that are created during harvest of merchantable timber.</td>
<td>(FAO 2004)</td>
</tr>
<tr>
<td>Stumps</td>
<td>Part of the tree stem below the felling cut.</td>
<td>(FAO 2004)</td>
</tr>
</tbody>
</table>
Pre-commercial thinnings | Selective cuttings in young stands, felled trees have no value for wood processing industry.

Commercial thinnings | Selective cuttings in middle age and maturing stands, a part of felled trees have value for wood processing industry, mainly as pulpwood.

Wood processing industry by-products and residues | Woody biomass by-products originating from the wood processing industry as well as the pulp and paper industry. (FAO 2004)

Sawdust | Fine particles created when sawing wood. (FAO 2004)

Cutter chips | Wood chips made as a by-product of the wood processing industry, with or without bark.

Bark | Organic cellular tissue that is formed by taller plants (trees, bushes) on the outside of the growth zone (cambium) as a shell for the wooden body.

Slabs | Parts of woody biomass created when cuts are made into the edges of logs and whereby one side shows the original rounded surface of the tree, either completely or partly, with or without bark. (FAO 2004)

Lump wood residues | Cut-offs created during sawing of timber.

Black liquor | Alkaline spent liquor obtained from digesters in the production of sulphate or soda pulp during the process of paper production, in which the energy content mainly originates from the content of lignin removed from the wood in the pulping process.

Table 4 Other relevant definitions related to forest biomass

<table>
<thead>
<tr>
<th>Item</th>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing volume</td>
<td>Volume of standing trees, living or dead, above-stump measured overbark to top (0 cm). Includes all trees with diameter over 0 cm (d.b.h.). Includes: Tops of stems, large branches; dead trees lying on the ground that can still be used for fibre or fuel. Excludes: Small branches, twigs and foliage.</td>
<td>UNECE/FAO, <a href="http://www.unece.org/timber/fra/definit.htm">http://www.unece.org/timber/fra/definit.htm</a></td>
</tr>
<tr>
<td>Net annual increment</td>
<td>Average annual volume over the given reference period of gross increment less that of natural losses on all trees to a minimum diameter of 0 cm (d.b.h.).</td>
<td>UNECE/FAO, <a href="http://www.unece.org/timber/fra/definit.htm">http://www.unece.org/timber/fra/definit.htm</a></td>
</tr>
<tr>
<td>Industrial wood</td>
<td>Wood, of which quality satisfies quality requirements of the wood processing industry (paper and pulp industry).</td>
<td></td>
</tr>
<tr>
<td>Non-industrial wood</td>
<td>Wood, of which quality does not correspond to quality requirements of the wood processing industry (pulp and paper industry, sawmills, construction).</td>
<td></td>
</tr>
<tr>
<td>Surplus of stem wood</td>
<td>Unutilised part of the net annual increment that can be potentially used for energy in a sustainable way.</td>
<td></td>
</tr>
<tr>
<td>Recovery rate</td>
<td>Ratio of collected biomass to volume of biomass available for collection.</td>
<td></td>
</tr>
<tr>
<td>Biomass expansion factor</td>
<td>Multiplication factor that expands growing stock, or commercial round-wood harvest volume, or growing stock volume increment data, to account for non-merchantable biomass components such as branches, foliage, and non-commercial trees.</td>
<td>(IPCC 2003), Good Practice Guidance for LULUCF - Glossary</td>
</tr>
<tr>
<td>Fuel wood</td>
<td>Stemwood and branches used as a fuel.</td>
<td></td>
</tr>
<tr>
<td>Wood fuel</td>
<td>A fuel made of woody biomass: wood chips, pellets, briquets, chopped wood, etc.</td>
<td></td>
</tr>
</tbody>
</table>

In order to estimate a biomass potential one can choose from three approaches – resource focused, demand-driven and integrated assessment models, and several methods – statistical analysis, spatially

1 Wood chips is chipped woody biomass in the form of pieces with a defined particle size produced by mechanical treatment with sharp tools such as knives. Wood chips have a subrectangular shape with a typical length 5 to 50 mm and a low thickness compared to other dimensions FAO (2004). Unified bioenergy terminology UBET. Wood Energy Programme. Food and agriculture Organization of the United Nations, Forestry Department: 58.
explicit analysis, cost-supply analysis, energy-economics and energy-system model analysis, feasibility and impact analysis and integrated assessment model analysis. Depending on the selected approaches, methods and assumptions, the following biomass potentials can be estimated: theoretical, technical, economic and implementation potentials. Table 5 and Table 6 describe the potentials, the approaches and the methods covered in this section. Table 5 lists assumptions and constraints that can be included in an assessment depending on the target type of biomass potential. Table 6 provides an overview of possible outputs and analytic abilities of different approaches.

Table 5 Assumptions and constraints related to the potentials

<table>
<thead>
<tr>
<th>Possible assumptions and constraints</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theoretical</td>
</tr>
<tr>
<td>Net annual increment</td>
<td>+</td>
</tr>
<tr>
<td>Volume of annual fellings (Maximum sustainable amount for volume of annual fellings)</td>
<td>+</td>
</tr>
<tr>
<td>Logging residue recovery rate</td>
<td>-</td>
</tr>
<tr>
<td>Wood reserved for material use (stemwood of considerable dimension)</td>
<td>-</td>
</tr>
<tr>
<td>Share of mechanisation</td>
<td>-</td>
</tr>
<tr>
<td>Steepness of slopes</td>
<td>-</td>
</tr>
<tr>
<td>Technical accessibility (forest road density, distance to forest resources, steepness of slope, etc.)</td>
<td>-</td>
</tr>
<tr>
<td>Economic accessibility (procurement costs, transportation distance, harvest system, stumpage price, etc.)</td>
<td>-</td>
</tr>
<tr>
<td>Set aside forest areas for various protective functions (biodiversity, soil, water)</td>
<td>(+)</td>
</tr>
<tr>
<td>Protection of forest soil</td>
<td>(+)</td>
</tr>
<tr>
<td>Protection of water</td>
<td>(+)</td>
</tr>
<tr>
<td>Wood mobilisation</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 6 Analytic abilities and possible outputs of different methods and approaches for assessments of woody biomass potentials

<table>
<thead>
<tr>
<th>Possible output and analytic abilities</th>
<th>Approaches / methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resource focused</td>
</tr>
<tr>
<td></td>
<td>Statistical analysis</td>
</tr>
<tr>
<td>Available volume of biomass (supply)</td>
<td>+</td>
</tr>
<tr>
<td>Analysis of technological options for biofuel production</td>
<td>-</td>
</tr>
<tr>
<td>Analysis of technological options for biomass harvesting</td>
<td>+</td>
</tr>
<tr>
<td>Carbon accumulation by biomass</td>
<td>+</td>
</tr>
<tr>
<td>Carbon emissions</td>
<td>-</td>
</tr>
<tr>
<td>Competitive use of wood(^2)</td>
<td>-</td>
</tr>
<tr>
<td>Economic accessibility</td>
<td>-</td>
</tr>
<tr>
<td>Economic competitiveness of biomass as a fuel</td>
<td>-</td>
</tr>
<tr>
<td>Economic impact of biofuels production/use</td>
<td>-</td>
</tr>
<tr>
<td>Environmental competitiveness of biomass as a fuel</td>
<td>-</td>
</tr>
<tr>
<td>Environmental constraints</td>
<td>+</td>
</tr>
<tr>
<td>Impact of biofuels production on air</td>
<td>-</td>
</tr>
<tr>
<td>Impact of biofuels production on biodiversity</td>
<td>-</td>
</tr>
<tr>
<td>Impact of biofuels production on employment</td>
<td>+</td>
</tr>
<tr>
<td>Impact of biofuels production on soil</td>
<td>-</td>
</tr>
<tr>
<td>Impact of biofuels production on water</td>
<td>-</td>
</tr>
<tr>
<td>Impact of policy options</td>
<td>+</td>
</tr>
<tr>
<td>Modelling of land use changes</td>
<td>-</td>
</tr>
<tr>
<td>Required volume of biomass (demand)</td>
<td>-</td>
</tr>
<tr>
<td>Technical accessibility</td>
<td>-</td>
</tr>
</tbody>
</table>

In the next sections the methods for the different biomass types are presented. Table 7 shows in which section the specific methods are presented.

Table 7 Sections covering specific methods forest biomass

<table>
<thead>
<tr>
<th></th>
<th>Statistical method</th>
<th>Spatially explicit method</th>
<th>Cost supply method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic</td>
<td>Advanced</td>
<td>Basic</td>
</tr>
<tr>
<td>Stemwood</td>
<td>3.2.1</td>
<td>3.2.2</td>
<td>3.4.1</td>
</tr>
<tr>
<td>Primary forestry residues</td>
<td>3.3.1</td>
<td>3.3.2</td>
<td></td>
</tr>
<tr>
<td>Secondary forestry residues</td>
<td>3.5.1</td>
<td>3.5.2</td>
<td>3.5.3</td>
</tr>
</tbody>
</table>

\(^2\) Usually based on fixed assumptions, specific assortments of stemwood are not considered as a potential for energetic use.
3.2 Stemwood

Stemwood is the main product derived from forests. It is harvested for material and energy use. The quality of the harvested wood and its demand are the main parameters that define future use of wood. The harvested wood, which does not satisfy the requirements of the wood processing industry (e.g. specific size and shape of stem), can be used as a fuel. In the case of high demand for energy there is competition for stemwood of industrial quality between material use and energy generation. Therefore, availability of stemwood for energy use depends on the demand for energy and industrial wood and also on quality requirements for industrial wood currently in force, which vary between EU countries.

3.2.1 Stemwood - basic statistical method

Method

The basic resource focused statistical method allows estimates of theoretical and technical potentials of stemwood considering minimum constraints and using results of forest inventories only. It requires minimum data on:

- net annual increment;
- wood removals.

In order to minimise the environmental impact of wood harvest for energy use, only forests available for wood supply are considered as a source of woody biomass. This refers to “forests where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood” (MCPFE 2007). When estimating potentials of woody biomass, the maximum volume of annual fellings should not exceed the net annual increment of woody biomass to ensure the sustainable use of forests in the area of concern.

\[
THP_{SW_{x,y}} = NAI_{x,y} \times (1 - Hl_{x,y}) - IRWrem_{x,y} \times (1 + Bf)
\]

(Equation 3.2.1.1)

Where:

- \(THP_{SW_{x,y}}\) = theoretical stemwood potential (m\(^3\)/year) for energy use in country \(x\) in year \(y\)
- \(NAI_{x,y}\) = net annual increment of stem wood (m\(^3\)/year) in country \(x\) in year \(y\)
- \(Hl_{x,y}\) = harvest losses (i.e. share of stem tops and small trees; 0-1) in country \(x\) in year \(y\)
- \(SWrem_{x,y}\) = roundwood removals (m\(^3\)/year) in country \(x\) in year \(y\) (m\(^3\)/year)
- \(Bf\) = bark fraction (0-1); this is needed in case roundwood removal data are reported underbark.

The method utilises ready data on current and future volumes of wood harvest available from public databases and studies (see Table 8). These datasets are collected with a systematisation that assumes traditional harvesting practices and that therefore have a focus on stemwood for industrial purposes. Most recent data on net annual increment (m\(^3\) overbark ha\(^{-1}\) yr\(^{-1}\)) can be obtained from (MCPFE 2007) or (Eurostat 2009).

Harvest losses can be calculated from TBFRA2000 data (UN-ECE/FAO 2000) on removals and fellings. The losses refer to stem tops, small trees cutting losses, etc. (IPCC 2006a) suggests default values of 0.08 for coniferous species and 0.10 for broadleaved species. (Fonseca and Task Force Members 2010) report an average bark fraction of 12% (range 4-30%). When projecting future volumes of fellings, the net annual increment derived from growth models or assumed for the respective year should be used. This future value of net annual increment should include both future increment of existing forests and increment of woody biomass from afforestation activities in the area of concern.
In the long-term annual fellings should not exceed the net annual increment. Annual fellings exceeding the net annual increment can be allowed only to level age-class distribution in areas where overmature stands prevail. The theoretical potential of energy stemwood is equal to the net annual increment of forests reduced by the harvesting loss and the industrial roundwood removals. The technical potential of stemwood for energy, however, depends on many factors, including volume of fellings, material use of wood, environmental, technical and economic factors, etc. The impacts of these factors on the quantification of the forest biomass potential can be taken into account with simple reduction factors, e.g. to consider fertility of forest soils, biodiversity, soil and water protection or technical accessibility.

\[
TCP_{\_\_SW,xy} = THP_{\_\_SW,xy} \times RFc_{1,xy} \times RFc_{2,xy} \times \ldots \times RFc_{n,xy} \quad \text{(Equation 3.2.1.2)}
\]

Where:

- \(TCP_{\_\_SW,xy}\) = technical stemwood potential for energy use in country \(x\) in year \(y\) (m\(^3\)/year)
- \(THP_{\_\_SW,xy}\) = theoretical stemwood potential for energy use in country \(x\) in year \(y\) (m\(^3\)/year)
- \(RFc_{1,xy}, RFc_{2,xy}, \ldots, RFc_{n,xy}\) = reduction factors for different sustainability criteria \(1, 2, \ldots, n\) in country \(x\) in year \(y\)

If the removal statistics report total removals including fuel wood, it is necessary to subtract fuel wood from that figure to quantify \(IRW_{rem,xy}\). The theoretical energy stemwood potential includes this already utilized fuel wood. To determine the so called “complementary roundwood potential for energy use”, the current fuel wood removals have to be subtracted again.

### Data sources

<table>
<thead>
<tr>
<th>Data item</th>
<th>Abbreviation</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net annual increment</td>
<td>NAI</td>
<td>Eurostat, national forest inventory</td>
<td>Eurostat → Forestry → Main tables → Agriculture, forestry and fisheries → Forestry → Forest increment and fellings (only FAWS)</td>
</tr>
<tr>
<td>Harvest loss</td>
<td>Hl</td>
<td>TBFRA2000 data on removals and fellings</td>
<td>(UN-ECE/FAO 2000)</td>
</tr>
<tr>
<td>Round wood removals</td>
<td>IWT/IWFF</td>
<td>Eurostat, national forest statistics</td>
<td>Eurostat → Forestry → Database → Agriculture, forestry and fisheries → Forestry → Removals → Removals by roundwood assortment (only FAWS)</td>
</tr>
</tbody>
</table>

### Advantages
- The described statistical method offers a straightforward approach to assess the stemwood potential. This method requires relatively little time to conduct an assessment and enables the estimation of biomass potentials using a few input data sets and simple calculations.
- The main input datasets – the net annual increment, volume of fellings and harvesting of industrial round wood are publicly available at Eurostat for most of the countries in EU-27.
- The method can be used for different spatial scopes for which required statistics exist – from local up to global scale.

### Disadvantages
- The method is based on results of national forest inventories, whose data collection procedures are not harmonised within the EU-27; comparability of national biomass assessments is not always ensured.
- Data of forest inventories are not complete or not available for some countries of the EU 27, e.g. Greece.
The assessment of technical potentials captures constraining factors to biomass availability in a simplistic way. When several constraints are combined, possible overlaps between the constraining factors are ignored and therefore double-counting may occur.

**Future biomass potentials**
- The method allows estimates of future biomass potentials by using projections or assumptions on future changes in net annual increment and in volumes of annual fellings instead of factual data.
- When estimating future biomass potentials it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis in 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

**Sustainability aspects**
- The method ensures overall sustainability of wood harvest limiting the amount of fellings, which cannot be higher than the net annual increment. Specific sustainability issues like biodiversity or soil protection can be considered with simple reduction factors. However, such data are not available from international data bases.

**Key uncertainties and future research needs**
- Differences in national forest inventory procedures cause inconsistencies in forest statistics within the EU, e.g. the minimal countable diameter of trees varies between countries and thus leads to uncertainties in estimates of growing stock and the net annual increment (Asikainen 2008). Harmonisation of the national forest inventories will improve consistency of the results obtained by the described method.
- Uncertainties in wood removals statistics and in projecting the future share of industrial wood in the total volume of fellings.

### 3.2.2 Stemwood - advanced statistical method

**Method**
The advanced resource focused statistical method is applicable to estimates of technical potential of biomass using more detailed forest resource information. Furthermore, the advanced resource focused statistical method is able to assess the availability of the biomass potential in more detail, including overlaps between constraining factors. This sets additional requirements to the availability and quality of input data because quantitative values for the factors influencing biomass potentials have to be pre-estimated.

Equation 3.2.2.1 is applied to different management units/classes (e.g. age classes, forest types, management systems) in the study region. Moreover, the biomass potential is calculated from more realistic felling potentials using the annual allowable cut for each management unit/class.

Equation 2.3.1.2 can be modified to take into account the impact of different factors on availability of wood for harvesting:

\[
THP _{SW}^{x,y} = \sum_{i=1}^{n} ARWC _{MU}^{x,y,i} \times (1 - Hl^{x,y}) - RWrem^{x,y} \times (1 + Bf) \quad \text{(Equation 3.2.2.1)}
\]

Where:
- \(THP _{SW}^{x,y}\) = theoretical stemwood potential for energy use in country \(x\) in year \(y\) (m\(^3\)/year)
- \(ARWC _{MU}^{x,y,i}\) = annual allowable stemwood cut per management unit/class \(i\) (e.g. age class, forest type, management system) in country \(x\) in year \(y\) (m\(^3\)/year)
- \(Hl^{x,y}\) = harvest losses (i.e. average share of stem tops and small trees; 0-1) in country \(x\) in year \(y\)
- \(IRWrem^{x,y}\) = industrial roundwood removals (m\(^3\)/year) in country \(x\) in year \(y\) (m\(^3\)/year)
- \(Bf\) = bark fraction; this is needed in case roundwood removal data are reported underbark.
Equation 3.2.2.1 can be modified to take into account the impact of different factors on availability of wood for harvesting:

\[ TCP_{SW_{x,y}} = THP_{SW_{x,y}} - \sum_{i=1}^{n} USWc_{i,x,y} \]  
(Equation 3.2.2.2)

Where:
- \( c_i \) = factors constraining wood harvest (e.g. protection of biodiversity, technical accessibility)
- \( USWc_{i,x,y} \) = stemwood biomass potential (m\(^3\)/year), which is not available for harvest due to \( c \) factor, e.g., technical inaccessibility, protection of biodiversity, soil or water in country \( x \) in year \( y \) (m\(^3\)/year)

For general recommendations on which factors should be considered when estimating the volumes of wood not available for harvest, see chapter 8. The unavailable biomass potential is calculated for each constraint separately. For example, to protect biodiversity in forests available for wood supply, harvesting of woody biomass can be limited to a part of the forest areas. In this case the volume of wood that becomes unavailable for harvest is:

\[ USWbc_{x,y} = A_{bc_{x,y}} \times NAI_{x,y} \times LH_{bc} \]  
(Equation 3.2.2.3)

Where:
- \( bc_{x,y} \) = stemwood biomass potential that is not available for harvest due to biodiversity protection measures (used now as example for factor \( c_j \) in country \( x \) in year \( y \) (m\(^3\)/year)
- \( A_{c,x,y} \) = area where wood harvest is limited due to \( c \)-factor in country \( x \) in year \( y \) (percentage of total area of forest available for wood supply)
- \( NAI_{x,y} \) = average net annual increment of wood in country \( x \) in year \( y \) (m\(^3\))
- \( LH_c \) = limiting coefficient for harvest (0-1), i.e. if \( LH=1 \) no harvest is allowed, all the net annual increment of the area is not available for harvest (e.g. forests at wetlands), if \( HL=0.1 \), 10% of the net annual increment is not available for harvest

Equation 3.2.2.2 can be applied to estimate volumes of wood that are not available for harvest due to different factors, e.g. fellings can be limited on steep slopes to avoid soil erosion, surface runoff etc.

The calculation of different constraints is done one after the other. If the constraints do not overlap, individual amounts of unavailable biomass are summed up and subtracted from the theoretical roundwood biomass potential. In case of overlapping constraints, only the additional volume of unavailable wood biomass potentials is considered to avoid double counting. For example, in the case of the two overlapping constraints biodiversity protection and inaccessible steep slopes in a mountainous region, the calculation of the unavailable biomass potential would first calculate the biomass volume in the biodiversity protection area and then add the biomass volume on steep slopes outside of the biodiversity protection areas. The volume on steep slopes inside the protected forests should not be counted a second time.
Data sources

Table 9 Data sources stemwood - advanced statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Abbreviation</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of stem wood not available for harvest</td>
<td>USV</td>
<td>National forest inventories, national and international studies, expert estimations</td>
<td>e.g. (EEA 2007a)</td>
</tr>
<tr>
<td>Annual allowable stemwood cut per management unit</td>
<td>ARWC_MU</td>
<td>National forest inventories, management plans</td>
<td></td>
</tr>
<tr>
<td>Areas where wood harvest is limited</td>
<td>A</td>
<td>National forest inventories, national and international studies</td>
<td>e.g. (Asikainen 2008)</td>
</tr>
<tr>
<td>Projections of future forest growth, wood harvest, consumption and production of wood processing industries</td>
<td></td>
<td>National and international plans, strategies and studies</td>
<td>e.g. (UNECE/FAO 2003), (Nabuurs et al. 2006)</td>
</tr>
</tbody>
</table>

Remarks

- The described advanced resource focused statistical method requires quantitative data on the impact of constraints on wood harvest.
- If such data are not available, the effect of the limitations should be quantified. Estimation of the quantitative impact of the constraining factors on wood harvest is beyond the scope of this handbook. Descriptions of methods for quantification of the influence of various factors on wood supply can be found in sections 3.4.1 and 3.4.2 and in specific studies e.g. the EEA report (EEA 2007a), (Asikainen 2008) and (Masera et al. 2006).

Advantages

- The advanced resource focused statistical method offers a simple way to calculate technical biomass potentials taking into account the impact of different factors on availability of biomass.

Disadvantages

- The abilities of the method are limited by data availability and data quality. The method does not take into account the differences between various wood supply technologies.
- In order to take into account the impact of different factors on availability of biomass, other methods, like spatially explicit analysis, can be required if necessary data are not available in the statistics form.

Future biomass potentials

- The method allows the estimation of future biomass potentials applying assumptions on future changes in net annual increment and in volumes of annual fellings. Additional assumptions have to reflect future changes in protected forests areas and standing volumes.
- When estimating future biomass potentials it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis in 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

Sustainability aspects

- The impact of various sustainability aspects (see also chapter 8) like biodiversity, soil and water protection on biomass potentials can be accounted for. Using the limiting coefficient for harvest, standing volume of selected areas can be excluded from harvestable biomass volumes completely or partly depending on the constraint.
- Additionally, factors like technical accessibility can be taken into account if the necessary input data are available. These factors are considered in the method as limitations that decrease the potential of woody biomass. In order to estimate the impact, the volumes excluded from wood supply due to any of the factors can be pre-estimated or assumed.
Key uncertainties and future research needs

- Differences between national forest inventory procedures cause inconsistencies in forest statistics within the EU, e.g. the minimum countable diameter of trees varies between countries leading to uncertainties in estimates of growing stock and net annual increment (Asikainen 2008).
- Harmonisation of the national forest inventories would improve the consistency of the results from this method.
- Quantification of roundwood potentials unavailable for energy use extraction can be highly uncertain depending on data availability and calculation method.

3.3 Primary forestry residues

The primary forestry residues (wood harvest residues) include logging residues (branches, tree tops and leaves or needles), and stumps. The key feature of logging residues is their low volume per hectare in comparison to stemwood. Recovery rate of logging residues strongly depends on local conditions and skills of forest workers.

The total theoretical potential of primary forestry residues is:

\[ THP_{PFR} = THP_{LR} + THP_{S} \]  (Equation 3.3.1)

Where:
- \( THP_{PFR} \) = total theoretical potential of primary forestry residues in country \( x \) in year \( y \), (m³/year)
- \( THP_{LR} \) = theoretical potential of logging residues in country \( x \) in year \( y \), (m³/year)
- \( THP_{S} \) = theoretical potential of stumps in country \( x \) in year \( y \), (m³/year)

3.3.1 Primary forestry residues - basic statistical method

Method

The basic method for estimating the potential of primary forestry residues is a simple resource focused statistical analysis. The method is applicable to estimates of theoretical or technical biomass potentials. It requires at minimum data on:
- potentials of fellings;
- volumetric relationships between stem wood and other tree compartments.

As the amount of primary forestry residues depends on the amount of wood and other tissues outside the stem compartment, expansion factors need to be applied to convert data on stem volume (e.g. from forestry inventories) to non-stem tree volume, or biomass, respectively. The biomass stock of forest trees in forest inventories is usually calculated by using biomass expansion factors (BEFs) that convert stemwood volumes or dry weight (density factor) to volume or dry weight of whole tree biomass (expansion factor) or its parts – crown biomass, stump and roots. BEFs are either constant or a function of stand development and exist for many species of temperate forest. In the equations given below, volume BEFs are used to estimate the volume in the different biomass compartments.
**Logging residues**

The theoretical potential of logging residues depends on the maximum allowable volume of final fellings and the species composition. The logging residues include residues from the industrial roundwood removals and additional residues that become potentially available with energy stemwood removals. Logging residues also include harvest losses from both industrial roundwood and energy stemwood removals. For both components logging residues include the crown wood and the harvesting losses:

\[
THP_{-LR_{x,y}} = \sum_{i=1}^{n}(IRWrem_{i,x,y} / (1 - Hl_{x,y}) \times BEF_{i,x,y}) + \sum_{i=1}^{n}(THP_{-SW_{i,x,y}} / (1 - Hl_{x,y}) \times BEF_{i,x,y})
\]

(Equation 3.3.1.1)

Where:

- \(i\) = tree species/tree species groups
- \(THP_{-LR_{x,y}}\) = theoretical potential of logging residues at maximum utilization rate in country \(x\) in year \(y\) (m\(^3\)/year)
- \(IRWrem_{i,x,y}\) = industrial roundwood removals for \(i\)-tree species in country \(x\) in year \(y\) (m\(^3\)/year)
- \(THP_{-SW_{i,x,y}}\) = theoretical stemwood potential for \(i\)-tree species for energy use in country \(x\) in year \(y\) (m\(^3\)/year)
- \(Hl_{x,y}\) = harvest losses (ie. share of stem tops and small trees; 0-1) in country \(x\) in year \(y\)
- \(BEF_{i,x,y}\) = crown biomass expansion factor for \(i\)-tree species in country \(x\) in year \(y\) (the factors usually range between 0.1-0.5 for mature stands and do as defined here not include the stemwood itself)

If species specific data about the industrial roundwood removals are unavailable, the calculation of logging residues can still be done using species-specific BEFs and the share of the species in the total growing stock of a country. Where species-specific BEFs are missing, average factors or IPCC default values have to be used. However, the calculation using average BEFs is usually very inaccurate.

The technical potential of logging residues is determined by the amount of industrial removals and technical potential of energy stemwood removals. Before applying the recovery rate and possible harvesting constraints to the calculation of technical potential, the technical potential of total logging residues must be defined. Before calculating the technical potential of logging residues, a technical potential for total logging residues, consisting of logging residues from industrial roundwood and technical energy stemwood potential needs to be calculated.

\[
TCP_{-TLR} = \sum_{i=1}^{n}(IRWrem_{i,x,y} / (1 - Hl_{x,y}) \times BEF_{i,x,y}) + \sum_{i=1}^{n}(TCP_{-SW} / (1 - Hl_{x,y}) \times BEF_{i,x,y})
\]

(Equation 3.3.1.2)

Where:

- \(TCP_{-TLR}\) = technical potential for total logging residues
- \(IRWrem_{i,x,y}\) = industrial roundwood removals for \(i\)-tree species in country \(x\) in year \(y\) (m\(^3\)/year)
- \(Hl_{x,y}\) = harvest losses in country \(x\) in year \(y\) (ie. share of stem tops and small trees; 0-1)
- \(BEF_{i,x,y}\) = crown biomass expansion factor for \(i\)-tree species in country \(x\) in year \(y\) (the factors usually range between 0.1-0.5 for mature stands and do, as defined here, not include the stemwood itself)
- \(TCP_{-SW}\) = technical stemwood potential for energy use for \(i\)-tree species in country \(x\) in year \(y\) (m\(^3\)/year)

The technical potential of logging residues depends on a general recovery rate resulting from harvesting techniques and the mix of harvesting situations (thinning, final cutting, other) and various reduction factors for different constraining criteria reducing the theoretical potential:
BEE Best Practices and Methods Handbook

\[ TCP_{-LR_{x,y}} = RR \times TCP_{-TLR} \times RFc1_{x,y} \times RFc2_{x,y} \times \ldots \times RFcn_{x,y} \]  \hspace{1cm} \text{(Equation 3.3.1.3)}

Where:

- \( TCP_{-LR_{x,y}} \) = technical potential of logging residues for energy use in country \( x \) in year \( y \) (m\(^3\)/year)
- \( RFc1,2,\ldots n_{x,y} \) = reduction factors for different constraining criteria 1, 2,\ldots n in country \( x \) in year \( y \) (0-1)
- \( RR \) = recovery rate of logging residues (0-1)

It must be noted that if constraints are applied to the logging residue potential then the same constraints should be applied to the technical potential of energy stemwood and stumps as well.

Aboveground biomass expansion factor can be calculated from (Teobaldelli 2009), based on growing stock data. Separate factors exist to convert to aboveground biomass with and without foliage. General BEFs are also available from (IPCC 2006a) or can be calculated from MCPFE data on (aboveground) carbon stock and growing stock.

In forest resource projection models, residues are sometimes expressed in Gg carbon or biomass. Volumetric data is therefore converted using species-specific basic wood densities from (IPCC 2003), or average wood densities from (Fonseca and Task Force Members 2010).

**Stumps**

The theoretical potential of stumps depends on the maximum allowable volume of fellings and the species composition. Thus it is calculated based on the net annual increment and expanded to stump volume by using the stump biomass expansion factor to estimate the theoretical underground biomass volume:

\[ THP_{-S_{x,y}} = \sum_{i=1}^{n} NAI_{x,y} \times BEFS_{i,x,y} \]  \hspace{1cm} \text{(Equation 3.3.1.4)}

Where:

- \( THP_{-S_{x,y}} \) = theoretical potential of stumps for energy use in country \( x \) in year \( y \) (m\(^3\)/year)
- \( BEFS_{i,x,y} \) = stump biomass expansion factor for \( i \)-tree species (the factors usually range between 0.14-0.23 and do not include the stemwood)
- \( NAI_{x,y} \) = net annual increment of wood in country \( x \) in year \( y \) (m\(^3\))

The technical potential of stumps depends on a general recovery rate resulting from harvesting techniques and the mix of harvesting situations (thinning, final cutting, other) and the various reduction factors for different sustainability criteria reducing the theoretical potential:

\[ TCP_{-S_{x,y}} = RS \times THP_{-S_{x,y}} \times RFc1_{x,y} \times RFc2_{x,y} \times \ldots \times RFcn_{x,y} \]  \hspace{1cm} \text{(Equation 3.3.1.5)}

Where:

- \( TCP_{-S_{x,y}} \) = technical potential of stumps for energy use in country \( x \) in year \( y \) (m\(^3\)/year)
- \( RFc1,2,\ldots n_{x,y} \) = reduction factors for different constraining criteria 1, 2,\ldots n in country \( x \) in year \( y \) (0-1)
- \( RS \) = recovery rate of stumps (0-1)

The calculation of constraints is done in the same way as explained above under ‘logging residues’.
## Data sources

**Table 10 Data sources primary forestry residues - basic statistical method**

<table>
<thead>
<tr>
<th>Data item</th>
<th>Abbreviation</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundwood removals</td>
<td>SWrem</td>
<td>National forest inventories, Eurostat or FAOSTAT data</td>
<td>Eurostat → Forestry → Database → Agriculture, forestry and fisheries → Forestry → Removals → Removals by roundwood assortment (only FAWS)</td>
</tr>
<tr>
<td>Biomass expansion factors</td>
<td>BEF/BEFS</td>
<td>Literature</td>
<td>(Lehtonen et al. 2004), (Teobaldelli 2009), (IPCC 2003)</td>
</tr>
<tr>
<td>Share of tree species</td>
<td></td>
<td>National forest inventories</td>
<td>e.g. (Peltola 2008)</td>
</tr>
<tr>
<td>Recovery rate for logging residues</td>
<td>RR</td>
<td>Literature</td>
<td>e.g. (Asikainen 2008), (EEA 2007a)</td>
</tr>
<tr>
<td>Recovery rate for stumps</td>
<td>RS</td>
<td>Literature</td>
<td>e.g. (Asikainen 2008)</td>
</tr>
<tr>
<td>Projections of future forest growth, wood harvest, consumption and production of wood processing industries</td>
<td></td>
<td>National and international plans, strategies and studies</td>
<td>e.g. (UNECE/FAO 2003), (Nabuurs et al. 2006)</td>
</tr>
</tbody>
</table>

**Remarks**
- For some countries tree species specific BEFS may not be available, in this case it is recommended to use average BEFs for deciduous and coniferous species.
- Distribution of volumes of round wood removals by tree species may also not be available. Assumptions or experts’ judgements should be used to enable the application of species-specific BEFs.
- In this approach harvest losses are considered to be part of logging residues. However, in some countries they are in fact regarded as a part of energy stemwood potential.
- Harvest losses are calculated in relation to the NAI but it should be noted that this potential depends on the level of industrial roundwood and energy stemwood removals.

**Advantages**
- The described statistical method offers a straightforward approach to assess the potential from primary forestry residues.
- This method requires relatively little time to conduct an assessment and allows the estimation of biomass potentials using a few input data sets and simple calculations. The main input datasets covering the volume of fellings, are publicly available from Eurostat for most of countries of the EU-27.
- The method can be used for different spatial scopes for which required statistics exist – from local up to the global scale.
- Depending on data availability, different technical and environmental constraint factors can be taken into account.

**Disadvantages**
- The method applies biomass expansion factors that are related to different tree species and areas. In fact, biomass expansion factors may vary significantly even for one species if that species has a wide geographical habitat (BEE 2009).
- The assessment of technical potentials captures constraining factors to biomass availability in a simplistic way. When several constraints are combined, possible overlaps between the constraining factors are ignored and therefore some double-counting may occur.

**Future biomass potentials**
- The method allows the estimation of future biomass potentials using assumptions on future changes in volumes of annual fellings.
• When estimating future biomass potentials it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

Sustainability aspects
• The method does not assess sustainability of wood harvesting, which in most European countries is legally enforced. However, in some countries annual fellings exceed net annual increment (MCPFE 2007). Other sustainability aspects (see chapter 8) can be considered using simple reduction factors.

Key uncertainties and future research needs
• Statistics on wood removals contain considerable uncertainty and are not always available by tree species. Logging residues collected by private households as wood fuel are not covered in the official statistics. Improved data are needed on the household consumption to better quantify the part of the biomass resource potential that is already utilized.

3.3.2 Primary forestry residues - advanced statistical method

Method
The collection of primary forestry residues after commercial thinning faces economical constraints due to their low volume per hectare and ecological constraints e.g. due to negative impacts on site nutrition and future stand productivity. In addition to the economic and environmental constraints, potential of primary forestry residues is affected by technical factors, many of which are site-specific (relief, soil bearing capacity etc). Moreover, the amount of logging residues that can be collected from cutting areas with reasonable costs depends on the share of mechanisation. In order to simplify calculations on national and global levels, it is reasonable to make the assumption that the impact of different logging methods and technologies is neglected.

The potential of primary forestry residues (logging residues & stumps) directly depends on the technical potential of final fellings (see section 3.2) and the factors limiting collection of primary forestry residues. These constraints can be taken into account in two different ways: a) by excluding volumes of primary forestry residues of areas where their collection is limited or not possible b) by the use of residue recovery ratios which are site-specific. The first approach will be used in the advanced statistical method described here. The second approach requires detailed data on site specific conditions and cannot be utilised by the means of the statistical method. Spatial explicit methods are better for this approach (see sections 3.4.1 and 3.4.2).

In addition to the economic and environmental constraints, potential of primary forestry residues is affected by technical factors, many of which are site-specific (relief, soil bearing capacity, etc.). Moreover, the amount of logging residues that can be collected from cutting areas with reasonable costs depends on the share of mechanisation. In order to simplify calculations, the impact of different logging methods and technologies is neglected.

The estimation of stemwood volumes shows parallels with the method presented in section 3.2.2. The difference is in the fact that on some sites stemwood can be harvested but logging residues not.
**Logging residues**

Equation 3.3.2.1 is applied to different forest types and management systems in the study region. Moreover, the biomass potential is calculated from more realistic felling potentials using the annual allowable cut for each management unit/class.

\[
THP\_LR_{x,y} = \left( \sum_{i=1}^{n} \sum_{s=1}^{n} ARWC_{i,s,x,y} \times BEF_{i} \right) / \left(1 - HI_{x,y} \right) 
\]  

(Equation 3.3.2.1)

Where:
- \( i \) = tree species/tree species groups
- \( s \) = management system
- \( THP\_LR_{x,y} \) = theoretical potential of logging residues in country \( x \) in year \( y \) (m\(^3\)/year)
- \( ARWC_{i,s,x,y} \) = annual allowable roundwood removals per \( i \)-species, \( s \)-management system, in country \( x \) in year \( y \) (m\(^3\)/year)
- \( BEF_{i} \) = crown biomass expansion factor for \( i \)-tree species for final felling, (0.1-0.5)
- \( HI_{x,y} \) = harvest losses in country \( x \) in year \( y \) (i.e. share of stem tops and small trees; 0-1)

The calculation of the technical potential of logging residues reduces the theoretical potential by subtracting residue potentials that are not available due to various sustainability limitations:

\[
TCP\_LR_{x,y} = RR \times \left( THP\_LR_{x,y} - \sum_{i=1}^{n} ULR_{c,i,x,y} \right) 
\]  

(Equation 3.3.2.2)

Where:
- \( c_{j} \) = factors constraining wood harvest (e.g. protection of biodiversity, technical accessibility)
- \( TCP\_LR_{x,y} \) = technical potential of logging residues in country \( x \) in year \( y \) (m\(^3\)/year)
- \( RR \) = recovery rate of logging residue biomass (0-1)
- \( ULR_{c,i,x,y} \) = logging residue potential which is not available for harvest due to \( c \)-factor, e.g., technical inaccessibility, protection of biodiversity, soil or water in country \( x \) in year \( y \) (m\(^3\)/year)

For general recommendations on which factors should be considered when estimating the volumes of wood not available for harvest, see chapter 8. The unavailable biomass potential is calculated for each constraint separately. For example, to protect biodiversity in forests available for wood supply, harvesting of woody biomass can be limited to a part of the forest areas. In this case the volume of wood that becomes unavailable for harvest is:

\[
ULRbc_{x,y} = A_{bc,x,y} \times THP\_LR_{x,y} \times LH_{bc} 
\]  

(Equation 3.3.2.3)

Where:
- \( bc_{x,y} \) = logging residue biomass potential that is not available for harvest due to biodiversity protection measures (used as example now for factor \( c_{j} \)) in country \( x \) in year \( y \) (m\(^3\)/year)
- \( A_{bc,x,y} \) = area where wood harvest is limited due to \( c \)-factor in country \( x \) in year \( y \) (percentage of total area of forest available for wood supply)
- \( THP\_LR_{x,y} \) = theoretical potential of logging residues in country \( x \) in year \( y \) (m\(^3\)/year)
- \( LH_{bc} \) = limiting coefficient for harvest (0-1), i.e. if \( LH=1 \) no harvest is allowed, all the net annual increment of the area is not available for harvest (e.g. forests at wetlands), if \( HL=0.1, 10\% \) of the net annual increment is not available for harvest
The calculation of different constraints is done one after the other. If the constraints do not overlap, individual amounts of unavailable biomass are summed up and subtracted from the theoretical roundwood biomass potential. In case of overlapping constraints, only the additional volume of unavailable wood biomass potentials is considered to avoid double counting. For example, in the case of the two overlapping constraints, biodiversity protection and inaccessible steep slopes in a mountainous region, the calculation of the unavailable biomass potential would first calculate the biomass volume in the biodiversity protection area and then add the biomass volume on steep slopes outside of the biodiversity protection areas. The volume on steep slopes inside the protected forests should not be counted a second time.

**Stumps**

Collection of stumps is not reasonable after thinning for technical and environmental reasons. Therefore, we calculate the theoretical and the technical potential of stump biomass only from stumps collected from final felling areas. The theoretical biomass resource potential of stumps depends on the maximum allowable volume of fellings and the species composition.

\[
THP_\text{S}_{x,y} = RS \times \sum_{i=1}^{n} \sum_{s=1}^{n} ARWC_{FF} \times BEFS_i (\text{Equation 3.3.2.4})
\]

Where:
- \( i \) = species/tree species groups
- \( s \) = management system
- \( ARWC_{FF} \) = annual allowable roundwood removals final fellings per \( i \)-species, \( s \)-management system, in country \( x \) in year \( y \) (m\(^3\)/year)
- \( NAI_{x,y} \) = average net annual increment of wood in country \( x \) in year \( y \) (m\(^3\))
- \( BEFS_i \) = stump biomass expansion factor for \( i \)-tree species for final felling, (0.14-0.23)

The technical potential takes into account various constraints on the utilization of stumps:

\[
TCP_\text{LR}_{x,y} = RS \times (THP_\text{LR}_{x,y} - \sum_{c=1}^{n} USC_{i,c,x,y}) (\text{Equation 3.3.2.5})
\]

Where:
- \( c \) = factors constraining wood harvest (e.g. protection of biodiversity, technical accessibility)
- \( TCP_\text{S}_{x,y} \) = technical potential of stumps in country \( x \) in year \( y \) (m\(^3\)/year)
- \( RS \) = recovery rate of stump biomass (0-1)
- \( USC_{i,c,x,y} \) = stump potential that is not available for harvest due to \( c \)-factor, e.g., technical inaccessibility, protection of biodiversity, soil or water in country \( x \) in year \( y \) (m\(^3\)/year)

\[
USbc_{x,y} = A_{bc,x,y} \times THP_\text{S}_{x,y} \times LH_{bc} (\text{Equation 3.3.2.6})
\]

Where:
- \( bc \) = stump biomass potential that is not available for harvest due to biodiversity protection measures (used as example now for factor \( c \)) in country \( x \) in year \( y \) (m\(^3\)/year)
- \( A_{bc,x,y} \) = area where wood harvest is limited due to \( c \)-factor in country \( x \) in year \( y \) (percentage of total area of forest available for wood supply)
- \( THP_\text{S}_{x,y} \) = theoretical potential of stumps in country \( x \) in year \( y \) (m\(^3\)/year)
- \( LH_{bc} \) = limiting coefficient for harvest (0-1), i.e. if \( LH=1 \) no harvest is allowed, all the net
annual increment of the area is not available for harvest (e.g. forests at wetlands), if HL=0.1, 10% of the net annual increment is not available for harvest

Data sources

Table 11 Data sources primary forestry residues - advanced statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Abbreviation</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery rate for logging residues</td>
<td>RR</td>
<td>Literature</td>
<td>e.g. (Asikainen 2008), (EEA 2007a)</td>
</tr>
<tr>
<td>Recovery rate for stumps</td>
<td>RS</td>
<td>Literature</td>
<td>e.g. (Asikainen 2008)</td>
</tr>
<tr>
<td>Biomass expansion factors</td>
<td>BEFC/BEFS</td>
<td>Literature</td>
<td>(Lehtonen et al. 2004), (Teobaldelli 2009), (IPCC 2003)</td>
</tr>
<tr>
<td>Projections of future forest growth, wood harvest, consumption and production of wood processing industries</td>
<td></td>
<td>National and international plans, strategies and studies</td>
<td>e.g. (UNECE/FAO 2003), (Nabuurs et al. 2006)</td>
</tr>
</tbody>
</table>

Remarks

- Further use of results of biomass assessments may require conversion of volume into weight. In case of crown biomass it is important to keep in mind that density of branches for some species is higher than density of stemwood.
- In this approach harvest losses are considered to be part of logging residues. However, in some countries they are in fact regarded as a part of energy stemwood potential.
- Harvest losses are calculated in relation to the annual allowable roundwood removals but it should be noted that this potential depends on the level of industrial roundwood and energy stemwood removals.

Advantages

- The method allows estimates of primary forestry residues using data on wood removals only.
- Low requirements for data and time input.

Disadvantages

- The assessment of the impact of environmental and technical factors limiting the availability of primary forest residue potentials may be challenging due to lack of suitable data.
- The method applies biomass expansion factors that are usually related to different tree species and areas. In fact, biomass expansion factors may vary significantly even for one species if that species has a wide geographical habitat (BEE 2009).

Future biomass potentials

- The method enables estimates of future biomass potentials by the use of assumptions on future changes in volumes of annual fellings.
- When estimating future biomass potentials it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis in 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

Sustainability aspects

- The impact of various sustainability aspects (see also chapter 8) like biodiversity, soil and water protection on biomass potentials can be accounted for. The impact of constraints can be considered in two ways – by adjusting the harvest intensity of primary forestry residues to minimise the impact or by completely excluding certain areas from woody biomass supply. Additionally, factors like technical accessibility can be taken into account if the necessary input data are available. These factors are considered as limitations in the method that decrease potential of woody biomass. In order to estimate the impact, the volumes excluded fromwood supply due to any of the factors can be pre-estimated or assumed.
Key uncertainties and future research needs

- Statistics on wood removals contain considerable uncertainty and are not always available by tree species. Logging residues collected by private households as fuel wood are not covered in official statistics. Improved household consumption data are needed to better quantify the already utilized part of the biomass resource potential.
3.4 Stemwood and primary forestry residues

3.4.1 Stemwood and primary forestry residues - basic spatially explicit method

Method
The resource-focused basic spatial approach, which is described in more detail below, provides a rough overview on the spatial distribution of the biomass increment and applies basic harvesting constraints to account for biomass not available for energy supply at regional or country level. The method starts from the best available forest area map, integrates statistics on the net annual increment (NAI) and biomass expansion factors (BEFs), and accounts for several sustainability-related criteria and basic technical constraints at pixel level and for wood removals with industrial use (commercial fellings and thinnings) at regional or country level. Table 12 specifies which constraints are considered.

As an intermediate product, this method provides a map on the distribution of the average biomass increment at pixel-level as an indicator of the annual production capacity. Alternatively, also the average growing stock distribution can be visualised with this method. However, it should be noted that the pixel-based map cannot be interpreted as harvesting potential. Therefore the final map shows the estimated technical potential at an aggregated level (region- or country-wise), depending on the level of detail of the applied statistics on commercial wood removals. Users of this method need to clearly differentiate between the annual biomass production capacity demonstrated at pixel-level and the annual harvesting potential, which can only be estimated at larger scales (regional or country level). Furthermore, this method assumes an even distribution of age classes for forest at regional/country level.

This assessment method is recommended if a detailed overview on the spatial distribution of growing biomass and a spatially explicit calculation of environmental constraints are required. Performing this method involves data processing in GIS (Geographical Information Systems) software.

<table>
<thead>
<tr>
<th>Possible assumptions and constraints</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theoretical</td>
</tr>
<tr>
<td>Net annual increment (NAI)</td>
<td>+</td>
</tr>
<tr>
<td>Maximal sustainable volume of fellings based on NAI</td>
<td>+</td>
</tr>
<tr>
<td>Volume of annual fellings for industry (industrial roundwood)</td>
<td>-</td>
</tr>
<tr>
<td>Accessibility based on steepness of slope</td>
<td>-</td>
</tr>
<tr>
<td>Maximum removal rate for residues and stumps (technical and environmental constraint)</td>
<td>-</td>
</tr>
<tr>
<td>Protection of soil and water: Consideration of slope steepness, soil type, soil depth, soil compaction risk</td>
<td>-</td>
</tr>
<tr>
<td>Protection of biodiversity: Exclusion of protected areas</td>
<td>-</td>
</tr>
</tbody>
</table>

The following instructions explain the different steps of the proposed method in detail:

A) Pixel-level modelling of biomass production capacity and environmental constraints

1) **Forest area map:** The approach utilises as main input a forest cover raster map (e.g. derived from Earth Observation data) with best possible resolution for the area of interest. The pixel values of this raster should represent the area of forest contained in each pixel, in unit hectare. If available, area maps for coniferous and broadleaved forest can be used instead of the forest area map, or in the best case area maps for tree species.
2) **Combination with NAI statistics**: The net annual increment (NAI) gives an indication on average biomass growth and forest productivity. This approach utilises inventory statistics on NAI per region to visualise the theoretical potential. The statistics are linked with polygon data of the respective regions and multiplied by the forest area raster. The resulting raster shows the spatial distribution of the average annual increment in stem-wood, in m³ per pixel:

\[ SW\_\text{NAI} = FA \times NAI\_\text{reg} \]  
(Equation 3.4.1.1)

Where:
- \( SW\_\text{NAI} \) = raster of average stem-wood net annual increment per pixel (m³ yr⁻¹)
- \( FA \) = raster of forest area (ha)
- \( NAI\_\text{reg} \) = raster of average stem-wood net annual increment per region based on inventory statistics (m³ ha⁻¹ yr⁻¹)

If the spatial distribution of the total growing stock should be visualized, then step 2) can be applied to regional growing stock statistics. The resulting raster will show the average growing stock of stemwood in m³ per pixel.

**Alternatively a more complex method can be applied to step 2 – Yield estimation from NPP maps**: Forest productivity can also be estimated independently from inventory statistics on the basis of Net Primary Productivity (NPP) maps derived from satellite observations. Estimates of annual NPP at 1 km spatial resolution are produced operationally for the global terrestrial surface using imagery from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. This product provides an average NPP over all terrestrial ecosystems. To extract pure forest NPP, areas where forest cover is high according to the MODIS Continuous Fields Tree Cover product (e.g. 90% or more), are chosen. To extrapolate forest productivity into areas with less forest cover, a simple function using average temperature, precipitation and soil condition can be applied. Estimated forest NPP can be transferred to NAI by dividing the NPP with 1.5, assuming that 2/3 of the NPP is allocated to the stem. Alternatively, the NPP map can be used to scale NAI values from forest inventories (if these are available) over the landscape. In this method NPP values located in a certain region are then calibrated to match on average the NAI value reported for that region. This secures regional consistency between statistics and remote sensing observations but also preserves spatially explicit deviations from average NAI within a region. NPP maps reflect a current state of the vegetation. Age-class effects and climate impacts change NPP over time. To exclude such effects, NPP values should be averaged over a certain period of time, e.g. five years. For more details about this method refer to (Kindermann 2008).

3) **Conversion from volume units to units of oven-dry weight**: The increment information is converted into tonnes of dry matter to be compliant with the weight-related biomass expansion factors proposed by (IPCC 2003), which will be applied in the next step.

\[ SW\_\text{NAI}_t = SW\_\text{NAI} \times D \]  
(Equation 3.4.1.2)

Where:
- \( SW\_\text{NAI}_t \) = raster of average stem-wood net annual increment (t dry matter m⁻³)
- \( SW\_\text{NAI} \) = raster of average stem-wood net annual increment (m³ yr⁻¹)
- \( D \) = factor of basic wood density (t dry matter m⁻³)

Note: Factor \( D \) is species specific. When using a forest/non-forest map in step 1) average wood density factors should be applied at regional level, e.g. based on a weighted average calculation, which considers the species composition of the increment per region.
4) **Including above-ground and below-ground biomass:** The increment information on stemwood can be multiplied by biomass expansion factors (BEFs) in order to include leaves, twigs, branches, and stumps, which are commonly not measured by the forest inventories and thus are not included in the increment raster yet. For the estimation of below-ground biomass a root-to-shoot ratio is applied.

A raster for the biomass increment in branches and foliage is created by multiplying the stemwood increment raster with general increment-related BEFs for above-ground biomass (Equation 3.4.1.3). The stem-wood increment is subtracted in order to gain an increment raster that only includes information on branches and foliage (above-ground forestry residues). A raster for the biomass increment in roots (below-ground forestry residues) is estimated by applying a root-to-shoot ratio (average belowground to aboveground biomass ratio, as defined by (IPCC 2003) to the total above-ground biomass (Equation 3.4.1.4).

\[
AGFR_{AAI_t} = (SW_{NAI_t} \times BEF_{above}) - SW_{NAI_t} \tag{Equation 3.4.1.3}
\]

\[
BGFR_{AAI_t} = SW_{NAI_t} \times BEF_{above} \times R \tag{Equation 3.4.1.4}
\]

Where:
- \(AGFR_{AAI_t}\) = raster of average annual increment in biomass from above-ground forestry residues (t\(_{dry\ matter}\) yr\(^{-1}\))
- \(BGFR_{AAI_t}\) = raster of average annual increment in biomass from below-ground forestry residues (t\(_{dry\ matter}\) yr\(^{-1}\))
- \(SW_{NAI_t}\) = raster of average stem-wood net annual increment (t\(_{dry\ matter}\) yr\(^{-1}\))
- \(BEF_{above}\) = average biomass expansion factor for conversion of annual net increment (in tonnes dry matter) to above-ground tree biomass increment
- \(R\) = root-to-shoot ratio appropriate to increments (average below-ground to above-ground biomass ratio for tonnes dry matter)

Note: If possible, species-specific national biomass expansion factors and root-to-shoot factors should be used.

5) **Excluding protected areas:** Protected forest areas are excluded from the analysis because harvesting of such sites is either restricted or completely prohibited. Increased fellings resulting from bioenergy targets might endanger the forest habitats. Thus, all forested sites located in the Natura2000 network or in other legally protected areas, are set to zero in the biomass increment rasters. Though stemwood harvest for industrial use is not necessarily prohibited in protected areas, primary residues from such fellings should be left in the forest to protect the local nutrient cycle.

Note: If, however, spatial information is available to differentiate between core zones and managed zones then only the core zones should be excluded from the biomass assessment while limited harvest levels for stemwood and residues can be applied to the other zones (based on statistical information on allowed felling levels in these areas).

6) **Including environmental criteria and basic technical constraints (pixel-level):**

   a) **Limitations for stemwood extraction**

   Stemwood removal is limited by technical constraints and by the capacity of the soil to bear heavy machinery. Harvesting in terrain with slopes up to ca. 40% can be performed using common technologies. For steeper slopes, special cable crane techniques are required that are very costly. Thus, in the here proposed method, areas with slopes steeper than 40% are excluded from the analysis for reasons of accessibility and risk of soil erosion. Based on a digital elevation model, these areas are set to zero in the increment raster for stemwood
Furthermore, stemwood harvest should not take place on soil types with low bearing capacity and high compaction risk. Therefore, all areas covered by Histosols, Fluvisols, Gleysols, Andosols, and pristine undrained (permanently wet) peatlands, should be set to zero in the stemwood raster as well, based on a soil map. An exception can be made for Fennoscandia where harvest can take place during winter on frozen soil, however not for undrained peatlands due to the risk of a rise of the water table. Undrained peatlands are usually not very productive anyway and thus economically not relevant.

Note: The 40% threshold is only a suggestion and should be adjusted based on harvesting techniques and local soil conditions.

b) Limitations for the extraction of primary forestry residues

In order to select areas suitable for the extraction of above- and below-ground residues, a map on site suitability is created for each of the two residue types based on an overlay of several spatial data layers including soil parameters and slope. These suitability maps define the extraction rate for the residues for each location. Both maps are then multiplied by the above- and below-ground residue increment rasters respectively in order to reduce the biomass production capacity by accounting for sustainability criteria.

The here proposed criteria on site suitability are related to soil and water protection. They aim at the prevention of erosion, maintenance of soil fertility and protection of soil biodiversity. The following parameters are considered: slope (derived from elevation data), soil type, soil depth, and soil compaction risk. These criteria are combined as shown in Table 13 to exclude unsuitable sites from residue removal. In addition, reduced maximum extraction rates are applied to keep the residue removal environmentally sustainable. If further spatial data on soil fertility are available, such as nitrogen availability (based on fertilisation or atmospheric nitrogen deposition), those can be integrated as well.

For above-ground residues, i.e. branches and foliage, the maximum technically possible extraction rate is around 65% (Ranta 2002). Also considering sustainability aspects, this rate is reasonable as it accounts for the exclusion of small twigs and some deadwood from the residue extraction (compare (EEA 2007a) and (Fernholz 2009)). For less suitable sites this rate should be limited to one third, or set to 0% (Table 13). It should be noted that the extraction rate for residues is also linked to the mechanisation rate, i.e. harvesting technology. If information on mechanisation rates is available at spatial level, this can be linked to the site suitability map as well.

For below-ground residues, i.e. stumps and roots, the maximum removal rate is set to one third (Asikainen 2008) though higher extraction rates are technically possible. At uneven terrain this rate is reduced to protect the soil. Unsuitable sites as specified in Table 13 should be completely excluded from stump removal.

Note 1: Root and stump harvesting is under heavy discussion in many countries, but a common practice in Scandinavian forests, Canada and the United States (Fernholz 2009). Also other countries, e.g. the UK have published guidelines for stump harvesting (UK Forest Research 2009). As the interest in the potential of below-ground biomass is increasing, it is included in this assessment method. However, it should be critically considered if below-ground biomass is of interest for the planned biomass assessment before applying this option. Alternatively, the assessment can be performed without the consideration of below-ground forestry residues.

Note 2: Knowledge on sustainable levels for residue and stump harvest is still weak. Different studies apply different thresholds. Therefore the proposed extraction rates for residue and stump removal in Table 13 should be seen as a recommendation only. They can be adjusted depending on local bio-physical conditions.
B) Estimating the technical biomass potential at an aggregated spatial level

7) **Aggregation to regional or country level:** Depending on the level of detail of available statistics on annual fellings from the national forest inventories, the increment rasters (output of step 6) are aggregated for the respective regions or countries by summing up the pixel values within each region or country for each of the rasters.

8) **Including of wood removals for industrial use (aggregated level):** Annual fellings per region or country are subtracted from the aggregated stemwood increment raster to exclude wood that is utilized for other purposes from the increment potentially available for energy:

\[
SWUU\_NAI\_t = SW\_NAI\_t\_reg - (WR\_reg \times D) \quad \text{(Equation 3.4.1.5)}
\]

Where:
- \(SWUU\_NAI\_t\) = aggregated raster of net annual increment in unutilized stemwood, reduced for environmental and basic technical constraints (t\(_{\text{dry matter yr}^{-1}}\))
- \(SW\_NAI\_t\_reg\) = aggregated raster of net annual increment in stemwood, reduced for environmental and basic technical constraints (t\(_{\text{dry matter yr}^{-1}}\))
- \(WR\_reg\) = aggregated raster of annual fellings per region based on felling statistics (m\(^3\) yr\(^{-1}\))
- \(D\) = factor of basic wood density (t\(_{\text{dry matter m}^{-3}}\))

Note: Factor \(D\) is species specific. When using a forest/non-forest map in step 1), then average wood density factors should be applied at regional level, e.g. based on a weighted average calculation that considers the species composition of the annual fellings per region.

9) **Total potentially available biomass increment:** The final map is the sum of the three increment rasters (stem-wood, above-ground forestry residues, below-ground forestry residues):

\[
TB\_AAI\_t = SWUU\_NAI\_t + AGFR\_AAI\_t + BGFR\_AAI\_t
\]

\[
\text{(Equation 3.4.1.6)}
\]

Where:
- \(TB\_AAI\_t\) = aggregated raster of total potentially available average annual increment in biomass (t\(_{\text{dry matter yr}^{-1}}\))
- \(SWUU\_NAI\_t\) = aggregated raster of net annual increment in unutilized stemwood (t\(_{\text{dry matter yr}^{-1}}\))
- \(AGFR\_AAI\_t\) = aggregated raster of average annual increment in biomass from above ground forestry residues (t\(_{\text{dry matter yr}^{-1}}\))
- \(BGFR\_AAI\_t\) = aggregated raster of average annual increment in biomass from below ground forestry residues (t\(_{\text{dry matter yr}^{-1}}\))

The final map gives an indication of the average biomass potential from unutilized stemwood and primary forestry residues, based on net annual increment, expansion factors, and under consideration of environmental criteria and basic technical constraints as well as annual fellings for industry. According to the types of biomass potentials defined within BEE (chapter 2), the resulting estimate can be referred to as technical biomass potential. The method also allows the separate presentation of results for unutilized stemwood, harvesting residues and stumps by omitting step 9.
Alternatively, the results can be expressed in primary energy units by multiplication with an averaged net calorific value for woody biomass. Net calorific values for different types of energy wood can be found e.g. in (Alakangas et al. 2007).

### Table 13 Suggested extraction rates for residues and stumps depending on site suitability

<table>
<thead>
<tr>
<th>Environmental parameters / limiting factors</th>
<th>Residues above-ground (branches, leaves, needles)</th>
<th>Residues below-ground (stumps, roots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum extraction rate</td>
<td>65%</td>
<td>33%</td>
</tr>
<tr>
<td>Slope</td>
<td>No extraction from slopes steeper than 35%</td>
<td>Extraction rate[%] = 33% - slope[%] * 0.33 (Asikainen 2008); No extraction from slopes steeper than 20%</td>
</tr>
<tr>
<td>Soil type</td>
<td>Limited (33%) or no extraction from poor soils</td>
<td>No extraction from poor soils</td>
</tr>
<tr>
<td>Soil depth</td>
<td>Limited extraction (33%) from shallow soils with depth below 50cm; No extraction from very shallow soils with depth below 20cm</td>
<td>No extraction from shallow and very shallow soils with depth below 50cm</td>
</tr>
<tr>
<td>Soil texture</td>
<td>No extraction from coarse sandy soils</td>
<td></td>
</tr>
<tr>
<td>Soil compaction risk / soil bearing capacity</td>
<td>No extraction from soils with high compaction risk and low bearing capacity (permanently wet soils, peatlands, Histosols, Gleysols, Fluvisols, Andosols)</td>
<td></td>
</tr>
</tbody>
</table>

Source: adapted from following references: (Asikainen 2008), (Bradley 2009), (EEA 2007a), (Egnell et al. 2007), (Fernholz 2009), (Koistinen and Äijälä 2006), (Stupak 2007), (UK Forest Research 2009), (Vasaitis 2008).

### Data sources

#### Table 14 Data sources stemwood and primary forestry residues - basic spatially explicit method

Optional datasets are indicated in *italic* font.

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest type map</td>
<td>Forest Map of Europe (broadleaved, coniferous), 1km resolution, European coverage</td>
<td>European Forest Institute, <a href="http://www.efi.int/portal/virtual_library/information_services/mapping_service/s/forest_map_of_europe">http://www.efi.int/portal/virtual_library/information_services/mapping_service/s/forest_map_of_europe</a></td>
</tr>
<tr>
<td></td>
<td>Note: any other forest map, possibly more detailed, can be used, e.g. national forest maps with information on forest types or tree species</td>
<td>National forest inventories, national environmental agencies</td>
</tr>
<tr>
<td>Regional inventory statistics on net annual increment, [m³/ha/yr]</td>
<td>Published results of national forest inventories, often accessible online</td>
<td>National authorities for the forest inventory and respective websites</td>
</tr>
<tr>
<td>Regional inventory statistics on growing stock [m³/ha]</td>
<td>Published results of national forest inventories, often online accessible</td>
<td>National authorities for the forest inventory and respective websites</td>
</tr>
<tr>
<td>Net Primary Production (NPP) maps</td>
<td>NASA MODIS GPP and NPP Products</td>
<td>NASA’s Land Processes Distributed Active Archive Center (LP DAAC)</td>
</tr>
<tr>
<td>Topic</td>
<td>Description</td>
<td>Source</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>--------</td>
</tr>
<tr>
<td>Species-specific national BEFs</td>
<td>Scientific publications</td>
<td>e.g. (Teobaldelli 2009), (Somogyi 2008) (Lehtonen et al. 2004), EC Joint Research Centre <a href="http://afoludata.jrc.ec.europa.eu/DS_Free/abc_intro.cfm">http://afoludata.jrc.ec.europa.eu/DS_F ree/abc_intro.cfm</a></td>
</tr>
<tr>
<td></td>
<td>World Database on Protected Areas (WDPA)</td>
<td>National nature conservation or environmental agencies <a href="http://www.wdpa.org">http://www.wdpa.org</a></td>
</tr>
<tr>
<td>Note: If more detailed spatial datasets on protected forest sites are available, these should be integrated instead.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: any other more detailed DEM can be used, e.g. national DEMs</td>
<td>National geodetic/cartographic services, national environmental agencies</td>
<td></td>
</tr>
<tr>
<td>Soil type, soil depth, soil water regime, soil surface texture</td>
<td>European Soil Portal - European Soil Database of the European Soil Bureau Network, resolution 1km, European coverage</td>
<td>EC Joint Research Centre, <a href="http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDB/index.htm">http://eusoils.jrc.ec.europa.eu/ESDB _Archive/ESDB/index.htm</a></td>
</tr>
<tr>
<td>Note: any other more detailed soil data can be used, e.g. national digital soil maps</td>
<td>National geological services, national environmental agencies</td>
<td></td>
</tr>
<tr>
<td>Soil compaction risk</td>
<td>European Soil Portal - Map on soil</td>
<td>EC Joint Research Centre,</td>
</tr>
</tbody>
</table>
susceptibility to compaction, 1km resolution, EU coverage


Table 1: Projections of future forest growth, wood harvest, consumption and production of wood processing industries

| National and international plans, strategies and studies | e.g. (UNECE/FAO 2003), (Nabuurs et al. 2006) |

Remarks

- This method aggregates spatially explicit estimates on biomass production capacity at regional or country level and can serve as an input for further calculations based on a statistical method.
- This method assumes an ideal even-aged forest. Therefore, the shown biomass increment has to be interpreted with care. For example, pre-mature stands have high levels of net annual increment but cannot be harvested yet. Thus the maps only provide an indication of the annual biomass production capacity. For the same reason, the output of step 2 cannot be interpreted at pixel-level. Though this step provides an overview of the spatial distribution of average increment, it does not show how much can be harvested at pixel-level.
- For application of this method at national scale it is recommended to apply national biomass expansion factors and root-to-shoot ratios in step 4. Furthermore, if there are distribution maps, increment data, fellings data and biomass expansion factors available at forest type or tree species level, then those maps and data should be applied instead of the datasets on total forests. This would allow the generation of more detailed biomass maps. The resulting maps for the different forest types or tree species can then be summed up to create a map on total available biomass.
- The method as presented results in a map on the average annual increment. If, however, the total volume (growing stock) should be visualized independently from net annual increment, then step 2 can be performed with statistical data on regional growing stock (m³/ha) instead of increment data. In this case, BEFs and root-to-shoot ratios related to volume data need to be applied. Optionally, steps 5, 6 and 8 can be omitted if the aim is demonstrating the distribution of the total biomass increment without considering environmental and technical constraints.
- If Natura2000 sites and other protected areas are completely excluded from biomass removal in step 5, i.e. if no differentiation between core zones and managed zones is applied, then the final map underestimates the amount of potentially available woody biomass: the potential from managed zones is neglected, while the subtraction of the total industrial roundwood removal by region (step 8) includes fellings from protected areas and thus results in an underestimation of the stemwood potential for energy. Furthermore, also the potential of forestry residues is reduced when existing harvesting levels in managed zones are neglected.

Advantages

- The presented approach offers a way to provide an overview on the spatial distribution of woody biomass growth at the European or national scale. It is easy to perform, and required input data exist for most European countries.
- The method allows the pixel-wise integration of environmental and basic harvesting constraints.
- While the detail of statistical assessments usually does not go beyond the regional scale, the biomass map produced in step 2) of this method offers insight into the local distribution of resources and growth. The results can be combined with statistics and be aggregated to regional or country level. They can also be combined with growth models to derive future projections.

Disadvantages

- The methods does not include technical constraints related to forest accessibility (apart from slope) and harvesting methods, social constraints such as forest ownership structure and availability of skilled labour and machinery, and economic constraints such as forest fragmentation, timber price, residue price, etc.
The applied average BEFs and root-so-shoot ratios (e.g. as proposed by IPCC) are very broad and only give a rough estimate of above- and below-ground biomass. If possible, they should be replaced by more accurate national factors. Furthermore, the conversion to oven-dry weight based on average wood density factors increases the uncertainties.

The integrated environmental criteria are basic and the defined thresholds for biomass extraction are rather coarse, thus only providing an indication.

Future biomass potentials

- This method can be applied for future projections of biomass potentials by integrating outputs of forest scenario models. Instead of current increment statistics from the national forest inventories, the method would then use predicted NAI values from scenario models as an input (step 2). Ideally, detailed land use projections could be applied to identify future forest areas instead of using a current forest area map (step 1). Furthermore, residue extraction rates as well as number and size of protected forest areas could be adjusted to meet future targets of environmental policy (steps 5 and 6). Future projections of annual fellings (step 8) can be derived from international or national models, e.g. the Motti model for Finland or the Weham model for Germany, in combination with predictions for roundwood demand from market models.

- When estimating future biomass potentials, it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis in 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

- When identifying future forest areas, land use projections should be applied that consider the afforestation of grasslands. For reasons of sustainability, grasslands that are part of the Natura2000 network should be excluded from afforestation activities. Also the drainage of currently pristine peatlands in order to increase future yields is not allowed according to the EU Directive on renewable energy sources (RES Directive) and thus should be avoided when carrying out assessments of future biomass potentials.

Sustainability aspects

- The presented approach integrates the main sustainability aspects related to forestry as described in detail in chapter 8. Sustainability criteria, which are covered by the approach, include the consideration of net annual increment (balance between increment and removals), the exclusion of protected forest areas from increased fellings for bioenergy, and the integration of environmental criteria related to soil and water protection. Furthermore, the recommended maximum allowed extraction rates for residues and stumps are limited to 65% and 33%, respectively.

- To prevent the loss of habitats with high biodiversity value, buffer zones between harvest sites and protected areas could be applied in which fellings and residue extraction are restricted and stump removal is avoided (compare Annex 3.2, Table 67, page 201). This could easily be integrated in the approach by applying a buffer function around all Natura2000 sites and other legally protected areas and thus excluding these zones from the biomass potential. The buffer size should be based on the size of the protected area. A similar approach could be applied for riparian areas and wetlands.

- To improve the accuracy of the results, the harvest levels in protected areas should be differentiated with respect to core zones (IUCN protection category I) and managed zones. While core zones should be completely excluded from the assessment, reduced harvest levels can be applied for managed zones. Note: Spatial overlaps between Natura2000 sites and other legally protected forest areas need to be identified to avoid double counting.

- Pristine undrained peatlands are excluded from harvesting activities due to the high risk of soil compaction, damage to soil biodiversity, and rise of the water table. Stemwood removal from drained peatlands is included in this method under the assumption of winter harvest on frozen soil or manual harvesting techniques. The extraction of residues and stumps from peatlands is generally not recommended, not only due to sustainability aspects but also for economical reasons.

- The approach could additionally include further sustainability aspects such as Sustainable Forest Management (SFM) certification. This could be applied through multiplication of the biomass map by a factor <1 serving as a proxy for reduced harvest/extraction levels due to certification.
schemes. Additionally, the described scheme on site suitability for residue and stump removal (Table 13) could comprise more environmental factors, e.g. soil fertility based on the level of available nitrogen, or climatic variables such as water availability.

Key uncertainties and future research needs
- The method provides only a coarse overview of available biomass and is not accurate at pixel level due to the combination with regional increment statistics (step 2). The results are aggregated at regional or country level due to the combination with regional or country-level statistics on annual fellings.
- The integration of environmental criteria adds further uncertainties to the map.
- In addition, the proposed thresholds for residue and stump removal (Table 13) are based on selected national harvesting guidelines and additional assumptions. They need further refinement at a regional scale and should be revised for each country separately under consideration of national recommendations for residue and stump harvest.
- The method could be improved by using more detailed environmental data on site suitability and main technical constraints (e.g. forest accessibility, mechanisation rate). In addition, the consideration of economic constraints and social constraints such as wood mobilization rate depending on forest ownership would help to refine the resulting map on the biomass potential.

3.4.2 Stemwood and primary forestry residues - advanced spatially explicit method

Method
The advanced spatial method estimates spatially explicit biomass potentials using remote sensing data, forest inventory data (e.g. NFI), thematic raster maps of forest attributes, regional felling statistics, road and street database, and GIS tools. The main idea of the method is to locate the final felling stands by segmenting remote sensing data and to give estimates of forest attributes to those stands using thematic maps. These maps can be produced by generalizing field inventory data with the aid of auxiliary information such as remote sensing data and base maps. The resulting potential is considered as a technical potential with integration of different kind of technical and environmental constraints (Table 15).

<table>
<thead>
<tr>
<th>Possible assumptions and constraints</th>
<th>Technical potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net annual increment</td>
<td>+</td>
</tr>
<tr>
<td>Volume of annual fellings and maximal sustainable volume of annual fellings</td>
<td>+</td>
</tr>
<tr>
<td>Recovery rate for logging residues</td>
<td>+</td>
</tr>
<tr>
<td>Wood reserved for material use (stem wood of considerable dimension)</td>
<td>+</td>
</tr>
<tr>
<td>Technical accessibility (forest road density, distance to forest resources, steepness of slope, etc.)</td>
<td>+</td>
</tr>
<tr>
<td>Economic accessibility (procurement costs, transportation distance, harvest system, stumpage price, minimum removal for forestry residues, etc.)</td>
<td>+</td>
</tr>
<tr>
<td>Set aside forest areas for various protective functions (biodiversity, soil, water)</td>
<td>+</td>
</tr>
<tr>
<td>Protection of forest soil</td>
<td>+</td>
</tr>
<tr>
<td>Protection of water</td>
<td>+</td>
</tr>
<tr>
<td>Wood mobilisation</td>
<td>-</td>
</tr>
</tbody>
</table>

Most of the constraints are spatial in nature and their proper consideration requires very detailed data. This assessment method is recommended when such data is available. Performing this method requires knowledge on GIS, and respective software capacities. The following instructions explain in details the different steps of the method:

1) **Forming thematic maps:** The spatial distribution of biomass can be shown with biomass maps. Biomass maps are formed by first combining forest inventory data with tree height and crown ratio models e.g. (Tuominen 2009). These model predictions are then used as an input to tree-level biomass equations e.g. (Repola 2007), which make it possible to obtain biomass
estimates for each sample plot. Plot-level biomass estimates are, in turn, used in combination with satellite images and digital maps (e.g. basic maps, soil maps and digital elevation models) in order to produce thematic maps of the forest biomass over the area of interest. The plot-level biomass estimates can be generalized to all raster cells with, e.g. k-NN estimation (Annex 1). At the same time other forest attributes can be generalized to all raster cells (see Table 15).

2) **Segmentation of remote sensing data:** In order to locate the stands of different standing forest stocks (and tree species), remote sensing data, e.g. satellite images, are segmented for the area of interest. In the segmentation, a forest area is stratified into homogeneous parcels (which are assumed to represent forest stands) based on the features of the remote sensing data (see e.g. (Pekkarinen 2002)). For the stratification of the forest area, remote sensing data should have high enough resolution, e.g. IRS satellite images can be used (See Annex 1).

3) **Excluding protected areas:** The method excludes all conservation areas and areas of the Natura2000 network where harvesting is not allowed, from the analysis. Thus, all areas covered by the areas where harvesting is not allowed are set to zero in the thematic maps.

4) **Forest characteristics for the segments:** After the stands are segmented, they are coupled to stand data. This is done by overlaying the stands on raster maps of stand attributes and calculating stand-level statistics (Table 16). The amount of logging residues is calculated as the sum of branch biomass, foliage biomass and the biomass of unmerchantable stem top.

5) **Including environmental criteria and technical constraints for wood removals:** This method uses constraints, which are country specific and highly dependent on harvesting conditions, i.e. the thresholds reported here are only guidelines for the biomass estimation. Local guidelines, if available, should be used in defining the constraint values. As an example, values feasible in Finnish conditions are given below.

In Finland the average forwarding distance in stemwood harvesting is about 250 meters. It can thus be assumed that the maximum distance from the stand border to the road side should be less than, e.g., 500 meters.

A technical recovery rate for each biomass source (e.g. logging residues, stumps and biomass from precommercial thinnings) is set in order to take into account the technical restrictions. E.g. in Finland, the recovery rate for logging residues is 65-80% (Nurmi 2007) and for stumps and whole trees c. 95% (Laitila et al. 2008b). To reduce nutrient loss, recovery rate can be further reduced or recovery can be directed to only suitable sites. E.g. in Finland, logging residues and stumps can be extracted only from fertile sites. Moreover, below-ground forest residue harvesting (stump and roots) is restricted around the water bodies because of the high probability of nutrient flow. The buffer size around the water bodies should be at least 10 meters.

6) **Harvesting level scenario:** As the actual availability of primary forest products and residues depends on the level of harvesting of industrial roundwood, a harvesting level scenario where the harvesting level equals to the level of the in recent years realized cuttings, i.e. Business As Usual (BAU), is defined. For the scenario, total final felling (FF) can be obtained for each municipality using regional felling statistics.

7) **Technical potential:** It is assumed that the stands are harvested in descending order of growing stock. Thus, the stands are sorted in descending order according to stand volume (m³/ha) and selected for final felling until the final felling removal of the scenario is met. The biomass potential is obtained as a sum of crown and stump masses from the final felling stands after applying the environmental and technical constraints. Before the final estimation
of technical potential, wood reserved for material and domestic use can be subtracted from the estimates using regional felling statistics. In order to convert biomasses to energy units, lower calorific value of logging residues and stumps (in GJ/t) is calculated based on species and moisture content, which can be defined seasonally (see e.g. (Ranta 2002)). Finally, lower calorific values are applied to obtain the potentials in GJ.

Table 16 Stand data obtained for each segmented stand: example from the Finnish Illustration Case

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>stem volume for Scots Pine</td>
<td>m³/ha</td>
</tr>
<tr>
<td>stem volume for Norway Spruce</td>
<td>m³/ha</td>
</tr>
<tr>
<td>stem volume for Birch</td>
<td>m³/ha</td>
</tr>
<tr>
<td>mean height</td>
<td>dm</td>
</tr>
<tr>
<td>basal area</td>
<td>m²/ha</td>
</tr>
<tr>
<td>soil type</td>
<td>organic/mineral</td>
</tr>
<tr>
<td>site type</td>
<td>1-7 (describes the site quality of a stand, e.g. 'Fertile')</td>
</tr>
<tr>
<td>biomass of stem for Scots Pine</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of stem for Norway Spruce</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of stem for Birch</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of living branches for Scots Pine</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of living branches for Norway Spruce</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of living branches for Birch</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of needles for Scots Pine</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of needles for Norway Spruce</td>
<td>t/ha</td>
</tr>
<tr>
<td>biomass of foliage for Birch</td>
<td>t/ha</td>
</tr>
<tr>
<td>total belowground biomass for Scots Pine</td>
<td>t/ha</td>
</tr>
<tr>
<td>total belowground biomass for Norway Spruce</td>
<td>t/ha</td>
</tr>
<tr>
<td>total belowground biomass for Birch</td>
<td>t/ha</td>
</tr>
</tbody>
</table>
### Data sources

<table>
<thead>
<tr>
<th>Data item</th>
<th>Finnish case item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street and road database</td>
<td>Digiroad</td>
<td>Digiroad National Road Administration</td>
<td></td>
</tr>
<tr>
<td>Forest inventory data</td>
<td>National Forest Inventory</td>
<td>NFI Published results of national forest inventories</td>
<td><a href="http://www.metla.fi/ohjelma/vmi/info-en.htm">http://www.metla.fi/ohjelma/vmi/info-en.htm</a></td>
</tr>
<tr>
<td>Thematic maps of forest attributes</td>
<td>Maps of stem volume, mean height, basal area, development class, soil type, site type and biomass</td>
<td>NFI</td>
<td><a href="http://www.metla.fi/ohjelma/vmi/info-en.htm">http://www.metla.fi/ohjelma/vmi/info-en.htm</a></td>
</tr>
<tr>
<td>National conservation areas + Natura2000 areas</td>
<td>National conservation areas + Natura2000 areas</td>
<td>Natura 2000 EUNIS database World Database on Protected Areas (WDPA)</td>
<td><a href="http://www.wdpa.org">http://www.wdpa.org</a></td>
</tr>
<tr>
<td>Guidelines for harvesting of forest biomass for energy</td>
<td>National guidelines for harvesting of forest biomass for energy</td>
<td>National guidelines for harvesting of forest biomass for energy</td>
<td><a href="http://www.tapio.fi">http://www.tapio.fi</a> (Finnish Forestry Development Centre)</td>
</tr>
</tbody>
</table>

#### Remarks

- In addition to BAU, other harvesting level scenarios can be utilised. The scenarios may maximize the net present value of timber production or seek maximum sustainable cutting possibilities (e.g. Kärkkäinen et. al 2008).
- The environmental constraints include sustainability aspects, which are built-in the silvicultural instructions.
- The technical potential calculated with the advanced spatially explicit method can be used as input to the cost-supply method for stemwood and primary forestry residues (section 3.4.3).

#### Advantages

- The method gives spatially explicit estimates of the biomass potentials and it can be used for different spatial scopes and with different constraints depending on user’s preferences.
- The spatially explicit biomass estimates helps bioenergy operators and politicians to plan courses of action. For example, the estimates give decision support when the locations of the new energy-wood fuelled power and heat plants are planned.
- The method is also fast to carry out when once established.
Disadvantages
- The high spatial resolution of the source data may give a biased impression of the spatial accuracy. The pixel-level errors of the MS-NFI maps are high and, therefore, the location and stand data of an individual stand are also uncertain. However, in the end a user may not be interested in the individual stands, but merely the total potentials. For this purpose, it is believed that the accuracy is high enough.
- The presented method might be challenging, because of the different input data sources. The method relies on the wide field plot network, e.g. NFI plots, which are not necessarily available in every country. In addition, the method is based on biomass maps that are formed with advanced national specific biomass models. Lack of national tree level biomass models might restrict the usability of the method.

Sustainability aspects
Because the presented method produces spatially explicit biomass estimates, various sustainability parameters can be incorporated in the analysis (see chapter 8).
- The method excludes all conservation areas and areas of the Natura2000 network where harvesting is not allowed from the analysis (cf. parameters 1 and 2 in Table 67). In some Natura2000 areas, harvesting is allowed but restricted in a way that harvesting will not endanger the object of conservation. The conservation methods depend on the area and the reason of conservation and the methods are monitored by the different environmental laws, e.g. forest legislation, act on soil excavation, and water law. These laws define what kinds of activities are allowed to be put into practice in the Natura areas. The national nature conservation act usually defines activities that are allowed to be implemented in the areas where common land use is most restricted. This act also defines compensations for land owners of protected areas.
- The buffer zones around the water bodies are defined where harvesting is not allowed because of the risk of the nutrient flow when removing stumps (parameters 8, 21 and 23 in Table 67). In addition, buffer zones can be defined around any other area, e.g. around conservation areas (parameter 4 in Table 67).
- The sustainability criteria are built-in in the present biodiversity oriented harvesting methods and the certificate systems (FSC, PEFC) control the harvesting methods and the quality of the felling. For example, in Finland, most of the commercial forest area (95 %) is certified with PEFC certificate.
- Additional sustainability criteria are listed in chapter 8. The usability of the criteria is case specific and depends on what kind of input data is available in each case.

Future biomass potentials
- Alternative harvesting level scenarios can be used when estimating future potentials. The GIS data are, however, always bound to present or past time.
- When estimating future biomass potentials it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

Key uncertainties and future research needs
- Future studies should search for new and more accurate methods for the tree species detection. E.g. Lidar data might give more precise biomass estimates in the future (see Annex 1).
- Reliable classification for the stand development class would enable estimation of potential from thinnings. With the classification young thinning stands could be separated for estimation of biomass potential.
3.4.3 Stemwood and primary forestry residues - cost-supply method

**Method**
The method involves the calculation of supply costs for woody biomass as well as optimisation of biomass flows between supply and demand sites based on a minimization of the overall cost of the supply chain. Finally, cost-supply curves can be determined by running the optimisation with varying demand levels.

**Supply chains and productivity of work phases**
The analysis is started by defining a (set of) feasible supply chain(s) and related work phases. Next, time consumption (min/m³) (or vice versa productivity (m³/h)) for each work phase is calculated based on time input per output unit. Productivity models based on time study measurements are required to estimate the time consumption of different work phases of the supply chains.

---

**First thinning**

1. Felling & bunching of whole trees by harvester
2. Hauling of whole trees by forwarder
3. Piling at roadside landing
4. Chipping at roadside landing
5. Transportation to plant
6. Transportation to terminal

**Final felling**

7. Integrated bunching of logging residues by harvester while felling
8. Hauling of logging residues by forwarder
9. Bundling of logging residues
10. Hauling of bundles by forwarder
11. Piling at roadside landing
12. Transportation to plant

**Figure 4** An example of a set of feasible supply chains and related work phases.
Source: (Laitila et al. 2008a)

**a) Harvesting**
The work phases of harvesting vary depending on the source of woody biomass. For thinning wood, harvesting includes felling, optionally cross-cutting and bunching. If only stemwood is harvested, the time consumption of delimming should be calculated as well. For logging residues, direct costs of all work phases apart from possible bundling and piling can be allocated to harvesting costs of industrial roundwood. For stump harvesting, moving and processing should be considered. Productivity functions for harvesting can be found in, e.g., (Ranta 2002), (Laitila et al. 2008b; Laitila et al. 2008c).
b) Forwarding to roadside storage (landing)
Time consumption for forwarding of the material to the roadside storage includes loading of material at the harvesting site, driving at the harvesting site during the process of loading, driving with load to the roadside storage, unloading at roadside storage, and driving back to the harvesting site without load. Productivity functions for forwarding have been presented by, e.g., (Ranta 2002), (Laitila et al. 2008b) and (Laitila et al. 2008c).

c) Chipping / crushing
Time consumption for chipping or crushing depends on the raw material, storage and work site arrangements, and chipper type see e.g. (Ranta 2002). If the processing chain is based on terrain chipping instead (chipping at the harvesting site), then time consumption for chipping is already included in the forwarding (b).

d) Bundling of logging residues at the roadside storage (landing)
Logging residues can alternatively be bundled at the roadside. Note that bundling is not necessarily always a feasible work phase. In short distances, transportation of loose residues is a more cost-effective solution. The productivity of bundling has been studied by e.g. (Ranta 2002) and (Kärhä and Vartiamäki 2006).

e) Transportation
Time consumption for long-distance transportation includes loading, driving with the load to the terminal and/or end-use facility, unloading at the end-use facility, optionally loading and unloading during the transport (at the terminal), and driving back to the worksite without load. Driving time can be calculated in GIS, if the average speed for each road section is known (see e.g. (Anttila et al. 2009)). If the average speeds are unknown, only transportation distances are calculated in a GIS. Subsequently, driving times are estimated with models (e.g. (Ranta 2002), (Nurminen and Heinonen 2007)).

In a GIS, the fastest routes from each supply site (a stand) to each demand site (an end-use facility) are calculated. In case the geographical locations of the demand sites are unknown (i.e. the end-use facilities have not been built yet), their locations can be optimized in order to estimate the cost supply curves (e.g. (Leduc et al. 2008)). To reduce the complexity of the task, maximum search radius for each supply site can be pre-determined (e.g. a transportation distance must not exceed 100 km). Another way to simplify the calculation is to aggregate supply sites (Ranta 2002). To aggregate stand-level information to a regional level, all selected stands in a specified search radius (e.g. 10 km) and within a specified aggregation distance are mathematically averaged into one aggregation point (geographical centre) that carries the aggregated stand information.

Procurement costs
All time consumptions (min/m³) for the different work phases are multiplied with the hourly costs (€/h) of resources (manpower, machines, tools) to derive the unit costs (€/m³) for the different working phases. The hourly rates should account for labour costs, operating costs, and capital costs (see Table 18). Labour costs cover wages including side costs and profit margins, capital costs include the depreciation of machines and interest on capital, and operating costs comprise fuel and lubricant costs, maintenance and repair costs, and insurance and administrative costs. Calculation of hourly costs has been described by e.g. (Harstela 1993), (Ranta 2002), (Laitila 2006), (Laitila et al. 2008b).
Table 18 An example of a cost calculation for a chipper. Source: (Röser et al. 2007)

<table>
<thead>
<tr>
<th>Price/Tractor/base machine</th>
<th>0 £</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price/Chipper</td>
<td>30000 £</td>
</tr>
<tr>
<td>Price/Loader</td>
<td>10000 £</td>
</tr>
<tr>
<td>Lifetime/Tractor</td>
<td>10 a</td>
</tr>
<tr>
<td>Lifetime/Chipper</td>
<td>7 a</td>
</tr>
<tr>
<td>Lifetime/Loader</td>
<td>10 a</td>
</tr>
<tr>
<td>Reselling value of tractor</td>
<td>15 %</td>
</tr>
<tr>
<td>Reselling value of chipper</td>
<td>20 %</td>
</tr>
<tr>
<td>Reselling value of loader</td>
<td>15 %</td>
</tr>
<tr>
<td>Management and overheads</td>
<td>2000 £/a</td>
</tr>
<tr>
<td>Insurance</td>
<td>1000 £/a</td>
</tr>
<tr>
<td>Risk</td>
<td>5 %</td>
</tr>
<tr>
<td>Interest rate</td>
<td>5 %</td>
</tr>
<tr>
<td>Salary of workers</td>
<td>20 £/h</td>
</tr>
<tr>
<td>Social expenses, %</td>
<td>60 %</td>
</tr>
<tr>
<td>Price/Fuel</td>
<td>1.0 £/l</td>
</tr>
<tr>
<td>Fuel consumption (chipping)</td>
<td>35 l/hour</td>
</tr>
<tr>
<td>Fuel consumption (transfer)</td>
<td>25 l/hour</td>
</tr>
<tr>
<td>Transfer 100km</td>
<td>4 h</td>
</tr>
<tr>
<td>Transfer cost</td>
<td>1.5 £/l</td>
</tr>
<tr>
<td>Hydraulic oil</td>
<td>1.8 £/l</td>
</tr>
<tr>
<td>Hydraulic oil consumption</td>
<td>0.1 £/h</td>
</tr>
<tr>
<td>Motor oil</td>
<td>1.2 £/l</td>
</tr>
<tr>
<td>Motor oil consumption</td>
<td>0.086 l/hour</td>
</tr>
<tr>
<td>Maintenance 50% of depreciation</td>
<td>1600 £/a</td>
</tr>
<tr>
<td>Work travel</td>
<td>5000 km</td>
</tr>
<tr>
<td>Travel compensation</td>
<td>0.38 £/km</td>
</tr>
<tr>
<td>Effective work hours</td>
<td>417 h/a</td>
</tr>
<tr>
<td>Work hours/shift</td>
<td>8 h/shift</td>
</tr>
<tr>
<td>Workdays/month</td>
<td>15 day/month</td>
</tr>
<tr>
<td>Maintenance time</td>
<td>41.7 h/a</td>
</tr>
<tr>
<td>Transfer time</td>
<td>100 h/a</td>
</tr>
<tr>
<td>Other working times</td>
<td>90 h/a</td>
</tr>
</tbody>
</table>

**Productivity**
- Small size wood (delimbed) 12 m³/h
- Pulpwood 12 m³/h
- Whole tree (with branches) 12 m³/h

**Annual work amount**
- Small size wood (delimbed) 5000 m³

**Fixed costs**
- Total depreciation 4,279 £
- Interest 2,375 £
- Insurance 1,000 £
- Management and overheads 2,000 £
- Fixed costs total 9,654 £

**Variable costs**
- Salaries 20,747 £
- Fuels and oils 18,125 £
- Maintenance 1,600 £
- Travelling 1,900 £
- Risk 2,601 £
- Variable costs total 44,973 £
- Total yearly costs 54,627 £/a
- Total costs per E15 hour 119 £/hour
- Unit cost 11 £/m³
- Green density of wood 660 t/m³
- Cost per green tonne 11 £/t
- Moisture content of wood 50 %

**Energy content of wood**
- Timber with bark 1.8 MWh/m³
- Cost per energy content 6.1 £/MWh

**Technical potential**

The technical potential of forest fuel resources is derived from thinnings and final fellings data at stand level. The volume of forestry residues can be estimated from stem volume (e.g. in forest management plan or inventory results), by applying biomass expansion factors, or by applying the advanced spatially explicit method for stemwood and primary forestry residues (section 3.4.2). Dry mass of forestry residues is converted into cubic metres according to average basic wood density. The lower calorific value of logging residues (in GJ/m³) is calculated based on species and moisture content which can be defined seasonally (see e.g. (Ranta 2002)).

Based on this stand level information, specific stand-level constraints are applied to determine the stands that are available for biomass supply at a desired cost and demand level. The constraints depend on wood fuel demand and procurement costs that the end-user facility is willing to pay. An example of constraints for the economic biomass potential for logging residues is given here (Ranta 2002):
- maximum recovery rate 65%;
- logging residue volume $\geq 40 \text{ m}^3$/stand (after applying recovery rate);
- logging residue density $\geq 30 \text{ m}^3$/ha (after applying recovery rate);
- forwarding distance $\leq 350 \text{ m}$;
- species composition: the share of spruce must be the largest in the total stand volume.

The constraints should be in line with the sustainability parameters defined in Table 65.

**Minimizing regional supply cost**

Now the geographical locations of the supply and demand sites, the volumes (in $\text{m}^3$ or GJ) that can be technically harvested from each supply site, the fuel demand of each demand site, and the supply costs from the supply sites to the demand sites with the selected supply chains, are known. Using a linear programming model, the demand is fulfilled (assuming the supply meets the demand) in a way that minimizes the supply costs in the studied region (see e.g. (Gunnarsson et al. 2004), (Leduc 2009)). The model also takes into account the demand by the forest industry.

The model can be presented by the following formulation (Leduc 2009):

$S$ is the number of supply sites, $P$ the number of demand sites, $F$ the number of biomass based industries (saw mills or pulp mills), $Y$ the number of years and $T$ the number of supply chains. The corresponding sets are:

$$S = \{1, \ldots, S\}, P = \{1, \ldots, P\}, F = \{1, \ldots, F\}, T = \{1, \ldots, T\} \text{ and } Y = \{1, \ldots, Y\}$$

The wood demand $d_{y,j}$ of the demand site $j$ is modelled using the following balance equation:

$$\sum_{i=1}^{S} \sum_{t=1}^{T} b_{i,j,t,y} = d_{y,j}, \quad j \in P, y \in Y.$$  \hspace{1cm} (Equation 3.4.3.1)

The biomass demand $d_{y,f}^{\text{industry}}$ from the industry $f$ has then to be met using biomass from the supply sites. It is then modelled using the following mass balance equation:

$$\sum_{i=1}^{S} \sum_{t=1}^{T} b_{i,f,t,y} = d_{y,f}^{\text{industry}}, \quad f \in F, y \in Y.$$  \hspace{1cm} (Equation 3.4.3.2)

The biomass delivered from site $i$ is restricted by:

$$\sum_{j=1}^{P} \sum_{t=1}^{T} b_{i,j,t,y} + \sum_{f=1}^{F} \sum_{t=1}^{T} b_{i,f,t,y} \leq \tilde{b}_{y,i}, \quad y \in Y, i \in S.$$  \hspace{1cm} (Equation 3.4.3.3)

Where $b_{i,j,t,y}$ is the amount of biomass delivered from supply site $i$ to demand site $j$ by the supply chain $t$ in the year $y$, $b_{i,f,t,y}$ is the amount of biomass delivered from the supply site $i$ to the existing industry $f$, and $\tilde{b}_{y,i}$ is the available biomass the year $y$ at the supply site $i$.

The cost for procuring biomass from supply site $i$ to the demand site $j$ by the supply chain $t$ in year $y$ is $l_{i,j,t,y}$. The cost for procuring biomass from the supply site $i$ to the existing industry $f$ is $l_{i,f,y}$. 

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Given the costs and prices, and given the constraints defined above, the overall cost of the problem is minimized and the mixed integer problem (Wolsey 1998) is defined as:

$$\min_b \left( \sum_{y=1}^{Y} \sum_{i=1}^{S} \sum_{j=1}^{P} \sum_{t=1}^{T} t_{i,j,y} b_{i,j,y} + \sum_{y=1}^{Y} \sum_{f=1}^{S} \sum_{j=1}^{F} \sum_{t=1}^{T} t_{f,j,y} b_{f,j,y} \right)$$

$$b_{y,i,j,t}, b_{f,j,y} \geq 0, \quad y \in \tilde{Y}, i \in \tilde{S}, j \in \tilde{P}, f \in \tilde{F}, t \in \tilde{T}.$$  

(Equation 3.4.3.4)

**Cost-supply curves**

The cost-supply curve here shows the average cost of procuring a certain amount of biomass. The curve can be used further in defining the economic potential. In this method, the curves are estimated by altering the amount of biomass needed by the demand sites. Minimizing regional supply costs with a certain demand level gives the average costs and amounts of biomass supplied between the supply and demand sites. This equals to one point in the cost-supply space. Running the optimization with different demand of the end-use facilities (e.g. with 10% lower demand), gives another point in the cost-supply space. Then the procedure is repeated until the desired demand range has been covered. The curve can then be traced by interpolating different cost-supply points.

![Figure 5 An example of a cost-supply curve](image-url)
Data sources

Table 19 Data sources stemwood and primary forestry residues - cost-supply method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data for calculating hourly costs</td>
<td>Scientific literature, statistics, machine manufacturers, machine entrepreneurs</td>
</tr>
<tr>
<td>Stand-level data on volume of thinnings and final fellings</td>
<td>Forest inventories, Advanced spatially explicit method</td>
</tr>
<tr>
<td>National biomass expansion factors</td>
<td>National forest inventories, scientific literature e.g. (Lehtonen et al. 2004), (Teobaldelli 2009)</td>
</tr>
<tr>
<td>Data from time studies for the work phases of different supply chains</td>
<td>Scientific literature, results of existing studies e.g. (Ranta 2002), (Laitila et al. 2008a) (Kärhä and Vartiamäki 2006), (Nurminen and Heinonen 2007)</td>
</tr>
<tr>
<td>Locations, supply policies and demand levels of regional bio-energy plants</td>
<td>National energy agencies, end-use facilities</td>
</tr>
<tr>
<td>Map on forest roads, long-distance roads, railway (GIS network data)</td>
<td>National and regional cadastral or land survey agencies; forest companies e.g. Digital Chart of the World Data Server, 2008 <a href="http://www.maproom.psu.edu/dcw/">http://www.maproom.psu.edu/dcw/</a></td>
</tr>
</tbody>
</table>

Remarks
Because the method uses rather detailed data, the computational demand grows when the area under consideration increases. Therefore the method is best suited for estimating regional potentials.

Advantages
The method enables determining the economic potential.

Disadvantages
- The method requires very detailed data and productivity models.
- The effect of an optimal number of machines for a single entrepreneur on the costs is not taken into account.
- In reality, there is no single decision maker on a region, which increases the costs from the optimal situation.

Future biomass potentials
- Future biomass potentials can be calculated based on economic scenarios that project future bio-energy demands, future demands for industrial roundwood (amount of fellings), future end-user locations, future prices and supply costs, future supply policies, and future technological development.

Sustainability aspects
- All sustainability aspects documented in the spatially explicit resource-focused assessment methods for stemwood and primary forestry residues (see section 3.4.1 and 3.4.2) should be applied in the here described cost-supply method when analysing the amount and location of supply resources. This means that certain areas should be excluded from stemwood and residue extraction depending on slope, soil parameters and protection status. In addition, the production costs could be adapted by considering certified forest management, i.e. taking into account fees for forest certification.
As an additional option, also social sustainability aspects can be considered in this method by adapting the applied labour costs to national regulations, e.g. regarding minimum wages.

**Key uncertainties and future research needs**

- The lack or uncertainty of data and models pose the greatest risk of using the method. Local productivity functions do not exist in many countries and the data on hourly costs may be weak. There can also be considerable uncertainty in the constraints. Further research should be directed at obtaining more accurate local data and models.
3.5 Secondary forestry residues

The secondary forestry residues (wood processing residues) can be grouped into resource segments following main industry branches: Sawmill by-products, black liquor (residues of the pulp industry) and other industrial wood residues. The residues include various types of biomass originating during industrial processing of timber: e.g. sawdust and cutter chips, bark, slabs, lump wood residues, and black liquor. Secondary forestry residues are a spatially concentrated resource – large amounts of the residues can be available from a single factory. In contrast to other types of forest woody biomass, all secondary forestry residues are technically accessible. Moreover, secondary solid forestry residues usually have lower moisture content than primary forestry residues and, as a result, a higher net calorific value. These features significantly facilitate collection and the energy use of secondary forestry residues.

3.5.1 Secondary forestry residues - basic statistical method

The basic method for estimating available volume of the secondary forestry residues for energy use applies a resource focused approach using production data of forest products and simple statistical analysis. The calculations require information about the wood processing efficiency, i.e. the ratio between the produced amount of final product and the total consumed volume of wood. Moreover, information on the current material and internal energy use of the secondary forestry residues is required to calculate the technical potential. The method does not distinguish between different types of secondary forestry residues. The theoretical potential of secondary forestry residues is:

\[
THP_{SR,x,y} = \sum_{i=1}^{n} (FP_{i,x,y} \times (\frac{1}{E_i} - 1)) - USR_{x,y}
\]

(Equation 3.5.1.1)

Where:
- \(THP_{SR,x,y}\) = theoretical potential of secondary forestry residues for energy use in country \(x\) in year \(y\), (m\(^3\)/year)
- \(i\) = type of wood product (lumber, pulp, wooden construction elements, etc.)
- \(FP_{i,x,y}\) = volume of the produced final product \(i\) in country \(x\) in year \(y\) (m\(^3\)/year)
- \(E_i\) = efficiency of processing for production of \(i\)-product (0-1)
- \(USR_{x,y}\) = volume of secondary forestry residues used for material production (e.g. wood chips, lump wood and bark consumed by board industry) or internally utilised by the wood processing industry as energy source, in country \(x\) in year \(y\) (m\(^3\)/year)

The processing efficiency can be estimated using a residue to consumed wood ratio, often referred to as conversion factors (c.f. Fonseca et al. 2010) or calculated using industry statistics on consumption and production:

\[
E_i = \frac{FP_{i,x,y}}{CW_{i,x,y}}
\]

(Equation 3.5.1.2)

Where:
- \(CW_{i,x,y}\) = volume of wood consumed for production of the final product \(i\) in country \(x\) in year \(y\), (m\(^3\)/year)

Environmental and social constraints do not affect technical potential of secondary forestry residues and economic factors may limit their use only. Thereby, technical potential of secondary forestry residues depends only on recovery ratio. The basic statistical method does not divide secondary forestry residues into different types of materials and therefore average recovery ratio should be used to estimate their technical potential:
TCP _SR$x,y$ = THP _SR$x,y$ × AR  \quad \text{(Equation 3.5.1.3)}

Where:

- TCP _SR$x,y$ = technical potential of secondary forestry residues in country x in year y, (m$^3$/year)
- AR = average recovery ratio of secondary forestry residues, (0-1)

The recovery ratio of secondary forestry residues varies depending on the state of wood processing technologies. When modern technologies are used, up to 98% of secondary forestry residues can be recovered (McKeever 2005).

In most countries of the EU 27, part of secondary residues are derived when processing imported wood (UNECE/FAO 2008). When it is necessary to estimate the potential of secondary residues from processing of only domestic timber, equation 3.5.1.1 can be modified to exclude imported timber from calculations:

\[
THP _{DSR}x,y = \left( \sum_{i=1}^{n} \left( FP_{i,x,y} \times \left( \frac{1}{E_{i}} - 1 \right) - USR_{x,y} \right) \times \left( 1 - SIT_{x,y} \right) \right) \quad \text{(Equation 3.5.1.4)}
\]

Where:

- THP _{DSR}x,y = theoretical potential of secondary forestry residues from processing of domestic timber,
  in country x in year y, (m$^3$/year)
- SIT$_{x,y}$ = share of imported timber used by the wood processing industry in country x in year y, (0-1)

Technical potential of secondary forestry residues from domestic timber is calculated according equation 3.5.1.3 taking into account recovery ratio.

A further simplification to derive a rough estimate of the technical potential is the use of a uniform factor that relates the energy potential expressed in m$^3$ to the totally processed round wood without a differentiation into single utilizations of wood. A general rough estimate for such overall ratio for European countries, provided by (Ericsson and Nilsson 2006), was 25%. Applying this simplified approach, the technical potential of secondary forestry residues results from a multiplication of industrial roundwood with that factor.

**Data sources**

<table>
<thead>
<tr>
<th>Data item</th>
<th>Abbreviation</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production of final products</td>
<td>FP</td>
<td>FAOSTAT</td>
<td>FAOSTAT → ForesSTAT → select: Country, Item, Production Quantity and Year</td>
</tr>
<tr>
<td>Processing efficiency</td>
<td>E</td>
<td>Compilation of conversion factors for the UNECE region published by UNECE/FAO timber section</td>
<td>(Fonseca and Task Force Members 2010)</td>
</tr>
<tr>
<td>Consumption of wood by the processing industry</td>
<td>CW</td>
<td>National and international statistics and studies, national industry associations</td>
<td>e.g. (Hetemäki and Hänninen 2009)</td>
</tr>
<tr>
<td>Average recovery ratio</td>
<td>AR</td>
<td>National industry associations, manufacturer, field studies</td>
<td>e.g. (McKeever 2005)</td>
</tr>
<tr>
<td>Projections of future forest growth, wood harvest, consumption and production of wood processing industries</td>
<td></td>
<td>National and international plans, strategies and studies</td>
<td>e.g. (UNECE/FAO 2003), (Nabuurs et al. 2006), (UN 2009)</td>
</tr>
</tbody>
</table>
Remarks

- The calculation of secondary forestry residues based on the volumes of wood consumed by the industry, shows amounts available under the given circumstances. The theoretical potential of production of secondary forestry residues could be larger in cases where the total production capacity of the industry is larger than the currently utilized capacity. Depending on market conditions, the wood processing industry might in such cases be able to increase its production. As data on production capacity are not generally available, the proposed method uses only production statistics and does not attempt to estimate the larger theoretical potential.

- Estimates of future potentials of secondary forestry residues should take into account projections of future wood consumption by the processing industry and the development of processing capacities in time.

- Processing efficiency may vary significantly even within one country depending on the mill sizes and the applied technology of the wood processing.

Advantages

- The described statistical method offers a straightforward approach to assess theoretical and technical potentials of the secondary forestry residues.

- This method requires relatively little time to conduct an assessment and enables estimates of biomass potentials using a few input data sets and simple calculations.

- The method can be used for different spatial scopes for which required statistics exist – from local up to the global scope.

Disadvantages

- The method is based on wood processing efficiency, which strongly depends on the used processing technology and may vary significantly even within one country.

- Only amounts of main residue generated during the production process can be estimated.

Future biomass potentials

- The method enables estimates of future biomass potentials by the use of assumptions on future changes in wood consumption by the processing industry, wood processing efficiency and recovery ratios.

- When estimating future potentials of secondary forestry residues, it should be kept in mind that projections of future industry wood consumption and production of wood goods published before 2008 do not take into account the impact of the economic crisis in 2008-2009 on the wood processing industry and on the demand of secondary forestry residues for material use.

Sustainability aspects

- When estimating potentials of secondary forestry residues, it is assumed that all sustainability aspects were taken into account during planning of wood supply for the processing industry.

- Utilisation of secondary forestry residues for energy generation instead of landfilling has numerous positive effects on sustainability of resource use. However, quantification of these effects is beyond the scope of this publication.

Key uncertainties and future research needs

- The main uncertainties are introduced by wood processing efficiency factors, which are very variable and also a very sensitive factor. Regular updates of publicly available information about wood processing efficiency will improve quality of assessments of secondary forestry residues.

- Information about the industrial capacity is not readily available in public data sources. Available statistics document the current output of the industry, but do not include data on capacity utilization. Therefore it is difficult to project theoretical potentials into the future.
3.5.2 Secondary forestry residues - advanced statistical method

The advanced statistical resource focused method gives a possibility to estimate amounts of all woody residues (sawdust, bark, slabs, cut-offs, etc.) generated by a production process using production capacities instead of the reported production of wood products. The method applies residue to consumed wood ratio that shows the amount of specific residue generated during processing of one volume or weight unit of raw wood. In addition, the method requires more detailed input data compared to the basic statistical method. Values of residue to consumed wood ratio depend on the used processing technologies, final products, quality of raw wood and even tree species. Therefore, only rough estimations can be found in the literature (Thivolle-Cazat 2008) or obtained from e.g. national wood processing industry associations. Exact values of the ratio can only be derived from a very detailed field study.

The amount of residue can be estimated in the following way:

\[
R_{i,p,x,y} = MW_{p,x,y} \times RCW_{i,x,y} - UR_{i,x,y} \quad (Equation \ 3.5.2.1)
\]

Where:
- \(i\) = type of secondary forest residue (sawdust, slabs, cut-offs, shavings, etc.)
- \(p\) = type of product (boards, beams, pulp, furniture elements, etc.)
- \(R_{i,p,x,y}\) = amount of \(i\)-residue generated during production of \(p\)-product in country \(x\) in year \(y\), (m\(^3\)/year)
- \(MW_{p,x,y}\) = maximal possible consumption of wood for production of \(p\)-product in country \(x\) in year \(y\), (m\(^3\)/year)
- \(RCW_{i,x,y}\) = \(i\)-residue to consumed wood ratio for production of \(p\)-product in country \(x\) in year \(y\)
  (0-1)
- \(UR_{i,x,y}\) = volume of \(i\)-residue used for production of goods (e.g. wood chips, lump wood or bark consumed by board industry) or utilised as energy source by wood processing industry, in country \(x\) in year \(y\) (m\(^3\)/year)

If it is necessary, volume of secondary forestry residues generated from processing of domestic wood and available for energy can be estimated using data on volumes of imported wood consumed by the processing industry.

\[
DR_{i,p,x,y} = R_{i,p,x,y} \times (1 - IT_{p,x,y} / TCW_{p,x,y}) \quad (Equation \ 3.5.2.2)
\]

Where:
- \(DR_{i,p,x,y}\) = amount of \(i\)-residue generated during production of \(p\)-product from domestic wood in country \(x\) in year \(y\), (m\(^3\)/year)
- \(IT_{p,x,y}\) = amount of imported timber for production of \(p\)-product in country \(x\) in year \(y\), (m\(^3\)/year)
- \(TCW_{p,x,y}\) = total amount of timber consumed for production of \(p\)-product in country \(x\) in year \(y\), (m\(^3\)/year)

The theoretical potential of secondary forestry residues is:

\[
THP_{-SFR_{x,y}} = \sum_{i,p=1}^{n} R_{i,p,x,y} \quad (Equation \ 3.5.2.3)
\]

Where:
- \(SFR_{i,x,y,\text{volume}}\) = theoretical potential of secondary forestry residues in country \(x\) in year \(y\), (m\(^3\)/year)
- \(R_{i,p,x,y}\) = amount of \(i\)-residue generated during production of \(p\)-product in country \(x\) in year \(y\), (m\(^3\)/year)
The technical potential of secondary forestry residues depends on recovery ratios of residues:

\[
SFR_{x,y,volume} = \sum_{i,p=1}^{n,m} \left( R_{i,p,x,y,volume} \times RR_{i,p,x,y} \right)
\]

Where:

- \(THP_{SFR,x,y}\) = technical potential of secondary forestry residues in country \(x\) in year \(y\), (m³/year)
- \(R_{i,p,x,y}\) = amount of \(i\)-residue generated during production of \(p\)-product in country \(x\) in year \(y\), (m³/year)
- \(RR_{i,p,x,y}\) = recovery ratio of \(i\)-residue generated during production of \(p\)-product in country \(x\) in year \(y\) (0-1)

### Data sources

<table>
<thead>
<tr>
<th>Data item</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Consumption of wood by the processing industry</td>
<td>CW</td>
<td>National and international statistics and studies</td>
<td>e.g. (Hetemäki and Hänninen 2009)</td>
</tr>
<tr>
<td>Production of final products</td>
<td>FP</td>
<td>FAOSTAT</td>
<td>FAOSTAT → ForesSTAT → select: Country, Item, Production Quantity and Year</td>
</tr>
<tr>
<td>Share of imported industrial wood</td>
<td>SIT</td>
<td>FAOSTAT</td>
<td>FAOSTAT → ForesSTAT → select: Country, Item, Import Quantity and Year</td>
</tr>
<tr>
<td>Residue to consumed wood ratio</td>
<td>RCW</td>
<td>Literature, national industry associations, manufacturers, field studies</td>
<td>e.g. (Thivolle-Cazat 2008), (UNECE/FAO 2009)</td>
</tr>
<tr>
<td>Volume of secondary residues used for production of goods or energy</td>
<td>UR</td>
<td>Statistics, literature, national industry associations,</td>
<td>e.g. (Mantau et al. 2008)</td>
</tr>
<tr>
<td>Recovery ratio</td>
<td>RR</td>
<td>National industry associations, manufacturers, field studies</td>
<td>e.g. (McKeever 2005)</td>
</tr>
<tr>
<td>Projections of future forest growth, wood harvest, consumption and production of wood processing industries</td>
<td></td>
<td>National and international plans, strategies and studies</td>
<td>e.g. (UNECE/FAO 2003), (Nabuurs et al. 2006), (UN 2009)</td>
</tr>
</tbody>
</table>

### Remarks

- The advanced statistical method requires detailed data on the residue to consumed wood ratio, which can be obtained from field studies.
- Depending on market conditions, wood processing industry may consume less wood than it can process. In this case two estimations of potential of secondary forestry residues can be made.
- The first estimation, based on actual volumes of wood consumed by the industry, will show amounts of secondary forestry residues available under the given circumstances.
- The second estimation can be done using data on maximal wood processing capacities of the industry. This estimation will show potential of secondary forestry residues in ideal conditions when processing capacities of the industry are fully utilised.
- Estimates of future potentials of secondary forestry residues should take into account projections of future wood consumption by the processing industry and the development of processing capacities in time.
- Current technical potential of the secondary forestry residues can be estimated using data on current consumption of wood by the processing industry.
Advantages

- The described statistical method allows the estimation of amounts of all secondary forestry residues generated by a production process.
- The method can be used for different spatial scopes for which required statistics exist – from local up to the global scope.

Disadvantages

- The method is based on the residue to consumed wood ratio, which depends on many factors and may vary significantly even within one country.
- The method requires detailed input data, which can be expensive and time consuming to collect.

Future biomass potentials

- The method enables estimates of future biomass potentials by the use of assumptions on future changes in wood consumption by the processing industry, residue to consumed wood ratios, and recovery ratios.
- When estimating future biomass potentials, it should be kept in mind that projections of future wood harvest published before 2008 do not take into account the impact of the economic crisis in 2008-2009 on volumes of fellings and consumption of wood by the processing industry.

Sustainability aspects

- When estimating potentials of secondary forestry residues, it is assumed that all sustainability aspects were taken into account during planning of wood supply for the processing industry.
- Utilisation of secondary forestry residues for energy generation instead of landfilling has numerous positive effects on sustainability of resource use. However, quantification of these effects is beyond the scope of this publication.

Key uncertainties and future research needs

- The main uncertainties are introduced by residue to consumed wood ratios, which are very variable. Regular updates of publicly available information about residue to consumed wood ratios will improve quality of assessments of secondary forestry residues.

3.5.3 Secondary forestry residues - spatially explicit method

The availability of secondary forestry residues (SFR) is spatially concentrated at processing units such as sawmills. The potential of SFR by processing unit is calculated based on statistical methods as described in sections 3.5.1 and 3.5.2 by applying data on the consumption of unprocessed wood by the processing units, the volume of final products in each unit, and the technical residue recovery rate. If such statistics are available by processing unit in combination with GIS data or coordinates on the location of these units, the statistics can be plotted in a spatial explicit way, demonstrating the potential of SFR at the level of processing units. If such detailed data are not available, the potential of SFR can also be shown at the regional or country level by combining regional/national statistics on SFR with GIS polygon data (boundaries) of the respective areas.

However, the described options are just a visualisation of existing statistical data, which neither require a specific spatial assessment nor provide any additional information for the calculation of the potential. Therefore, no method description for a spatially explicit way to estimate the SFR potential is provided here.

Spatially explicit modelling can be useful, though, to carry out further assessments that use statistics on SFR as an input. An example is the GIS based allocation modelling for new pellet factories based on the location of existing sawmills and the amount of sawdust that is generated as a processing residue by the mills. Pellet factories can use the sawdust to produce pellets and thus should be allocated in places with good connections to big sawmills that generate large amounts of sawdust.
3.5.4 Secondary forestry residues - cost-supply method

The aim of the described cost-supply method is to evaluate the economic potential of secondary forestry residues for a bioenergy facility. The method is not suitable for selection of locations of bioenergy facilities and therefore the position of a bioenergy plant should be defined in advance using appropriate methods (see e.g. (Masera et al. 2006); (Ranta 2002; Panichelli and Gnansounou 2008)) or assumed.

The method is designed to estimate the amounts of secondary forestry residues available within given transportation distance from the wood processing facilities to the end-user facility (e.g. combine heat and power plant). The basis of the cost-supply method is comparison of costs of secondary forestry residues with costs of alternative fuels at the utilisation site. The method requires at minimum the following input data:

- price of secondary forestry residues at wood processing facilities
- price of alternative fuels at the utilisation site of secondary forestry residues
- transportation distance between a wood processing facility and the utilisation site of secondary forestry residues
- technical potential of secondary forestry residues in the area of concern (can be calculated as described in sections 3.5.1 and 3.5.2).

Assessment of the economic potential of secondary forestry residues is performed in several steps:

1. Calculation of costs of secondary forestry residues at the utilisation site;
2. Comparison of the costs of secondary forestry residues with the prices of alternative fuels;

**Calculation of costs of secondary forestry residues at the utilisation site**

All calculations shown here are done regarding solid cubic meters and the primary energy content. Bulk density of secondary forestry residues varies depending on the type and for further calculations bulk or loose volumes should be converted into solid volumes using a bulk factor (a solid to loose volume ratio):

\[ SV_i = LV_i \times BF_i \]  
(Equation 3.5.4.1)

Where:

- \( i \) = type of secondary forest residue
- \( SV_i \) = solid volume of \( i \)-secondary forest residue, €/m³
- \( LV_i \) = loose volume of \( i \)-secondary forest residue, €/m³
- \( BF_i \) = bulk factor of \( i \)-secondary forest residue (0-1)

Results of a biomass assessment can be presented as weight, volume and primary or secondary energy. When using the cost-supply method, it is preferable to show the final results in primary energy that shows amounts and costs of energy that can be utilised by a bioenergy facility. Biomass to primary energy conversion factors are used to convert weight or volume units into units of primary energy – joules. Residue-specific conversion factors should be used as much as possible, because the content of primary energy in biomass depends on type of secondary forestry residues.

The costs of secondary forestry residues at the end-user facility depend on many factors. Transportation distance is one of them and it is seldom that transportation of secondary forestry residues is economically feasible for distances longer than 100 km, due to their low bulk density. Therefore, when calculating the total costs of secondary forestry residues, it is recommended to select...
wood processing facilities located closer than 100 km from the bioenergy facility. The total cost of secondary forestry residues is:

\[ C_i = (P_i + TC_i \times T_{i,d}) \times CF_i + \sum_{i,k=1}^{n,m} AC_{i,k} - S_i \]  

(Equation 3.5.4.2)

Where:
- \( k \) = type of additional costs
- \( d \) = distance, 10, 20, 30...n km
- \( C_i \) = total cost of \( i \)-secondary forest residue at end-user facility, €/MJ
- \( P_i \) = price of \( i \)-secondary forest residue at wood processing site, €/m³
- \( TC_i \) = transportation cost of \( i \)-secondary forest residue, €/km/m³
- \( T_{di} \) = transportation distance of \( i \)-secondary forest residue, km
- \( CF_i \) = biomass volume to primary energy conversion factor for \( i \)-secondary forest residue
- \( AC_{i,k} \) = additional costs (costs of loading/unloading work, processing of residues at the end user facility (e.g. drying or chipping), costs of storing, marketing etc), €/MJ
- \( S_i \) = subsidies or other financial incentivises for the use of secondary forestry residues, €/MJ

Transportation cost of secondary forestry residues is:

\[ TC_i = CM_i / L_i \]  

(Equation 3.5.4.3)

Where:
- \( CM_i \) = utilisation cost of the truck used for transportation of \( i \)-secondary forest residue, €/km
- \( L_i \) = amount of transported \( i \)-secondary forest residue by the truck, m³

Description of methods for the calculation of utilisation costs of trucks and the additional costs is beyond the scope of this handbook. Values of these costs can be available at operating bioenergy facilities. If such data are not available, the costs can be calculated (see e.g. (Asikainen et al. 2002; Khanna et al. 2010)) or assumed.

**Comparison of the costs of secondary forestry residues with the prices of alternative fuels**

Transportation distance is one of the main factors that affect the total costs of secondary forestry residues and their economic potential. The total costs of secondary forestry residues should be compared to the price of alternative fuels to see if transportation of secondary forestry residues from the selected wood processing sites is economically feasible or not. If the following inequality is true, then the wood processing facility can be included in the economic potential of the secondary forestry residues:

\[ C_{i,d} \leq PF_a \]  

(Equation 3.5.4.4)

Where:
- \( a \) = type of alternative fuel
- \( PF_a \) = price of alternative fuel at the bioenergy facility

If the total cost of secondary forestry residues is significantly less than the price of alternative fuels, the transportation distance for secondary forestry residues can be increased to extend the catchment area for supply of biomass. In the opposite case, the transportation distance should be decreased.

**Estimation of economic potential of secondary forestry residues**

When the maximal economically feasible transportation distance is know, technical potential of secondary residues for each of the wood processing facilities located within the defined distance is
calculated as described in section 3.5.1 or 3.5.2. The economic potential of secondary forestry residues for the selected bioenergy facility will be the sum of the technical potentials of these wood processing facilities:

$$EP_i = \sum_{f,i=1}^{n,m} TP_{f,i} \quad \text{(Equation 3.5.4.5)}$$

Where:
- \( f \) = wood processing facility
- \( EP_i \) = economic potential of \( i \)-secondary forest residue, MJ
- \( TP_{f,i} \) = technical potential of \( i \)-secondary forest residue from \( f \)-wood processing facility, MJ

### Data sources

<table>
<thead>
<tr>
<th>Data item</th>
<th>Abbreviation</th>
<th>Data source</th>
<th>Exact location</th>
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<tr>
<td>Bulk factors</td>
<td>BF (_i)</td>
<td>Studies</td>
<td>e.g. (FAO 2004)</td>
</tr>
<tr>
<td>Price of residues</td>
<td>P (_i)</td>
<td>Wood processing industry</td>
<td></td>
</tr>
<tr>
<td>Biomass volume to primary energy conversion factors</td>
<td>CF (_i)</td>
<td>Studies</td>
<td>e.g. (FAO 2004; Alakangas et al. 2007)</td>
</tr>
<tr>
<td>Additional costs</td>
<td>AC (_i,k)</td>
<td>Bioenergy producers</td>
<td></td>
</tr>
<tr>
<td>Subsidies and other financial incentives</td>
<td>S (_i)</td>
<td>Bioenergy producers</td>
<td></td>
</tr>
<tr>
<td>Utilisation cost of a truck</td>
<td>CM (_i)</td>
<td>Bioenergy producers, residue suppliers, studies</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks**

- Depending on the type of secondary forestry residues, the method may require conversion from weight of volume measurement units to units of primary energy.
- The method uses various costs as input data, therefore it is important to use the most recent data sources available, because costs are rapidly changing variables.

**Advantages**

- The method offers a relatively simple way to calculate economic potential of secondary forestry residues.
- Flexibility - the economic potentials can be calculated separately for different types of secondary forestry residues.

**Disadvantages**

- The need to convert different measurement units introduces uncertainties into the final results.
- Reliability of results of the cost-supply analysis strongly depends on actuality of input data, especially costs.
- Quality of roads, which also affect transportation costs of secondary forestry residues, cannot be taken into account.
- Impact of competition between bioenergy facilities and other users of secondary forestry residues on their potential cannot be estimated or taken into account.

**Future biomass potentials**

The method is suitable for estimation of future economic potentials of secondary forestry residues. Future potentials can be estimated by including projections on development of wood processing industry, construction of new roads and bioenergy facilities in the analysis.

**Sustainability aspects**

Not relevant, because the method is designed for assessments of economic potentials.
Key uncertainties and future research needs

Key uncertainties are related to conversion factors. Even when using a residue-specific conversion factor, it is not possible to take into account variability of physical properties within one type of secondary forestry residues.

3.6 Conversion of biomass potentials from volume or mass estimates to energy units

3.6.1 Primary forestry residues - conversion from volume units to energy units

When converting the volume based potentials of different primary forest residue types to lower heat values, one should take into account that the energy yield depends on several factors. The most crucial factor is the moisture content of the residue type in question. Other defining factors are the density, type of fuel and tree species.

Total energy potential (Lower Heat Value) of primary forestry residues in GJs is:

\[ LHV_{PFR} = TP_{PFR_{x,y}} \times D \times C_w \]  (Equation 3.6.1.1)

Where:
- \( TP_{PFR_{x,y}} \) = total potential of primary forestry residues (m\(^3\)/year) in country x in year y,
- \( D \) = bulk density of the total potential of primary forestry residues (kg/m\(^3\))
- \( C_w \) = net calorific value of the total potential of primary forestry residues (including water) (GJ/kg)

Table 23 presents the range of lower heat value of different types of primary forest fuels according to their typical moisture content and the bulk densities.

<table>
<thead>
<tr>
<th>Moisture content, %</th>
<th>Logging residue chips</th>
<th>Whole tree chips</th>
<th>Log chips</th>
<th>Stump chips</th>
<th>Coniferous bark</th>
<th>Birch bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 - 60</td>
<td>45 - 55</td>
<td>40 - 55</td>
<td>30 - 50</td>
<td>50 - 65</td>
<td>45 - 55</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bulk density, kg/loose m(^3)</th>
<th>Logging residue chips</th>
<th>Whole tree chips</th>
<th>Log chips</th>
<th>Stump chips</th>
<th>Coniferous bark</th>
<th>Birch bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 - 400</td>
<td>250 - 350</td>
<td>250 - 350</td>
<td>200 - 300</td>
<td>250 - 350</td>
<td>300 - 400</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lower heat value, GJ/kg</th>
<th>Logging residue chips</th>
<th>Whole tree chips</th>
<th>Log chips</th>
<th>Stump chips</th>
<th>Coniferous bark</th>
<th>Birch bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.006 - 0.009</td>
<td>0.006 - 0.009</td>
<td>0.006 - 0.01</td>
<td>0.006 - 0.01</td>
<td>0.006 - 0.01</td>
<td>0.006 - 0.01</td>
<td>0.007 - 0.01</td>
</tr>
</tbody>
</table>

Source: (Alakangas 2005)

3.6.2 Secondary forestry residues - conversion from volume units to energy units

When converting the volume based potentials of different secondary forest residue types to lower heat values, the conversion factors differ from primary forestry residues due to different moisture contents, etc.

Total energy potential (Lower Heat Value) of secondary forestry residues in GJs is:
\[ LHV_{SFR} = TP_{SFR_{x,y}} \times D \times C_W \] (Equation 3.6.2.1)

Where:
- \( TP_{SFR_{x,y}} \) = total potential of secondary forestry residues (m\(^3\)) in country \( x \) in year \( y \), (m\(^3\)/year)
- \( D \) = bulk density of the secondary forestry residues (kg/m\(^3\))
- \( C_W \) = net calorific value of the secondary forestry residues (including water) (GJ/kg)

### Table 24 Lower heat values of different types of secondary forestry residues

<table>
<thead>
<tr>
<th>Moisture content, %</th>
<th>Wood residue chips</th>
<th>Saw residue chips</th>
<th>Sawdust</th>
<th>Cutter chips</th>
<th>Grinding dust</th>
<th>Plywood residue</th>
<th>Uncovered wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 - 50</td>
<td>0.006</td>
<td>0.006</td>
<td>0.013</td>
<td>0.016</td>
<td>0.017</td>
<td>0.017</td>
<td>0.012</td>
</tr>
<tr>
<td>45 - 60</td>
<td>0.006</td>
<td>0.006</td>
<td>0.013</td>
<td>0.016</td>
<td>0.017</td>
<td>0.017</td>
<td>0.012</td>
</tr>
<tr>
<td>45 - 60</td>
<td>0.016</td>
<td>0.016</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 15</td>
<td>0.016</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 15</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 15</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 - 30</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk density, kg/loose m(^3)</td>
<td>150 - 300</td>
<td>250 - 350</td>
<td>250 - 350</td>
<td>80 - 120</td>
<td>100 - 150</td>
<td>200 - 300</td>
<td>150 - 250</td>
</tr>
<tr>
<td>Lower heat value, GJ/kg</td>
<td>0.015</td>
<td>0.011</td>
<td>0.016</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Source: (Alakangas 2005)

### 3.7 Future research needs

**Stemwood and Primary Forestry residues (statistical methods)**
- Harmonisation of the national forest inventories would improve the consistency (sections 3.2.1, 3.2.2, 3.3.1, 3.3.2).

**Stemwood and Primary Forestry residues (spatially explicit methods)**
- Future studies should search for new and more accurate methods for tree species detection. E.g. LIDAR data would give more precise biomass estimates in the future (section 3.4.2).
- Further research should be directed at obtaining more accurate local data and models (section 3.4.3).

### 3.8 Improvement of data sources

- The availability of statistics for trees outside forests (TOF) at the broader scale is low. An approach to assess TOF using automatic detection with LIDAR data was developed by (Straub et al. 2008) and (Straub 2010). This cost efficient technique to assess the physical potential and to locate the resource in regional to national level studies.

**Stemwood and Primary Forestry residues (statistical methods)**
- Differences between national forest inventory procedures cause inconsistencies in forest statistics within the EU. Harmonisation of the national forest inventories would improve the consistency (sections 3.2.1, 3.2.2, 3.3.1, 3.3.2).
- Effort is needed to collect data to allow for calculation of more reliable factors for converting stemwood removals to felling volumes (sections 3.2.1, 3.3.1).
- Biomass expansion factors are highly variable between species and countries. Effort is needed to collect the data to enable calculation of the more reliable biomass expansion factors for different species and countries (sections 3.3.1, 3.3.2, 3.4.1).
- Data on current utilization of stemwood and primary forestry residues in private households needs improvement, as such removals are currently not included in official statistics (sections 3.2.1, 3.3.1).
Stemwood and Primary Forestry residues (spatially explicit methods)

- Proposed thresholds for residue and stump removal need further refinement at a regional scale and should be revised for each country separately under consideration of national recommendations for residue and stump harvest (section 3.4.1).
- The method described in section 3.4.1 could be improved by using more detailed environmental data on site suitability and main technical constraints (e.g. forest accessibility, mechanisation rate). In addition, the consideration of economic constraints and social constraints such as wood mobilization rate depending on forest ownership would help to refine the resulting map on biomass potential.

Stemwood and Primary Forestry residues (cost-supply method)

- For the cost-supply method (section 3.4.3), the lack or uncertainty of data and models pose the greatest risk. Local productivity functions do not exist in many countries and the data on hourly costs may be weak. There can also be considerable uncertainty in the constraints.

Secondary Forestry residues (statistical methods)

- The main uncertainties are introduced by wood processing efficiency factors, which are very variable and also a very sensitive factor. Regular updates of publicly available information about wood processing efficiency will improve quality of assessments of secondary forestry residues (section 3.5.1).
- Data on capacity utilization are not readily available, but also very sensitive information for the industry.
- The main uncertainties are introduced by residue to consumed wood ratios, which are very variable and also a very important factor. Regular updates of publicly available information about residue to consumed wood ratios will improve quality of assessments of secondary forestry residues (section 3.5.2).

Secondary Forestry residues (cost-supply method)

- Key uncertainties are related to conversion factors. Even using a residue-specific conversion factor, it is not possible to take into account variability of physical properties within one type of secondary forestry residues (section 3.5.4).
4 Energy crops

4.1 Scope and definitions

Scope
In this chapter, approaches and methods for estimating the present and future potential of biomass energy from annual and perennial crops are presented. All approaches and methods are suitable for all types of energy crops.

Five main types of energy crops can be distinguished, and are further classified as annual (a) or perennial (p) crops:
- Oil containing crops: like sunflower (a), rape (a), soy (a), oil palm (p), jatropha (p)
- Sugar crops: like sugar cane (p), sugar beet (a), sweet sorghum (a)
- Starch crops: like corn (a), wheat (a), barley (a), cassava (a)
- Woody crops: like poplar (p), eucalyptus (p)
- Grassy crops: like miscanthus (p), switchgrass (p).

Woody energy crops are also considered in chapter 3 “Forestry and forestry residues”. In this chapter short rotation coppice (SRC) production systems are considered, while in chapter 3 short rotation forestry (SRF) is included. In an SRC plantation, trees are planted in much higher densities compared to in an SRF system. After harvesting, an SRF needs to be replanted, whiles an SRC crop would regenerate as new growth emerges from the original stools (stumps).

Three approaches for estimating the present and future theoretical, technical and economic potentials of biomass energy crops are discussed. These three are statistical analysis, spatially explicit analysis, and cost-supply analysis. All three focus on the resources available for energy crop production. Typically, only “surplus agricultural land” is allowed to be used for energy crop production, i.e. land that is not needed for other purposes. Surplus agricultural land may include different categories, e.g. set-aside land, abandoned agricultural land, marginal land and low productive land (for definitions, see Table 25). In this handbook, the concept of surplus land is a theoretical construct that is derived by subtracting the amount of land needed for feed, food and biomaterial production from the total available area. It has to be noted that from a strict economic point of view, this kind of surplus land does not exist. As soon as prices enter the analysis, there is no surplus land since this term refers to land that has no value, i.e. which is not scarce. However, this simplification is necessary for doing simpler statistical and spatially explicit analyses which are based on a certain amount of land allocated to biomass for energy production. More advanced modelling approaches and integrated assessment models are needed to include market prices and mechanisms and thus to reflect land allocated to different uses (including energy crops) in a more realistic way.

In chapter 7 agricultural and energy-economics and energy-system model analyses and integrated assessment models are discussed.

In this chapter the potential of energy crops is evaluated using the following equation:

\[ P = \sum (A_i \times Y_i) \] (Equation 5.2.1)

Where:
- \( P \) = potential of energy crops i (tonne)
- \( A_i \) = area surplus agricultural land suitable for energy crop i (ha)
- \( Y_i \) = yield energy crop i (t/ha)

Because bioenergy crop production is not allowed to compete with food crop, only surplus agricultural land and land that is not suitable for food or feed production are considered. Also other sustainability
criteria that are listed in Annex 3 are integrated in the methodologies to estimate the potential of energy crops.

**Definitions of energy crops**

Table 25 provides definitions related to energy crops, which are frequently used and are therefore proposed to be used in future biomass potential assessments. However, we acknowledge that these definitions are not always applicable or useful. The reasons are that the definitions in Table 25 are derived from the databases of the United Nations Food and Agricultural Organisation (FAO) and from the European Commission (EC), but in some cases data from other sources might be more useful, accurate or reliable and consequently also accompanying definitions from other sources need to be used.

Furthermore, it should be noted that some of the definitions overlap. For example, degraded land might partially overlap with agricultural land, and degraded land typically is often of poor quality and might therefore be classified as marginal land. Therefore, it is crucial that definitions are clearly specified in any bioenergy potential assessment and that, if data from different sources are used, the definitions are checked for consistency.

**Table 25 Definitions of energy crops**

<table>
<thead>
<tr>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy crop</td>
<td>An energy crop is a crop grown specifically for its fuel value.</td>
</tr>
<tr>
<td>Crop land</td>
<td>Crop land can be called gross area as against the net area, which includes only the portion of the gross area actually cultivated. (FAO 2008) [<a href="http://faostat.fao.org">http://faostat.fao.org</a> -&gt; Glossary -&gt; Glossary (list)]</td>
</tr>
<tr>
<td>Area sown</td>
<td>Refers to the area on which sowing or planting has been carried out, for the crop under consideration, on the soil prepared for that purpose. The area is usually reported net of uncultivated patches, footpaths, ditches, headlands, shoulders, shelterbelts, etc. For tree crops, the gross concept may be applied. (FAO 2008) [<a href="http://faostat.fao.org">http://faostat.fao.org</a> -&gt; Glossary -&gt; Glossary (list)]</td>
</tr>
<tr>
<td>Area harvested</td>
<td>The fraction of the area sown that is harvested. N/a</td>
</tr>
<tr>
<td>Permanent crops</td>
<td>Permanent crops is the land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees, which should be classified under &quot;forest&quot;). (FAO 2008) [<a href="http://faostat.fao.org">http://faostat.fao.org</a> -&gt; Glossary -&gt; Glossary (list)]</td>
</tr>
<tr>
<td>Permanent pastures and meadows</td>
<td>Permanent meadows and pastures is the land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). (FAO 2008) [<a href="http://faostat.fao.org">http://faostat.fao.org</a> -&gt; Glossary -&gt; Glossary (list)]</td>
</tr>
<tr>
<td>Fallow agricultural land or set aside land</td>
<td>Arable land not under rotation that is set at rest for a period of time ranging from one to five years before it is cultivated again, or land usually under permanent crops, meadows or pastures, which is not being used for that purpose for a period of at least one year. Arable land which is normally used for the cultivation of temporary crops, but which is temporarily used for grazing is included. (EU 2008)</td>
</tr>
<tr>
<td>Degraded land</td>
<td>A wide variety of definitions is used in the literature, see further UNE (UNE 2008). One of these definitions is: land where the balance between the attacking forces of climate and the natural resistance of the terrain against these forces has been broken by human intervention, resulting in a decreased current and/or future capacity of the soil to support human life. These and most other definitions imply that crop yields on degraded areas are reduced compared to fertile soils, although this aspect is usually not included in the definition. Note that this definition (partially) overlaps with the definition of marginal land that is given below. (Oldeman 1994)</td>
</tr>
<tr>
<td>Marginal land</td>
<td>Marginal land is land of poor quality with regard to conventional agricultural use, and unsuitable for housing and other uses. This definition is modified from the original modified from (OECD 2009a)</td>
</tr>
</tbody>
</table>
source, in which marginal land is also unsuitable for housing and other uses. The term marginal seems to refer to the yield and also to the economic profitability of conventional agriculture, i.e. the productivity of these areas is low / marginal compared to the productivity of areas that are used for conventional agriculture. Because of this rather unclear definition we propose to use the term low productive land, which refers only to the productivity of the land and not to the economic aspects.

| Low productive land | Land with a low productivity for conventional agriculture. Note that the term low productive land and marginal land are both not entirely unambiguous, as technological developments can increase the productivity of these areas. | N/a |

### 4.2 Energy crops - statistical method

#### Basic method
Two categories of land are considered for the production of energy crops that do not compete with the production of food, as stipulated in the sustainability criteria outlined in Annex 3. These two categories are:

- Surplus agricultural land, i.e. land that is not needed any more for the production of food and feed crops or for other purposes;
- Degraded or low productive land, i.e. land that is not suitable or no longer suitable for conventional commercial agriculture.

#### Surplus agricultural land
Surplus agricultural land includes set-aside land and abandoned agricultural land.

In Europe, set-aside was introduced as a political measure by the European Union (EU) in 1988 to (1) help reduce the large and costly surpluses produced in Europe under the guaranteed price system of the Common Agricultural Policy (CAP); and (2) to deliver some environmental benefits following considerable damage to agricultural ecosystems and wildlife as a result of the intensification of agriculture. This has now been abolished and set-aside land is therefore no longer included in the statistics of the EC.

Another type of surplus agricultural land is abandoned agricultural land. Statistics on abandoned agricultural land are usually not available, because abandoned agricultural land is usually not left idle, but used for other purposes and thus not classified as surplus land. Therefore, data on abandoned agricultural land typically refer to a decrease of the area of agricultural land.

Specific attention should be paid to the difference between the total area classified as ‘cropland’ and the ‘harvested area’ (Table 25) when calculating the area surplus agricultural land. Compatibility of the two data-sets can be evaluated indirectly by computing the ratio of area harvested to cropland, i.e. the cropping intensity (CI). This is also an important parameter that can signal defects in the land use data. The cropping intensity in West Europe and North America is typically in the range of 0.6-0.7, which indicates that the difference between arable land and harvested areas is too large to be ignored when investigating biomass energy potentials. Cropping intensities larger than 1 are also possible, in case of multiple harvests (double or triple cropping).

#### Degraded and low productive land
The rationale for using these areas is that these areas are not suitable for conventional agriculture and that these areas can be used for bioenergy production without competition with the production of food. However, competition with food production is in reality an economic issue, but economic aspects are not investigated in the basic statistical method. Especially the term marginal seems to refer to the economic dimension, even more than the terms low productive or degraded land, which directly refers to the productivity of the land in comparison to other areas. Therefore we suggest to use the terms degraded and low productive and avoid the term marginal land.
The simplest best-practice basic statistical method to estimate the potential of degraded and low productive land is to use statistics in combination with estimations of the yields of energy crops on these areas (similar to the equation above) (see further Figure 6). Yet, to identify degraded land and abandoned farmland, which could potentially be used for sustainable biomass production, a further differentiation of “degraded” is needed:

- Identification of degraded land. An important bottleneck is that data are scarce and notoriously uncertain (Sonneveld and Dent 2009). Several studies are available on soil erosion (Oldeman 1994), (EEA 2000), but time series about the extent and severity of degradation are not available and the uncertainty about these data is high.
- Identification of abandoned farmland, in order to verify that the land does not contribute to the supply of food and feed or to the well-being of local people. Especially the use of these areas for extensive grazing requires attention. If not, then energy crop cultivation is possible if the land fertility is adequate.
- Check possible overlap with high nature value areas (including buffer zones and corridors).
- Check if biomass production on land under consideration might halt ongoing regeneration, and if its conversion to natural habitats would be a more beneficial use. The fourth step refers to the expected effects of the intended energy cultivation on soil carbon and ecosystem function. Hence, the fourth step is not part of the identification process, and not shown in Figure 6.

![Figure 6 Steps to identify degraded and abandoned farmland for potential bioenergy feedstock production](image)

Data about the productivity of degraded or low productive types of land are typically not readily available from statistical databases. Ideally, the productivity is evaluated taking into account the specific soil or climate conditions. This can be done using crop growth models, field measurements or by using statistics that are corrected for degradation or by estimating the impact of soil quality on the
yields that are reported in literature. Also field trials and expert judgement are important sources of information.

**Advanced method**
The advanced method follows the same approach as the basic method. The main difference is that higher resolution data are used, more parameters are included and that more attention is paid to sustainability issues, as further described in chapter 8 and in the section below on future biomass potentials.

**Data sources**
Historic data on land use (e.g. crop land, permanent pastures, build-up land, forests) and on crop yields of conventional crops are publically available from various databases (Eurostat (EU 2008) and FAOSTAT (FAO 2008)). For most countries also national sources are available. Data on the future use of land for food, feed and wood and future crop lands can be taken from existing forecasting studies or can be calculated as described above. For land degradation various data sets are available as further described in the ‘Data Sources Handbook’.

**Table 26 Data sources for estimating the potential of energy crops using the statistical method.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demography</td>
</tr>
<tr>
<td></td>
<td>Population projections</td>
</tr>
<tr>
<td></td>
<td>indicators -&gt; Natural resources -&gt; Built-up areas</td>
</tr>
<tr>
<td>Crop production (area and production)</td>
<td>(EU 2008) <a href="http://epp.eurostat.ec.europa.eu/">http://epp.eurostat.ec.europa.eu/</a> -&gt; Statistics -&gt; Search for agriculture -&gt;</td>
</tr>
<tr>
<td></td>
<td>Agricultural products -&gt; Crop products</td>
</tr>
<tr>
<td>Land use</td>
<td>(FAO 2008) <a href="http://faostat.fao.org/">http://faostat.fao.org/</a> -&gt; Resources -&gt; ResourceSTAT -&gt; Land</td>
</tr>
<tr>
<td>Animal products (production and number of animals)</td>
<td>(EU 2008) <a href="http://epp.eurostat.ec.europa.eu/">http://epp.eurostat.ec.europa.eu/</a> -&gt; Statistics -&gt; Search for agriculture -&gt;</td>
</tr>
<tr>
<td></td>
<td>Agricultural products -&gt; Animal production / Poultry farming / Milk and milk products</td>
</tr>
<tr>
<td>Soil degradation</td>
<td>(Oldeman 1994) <a href="http://www.isric.org/UK/About+ISRIC/Projects/Track+Record/GLASOD.htm">http://www.isric.org/UK/About+ISRIC/Projects/Track+Record/GLASOD.htm</a></td>
</tr>
<tr>
<td>Food demand projections and agricultural land use projections</td>
<td>(Bruinsma 2002; FAO 2006a) EU Ruralis <a href="http://www.eururalis.eu/">http://www.eururalis.eu/</a> (Rounsevell et al. 2006)</td>
</tr>
<tr>
<td>Productivity of the animal production system</td>
<td>(Wirsenius 2000) (Bouwman et al. 2006)</td>
</tr>
<tr>
<td>Productivity of land</td>
<td>(IIASA and FAO 2002) <a href="http://www.iiasa.ac.at/Research/LUC/SAEZ/index.html">http://www.iiasa.ac.at/Research/LUC/SAEZ/index.html</a> -&gt; Plates or</td>
</tr>
<tr>
<td></td>
<td>Spreadsheets</td>
</tr>
</tbody>
</table>

Many more datasets are potentially useful, as further described in the ‘Data Sources Handbook’.

**Advantages**
An advantage of this method is that it is relatively simple and straightforward, and therefore relatively easy to carry out, with limited tabular data and simple software (Excel) and at limited costs (unless detailed calculations of the use of animal feed are included). The methodology and results are therefore transparent, easy to understand and can therefore be easily communicated to different stakeholders.
Disadvantages
A disadvantage is the lack of detailed, bottom-up analysis of the underlying factors that determine the availability of land. Also the lack of integration of different scenario variables is a clear disadvantage, but also the evaluation of crop yields is often based on expert judgement and thus uncertain.

Future biomass potentials
Crucial underlying variables for estimating the area of surplus agricultural land are thus the growth of the population, the demand for food, the efficiency with which food is produced and the productivity of land. The availability of surplus land is calculated using the equation below. It should be noted that the various types of land use can be varied depending on the desired level of detail and availability of data. Further, the area of land that is available for bioenergy is multiplied by the yield of energy crops, which is estimated using statistics, expert judgement, field studies, etc.

\[
\text{ABioEnergy}_{t,c} = \text{AAgric}_{c} - \text{ABuiltUp}_{t,c} - \text{ANature}_{t,c} - \text{AOther}_{t,c} - \text{AFood}_{t,c} - \text{AFeed}_{t,c} \quad [\text{ha}]
\]

(Equation 4.2.1)

\[
\text{ABioEnergy}_{t,c} = \text{the area of land that is available for bio-energy production in future year } t \text{ of country } c
\]

\[
\text{AAgric}_{c} = \text{the area of agricultural land in country } c \text{ in base year}
\]

\[
\text{ABuiltUp}_{t,c} = \text{the area of agricultural land that is converted into built-up land between the base year and the future year } t \text{ in country } c
\]

\[
\text{ANature}_{t,c} = \text{the area of agricultural land that is converted into natural vegetation between the base year and the future year } t \text{ in country } c
\]

\[
\text{AOther}_{t,c} = \text{the area of agricultural land that is converted into other land between the base year and the future year } t \text{ in country } c
\]

\[
\text{AFood}_{t,c} = \text{the area of agricultural land required for the production of food between the base year and the future year } t \text{ in country } c
\]

\[
\text{AFeed}_{t,c} = \text{the area of agricultural land required for feed production in the base year and the future year } t \text{ in country } c
\]

\[
\text{APast}_{t,c} = \text{the area of pastures required for feed production in the base year and the future year } t \text{ in country } c
\]

\[
t = \text{future year } t
\]

\[
c = \text{country } c
\]

There are various ways in which future use of land can be estimated. In the case of the basic statistical method we propose not to undertake any calculations to project future land use patterns. Projections can be taken from existing studies or calculated by combining projections from literature of the underlying drivers of land use change. If such data are not available an advanced statistical method is needed whereby calculations need to be carried out to estimate future land use patterns.

An example of an advanced statistical method to estimate future potentials is shown in the figure below (taken from the REFUEL project (Fischer et al. 2007a)). Various studies have shown that the future efficiency of crops and animal production are crucial parameters that deserves specific attention. High(er) efficiencies limit the use of land for food production and thus increase the availability of land for energy crop production. Therefore, detailed calculations of the future use of land for food and feed need to be carried out. It is not possible to formulate detailed calculation procedures, because the choice of the calculation procedure depends largely on the availability of data, the desired level of detail, the importance of parameters for certain regions and therefore the need for detailed calculations, and the availability of existing projections that limits the need for these detailed and time-consuming calculations. However, a generalized calculation procedure is shown in the figure below. Important is that the scenario assumptions are consistent and clearly defined. Preferably also intermediate results are shown to facilitate comparison with other studies.
The calculation procedure starts from estimating future food demand separately for a) vegetarian food from cereals, b) vegetarian food from other crops, c) livestock products from ruminants and d) livestock products from other livestock. Food demand (or domestic use) described as a function of population number and per capita food consumption levels is first converted to domestic production levels using self-sufficiency ratios or trade forecasts. Domestic production and consumption levels depend on trade. Commodities may stem from domestic production and from imports and some commodities are exported. Trade can be included by assuming a self-sufficiency ratio (SSR), which describes the relationship between domestic production and domestic use and is defined as the ratio of domestic production over domestic use. An alternative is the use of existing projections. Vegetarian food production levels can directly be related to cultivated land area requirements via crop yields.

**For domestic livestock production, feed requirements are calculated with the help of livestock energy balances or data about feed conversion and feed composition (see also Table 26).** Because of different types of land area requirements, a distinction between two livestock animal groups is essential, namely ruminants and other livestock. Ruminants rely on both feed crops from cultivated land and feed from grazing on pasture land. The use of pasture land is also estimated using energy balances or data about feed conversion and feed composition. In contrast, other livestock, primarily pigs and poultry, are only raised with feed crops, but ideally these categories are also evaluated separately. The use of land for the production of food and feed crops is evaluated by estimating crop yields using statistics, field studies or expert judgement.

After the availability of land for energy crop production is determined, the yield of energy crop needs to be estimated to determine the total biomass energy potential. Yield estimations can be done using a variety of approaches. Examples are the use of expert judgement, the extrapolation of historic yields, and the use of results from field and pot trials. These methods are suitable, as long as up-to-date data are used and provided that the results are based on realistic estimates. This is especially crucial when degraded and marginal areas are considered (see also Figure 6). Also, the crop management system can be an important factor when evaluating the yields. Furthermore, it is recommended that the uncertainties are analysed and that the calculations are checked with estimates from literature.
**Sustainability aspects**

Various sustainability parameters can be included in the basic statistical method, as long as data are available (see further Annex 3). A crucial included sustainability factor is that only surplus agricultural land and degraded and low productive land are considered. In addition, certain areas need to be excluded, such as Nature 2000 areas, legally protected areas, and wetlands. Moreover, the conversion of pastures is not allowed in Europe. These sustainability issues have an important spatial component, but can only be included in the statistical method if statistical data are available about the overlap of these areas with the surplus agricultural land and degraded and low productive land. Such detailed data are usually not available and can be investigated preferably by means of spatially explicit analyses. Furthermore, the sustainability criteria mentioned in Annex 3 state that the conversion of pastures to cropland in the EU is not allowed. However, also pastures can be harvested for energy production.

**Key uncertainties and future research needs**

An important uncertainty is the quality of data about degraded and low productive soils. The estimation of current and especially future yields of energy crops is also typically a source of uncertainty and is therefore a key target for future research. The efficiency of the animal production systems and the productivity of pastures is a key target for future research too, considering the large areas that are needed for the production of animal products.

### 4.3 Energy crops - basic and advanced spatially explicit method

**Basic method**

Resource-focused spatially explicit methods are comparable to the resource-focused statistical methods, except that spatially explicit data are used instead of tabular data. Data on the availability of surplus agricultural land are usually not available and need to be estimated by calculating future land use patterns. Data about the availability of degraded and low productive land are available from various databases (see Table 27), although the quality is often poor. A key advantage of spatially explicit analyses is that the yield of crops can be evaluated in more detail using crop growth models that use data on soil and climate.

**Advanced method**

The best practice advanced method is virtually identical to the basic method, except that the number of factors or the level of detail that is considered is higher and thereby also the complexity of the analyses. Data on the availability of surplus agricultural land are usually not available and need to be estimated by calculating future land use patterns. Data about the availability of degraded and low productive land are available from various databases (see Table 27), although the quality is often poor. It is not practical to formulate detailed calculation procedures, because the choice of the calculation procedure depends largely on the availability of data, the desired level of detail, the importance of parameters for certain regions and thereby the need for detailed calculations. The availability of existing projections also limits the need for detailed and time-consuming calculations. Important is that the scenario assumptions are consistent with each other and that the scenario assumptions are clearly defined in the text. Preferably, also intermediate results are shown to facilitate comparison with other studies. However, a generalized calculation procedure is shown in Figure 7.

**Data sources**

In principle, a wide variety of data types are potentially useful: geodata, earth observation data, but also statistical data on land use and crop yields. The number of parameters for which data are required varies widely depending on the complexity of the assessment with respect to the number of factors that are included. Examples are: crop production, harvested area, land use, vegetation cover, climate and soil data, population density, grassland productivity, infrastructure, roads, livestock density, feed conversion efficiency, animal off-take rates, irrigation infrastructure, and agricultural management. A
few of the most important data resources are listed in Table 27, although many more publicly available data sources can be found on the internet (see also the Data Sources Handbook).

Table 27 Data sources for estimating the potential of energy crops using the spatially explicit analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-up areas</td>
<td>Global Land Cover Characterisation <a href="http://edc2.usgs.gov/glcc/glcc.php">http://edc2.usgs.gov/glcc/glcc.php</a></td>
</tr>
<tr>
<td>Permanent pastures</td>
<td></td>
</tr>
<tr>
<td>Crop distribution</td>
<td>(Ramankutty and Foley 1998), see also <a href="http://www.sage.wisc.edu/iamdata">http://www.sage.wisc.edu/iamdata</a></td>
</tr>
<tr>
<td>Productivity of land</td>
<td>(IIASA and FAO 2002) <a href="http://www.iiasa.ac.at/Research/LUC/SAEZ/index.html">http://www.iiasa.ac.at/Research/LUC/SAEZ/index.html</a> -&gt; Plates or Spreadsheets</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Conservation International Biodiversity hot spots</td>
</tr>
</tbody>
</table>

Advantages
An important advantage of using spatially explicit data over statistical methods is that the availability of land for energy crop production can be calculated. This avoids errors compared to statistical analysis, because of the productivity of the land (and especially the impact of the availability of water) is explicitly considered. Data, taken from various resources, do not have to be heterogeneous within administrative units like statistical data

Disadvantages
A disadvantage is the lack of integration of different scenario variables, but also the evaluation of crop yields is often based on expert judgement and thus uncertain. Also, the complex software and the availability of reliable and high resolution spatial data can be a limiting factor. Especially advanced spatially explicit analyses in which many scenario variables are included can be complex and time consuming. Such analyses require experienced personnel and the models are difficult to use by others.

Future biomass potentials
Future biomass potentials are investigated in the same way as in the statistical analysis, except that spatially explicit analyses are required. The basic method enables the evaluation of both present and future biomass potentials of energy crops using existing projections. In the advanced method also bottom-up calculations are carried out.

Sustainability aspects
Sustainability parameters can be included in the basic statistical method, as long as data are available (see further Annex 3). Specific areas can be excluded (e.g. wetlands, Natura2000 areas, high biodiversity areas, areas with steep slopes) and the yield of crops can be corrected for adaptations in management. Furthermore, crop growth models can also be used to compare land management systems and their effects on water, nitrogen, phosphorus, and green house gas emissions. Biophysical crop yield models typically integrate a large number of biophysical processes and allow assimilation of earth observation products allowing for global calibration of environmental impact assessments. Major components of these models are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. In addition to biophysical processes, models using this advanced method simulate different management systems and their effects on water, carbon, and nutrient cycling. Management can include crop rotations, crop/grass mixes, tillage operations, irrigation scheduling, drainage, furrow diking, liming, grazing, burning operations, tree pruning, thinning and clear cut harvest or regeneration cuts, manure handling, and fertilizer and pesticide
application rates and timing. An example of a biophysical crop model is the Environmental Policy Integrated Climate (EPIC) model (Izaurralde et al. 2006), (Williams 1995).

**Key uncertainties and future research needs**

An important uncertainty is the availability and current use of degraded and marginal soils for which data are typically scarce and uncertain. This also goes for the yields that can be realised on these areas. Furthermore, the estimation of future yields of energy crop is typically a source of uncertainty and therefore a key target for future research. Crop growth models allow an estimation of the agro-ecologically attainable crop yields, assuming a certain management system, but such models do not include yield projections. Also, the efficiency of the animal production systems and the productivity of pastures is a key target for future research, considering the large areas that are needed for the production of animal products.

### 4.4 Energy crops - cost-supply method

**Method**

Cost-supply analyses start with a bottom-up analysis of the potential from surplus agricultural land and degraded and low productive land as described in the previous sections. The resulting bioenergy supply curves are combined with estimates of the costs of the production of the energy crops and of the conversion of biomass to final energy. The costs can be calculated following Figure 8 below.

![Figure 8 Schematic overview of cost factors in the agricultural production system.](image)

Indicated in light grey are input parameters that are assumed to be constant, indicated in darker grey are variables that are assumed to be subject to change as described in the scenario development. Source: (De Wit et al. 2008)

Data about the costs of land, labour, machinery, agro-chemicals and other inputs need to be collected. When the costs of the final energy carriers are estimated, the costs of transportation and conversion
need to be taken into account too. Transportation of biomass can be a crucial factor for the economic performance, which can be investigated using spatially explicit data on the availability of biomass for energy, combined with data on the costs of transportation and the location of the facilities where the biomass will be converted into bioenergy. Spatially explicit data and analysis are thus crucial for the optimisation of biomass production chains. Another important issue is the value of co-products and residues from the production of energy crops and from the conversion of biomass into bioenergy. The resulting cost supply curves are then compared with other energy systems or policy alternatives, often with specific attention for policy incentives (e.g. tax exemptions, carbon credits, and mandatory blending targets).

Data sources
Data on the price of labour, fertilizers, land, seed and fuels are available from various statistical databases, such as the Eurostat and FAOSTAT databases and crop or chain specific studies (Table 28). These data are combined with estimations or assumptions about future prices. Data about the costs of machinery and biomass processing plants can be estimated from existing literature or by using cost assessment handbooks or advanced engineering software.

Table 28 Data sources for estimating the potential of energy crops using the cost supply method

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour costs</td>
<td>LABOURSTA (ILO 2008) <a href="http://laborsta.ilo.org/">http://laborsta.ilo.org/</a> -&gt; By topic -&gt; Main statistics (annual) wage by economic activity, in manufacturing or wages and hours of work in 159 occupations</td>
</tr>
<tr>
<td>Fertilizer costs</td>
<td>Eurostat -&gt; Agriculture -&gt; Agricultural prices and price indices</td>
</tr>
<tr>
<td>Land prices</td>
<td>Eurostat -&gt; Agriculture -&gt; Agricultural prices and price indices</td>
</tr>
<tr>
<td>Oil price projections</td>
<td>(IEA 2008b)</td>
</tr>
<tr>
<td>Costs of energy conversion technologies</td>
<td>IEA Energy Technology Perspectives 2008 (IEA 2008a)</td>
</tr>
</tbody>
</table>

It should be noted that it goes beyond the scope of this report to list all relevant data sources. Many more datasets that include data on prices and costs are potentially useful, as further described in the ‘Data Sources Handbook’.

Advantages
The method is relatively straightforward and therefore relatively easy to carry out with limited tabular data and simple software (Excel) and at limited costs. The methodology and results are therefore transparent, easy to understand and can therefore be communicated easily to different stakeholders.

Disadvantages
A crucial disadvantage is that the competition for land, labour, machinery, agro-chemicals and other inputs are not considered. Competition might have an impact on the prices.

Future biomass potentials
Future supply curves can be estimated as described in the previous sections. Future costs can be estimated using projections of prices or using assumptions. Furthermore, also the development of technology and technical learning can have a large impact on bioenergy cost supply curves. This goes especially for the production of second generation biofuels from lignocellulosic biomass via gasification and enzymatic hydrolysis.

Sustainability aspects
Various sustainability criteria can be included when estimating the supply curves, as further described in Sections 4.2 and 4.3. Furthermore, the impact of sustainability criteria can also be investigated by estimating the additional costs associated with compliance with certain sustainability criteria, e.g. by assuming a lower yield in case organic agriculture or a less intensive management system is needed. However, such analyses are typically problematic due to a lack of data and experience in this field, although an exception is organic agriculture, with which there are decades of experience.
Key uncertainties and future research needs

Key uncertainties are the estimations of future prices, which are highly uncertain. Furthermore, data about the price of land are typically scarce and uncertain, because land prices depend on the soil quality, the availability of irrigation and other infrastructure. Also, the impact of technological developments and technological learning on the costs of biomass energy crop production is uncertain, especially with respect to new energy crops.

4.5 Future research needs

Based on the previous sections it can be concluded that future research should especially focus on the following issues, which are crucial to enhance the reliability and accuracy of biomass energy potential assessments:

- Degraded and marginal soils. Experiences with (re)cultivation and knowledge of degraded and marginal soils (that represent a wide diversity of settings) are limited. More research is required to evaluate the severity and type of soil degradation, because at this moment only coarse resolution datasets are available. Research and demonstration activities required to understand the economic and practical feasibility of using degraded/marginal land is needed.

- The current use and the availability of degraded and marginal soils. Data on the present use of degraded and marginal soils are typically not included in statistics. Such data can be derived by comparing maps of degraded areas with data on land use or vegetation cover. A limiting factor is that the resolution of data on soil degradation is much lower than of the data on land use or vegetation cover, which make it problematic to determine the current use of degraded areas. Data on marginal areas are usually also not readily available. However, crop growth models that use data on soil and climate in combination with data on crop management can provide insight into the areas marginal lands.

- The future yields of energy crops, especially on degraded and low productive areas. Experiences with new energy crops are limited to a few experimental field trials, so additional research is required to improve estimates of future yields. Crucial thereby is the crop management system and the availability of water, which can be evaluated using crop growth models in combination with expert judgement. Furthermore, yields on degraded and marginal soils are also highly uncertain, due to a lack of experience.

- The feasibility of increasing the efficiency of agricultural production systems. The efficiency of agricultural production systems is a crucial parameter for the availability of land for energy crop production. It is important that further insight is gained into the dynamics of increases in the efficiency of the agricultural production systems and the feasibility of such developments.

- The dynamics and efficiency of the animal production system. The production of animal products is very land intensive because of the losses when converting feed crops into animal products and because of the large pasture areas that are involved. Further research is required to investigate the turnover of biomass in the animal food sector. Typically only statistics on the amount of feed crops and hectares of pasture land are available, but data on the total biomass throughput and land use dynamics are scarce, especially in relation to estimations of the feasibility of increases in the efficiency of the animal production system.

- The future costs of energy crop production. The future costs of energy crop production are highly uncertain due to the uncertain changes in the costs of land, labour, fuel and other inputs, but also due to the uncertainties when estimating crop yields. Last but certainly not least, the costs of compliance with sustainability criteria are typically not investigated.

- The impact of technical developments and technical learning. Both aspects can be crucial for the overall performance, but data is scarce, except for some bioenergy systems, and therefore deserve further attention.

Furthermore, more detailed analyses are needed to allow an evaluation of the impact of energy crop production on water and biodiversity, which is further described in Section 8 on sustainability.
4.6 Improvement of data sources

A wide variety of data is used in statistical and spatially explicit methods, which need improvement, as partially already discussed in the previous section. This goes especially for data on:

- The extent of degraded and low productive soils
- The current use of degraded and marginal soils
- The dynamics and feasibility of changes in the efficiency of the agricultural production system
- The efficiency and biomass turnover in the animal production system
- The use and carrying capacity of pastures in the animal productions system.

Furthermore, there is a need for better spatially explicit data, such as earth observation data or data from geographic information systems. The data sets used in the studies for that propose are characterised by relatively long update cycles in the range of 10 years and by coarse mapping resolutions. Several EU and global projects aim to update and improve earth observation data with respect to spatial, spectral and thematic accuracy and consistency of these data sets. In fact, the situation is already improved compared to that of past years. Also, the availability of standardised earth observation data sets is important, since they can build the basis for direct mapping or estimation of the physically available biomass at high spatial resolution.
5 **Agricultural residues**

5.1 **Scope and definitions**

**Scope**
In this chapter, methods estimating the biomass potential from agricultural residues are described. Agricultural residues include a wide variety of biomass types, which can be divided into three main classes:

- Primary agricultural residues, like straw of wheat, barley, oat, corn, rice etc. that remain after harvesting in the fields.
- Secondary agricultural residues, like bagasse, rice husks, sunflower husks, nut shells, coffee and cocoa bean shells, kidney bean shells and similar biomass, arise after processing of the primary crops.
- Manure like pig, cattle and chicken manure.

**Definitions**
Agricultural residues include crop residues remaining in fields after harvest (primary residues) and processing residues generated from the harvested portions of crops during food, feed, and fibre production (secondary residues). Secondary residues are generally more easy to collect since they are released at a central processing facility, while primary residues have to be collected from the fields. Industrial by-products and residues that originate from biological, chemical or thermal processes like for instance DDGS from ethanol production and glycerine from biodiesel production, are excluded from the category secondary agricultural residues. Manure is organic matter used as organic fertilizer in agriculture. Animal manure can be available as a liquid (farm slurry) or in a more solid form. Manure can be collected centrally from stables if intensive livestock rearing systems are applied. Manure from animals in the field is difficult to collect and therefore not included in the technical potential. The relevant definitions are presented in Table 29.

<table>
<thead>
<tr>
<th>Biomass type</th>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>Consists of animal urine and faeces, wasted feed and bedding collected to put into the digester as influent.</td>
<td>Penn State University, Dept. of Agricultural &amp; Biological Engineering; <a href="http://www.biogas.psu.edu/terminology.html">http://www.biogas.psu.edu/terminology.html</a></td>
</tr>
<tr>
<td>Industrial by-products and residues</td>
<td>Food/feed processing residues that originate from biological, chemical or thermal processes (not included in the Methods Handbook).</td>
<td>(Perlack et al. 2005)</td>
</tr>
</tbody>
</table>
Other relevant definitions

Table 30 Other relevant definitions related to agricultural residues

<table>
<thead>
<tr>
<th>Biomass type</th>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural by-products, agricultural residues</td>
<td>Biomass by-products originating from production, harvesting, and processing in farm areas.</td>
<td>(FAO 2004)</td>
</tr>
<tr>
<td>Crop production by-products, crop production residues</td>
<td>Agricultural by-products originating from crop production, harvesting, and processing in farm areas. It includes for instance wood, straw, stalks, and husks.</td>
<td>(FAO 2004)</td>
</tr>
</tbody>
</table>

5.2 Primary agricultural residues

Regarding primary agricultural residues (PAR), the most important type of agricultural biomass available for bioenergy is straw. It is left after the harvesting of mainly cereals and other annual lignocellulosic crops. The parameters that affect the straw potential are the area of land covered by these crops and the amount of straw produced per hectare or tonne of crop. Competitive uses reduce the straw potential for bioenergy like the use for litter and animal feeding. Other types of residues that should be included in the category of primary residues are the products of cultivation process (e.g. fruit trees prunings). The potential of primary residues could be reduced in case environmental and sustainability issues would be taken into account, like the remaining of residues on the agricultural terrain for recycling of nutrients.

5.2.1 Primary agricultural residues - basic and advanced statistical method

Basic statistical method

The theoretical potential of annual crop residues, like cereals, are estimated on the basis of cultivated area, and agricultural production (AP) in tonnes per hectare, for each specific crop and average product to residue ratios (PtR).

\[ THP_{\text{PAR}} = \sum (CA_i \times AP_i \times PtR_i \times Av_i) \] (Equation 5.2.1.1)

Where:
- \( PAR \) = primary agricultural residues (e.g. straw, stalks), in tonnes
- \( CA_i \) = cultivated area of i crop, in hectares (ha)
- \( AP_i \) = agricultural production of i crop, in tonnes per hectare (t/ha)
- \( PtR_i \) = product to residue ratio of i crop
- \( Av_i \) = availability of residues for i crop according to current harvesting system

Alternatively, the potential of crop residues can be estimated on the basis of cultivated area, and residue yields for specific crops, derived from literature.

\[ THP_{\text{PAR}} = \sum (CA_i \times RY_i \times Av_i) \] (Equation 5.2.1.2)

Where:
- \( PAR \) = primary agricultural residues (e.g. straw, stalks), in tonnes
- \( CA_i \) = cultivated area of i crop, in hectares (ha)
- \( RY_i \) = residues yields of i crop, in tonnes per hectare (t/ha)
- \( Av_i \) = availability of residues for i crop according to current harvesting system
The estimation for fruit tree prunings is based on an average of prunings per tree (Pr) for specific cultivations. The number of trees (TNumb) per hectare is recommended to estimate the residues potential per hectare.

\[
THP\_\text{PAR}_{pr} = \sum \left( TNumb_{i} \times Pr_{i} \times Av_{i} \right) \quad \text{(Equation 5.2.1.3)}
\]

Where:
- \( PAR_{pr} \) = primary agricultural residues (prunings), in tonnes
- \( TNumb_{i} \) = number of trees per hectare of \( i \) crop (n/hectare)
- \( Pr_{i} \) = residues yields per tree of \( i \) crop, in tonnes (t)
- \( Av_{i} \) = availability of residues for \( i \) crop according to current harvesting system

The technical potential of the various primary residues can be calculated by taking into account maximum extraction rates to reserve soil quality and alternative uses (like livestock bedding).

\[
TCP\_\text{PAR}_{i} = THP\_\text{PAR}_{i} \times EX_{i} \times UF_{i} \quad \text{(Equation 5.2.1.4)}
\]

Where:
- \( TCP\_\text{PAR}_{i} \) = technical potential of crop \( i \)
- \( THP\_\text{PAR}_{i} \) = theoretical potential of crop \( i \)
- \( EX_{i} \) = maximum sustainable extraction rate (soil)
- \( UF_{i} \) = use factor (taking into account alternative uses of the residue)

In order to ensure the productivity of agricultural land and to avoid reduction of organic matter in the soil, only part of the residues should be harvested for bioenergy purposes. In a basic statistical approach, \( EX_{i} \) and \( UF_{i} \) are taken into account by a single sustainability factor. For \( EX_{i} \), a value of 0.25 or 0.33 has often been used, arbitrary chosen. For \( UF_{i} \) it is assumed that almost one third of the harvested straw has to be used in animal husbandry (Ericsson and Nilsson 2006).

**Advanced statistical method**

In the advanced statistical method, basically more attention is paid to the sustainable extraction rates and use factor. The alternative uses of the crop residues should be evaluated carefully. In order to obtain justifiable sustainable extraction rates, a humus balance method could be applied, calculating the amounts of primary residues that can be extracted while maintaining sustainable carbon and nitrogen levels in the soil. The humus balance method makes it possible to determine the balance between humus supply and humus demand. The “humus saldo” reflects the net effect on humus content, “humus supply” refers to organic matter supply from plant residues and organic fertilizers and “humus demand” denotes the decrease of soil organic matter due to mineralization. The parameters ‘humus supply’ and ‘humus demand’ are attained by using humus reproduction coefficients (hrc) allotted to crops and fertilizers (Brock et al. 2008). If regionalised information is available on the humus balance, it could be used to determine sustainable harvest levels of straw for energy uses. For illustration purposes, the assessment of \( hrc \) based on (Brock et al. 2008) is worked out below. The assessment of \( hrc \) is based on the carbon (C) inputs from biomass in combination with organic fertilizers and nitrogen (N) mineralisation (Brock et al. 2008). For the harmonization of units, the \( k \) factor is used to convert humus-N to humus-C units.

\[
hrc = C_{h} - N_{h} \times k \quad \text{(Equation 5.2.1.5)}
\]

Where:
- \( hrc \) = humus reproduction coefficient (kg C/ha)
- \( C_{h} \) = C from organic input contributing to humus build-up (kg C/ha)
- \( N_{h} \) = mineralization of N from the humus pool (kg N/ha)
- \( k \) = conversion factor of mineralized humus-N (kg N/ha) to mineralized humus-C (kg C/ha)
The estimation of the C input takes into account the C potential from different parts of plants and their humification rates.

\[
C_H = C_R \cdot h_R + C_{RT} \cdot h_{RT} + C_{EX} \cdot h_{EX} + C_{RE} \cdot h_{RE} \quad \text{(Equation 5.2.1.6)}
\]

Where:

- \( C_{R,RT,EX,RE} \) = C input from roots (R), root turnover during the vegetation period (RT) and root exudates (EX) or plant residues (RE) (kg C/ha)
- \( h_{R,RT,EX,RE} \) = humification rate for a defined organic substrate input (factor)

The estimation of N mineralisation is influenced by the N in plants biomass, the N inputs from the atmosphere (symbiotic fixation, deposition) and fertilisers, the N utilization rate and the net change of mineral N in soil.

\[
N_H = \left( N_{PB} - N_{dfs} - N_D \cdot w_{P,D,FERT} - N_{FERT} \cdot w_{P,FERT} \right) / w_{P,H} + \Delta N_{min} \quad \text{(Equation 5.2.1.7)}
\]

Where:

- \( N_{PB} \) = N in plant biomass as identified by crop yields (kg N/ha)
- \( N_{dfs} \) = N derived from the atmosphere by symbiotic fixation (kg N/ha)
- \( N_{D,FERT} \) = mineral N from atmospheric deposition (D) and fertilisation (FERT) (kg N/ha)
- \( w_{P,D,FERT,H} \) = whole plant utilisation rate for N from a defined source pool (factor)
- \( \Delta N_{min} \) = net change of mineral N in soil solution during cropping period (kg N/ha)

Finally, the estimation of technical potential of PAR is based on the theoretical potential of primary agricultural residues (\( THP_{PAR} \)), the humus reproduction coefficient, and alternative uses. The humus reproduction coefficient for specific types of crops was estimated (Brock et al. 2008).

**Data sources**

**Table 31 Data sources primary agricultural residues - basic statistical method**

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trees for specific crops</td>
<td>Literature</td>
<td><a href="http://ec.europa.eu/environment/etap/pdfs/bio_energy.pdf">http://ec.europa.eu/environment/etap/pdfs/bio_energy.pdf</a></td>
</tr>
<tr>
<td>Sustainability factor</td>
<td>Literature</td>
<td>Example: RENEW deliverable D.5.01.03 at <a href="http://www.renew-fuel.com/fs_documents.php">http://www.renew-fuel.com/fs_documents.php</a>, click on EC_BREC - Residue biomass potentials - Country profiles</td>
</tr>
<tr>
<td>Use factor - availability of residues for animal</td>
<td>Literature</td>
<td>Example: RENEW deliverable D.5.01.03 at <a href="http://www.renew-fuel.com/fs_documents.php">http://www.renew-fuel.com/fs_documents.php</a>, click on</td>
</tr>
</tbody>
</table>
### Humus reproduction coefficient

<table>
<thead>
<tr>
<th>Husbandry</th>
<th>EC_BREC - Residue biomass potentials - Country profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock units</td>
<td>National statistics</td>
</tr>
</tbody>
</table>

### Remarks

- Factors and ratios used in this method were estimated in previous research activities for specific areas. If there are relevant factors available for other areas or previous ones have been updated, it is recommended to use those.

### Advantages

- The basic resource-focused statistical method for primary agricultural residues is easy for implementation, thanks to the simple equation used and availability of core data on national and international databases. Especially data for cultivated areas of crops and agricultural production for specific crops are freely available on international databases, like Eurostat and FAOSTAT.
- Additional parameters like product to residue ratio, residue yields, number of trees for fruit crops and availability of residues for bioenergy have been studied previously. Results of these studies can be provided by literature.
- In the advanced statistical method the sustainable extraction rates are underpinned by analyses.

### Disadvantages

- The ancillary parameters, used in estimating the potential of residues, were defined in previous research studies in specific areas, under specific environmental, soil and climatic conditions for specific varieties of species and under specific cultivation and harvesting techniques. In order to manage the lack of information and data for other agricultural conditions, it is recommended to use these parameters in areas with similar conditions with the previously studied ones. It must be mentioned that these parameters should be updated under rules and specific rotation.
- The consideration of sustainable extraction rates in the advanced method can be quite complex, since soil conditions etc. may vary from area to area.

### Future biomass potentials

- The agricultural sector is affected by several factors. The agricultural production could be influenced by market issues, the diet of the population, the land use change, and climatic conditions (e.g. precipitation). As a result, the biomass potential of produced residues could be changed. The development and use of specific models in which all important parameters are included, is the key issue in order to make future projections concerning the estimation of this potential in a pre-defined time frame. Land use and its changes are monitored by the European Environmental Agency (EEA). The project is updated every ten years and related changes are also available to the public by the EEA’s website. Climate data can be provided by the European Climate Assessment & Dataset (ECA&D) project. The ECA dataset contains information and updates of observations from 3126 meteorological stations throughout Europe and the Mediterranean. Daily data are also available and a web-based GIS provides spatial information after registration by the user.
- Possible increment of cereal yields in the future does not result in a proportional increase the production of PAR, since ongoing plant breeding leads to less straw per tonne of grain produced (Ericsson and Nilsson 2006). Additionally, as the area used for energy crops increases, the cereal and maize crop areas are reduced by an equivalent area. The land use change is not included in this method.
Sustainability aspects

- Only a part of PAR are available for harvesting to avoid depletion of organic matter in the soil and ensure the potential of nutrients in agricultural lands and their productivity in the long terms. See for instance the Renew project.
- In an advanced statistical approach, sustainability is taken into account in a more detailed manner. Regarding cultivation and crop management, the practice must focus on optimum exploitation of residues but with attention on negative impacts on soil in order to secure minimum soil erosion and protection of soil quality (nutrients content, porosity, etc.). A humus balance method can take this into account. Additionally, the potential of available water should be taken into account, to avoid overexploitation of water resources.
- In order to estimate the future agricultural areas available for residues exploitation, it should be taken into account that the conversion of grasslands, wetlands or wooded lands must be limited.
- For an overview of sustainability issues to be considered in the assessment of primary agricultural residues see also section 8.4 and Annex 3.

Key uncertainties and future research needs

- The agricultural sector is influenced by several factors. The market of agricultural products, the availability of resources (e.g. water, nutrients), productivity issues, diet of population, modification of varieties. Several factors used in the method to estimate the biomass potential of primary agricultural residues can be changed.
- The update of these factors, based on field trials, as well as the update of data sources, must be continuous in order to secure more accurate and reliable estimation of biomass potential.
- Future plant breeding for increment of cereal yields will not necessarily increase the residue production, since ongoing research focuses on optimising grain production, lowering straw production per tonne of grain. This issue must be taken into account in future biomass resource assessments.

5.2.2 Primary agricultural residues - basic spatially explicit method

Method

A basic spatially explicit method to estimate the availability of primary agricultural methods is to use (statistical) crop yield data on a regionalised level and to determine the straw yields accordingly. The straw yield can be determined taking into account the effect that cereal varieties with higher production yields have a relatively higher share of grains in the total mass of the plant. Therefore, when the yield of grain per hectare is increased, the yield of straw per tonne of grain is decreased. This can be expressed in a function (Edwards et al. 2005):

$$Straw = Grain \times 0.769 - 0.129 \times \arctan((Grain - 6.7)/1.5)$$  (Equation 5.2.2.1)

The straw to grain ration has no stable value but it ranges from a maximum of 0.94 to a minimum of 0.62. This equation is used not only for wheat straw but for barley straw as well. The total theoretical potential is estimated by using the straw yields in combination with data provided by Eurostat for the agricultural products and crops (yields, area and production).

Results are joined with GIS data of Eurostat’s NUTS2 regions (vector data) producing a map of the total straw in tonnes per region (Edwards et al. 2005).

The produced straw quantities are not entirely available for bioenergy. Environmental constraints and competitive uses must also be taken into account. A part of the straw should remain on the terrain of agricultural land with unfavourable soil conditions for recycling of nutrients (fertilizing). Additionally, straw is used for animal feeding and bedding.
The straw potential used for animals could for instance be estimated according to the following equation (Edwards et al. 2005):

\[
SUPH = 2 \times \left(1 - \exp\left(-\frac{SPPH}{2}\right)\right) \quad \text{(Equation 5.2.2.2)}
\]

Where:
- \(SUPH\) = straw used per head, in tonnes per head
- \(SPPH\) = total straw produced per head in the region, in tonnes per head

The straw potential available for bioenergy is estimated by subtracting the total harvested straw and the straw available for competitive uses. The result is a map, in the scale of a region presenting the net surplus straw potential for bioenergy.

All these results are distributed, based on classification of NUTS2 regions. In order to prepare the data for use in cost supply methods, for instance to calculate transport distances to future bioenergy plants, the results could be converted into 5x5 km grid information as used in CLC2000 (Corine Land Cover 2000). The new result provides information about the spatial distribution of straw potential only for cells that are classified in the CLC2000 file as arable land.

### Data sources

| Table 32 Data sources primary agricultural residues - basic spatially explicit method |
|-----------------------------------------------|---------------------------------|---------------------------------|
| **Data item**                                 | **Data source**                 | **Exact location**              |
| Complementary data: Agro-technical and environmental aspects of straw; effects of straw collection on soil fertility; competitive use of straw; energy-technology options; transport costs; case studies on existing bioenergy installations. | Studies; Papers; national reports; regional studies; direct communication with research and regional authorities. | |

### Remarks

Complementary data provided by studies, papers and reports must be reviewed before using them. Possible updates of these data should be used.

### Advantages

Spatially explicit methods give us the opportunity to plot the biomass resources of agricultural residues and identify locations where these residues are produced. Necessary data are collected under the same scale (NUTS2 regions) and given the advantage of joined processes between numeric and geodata, making further processing feasible. The conversion of vector data onto grid cell data provides the opportunity for spatial analysis (e.g. based on distance) between data of different features, like land use and straw production. Produced maps are easier to understand by users of the results.
Disadvantages
The straw potential available for fertilizing is not considered. So, environmental limitations are not taken into account. The classification of agricultural land in general classes is not so detailed and only general information about arable land is available.

Future biomass potentials
The future biomass potential depends on the future state of the agricultural sector, regarding land use and land cover change, distribution and area of crop species, production and yields. The basic method estimates the current potential of residues based on current data and does not provide any future projection.

Sustainability aspects
- Regarding environmental issues on agro-residues resource assessments, the land included in the Natura2000 areas and buffer zones between cultivated land and areas of high biodiversity value should be excluded in the method for residues potential estimation.
- Environmental parameters like organic matter content, water level, degradation of soils and climate change should be taken into account in order to estimate the sustainable potential of residues.

Key uncertainties and future research needs
It is not defined that all arable land is used for cereals crops. The deviation of arable land in specific species of cereals could provide more detailed results. Effects of systematic collection of straw from agricultural areas and environmentally sensitive soils must be studied on site for different types of areas and soils. Studies on straw potential that should remain on site should be also addressed.

5.2.3 Primary agricultural residues - advanced spatially explicit method

Method
It is possible to use satellite data to detect the areas of crops that are covered by straw after harvest, or areas of olive trees. In the EOBEM project (EOBEM 2001) such information is presented based on high resolution images of the IKONOS satellite in combination with sampling plots.

The image processing of satellite data, which was produced after the harvesting of grain, can detect the area of the crops that is covered by straw and bare soil. The use of these results in combination with establishment of sampling plots will result in estimation of crop residues, in tonnes per hectare. With this advanced method the number of fruit trees can be estimated, alternatively, by counting trees with the use of remote sensing and IKONOS images.

This method has been developed to classify and recognize the fruit trees and to produce a tree counting map (the method was tested for olives trees). It accepts in input a vegetation map and the following parameters: minimum and maximum radiometric value of the top of the fruit trees, tree dimension (in pixels), variance threshold, and a filter dimension.

The image model is defined by both geometric and radiometric aspects. The geometric aspects consist of the crown envelope shape and the sensing geometry. The radiometric aspect consists of the scene irradiance, the interaction of the scene irradiance and the tree crown, and the sensor irradiance.

It works according to the following three steps (EOBEM 2001):
1. Smoothing filter to enhance the peaks of the top of the trees
2. Peaks of the top of the trees extraction
3. Pattern recognition for detection of fruit trees and marking.
Figure 9 Output of IKONOS image process
Olive trees are marked by dots and pine trees by crosses. Source (EOBEM 2001)

Data sources

Table 33 Data sources primary agricultural residues - advanced spatially explicit method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical data of agricultural production for EU at level 2 of NUTS</td>
<td>Eurostat</td>
<td><a href="http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/">http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/</a></td>
</tr>
<tr>
<td>Complementary data: Agro-technical and environmental aspects of straw;</td>
<td>Studies;</td>
<td></td>
</tr>
<tr>
<td>collection to soil fertility; competitive use of straw; energy-technology options; transport costs; case studies on existing bioenergy installations</td>
<td>Papers;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>regional studies; direct communication with research and regional authorities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>National and international authorities; literature</td>
<td></td>
</tr>
<tr>
<td>Transportation network; transportation cost; location of bioenergy plants</td>
<td>National and international authorities; literature</td>
<td></td>
</tr>
</tbody>
</table>

Remarks
There are several vector data about transportation networks available to use, but their supply is not ensured. Additionally, it is not sure that these data were created under the same framework of specifications (e.g. scale).

Advantages
- The availability of primary data.
- Logistics are applied via network analysis.
Disadvantages
- The supply of vector data about the transportation network is not ensured. The use of spatial analysis, as an alternative method for logistics, provides results with lower accuracy. The advanced method inherits disadvantages of the basic method.
- There is no significant literature about methods using satellite images to estimate the potential of straw on site.
- The method is not common practice.

Future biomass potentials
- CLUE-s is a spatially explicit model that simulates the land use change based on competition between different land uses and the use of spatial allocation rules and environmental policies. The allocation of biofuel areas is also accounted for and results from the LEITAP/IMAGE model are imported. Country-specific location factors and quantified indicators, like the biodiversity index, N-surplus, carbon sequestration and soil degradation, are used in simulations. Europe-specific results are available on NUTS2-level and even at a scale of 1X1 km.
- The demand for urban and agricultural area and changes in nature and forest area are also conducted (Eickhout and Prins 2008).

Sustainability aspects
- The land included in the Natura2000 areas (http://www.eea.europa.eu/data-and-maps/data/natura-2000) and buffer zones between cultivated land and areas of high biodiversity value should be excluded in the method for residues potential estimation. Buffer zones are easy to be plotted through spatial analysis on a GIS.
- In order to estimate the future agricultural areas available for residues exploitation, we should take into account that the conversion of grasslands, wetlands or wooded lands must be limited because of the protection of highly biodiverse areas. Land cover and land cover change can be provided by the EEA (http://www.eea.europa.eu/data-and-maps/data#c5=all&c0=5&b_start=0&c11=landuse).

Key uncertainties and future research needs
Possible lack of vector data about transportation networks will reduce the accuracy of results. The use of satellite data in the estimation of residues is definitely no common practice so far. So, further research is recommended.
5.2.4 Primary agricultural residues - cost supply method

Method

The main objective of this method is the establishment of cost-supply curves for primary agricultural residues in order to decide how much of the technically available potential of biomass can be exploited at feasible price. It includes the costs of primary residue collection and transportation. Information on the technical biomass potential is retrieved from the (basic) spatially explicit method. The production cost is assessed in specific data and assumptions for future estimates. The main factors used in this approach are: the labour costs, capital costs and land rental costs. Other factors, related to production costs, are the productivity and the relative cost of labour and capital. Land productivity is provided by literature and agricultural databases (like the databases of FAOSTAT and Eurostat).

The following parameters must be taken into account, in order to estimate the production cost of energy produced by residues:

- Primary biomass residue collection and acquisition costs
- Transport costs

The residues cost \( C_{\text{res}} \), in Euros per GJ, is given by the following equation:

\[
C_{\text{res}} = \frac{p_k \cdot \lambda_r \cdot K_r + p_{\lambda} \cdot \lambda_r \cdot L_r + p_A}{Y_i} \quad \text{(Equation 5.2.4.1)}
\]

Where:
- \( C_{\text{transport}} \) = the cost of collected residues (Euro/GJ)
- \( P_k \) = the interest rate
- \( p_r \) = the price of labour
- \( p_A \) = the price of land (set at zero if not allocated to residues)
- \( \lambda_r \) = the cost reduction factor
- \( L_r \) = the required labour, in man-hours per hectare and year
- \( K_r \) = the required capital, in Euros per hectare and year
- \( Y_i \) = the biomass yield in GJ/ha/year

The cost of the biomass transport \( C_{\text{transport}} \), is given by the following equation:

\[
C_{\text{transport}} = \frac{p_{\text{pl}} + T + D \cdot \tau \cdot F_r}{B_i} \quad \text{(Equation 5.2.4.2)}
\]

Where:
- \( C_{\text{transport}} \) = the cost of transport (Euro/GJ)
- \( p_{\text{pl}} \) = the price of labour, in Euro/load
- \( T \) = the fixed transport cost, in Euro/load
- \( D \) = the distance (can for instance be set at 50 km)
- \( \tau \) = the transport cost per litre
- \( F_r \) = the fuel consumption (liter/km)
- \( B_i \) = Biomass transported (in GJ)

The drawing of cost-supply curves in a simple chart, where biomass quantities and production costs represent the two axes, and the evaluation of production costs of energy produced from the use of other fuels, give the opportunity to detect the biomass potential that can be exploited for electricity production at feasible costs.
Data sources

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land productivity</td>
<td>FAOSTAT; Eurostat; National statistics</td>
<td><a href="http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/">http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/</a></td>
</tr>
<tr>
<td>Fixed transport cost</td>
<td>National authorities</td>
<td></td>
</tr>
</tbody>
</table>

Remarks
The method can be applied to obtain cost-supply curves for any type of bioenergy output (e.g. electricity, heat or ethanol) using agricultural residues as energy source.

Advantages
The method exploits the results of resource focused methods. Equations are easy to apply and used factors are available in literature or web sources.

Disadvantages
The production costs of residues and energy depend on factors influenced by technology (efficiency), markets (fuels costs) and policy and social issues (labour price), which are subject to change.

Future biomass potentials
The estimation of future and economically feasible potential of primary agricultural residues requires in the first place the estimation of technical biomass potential. Parameters included in the estimation process are not stable (e.g. fuels cost, transportation costs) and its update is necessary for future evaluation of cost-supply curves estimation of the potential.

Sustainability aspects
The sustainability aspects related to sustainable straw removal are already included in the statistical and spatially explicit methods. In addition, the cost supply methods can be used to present and minimise the energy use and carbon emissions related to straw collection and transport.

Key uncertainties and future research needs
Factors used in this approach are strongly affected during time and are recommended to be updated on a regular base.
5.3 Secondary agricultural residues

5.3.1 Secondary agricultural residues - basic and advanced statistical method

Basic method
The basic statistical method for assessment is applicable to assessment of the theoretical and technical potential of secondary agricultural residues (SAR) that are generated and collected at the enterprises which process harvested portions of agricultural crops for food/feed production.

It may be the case that the enterprises are obliged to report the volumes and ways of utilisation of their residues to national statistical institutions. Relevant statistical data may be found in the consolidated report on the residues obtained from the national statistics body (for example State Statistics Committee) by request. In this case the theoretical potential of SAR may be just derived from the statistical data on the amount of generated residues of a relevant type.

If direct statistical data on SAR volumes are not available, the methodology for assessment is the following. The starting point is the statistical data on a certain agricultural crop production quantity (like sunflower or sugar beet etc.) in tonnes. Then this amount is multiplied by the product to secondary residue ratio which is specific for each type of product and the obtained result represents the theoretical potential of a certain SAR. The calculation of the theoretical potential can be presented as follows:

\[ P_{t,i} = Cr_i \cdot PtSR_i \]  

(equation 5.3.1.1)

Where:
- \( P_{t,i} \) = theoretical potential of SAR from a crop \( i \), t
- \( Cr_i \) = production quantity of a crop \( i \), t
- \( PtSR_i \) = product to secondary residue ratio for a crop \( i \)

\( i = 1, 2, 3…n \), \( n \) corresponds the number of agricultural crops taken into account for a certain assessment.

The technical potential is calculated via multiplying the theoretical potential by the Availability Factor and Use Factor which are individual for each type of SAR:

\[ P_{tech,i} = P_{t,i} \cdot Av_i \cdot UF_i \]  

(equation 5.3.1.2)

Where:
- \( P_{tech,i} \) = Technical potential of SAR from a crop \( i \), t
- \( Av_i \) = Availability Factor for a crop \( i \)
- \( UF_i \) = Use Factor for a crop \( i \)

In fact, since SAR are generated and collected at the enterprises, which process harvested portions of agricultural crops for food/feed production, the availability factor will generally be equal to one. The Use Factor shows what part of the actually collected residues can be used for energy production taking into account other possible users of the residues (biomaterial, food, feed, and soil improvement). For example, such secondary agricultural residues as bagasse may be used for food and feed production and can also be used in medicine and pharmacology. Thus, application of the Use Factor takes into consideration the availability limitations due to sustainability. The product to secondary residue ratio and Availability Factor should be taken from dedicated literature on agricultural biomass, agriculture or food industry or on the basis of expert estimation of core specialists.

As the assessment of potentials is based on statistical data attached to a certain year, the obtained results are in tonnes per year. Then the potential of each SAR can be converted into energy units.
through multiplying the potential in t/yr by the lower heating value of the certain residues (GJ/dry t). Or the potential can be expressed in tonnes of oil equivalent (toe) through multiplying the potential in t/yr by the lower heating value of the certain residues (GJ/dry t) and dividing it by the lower heating value of oil (42 GJ/t).

**Advanced method**

Though the difference between the advanced and basic methods is rather arbitrary, the following distinction could be noted. While the basic method relies on publicly available data on production quantity of agricultural crops in all European countries (Eurostat, FAOSTAT) and assumes that the whole production quantity of a crop is processed in a certain country, the advanced method requires sector level data on actually processed volumes of agricultural products by categories. For example, data on processed paddy rice to assess the volume of generated hulls, data on processed sugarcane to assess the volume of generated bagasse etc. Such statistical data seem to be available on a national level via National statistics bodies or through sector organisations.

**Data sources**

| Table 35 Data sources secondary agricultural residues - statistical method |
|-------------------------------------------------|-----------------------------------|-------------------------------------------------|
| **Data item**                                   | **Data source**                   | **Exact location**                              |
| Volume of generated residues                    | Consolidated report on the residues (national) | National statistics body (for example the State Statistics Committee) |
| Production quantity of agricultural crops       | Eurostat                          | http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database |
|                                                | FAOSTAT                           | http://faostat.fao.org/site/567/default.aspx#ancor |
|                                                | Core literature (agricultural biomass for energy, agriculture and food industry) | Examples:  
|                                                |                                   | • Silin P.M. Sugar Technology. – M.: Food industry, 1967 |
| Availability Factor                             | Core literature (agricultural biomass for energy, agriculture and food industry) | Expert estimations on the national or regional level |
|                                                |                                   | Examples:  
|                                                |                                   | • Silin P.M. Sugar Technology. – M.: Food industry, 1967 |
| Use Factors                                     | REFUEL data                       | REFUEL Assessment of biomass potentials for biofuel feedstock production in Europe (Fischer et al. 2007b) http://www.refuel.eu/publications/ |
|                                                |                                   | Expert estimations on the national or regional level |
| Processed volumes of the agricultural products  | Data of national statistics body  | National statistics body (for example the State Statistics Committee) |
| with breakdown into categories of the processing enterprises (advanced method) |                                   |                                                 |

**Remarks**
- For accurate estimation, SAR should be clearly distinguished from primary agricultural residues and food processing wastes. In some studies these types of residues are mixed, and in many
studies agricultural residues are evaluated as a whole without separation into primary and secondary ones.

- Use Factor of certain SAR may differ a lot in different regions and countries, which should be taken into account in the assessment.

Advantages
The main advantage of this method is its simplicity. The described method offers a straightforward approach to assess SAR potential starting from the available data on production quantity of agricultural crops.

Disadvantages
There is no exact tool to estimate future potentials except sensitivity analysis based on expert estimation.

Future biomass potentials
Future potentials of SAR can be estimated based on current potentials taking into account the following key influencing factor: land use change that results in rise/drop in production quantities of certain agricultural crops and therefore in amount of certain SAR (Perlack et al. 2005). This factor and other factors influencing the potential of SAR can be taken from existing agricultural outlooks. Examples of the agricultural outlooks are presented in Table 35 (annual OECD-FAO Agricultural Outlooks).

There is no special tool to take into account all these factors. Influence of a certain factor can be evaluated on the basis of sensitivity analysis in which expert estimation of the factor future change is used.

Sustainability aspects
SAR are generated when processing already available volumes of agricultural products and as usual, SAR make up the minor part of the total potential of agricultural residues. SAR may have different ways of utilisation (biomaterial, food, feed, or soil improvement) and energy production is only one of them. Sustainability aspects related to other users of SAR are taken into account in this method by application of Use Factor.

Key uncertainties and future research needs
Key uncertainty remains regarding the exact scope of SAR which should be included in the assessment. Future research is needed to identify all the possible residues that can be classified as SAR and that can be used for energy production.

5.3.2 Secondary agricultural residues - basic spatially explicit method

Method
The basic spatially explicit method is based on regional statistical data that are plotted in a spatially explicit way. The general approach and methodology are the same as for the basic statistical method (see description in section 5.3.1 ‘Secondary agricultural residues - basic statistical method’) but all the data are used and calculations are made not for a country as a whole but for the country’s regions.

Data sources
See data sources table 35 in section 5.3.1 ‘Secondary agricultural residues - basic statistical method’.

Remarks
As the method uses regional statistical data, first it is necessary to define clearly the regional structure of a certain country and choose a NUTS level for the potentials assessment.
Advantages
The main advantage of this method is its simplicity. The described method offers a straightforward approach to assess SAR potential starting from the available data on production quantity of agricultural crops.

Disadvantages
The method offers no exact tool for future potentials assessment. The assessment can probably only be performed on the basis of different expert estimations, and its accuracy strongly depends on the accuracy of the assumptions and predictions made.

Future biomass potentials
Assessment of the future biomass potential requires information on future change in land use, agricultural crops yield etc. on a regional level. As a rule, existing agricultural outlooks offer prognoses on a country level. So, assessment of future potentials can be performed only on the basis of different expert estimations.

Sustainability aspects
SAR are generated when processing already available volumes of agricultural products and as usual SAR make up the minor part of the total potential of agricultural residues. SAR may have different ways of utilisation (biomaterial, food, feed, or soil improvement) and energy production is only one of them. Sustainability aspects related to other users of SAR are taken into account in this method by application of Use Factor.

Key uncertainties and future research needs
Key uncertainties are the same as for the basic statistical method (section 5.3.1) plus additional ones connected to the expert assumptions and predictions for assessment of the future potentials.

5.3.3 Secondary agricultural residues - advanced spatially explicit method
The advanced spatially explicit method is applicable to the assessment of technical and environmentally sustainable potential of biomass. The method is based on using agricultural sector models. The models allow analyses of the impacts of policy changes and are often based on partial equilibrium models.

A good example of such an agricultural sector model is the Common Agricultural Policy SIMulation (CAPSIM) model that provides results for all agricultural commodities expressed in production size, yields and land requirements by 2010, 2020 and 2025. It covers 25 Member States of the European Union. The CAPSIM software also has an exploitation tool to show data in maps. The map shows the EU member states with their NUTS II regions.

Other examples of agricultural models which can be applied to individual countries are CRAM (Canada), DRAM (Holland), SASM (Sweden) and KVL (Denmark).

The steps for application of the method are as follows:

1. Obtaining production quantities of agricultural crops in a certain year by means of selected agricultural sector model.

2. With the available the production quantities, one can assess the potentials of SAR by means of equations presented in section 5.3.1 that is via application of the product to secondary residue ratio, Availability Factor and Use Factor.
Table 36 Data sources secondary agricultural residues - basic spatially explicit method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production quantity of agricultural crops</td>
<td>CAPSIM14 code</td>
<td>European Commission's Joint Research Centre Institute for Prospective Technological Studies <a href="http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1480">http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1480</a></td>
</tr>
</tbody>
</table>

Remarks

Remark to step 1
To apply this method, one should first choose a proper agricultural sector model. As an example, the CAPSIM model can be recommended. Comprehensive description and instructions for using this model are given in the technical report “The Common Agricultural Policy SIMulation (CAPSIM) Model: Structure and Applications” (Witzke et al. 2007). Comparative analysis of agricultural sector models for individual countries is given in (Wiborg 2000).

Advantages
Advantages of the method for biomass potential assessment relate to those of partial equilibrium (PE) models. Agricultural sector models provide robust and quick analysis of the impacts of policy changes. PE analysis of one market always makes the assumption that all relevant variables except the price in question are constant. Thus, we assume that the prices of all substitutes and complements, as well as income levels of consumers are constant. We can thus focus on the impact of a tax in one market, without worrying about indirect effects from other markets. PE it is a very useful tool to anticipate the main effects of a policy. Generally, the more narrowly we define a market, the more suitable PE analysis is.

Disadvantages
Disadvantages of the method for biomass potential assessment are related to those of partial equilibrium models. PE models are based on a lot of strong assumptions to make the analysis clearer. But these assumptions may lead to certain simplification. Besides, scenarios for future biomass potentials assessment does not take into consideration renewable energy targets set in future EU policy.

Future biomass potentials
Agricultural sector models include scenarios for future biomass potentials assessment. For example the CAPSIM model has the ‘Animlib’ scenario which provides agricultural crops yield increase by 2011, 2020 and 2025. The Animlib scenario assumes that no renewable energy targets are set in future EU policy and therefore only includes changes in agricultural markets resulting from the reform of the Common Agricultural Policy.

Sustainability aspects
As the assessment method is based on agricultural sector models, which are used to analyse the impacts of agricultural policy changes, it may be considered that most sustainability aspects (like food demand) are taken into account.

Key uncertainties and future research needs
Key uncertainties originate from the basic assumption of partial equilibrium models. The models allow anticipation of the main effects of agricultural policy but the future potentials can be affected by future EU renewable energy policy which is not taken into consideration in the PE models.
5.3.4 Secondary agricultural residues - cost supply method

In case of secondary agricultural residues (SAR), cost supply analysis focuses on transportation of biomass, because this factor can be the crucial one for the economic performance. This method starts from evaluation of theoretical and technical potential of SAR and ends with the economic potential. Two steps may be distinguished in it:

**Step 1. Assessment of theoretical and technical potential**
This assessment is performed by means of (advanced) statistical method as described in section 5.3.1.

**Step 2. Calculation of economic potential**
As usual, transportation of biomass is considered to be feasible within a distance of up to 100 km. In case of SAR, which have very low bulk density this distance should be reduced to 50 km. The scenario used is that SAR are utilized for energy production on the site of their generation or are transported to a biomass conversion plant located at a distance not more than 50 km from the enterprise where SAR are generated. For SAR that are used for energy production on site, the economic potential is the same as the technical potential.

To check whether utilisation of SAR at a concrete plant is economically feasible, the following sub-steps should be taken. The exact location of biomass conversion plants or power plants where SAR can be co-combusted, a distance between these and sites of SAR generation should be known.

2.1. Transportation costs of SAR per km per m³ of a truck or other transportation vehicle ($C_v$, Euro/km/m³) is converted into costs per km per kg of the specific SAR ($C_{mi}$, Euro/km/kg):

$$C_v \cdot \rho_i = C_{mi} \quad \text{(Equation 5.3.4.1)}$$

where $\rho_i$ is bulk density of SAR$_i$.

2.2. Transportation costs of SAR$_i$ per km per kg is converted into costs per km per MJ of energy content ($C_{Qi}$, Euro/km/MJ):

$$C_{mi} \cdot Q_i = C_{Qi} \quad \text{(Equation 5.3.4.2)}$$

where $Q_i$ (MJ/kg) is low heating value of SAR$_i$.

2.3. Calculation of costs of SAR$_i$ transported to a biomass conversion plant n ($C_{Qin}$, Euro/MJ).

$$C_{Qi} \cdot S_n = C_{Qin} \quad \text{(Equation 5.3.4.3)}$$

where $S_n$ is a distance to biomass conversion plant n.

2.4. Comparison of fuel costs
Costs of transported SAR is compared to the costs of biomass used at a plant. If SAR is supposed to be co-combusted with a fossil fuel, its cost are compared to the costs of coal (or natural gas, fuel oil etc.) which is the main fuel at the plant. In this case, possible subsidies on the renewable electricity compared to fossil electricity, e.g. feed in tariff should be taken into account too.

2.5. Determination of economic potential
The part of technical potential that can be utilised on site of its generation or transported to a conversion plant at a price lower than the price of main fuel used at the plant is included in the economic potential of SAR.
Table 37 Data sources secondary agricultural residues - cost supply method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of agricultural/food enterprises with their processed volumes of</td>
<td>National authorities</td>
<td>Ministry of Agriculture</td>
</tr>
<tr>
<td>agricultural products</td>
<td>National statistical data</td>
<td>Ministry of Food Industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>State Statistics Committee</td>
</tr>
<tr>
<td>List of power plants and their location</td>
<td>National authorities</td>
<td>Ministry of Energy</td>
</tr>
<tr>
<td>Transportation cost of SAR per km per m³ by a truck or other transportation vehicle</td>
<td>Transportation tariffs of local companies which supply biomass including SAR to power plants</td>
<td>Local companies which supply biomass including SAR to power plants</td>
</tr>
</tbody>
</table>

Remarks
Step 1 corresponds to the advanced resource-focused statistical method described in section 5.3.1. Its results are input data for Step 2.

Advantages
The main advantage of this method is its relative simplicity. The described method offers a straightforward approach to assess SAR potential.

Disadvantages
This method requires quite a lot of statistical data on national level and gives result on economic potential only for one particular moment in time.

Future biomass potentials
Future potentials of SAR can be estimated based on the current potentials taking into account the following key influencing factor:
• land use change that results in rise/drop in production quantity of certain agricultural crops and therefore in amount of certain SAR (Perlack et al. 2005).

Key factors that need to be taken into account if an advanced method is applied:
• application of advanced farming systems that lead to an increase in crops yield and therefore in the amount of SAR (Perlack et al. 2005);
• impact of climate change on crops yield;
• development of advanced processing technologies that lead to a decrease in the amount of SAR due to more optimal processing of agricultural products;
• construction of new biomass conversion plants on sites of SAR generation or nearby;
• changes in biomass and fossil fuel prices.

There is no special tool to take into account all these factors. Influence of a certain factor can be evaluated on the basis of sensitivity analysis in which expert estimation of the factor future change is used.

Sustainability aspects
SAR are generated when processing already available volumes of agricultural products and as usual, SAR make up the minor part of the total potential of agricultural residues. SAR may have different ways of utilisation (biomaterial, food, feed, or soil improvement) and energy production is only one of them. Sustainability aspects related to other users of SAR are taken into account in this method by application of Use Factor.

Key uncertainties and future research needs
The key uncertainty is connected to exact locations of biomass conversion plants. Future research on optimised transportation ways and routes is required.
5.4 Manure

5.4.1 Manure - statistical method

Method
The method estimating the theoretical manure potential is based on the factor “Heads of livestock of animals and poultry”. By multiplying the amount of heads with the ratio “manure per head” for specific type of livestock, we can estimate the total amount of manure that is produced, which equals the theoretical potential. The above mentioned method is simple and is represented by the following equations:

\[
THP_{Manure} = \sum NHeads_i * MpH_i \quad \text{(Equation 5.4.1.1)}
\]

Where:
- \(THP_{Manure}\) = theoretical potential of manure (tonnes/year)
- \(NHeads_i\) = the number of heads for the i type of livestock
- \(MpH_i\) = amount of manure for the i type of livestock, in tonnes per head
- \(i\) = type of livestock, i.e. cattle, pig, poultry etc.

Biogas is the main product from the digestion of manure that is used for energy exploitation. Therefore, in order to provide the energy potential, the amount of manure can be multiplied with the specific biogas yield and the energy content of biogas.

\[
Energy_{Manure} = \sum NHeads_i * MpH_i * BY_i * GEC_i \quad \text{(Equation 5.4.1.2)}
\]

Where:
- \(BY_i\) = biogas yields for the i type of livestock manure, in cubic meters (m3) per tonne
- \(GEC_i\) = energy content of gas produced from the i type of livestock manure, in joules per cubic meter

If combustion is considered, for instance in case of chicken manure, the amount of manure should be multiplied with the lower heating value of the manure in stead of using the biogas yield.

In order to determine the technical potential, only manure that can actually be collected, i.e. in general the manure produced in stables, should be considered. This means that daily manure production will be multiplied by the number of days per year that the animals are in stables. In a more accurate approach the number of heads of animals would be replaced by livestock units (LU). An availability factor \(Av_i\) should be established reflecting the share of manure per year that can be collected from the stables by each type of animal. The availability factor will require literature review or an analysis of common agricultural practice in the investigated area or country. Secondly, a use factor \(UF_i\) could be considered, showing alternative uses of manure. However, after digestion, the manure is still available for other uses, therefore in general the use factor is only needed if combustion is considered.

\[
TCP_{Manure} = \sum NHeads_i * LUs_i * MpU_i * AHD_i * Av_i * UF_i \quad \text{(Equation 5.4.1.1)}
\]

Where:
- \(TCP_{Manure}\) = technical potential of manure (tonnes/year)
- \(NHeads_i\) = number of heads for the i type of livestock
- \(LUs_i\) = number of livestock units per head for the i type of livestock
- \(MpH_i\) = amount of manure per livestock unit for the i type of livestock, in tonnes per head per day
AHD<sub>i</sub> = number of animal housing days per year  
i = type of livestock (e.g. cattle, pig, poultry)  
Av<sub>i</sub> = availability factor (percentage of manure that can technically be collected from stables)  
UF<sub>i</sub> = use factor (percentage of manure that has no important alternative uses)

Data sources

Table 38 Data sources for estimation of manure in resource-focused statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of heads of livestock</td>
<td>Eurostat</td>
<td><a href="http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database">http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td>click on agricultural products ➞ animal production ➞ livestock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>click on livestock</td>
</tr>
<tr>
<td>Amount of manure</td>
<td>Literature, like Environment Agency UK</td>
<td>For instance</td>
</tr>
<tr>
<td>Animal housing days</td>
<td>Literature</td>
<td>For instance</td>
</tr>
<tr>
<td>Energy content</td>
<td>Phyllis database</td>
<td><a href="http://www.ecn.nl/phyllis/">http://www.ecn.nl/phyllis/</a></td>
</tr>
</tbody>
</table>

Remarks

- The estimation of manure potential requires detailed data on the type animals, its phase of life and its function, for instance a distinction is made between male and female, young, adult sowing pigs and possibly between the species of pigs.
- Agricultural practices can differ considerably between countries, therefore, the number of housing days, the availability and alternative use factors need to be determined on a national or regional level.

Advantages

- The method is straightforward and data about livestock units are available in Eurostat and national statistics.

Disadvantages

- Data collection especially on the animal housing days, availability and use factor based on national and regional practices can be time consuming.
- Literature data on the amount of manure that is produced for specific types of livestock was estimated in previous trials for specific areas. The lack of information and data for other areas might be critical.

Future biomass potentials

The future potential of manure is strongly related to the estimation of number of livestock units in a specific time frame. It is well known that livestock is used mainly for the production of food. So, the amount of livestock is influenced by the population and its diet. In this method no future manure potential is addressed.

Sustainability aspects

The total manure potential must be managed in order to avoid pollution of soils or waters. The by-products of manure digestion for biogas production can be used as fertilisers in agricultural practice.
Key uncertainties and future research needs
Possible lack of information about the yields of manure per livestock unit creates uncertainties for the estimation of manure potential. To secure the accuracy and reliability of results, further research on that topic should be addressed.

5.4.2 Manure - spatially explicit method

Method
Results from the resource-focused statistical method for manure (see section 5.4.1) can be used in this spatially explicit method, in case that provided data are divided according to regional administration units (e.g. NUTS regions). By the use of a common in code, all necessary data can be joined with spatial data of a geographical information system. Additionally, the manure potential can be spatially distributed in high accuracy, in case that coordinates of livestock units are available.

Data sources

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NUTS regions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of heads of livestock</td>
<td>National statistics</td>
<td><a href="http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/">http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/</a></td>
</tr>
</tbody>
</table>

For more data sources see Table 38 in the previous section.

Remarks
Spatial data for livestock units are not always available and the method must be developed on the base of available administrative units.

Advantages
The method is very simple and data about livestock units are available in Eurostat and national statistics. The method imports results and data from a previous method, in a GIS, using a very simple process of data analysis (joining). In case that detailed spatial data for livestock units are available (coordinates), a further spatial analysis process is possible, for example, logistics or detection of a feasible position for installation of digestion units and biogas plants, using data for quantities (potential) and distances.

Disadvantages
The use of statistical data from (larger) administrative units for spatially explicit analysis can result in rather coarse results that have a low accuracy. Thus, the method is limited by the administrative scale in which the statistical information is available. In case the coordinates of separate livestock units are available, a higher level of accuracy can be obtained.

Future biomass potentials
The future potential of manure is strongly related to the estimation of number of livestock units in a specific time frame. It is well known that livestock is used mainly for the production of food. So, the amount of livestock is influenced by the population and its diet. In this method, no future manure potential is addressed. In the statistical method, the future potential of manure is strongly related with the estimation of number of livestock units in specific time frame. This issue is also addressed in this method.
Sustainability aspects
Sustainability issues are not applied in this method.

Key uncertainties and future research needs
Possible lack of information about the yields of manure per livestock unit creates uncertainties for the estimation of manure potential. To secure the accuracy and reliability of results, further research on that topic should be addressed. The exact location of livestock units creates favourable conditions for further analysis of basic data and creation of spatial data for livestock units must have high priority.

5.5 Future research needs

Primary & secondary agricultural residues
- In many biomass resource assessments, sustainable harvest levels are based on common but arbitrary primary residue harvest levels (often 25% or 30% of total residues available). These harvest levels do not seem to be based on any research, but rather on a feeling that this should be on the safe side. The issue is however rather complex: sustainable harvest levels depend on the type of soil, alternative uses of the residues (especially animal feed), slope of the land, etc. Further research is needed to understand what sustainable harvest levels could be, in order to support agrobiodiversity and soil quality (see also section 8.3 and Annex 2), and ultimately, to present sustainable availability of (primary) agricultural residues.
- The agricultural sector is influenced by several factors. The market of agricultural products, the availability of resources (e.g. water, nutrients), productivity issues, diet of population, modification of varieties. Several factors used in the method to estimate the biomass potential of primary agricultural residues can be changed. The update of these factors, based on field trials, as well as the update of data sources, must be continuous in order to secure more accurate and reliable estimations of biomass potential.
- Future plant breeding for increment of cereals’ yields will not necessarily increase the residues production, since ongoing research focuses on less straw per tonne of grain produced. This issue must be taken into account in future biomass resource assessments.
- It is not defined that all arable land is used for cereal crops. The deviation of arable land in specific kind of cereals could provide more detailed results. Effects of systematic collection of straw from agricultural areas and environmentally sensitive soils must be studied on site for different types of areas and soils. Studies on straw potential that should remain on site should also be addressed.
- Related to spatially explicit analysis, it is observed that possible lack of vector data about transportation networks will reduce the accuracy of results. Key uncertainty is connected to exact locations of biomass conversion plants. Future research on optimised transportation ways and routes is required.
- The use of satellite data in the estimation of residues has not been applied at every turn. So, further research is recommended.
- Related to secondary residues: key uncertainty remains regarding the exact scope of secondary agricultural residues, which should be included in assessments. Future research is needed to find data on all the possible residues which can be classified as SAR and which can be used for energy production.

Manure
Possible lack of information about the yields of manure per livestock unit creates uncertainties for the estimation of manure potential. To secure the accuracy and reliability of results further research on that topic should be addressed.
5.6 Improvement of data sources

Primary and secondary agricultural residues
- Regarding statistical methods for the estimation of primary agricultural residues, several parameters (e.g. agricultural land, crop types, production) are inventoried on annual basis by reliable international organizations, but important parameters are available only in literature (e.g. product to residue ratio). The development of a dataset (or publications site) where all information would be available is desirable.
- Spatial explicit data are not always readily available. There is often a lack of available information regarding (1) quantities of straw that should remain on site due to environmental limitations, (2) spatial distribution of straw needed for uses other than bioenergy. Both need to be combined with a detailed transportation network to determine the spatial distribution available primary agricultural residues.

Manure
- The detailed spatial distribution of livestock units and manure potential could give significant potential to spatial analysis and create new results for further exploitation (e.g. estimation of feasible positions for biogas installations).
6 Organic waste

6.1 Scope and definitions

Scope
Organic waste, also called biomass waste, biowaste or tertiary residues, originates from the final use of biomass containing products. Important examples are biodegradable municipal waste, demolition wood, and sewage sludge. Generally, these wastes are released throughout the country and collected, transported and treated according to European, national and regional regulations for waste treatment, by public and/or private organisations. Unlike dedicated energy crops, organic waste is not produced specifically for energy use, nor does it serve important environmental functions. Organic waste is produced in significant quantities. It is the result of economic activity and the production of goods in almost all sectors of the economy (EEA 2006). To minimise negative environmental effects and promote positive environmental effects of (organic) waste processing, policy and legal frameworks are in place to promote minimisation of waste production, recycling, and energy generation. Therefore, the availability of organic waste for energy is usually determined taking into consideration the regulatory framework.

Definitions
In this chapter, methods are presented to estimate the biomass potential of biodegradable municipal waste, landfill gas, demolition wood, and sewage sludge. Their definitions are presented in Table 40.

<table>
<thead>
<tr>
<th>Biomass type</th>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodegradable municipal waste</td>
<td>Waste from households, as well as other waste that, because of its nature or composition is similar to waste from households, that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, paper and cardboard.</td>
<td>Combination of Municipal waste and biodegradable waste</td>
</tr>
<tr>
<td>Landfill gas</td>
<td>All the gases generated from landfilled waste.</td>
<td>(1999/31/EC 1999)</td>
</tr>
<tr>
<td>Construction and demolition wood</td>
<td>Construction and demolition wood is a part of construction and demolition waste which arises from activities such as the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning and maintenance.</td>
<td>ETC STP (The European Topic Centre on Sustainable Consumption and Production)</td>
</tr>
<tr>
<td>Sewage gas</td>
<td>Sewage gas is biogas produced during anaerobic digestion of sewage sludge which is applied to stabilise the sludge.</td>
<td></td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>Sludge means: (i) residual sludge from sewage plants treating domestic or urban waste waters and from other sewage plants treating waste waters of a composition similar to domestic and urban waste waters; (ii) residual sludge from septic tanks and other similar installations for the treatment of sewage; (iii) residual sludge from sewage plants other than those referred to in (i) and (ii).</td>
<td>Sewage Sludge Directive (86/278/EEC 1986)</td>
</tr>
</tbody>
</table>
Other relevant definitions are presented in the table below:

### Table 41 Other relevant definitions related to organic waste

<table>
<thead>
<tr>
<th>Item</th>
<th>Definition</th>
<th>Source (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste</td>
<td>Any substance or object which is covered by directive 2008/98/EC.</td>
<td>(2008/98/EC 2008)</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>Waste from households, as well as other waste that, because of its nature or composition is similar to waste from households.</td>
<td>(1999/31/EC 1999)</td>
</tr>
<tr>
<td>Biodegradable waste</td>
<td>Any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and cardboard.</td>
<td>(1999/31/EC 1999)</td>
</tr>
<tr>
<td>Landfill</td>
<td>A waste disposal site for the deposit of the waste onto or into land (i.e. underground), including - internal waste disposal sites (i.e. landfill where a producer of waste is carrying out its own waste disposal at the place of production), and - a permanent site (i.e. more than one year) which is used for temporary storage of waste.</td>
<td>(1999/31/EC 1999)</td>
</tr>
<tr>
<td>Landfill gas</td>
<td>All the gases generated from the landfilled waste.</td>
<td>(1999/31/EC 1999)</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>Sewage sludge is a residual product from the treatment of urban and industrial wastewater. Sewage sludge from wastewater treatment.</td>
<td>(Brodersen et al. 2002) (SenterNovem 2005)</td>
</tr>
</tbody>
</table>

### 6.2 Biodegradable municipal waste

#### 6.2.1 Biodegradable municipal waste - basic statistical method

A straightforward approach to determine the theoretical and technical potential of biodegradable municipal solid waste (BMW) based on thermal applications (like incineration) is described in equation 6.2.1.1.

\[
TP_{BMW_{x,y}} = MSW_{x,y} \times POP_{x,y} \times ACC_x \times OC_x \times LHV_{BMW} \times 10^{-6} \quad \text{(Equation 6.2.1.1)}
\]

Where:

- \( TP_{BMW_{x,y}} \) = biomass potential of BMW of country x in year y (PJ/year)
- \( MSW_{x,y} \) = municipal waste production per capita of country x in year y (tonnes/person/year)
- \( POP_{x,y} \) = population of country x in year y (persons)
- \( ACC_x \) = percentage of the population served by municipal waste services (%)
- \( OC_x \) = organic content of MSW in country x (dimensionless)
- \( LHV_{BMW} \) = lower heating value of BMW (GJ/tonne)
- \( x \) = country
- \( y \) = year

Biodegradable municipal waste consists of mainly paper and cardboard and kitchen and garden waste.

- For calculation of the theoretical potential, paper and cardboard is included in \( OC_x \).
- For calculation of the technical potential, paper and cardboard are excluded, since paper and cardboard can be/are being recycled. Some paper and cardboard cannot be recycled due to technical barriers. If data are available, the non-recyclable fractions can be included.
- Textile is excluded, since part of the textile is synthetic. Textile can be recycled and its share in total waste generation is relatively low. If known, the organic part of the textile fraction could be included.

Data sources
Table 42 presents the location of the data sources needed to calculate the theoretical potential of BMW.

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>The organic content (OCx) of MSW</td>
<td>OECD</td>
<td>OECD Environmental data compendium 2008 (OECD 2008) table 2B provides data on the composition of municipal waste. Take ‘organic material’ for technical potential and add ‘paper and cardboard’ for theoretical potential.</td>
</tr>
<tr>
<td>Percentage of the population served by municipal waste services (%)</td>
<td>OECD</td>
<td>OECD Environmental data compendium 2008 (OECD 2008) table 2C provides data on the percentage of the population served by municipal waste services.</td>
</tr>
<tr>
<td>Lower heating value of BMW (LHVBMW)</td>
<td>2006 IPCC Guidelines for national greenhouse gas inventories, volume 2, energy, (IPCC 2006b)</td>
<td><a href="http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html">http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html</a> → section 1.4.1.3, Table 1.2, Municipal wastes (biomass fraction). Composition specific LHV should be used if available.</td>
</tr>
<tr>
<td>The population (POPx,y)</td>
<td>Eurostat</td>
<td>Eurostat → Statistics database → Tables by themes → Population and social conditions → Population → Demography → Main demographic indicators → total population (t_popula).</td>
</tr>
</tbody>
</table>

Remarks
- As a first estimate of the energy potential, this method assumes incineration/combustion of the BMW. If data are available on the fractions that are can be digested or incinerated, the advanced statistical method can be used (see section 6.2.2).
- Municipal waste consists of waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yard and garden waste, street sweepings, the contents of litter containers, and market sweeping waste. The definition excludes waste from municipal sewage networks and treatment, as well as municipal construction and demolition waste.
- When presenting results, always indicate clearly whether waste paper and cardboard (and textile) are included or excluded.
- The LHVBMW depends on the composition of waste; i.e. paper has higher LHV than kitchen and garden waste. Since the composition of BMW can vary considerably, this LHV could vary as well.

Advantages
- The presented basic method is straightforward, all necessary data can be easily obtained from international public accessible literature.

Disadvantages
- Next to differences in waste management practices between countries, it should be borne in mind that the definition of municipal waste, and the surveying methods used, vary from country to country, which limits the comparability of data between countries.
- This applies to the determination of the quantities of MSW as well as to the determination of the organic content (OCx) of MSW and the calorific value of the BMW.
Future biomass potentials
Future quantities of BMW generation depend on changes in MSW generation per capita, population growth and changes in the organic content of MSW. The quantity of municipal waste generated in the OECD area (thirty countries) has been rising since 1980, the starting year of the OECD statistical records on waste. The MSW production per capita has risen mostly in line with private final consumption expenditure and GDP, but there has been a slowdown in the rate of growth in recent years. Only a few countries have succeeded in reducing the quantity of solid waste to be disposed of annually (OECD 2009b).

Future biomass potentials can be estimated based on GDP growth or to population growth. Since most EU countries have not even achieved relative decoupling between GDP growth and waste production, the linkage to the GDP is still more representative than the population growth. Therefore Eurostat forecasts of GDP growth in relation to the current BMW production and the current GDP can be used to assess the future BMW production.

Sustainability aspects
Sustainability aspects already included in the methodology:
- The theoretical potential includes all organic municipal waste; this is a relevant number in the frame of the landfill directive (1999/31/EC 1999).
- A large part of the waste paper and textiles can be recycled and are not considered part of the technical potential.

Further sustainability aspects that could be included in the methodology:
- Separately collected biodegradable municipal waste is often converted into compost. Since composting can be combined with preceding anaerobic digestion, the biogas energy potential of separately collected BMW could be used to determine the technical potential. Instead of LHV\textsubscript{BMW} a separate factor should be used to convert mass potential to energy potential. The biogas yield can be about 100 m\textsuperscript{3}/tonne with a methane yield of 55% (see for instance (Ewijk 2008)), resulting in an energy potential of 2 GJ/tonne BMW. The amount of composted municipal waste can be found in (OECD 2008) table 2c.
- For BMW not separately collected, thermal conversion (like incineration with energy recovery) has the highest energy potential. Therefore, for this type of waste the LHV\textsubscript{BMW}, which is already part of the methodology, should be used. As a useful alternative to incineration, Mechanical and Biological Treatment (MBT) can be applied, which usually consists of shredding and removal of recyclable material followed by anaerobic digestion or composting. If data are available on the quantities of organic waste separated for anaerobic digestion, the advanced statistical method should be used.
- For further discussion the sustainable potential of for instance waste, please see section 8.3 and Annex 3.1.

Key uncertainties and future research needs
- Since the definition of municipal waste and surveying methods used vary from country to country, comparability of data is limited. However, most uncertainty is related to the determination of the organic content and the energy value of the wastes.
- Because the amount of organic waste generated and the share diverted from landfill are important parameters for verification of whether the requirements of the article 5 of the landfill directive (1999/31/EC 1999) are met, it is expected that Eurostat and DG Environment will develop a methodology for determination of these parameters (Kloek 2000). This method will generate official data on BMW quantities. It is therefore advisable to observe, and, if relevant, implement this upcoming method.
- Information on organic content (OC\textsubscript{x}) is difficult to find and the use of average values can lead to substantial deviation between countries.
6.2.2 Biodegradable municipal waste - advanced statistical method

Method
The advanced best practice method for determination of the biomass potential is similar to the basic method. However, a distinction will be made between separately and not-separately collected BMW, assuming anaerobic digestion combined with composting as the technology for separately collected BMW and incineration with energy generation as the main technology for not-separately collected waste. Also the LHV of the BMW should be based on analysis on the average biodegradable waste composition per country.

The potential of biodegradable municipal solid waste (BMW) for combustion and anaerobic digestion is described in equation 6.2.2.1 and 6.2.2.2.

\[
TP_{BMW, x,y, INC} = (MSW_{x,y} \times POP_{x,y} \times OC_{x,y} - BMW_{x,y, compost}) \times LHV_{BMW, INC} \times 10^{-6}
\]

(Equation 6.2.2.1)

\[
TP_{BMW, x,y, AD} = BMW_{x,y, compost} \times LHV_{BMW, AD} \times 10^{-6} =
BMW_{x,y, compost} \times LHV_{CH4} \times \%_{CH4} \times 10^{-6}
\]

(Equation 6.2.2.2)

Where:
- TP_{BMW, x,y, INC} = biomass potential of BMW for incineration of country x in year y (PJ/year)
- TP_{BMW, x,y, AD} = biomass potential of BMW for anaerobic digestion of country x in year y (PJ/year)
- MSW_{x,y} = municipal waste production per capita of country x in year y (tonnes/person/year)
- POP_{x,y} = population of country x in year y (persons)
- OC_{x} = organic content of MSW in country x (dimensionless)
- LHV_{BMW, INC} = lower heating value of BMW (GJ/tonne)
- LHV_{BMW, AD} = lower heat value of biogas generated from anaerobic digestion of one tonne of organic waste (GJ/ton)
- LHV_{CH4} = lower heating value of methane
- \%_{CH4} = percentage of methane in biogas generated from anaerobic digestion of organic waste
- BMW_{x,y, compost} = quantity of BMW composted in country x in year y (tonnes/person/year)
- x = country
- y = year

Biodegradable municipal waste consists of mainly paper and cardboard and kitchen and garden waste.
- For calculation of the theoretical potential, paper and cardboard is included.
- For calculation of the technical potential, paper and cardboard are excluded, since paper and cardboard can be/are being recycled.
- Textile is excluded, since part of the textile is synthetic. Textile can be recycled and its share in total waste generation is relatively low.
Data sources
Table 42 presents the location of the additional data sources needed for the advanced method in addition to parameters already included in the basic method.

Table 43 Data sources biodegradable municipal waste - advanced statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMW&lt;sub&gt;x,y&lt;/sub&gt; compost</td>
<td>Eurostat, Environmental Data Centre on Waste</td>
<td><a href="http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/introduction">http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/introduction</a> → sectors → municipal waste → Additional statistics on municipal waste → Municipal waste composted, kg per capita</td>
</tr>
<tr>
<td>Lower heating value of methane (LHV&lt;sub&gt;CH₄&lt;/sub&gt;)</td>
<td>2006 IPCC Guidelines for national greenhouse gas inventories, volume 2, energy, (IPCC 2006b)</td>
<td><a href="http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html">http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html</a> → section 1.4.1.3, Table 1.2, gas biomass, landfill gas</td>
</tr>
<tr>
<td>Methane fraction in landfill gas (%&lt;sub&gt;CH₄&lt;/sub&gt;)</td>
<td>National GHG Inventory submissions at <a href="http://www.unfccc.int">www.unfccc.int</a></td>
<td><a href="http://www.unfccc.int">www.unfccc.int</a> → home → National Reports → GHG Inventories (Annex I) → National Inventory Submissions → take the inventory of the latest year available. Take the common reporting format (CRF) of country x → open the zip file with excel sheets → open xls sheet with the year from which data is required → open worksheet &quot;Table 6.A.C&quot; → Table 6A → Additional information → CH₄ fraction in landfill gas</td>
</tr>
</tbody>
</table>

Remarks
- The data sources are similar to the basic methodology. However, for the advanced methodology, national data should be consulted for amounts of separately collected waste.
- Information on the organic content of MSW should be scrutinised, ensuring that it covers non-separately collected BMW.
- For further remarks see section 6.2.1 on the basic method.

Advantages
- The presented advanced method is straightforward; most data can be easily obtained from international public literature, although especially for determination of the organic content of MSW (OC<sub>x,y</sub>), national data need to be consulted.

Disadvantages
- Like in case of the basic methodology, next to differences in waste management practices between countries, it should be borne in mind that the definition of municipal waste, and the surveying methods used, vary from country to country, which limits the comparability of data between counties.

Future biomass potentials
In the advanced method, the future biomass potential needs to be determined separately for each country, based on current trends and expectations from official governmental institutes. If no such data are available, the future biomass potential can be determined as described in the basic method.

Sustainability aspects
Sustainability aspects already included in the methodology:
- The theoretical potential includes all organic municipal waste; this is a relevant number in the frame of the landfill directive (1999/31/EC 1999).
- Waste paper and textiles can be recycled and are not to be considered as part of the technical potential.
- Separate energy potentials are determined for BMW that is currently being composted and other BMW, thereby respecting the preference of recycling over energy generation.
Key uncertainties and future research needs

- In many countries there is uncertainty about the organic content of not separately collected municipal waste. Efforts should be made to make existing waste composition analyses available in an internationally accepted format. In case these analyses are not available at all, they should be carried out using relevant surveying methods.
- Based on waste analyses, country specific lower heating values of BMW could be determined.
- Many parameters are a source for uncertainty due to technical reasons, such as the methane efficiency and content in the landfill gas.

6.2.3 Biodegradable municipal waste - basic spatially explicit method

Method

- Spatially explicit information on the production of biodegradable municipal waste can be obtained using regionalized population data, assuming that the municipal waste production per capita on regional level is constant.
- For the determination of the availability of biodegradable municipal waste, the same formulae as described in section 6.2.1 can be used, except that the population data need to be regionalized.

Data sources

- The Eurostat website provides regionalised population statistics on NUTS 3 level (mostly province level). Data on municipal level (LAU 2) should be available as well.

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population on regional level (NUTS 3)</td>
<td>Eurostat</td>
</tr>
</tbody>
</table>

Remarks

- EEA publishes population data on hectare level, using Corine land cover 2000 (See http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=1018) that could be used if a higher level of spatial accuracy is needed.
- It should be taken into account that other parameters like organic content of MSW and the lower heating value of BMW are based on country level estimations, which can vary on a regional scale.

Advantages

- The method gives a good indication of areas where BMW energy installations should be located, i.e. not too far from highly populated areas.

Disadvantages

- The method does not take into account that the generation of BMW can vary on regional level. For instance, it is expected that more BMW is generated in rural areas where households generated more garden waste.
- Since most BMW and MSW is already collected from households, the locations in which the waste is currently stored or processed could be of more interest than the locations of the households where the BMW is generated.

Future biomass potentials

Please refer to the basic statistical method described in section 6.2.1.

Sustainability aspects

Please refer to the basic statistical method described in section 6.2.1.
Key uncertainties and future research needs
Please refer to the basic method described in section 6.2.1.

6.2.4 Biodegradable municipal waste - advanced spatially explicit method

Method
- Like in the basic spatially explicit method, regionalized population data could be used to obtain a spatially explicit biomass potential of BMW, and for high spatial resolution the population data disaggregated with Corine Land Cover 2000 could be used.
- Furthermore, a division between separately and non-separately collected BMW can be made following the advanced statistical method as described in section 6.2.2.
- Some national statistic institutes, like the Dutch national statistical institute (CBS), provide statistics on MSW and separately collected BMW on a regional and even municipal level. These data should be integrated in the approach, while keeping national data for countries that do not have such information available.

Data sources

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population on regional level (NUTS 3)</td>
<td>Eurostat</td>
<td>Eurostat navigation tree → Database → General and regional statistics → Regional statistics → Regional demographic statistics → Population and area (reg_dempoor)</td>
</tr>
</tbody>
</table>

Remarks
- The approach requires an assessment of statistical data on MSW and separate collected BMW production available on regional level. If no regional statistics are available, national data need to be used.

Advantages
- The method optimally uses statistical data available on a regional level and gives a good indication of areas where MSW biomass installations could be located, i.e. near highly populated areas.

Disadvantages
- The method requires an assessment of statistical data available in each country, which is time-consuming when the EU 27 needs to be investigated.
- Not all countries have regionalised data available, which leads to differences in the accuracy of data between countries, which limits the benefits compared to the basic spatially explicit method.

Future biomass potentials
Please refer to the advanced statistical method described in section 6.2.2.

Sustainability aspects
Please refer to the advanced statistical method described in section 6.2.2.
Key uncertainties and future research needs

- More research on regional availability on MSW and BMW production could help to improve data sources.
- For further analysis of key uncertainties and future research needs, please refer to the advanced statistical method described in section 6.2.2.

6.2.5 Biodegradable municipal waste - cost-supply method

In general, the costs of biomass supply consist of: (1) Economic value or production costs of the crop or residue, (2) costs of collection, handling and transportation. The economic value of waste can be set at zero; the costs of collection and processing are paid by the households and governed by local authorities. In a cost-supply method the local authorities should have a central role, since they have decisive power in the selection of a waste processing option. Local authorities will basically try to keep the collection & transport costs and final processing costs as low as possible. Collection and transport costs will depend on the local situation, i.e. the location of landfills, incinerators etc. To determine final processing costs will require a techno-economic evaluation of different waste processing technologies. This is outside the scope of the Handbook and therefore, the costs supply method is not worked out in detail in this Handbook.

6.3 Landfill gas

6.3.1 Landfill gas - statistical method

Method

For determination of the energy potential from landfill gas, the methane production from Solid Waste Disposal Sites (SWDS), as determined in national Greenhouse Gas Inventory submissions to UNFCCC, can be used. The method is summarised in Equation 6.3.1.1.

\[ TP_{LFG_{x, energy}} = CH_4\,generated \times LHV_{CH_4} \] (Equation 6.3.1.1)

Where:
- \( TP_{LFG_{x, energy}} \) = theoretical / technical potential of landfill gas in country x (PJ)
- \( CH_4\,generated \) = amount of methane (\( CH_4 \)) generated from decomposable material (ktonnes \( CH_4 \))
- \( LHV_{CH_4} \) = lower heating value of methane (PJ/ktonne)

The amounts of methane generated from landfills on country level can be found in the National Inventory Submissions of UNFCCC presented in a Common Reporting Format (CRF). The methods are based on the first order decay (FOD) model of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Waste (IPCC 2006c). The methane emissions are calculated for year y, based on waste sent to landfill in the years x=1 to x=y. See section 6.3.3 for details on a similar method used for individual landfill sites.

Data sources

The amount of methane generated from landfills or solid waste disposal sites can be easily obtained from national reports from signatories of the Kyoto protocol and UNFCCC.
Table 46 Data sources landfill gas - statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 generated</td>
<td>National GHG Inventory submissions at <a href="http://www.unfccc.int">www.unfccc.int</a></td>
<td><a href="http://www.unfccc.int">www.unfccc.int</a> → home → National Reports → GHG Inventories (Annex I) → National Inventory Submissions → take the inventory of the latest year available. Take the common reporting format (CRF) of country x → open the zip file with excel sheets → open xls sheet with the year from which data is required → open worksheet &quot;Table 6.A,C&quot;→ Table 6A → add ‘emissions’ and ‘recovery’ of CH4 emissions of ‘managed waste disposal on land’, and for determination theoretical potential also data of ‘unmanaged waste disposal sites’ (if any data available).</td>
</tr>
<tr>
<td>LHV&lt;sub&gt;CH4&lt;/sub&gt;</td>
<td>2006 IPCC Guidelines for national greenhouse gas inventories, volume 2, energy, (IPCC 2006b)</td>
<td><a href="http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html">http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html</a> → section 1.4.1.3 → Table 1.2, landfill gas.</td>
</tr>
</tbody>
</table>

Remarks

- The National GHG Inventory submissions present the methane emitted as well as the methane recovered. The two values need to be added to obtain the energy potential. The resulting energy potential will be an overestimation, since not all methane emitted can be recovered due to technical limitations. The recovered methane is either flared or used for energy generation, but this is not directly indicated in the Common Reporting Format (CRF) of UNFCCC.
- In order to estimate the theoretical and practical potential, the emitted and recovered methane should be summed up.
- In case the theoretical potential is estimated, the emissions from unmanaged waste disposal sites and other sites, as provided in Table 6A of the common reporting format of the UNFCCC National GHG Inventory should be added as well. This is not necessary for estimations of the technical potential.
- Note that there is some overlap with the biomass potential of BMW. BMW sent to landfill in year y will not be available for other purposes, like thermal conversion. However, the overlap is not 100% since also historic quantities of BMW (year x=1 to x=y-1) contribute to the landfill gas production in year y as well.

Advantages

- The public available data from the standardized ‘Common Reporting Formats’ that are presented together with the National Inventory Reports prepared for UNFCCC is easy to use.
- Optimal use is made of the efforts of national governmental institutes and IPCC methodologies. Since the data will be used for compliance with the Kyoto obligations, the delivered data will be scrutinised by experts, which secures that the data are as reliable as reasonably achievable.
- Moreover, the National Inventory Reports clearly indicate how the waste is collected and what uncertainties in data are found.

Disadvantages

- The first order decay model is a simple model of methane generation in landfills, while methane generation from landfills is a very complex and poorly understood system. This will inherently create uncertainty.
- It will be difficult to verify all data since methane generation data are directly taken from national GHG Inventory submissions. Some countries use average IPCC suggested values for the parameters involved in the methane calculation or use the simple Tier 1 methodology. This increases uncertainty.

Future biomass potentials

- The energy potential of landfill gas depends on the historic and current amounts of biodegradable waste sent to landfill. Even if no new biodegradable waste would be landfilled, landfill gas
production would continue for several years. Therefore, the relation between waste production in year x and landfill gas energy potential of the same year is not linear. The time delay of the methane emissions actually requires a complex model for projections. Nevertheless, trends in amounts of BMW sent to landfill determine the long-term biogas potential. Therefore, the future amounts of BMW produced and diverted to landfill are taken as indicators of the future biomass potential.

- The landfill directive (1999/31/EC 1999), promotes the diversion of BMW from landfills to other uses like composting and incineration. (Skovgaard et al. 2008) have estimated the percentage of MSW expected to go to landfill in 1995-2006, 2009 and 2016 (see Table III.1 of Annex IV of (Skovgaard et al. 2008)). The change in landfill rate can be expressed as landfill rate year x divided by the landfill rate of base year y.
- Therefore, future landfill gas potentials up until 2020 will be estimated by using the most recent biomass potential, corrected for the future size of the population (like in section 6.2.1 on BMW), and corrected for the change in landfill rates as derived with data from (Skovgaard et al. 2008).

**Sustainability aspects**

Sustainability aspects are not explicitly part of the basic methodology. Anyhow, the following general observations can be made. Recycling and incineration with energy recovery are more sustainable applications of BMW than landfill. However, flaring and (preferably) energy generation of landfill gas is an important way to reduce methane emissions into the atmosphere. Promotion of energy generation from landfill gas without promoting additional landfill of waste is regarded sustainable practice and is also an objective of the Landfill directive.

**Key uncertainties and future research needs**

There are two areas of uncertainty in the estimation of methane emissions from SWDS: (i) the uncertainty attributable to the method; and (ii) the uncertainty attributable to the data (activity data and parameters). Both are described in section 3.7.2 of (IPCC 2006c). The following main observations are made below:

- The used First Order Degradation (FOD) model takes into account historic waste volumes, which is an improvement compared to the default (Tier 1) method in previous versions of the IPCC guidance, like (IPCC 1996), that assumed that all methane would be released in the same year that the waste was deposited. However, it is important to remember that the FOD method is a simple model of a very complex and poorly understood system.
- Decay of carbon compounds to methane involves a series of complex chemical reactions and may not always follow a first-order decay reaction. Higher order reactions may be involved, and reaction rates will vary with conditions at the specific SWDS. Reactions may be limited by restricted access to water and local variations in populations of bacteria.
- SWDS are heterogeneous. Conditions such as temperature, moisture, waste composition and compaction vary considerably even within a single site, and even more between different sites in a country. Selection of ‘average’ parameter values typical for a whole country is difficult.
- Use of the FOD method introduces additional uncertainty associated with decay rates (half-lives) and historical waste disposal amounts. Neither of these are well understood or thoroughly researched.
6.3.2 Landfill gas - basic spatially explicit method

Method
- In order to provide spatially explicit data of the landfill gas potential, the landfill sites in a country need to be identified and the landfill gas potential of each landfill needs to be assessed.
- The basic method therefore consists of the collection of site-specific data on the methane generation, usage and flaring.
- For the conversion of methane to energy potential the equation presented in section 6.3.1 can be used.

Data sources
- National studies that publish overviews on methane generation from individual landfill sites, are the preferred data sources.
- If no national studies are available, the owners of individual landfill sites need to be consulted.
- If no site-specific data are available at all, the advanced method (see section 6.3.3) should be applied.

Table 47 Data sources landfill gas - basic spatially explicit method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source (example)</th>
<th>Exact location</th>
</tr>
</thead>
</table>

Remarks
- The statistical method (sections 6.3.1) is based on methods for national reporting on Greenhouse Gas Emissions provided by IPCC, which provide data on the methane production from landfills on national level only. In these reports, no data on methane production of individual landfills is found. Therefore, in order to obtain site specific data, preferably national overview studies need to be consulted.
- If it is not possible to obtain national overview studies, the advanced spatially explicit method could be considered.

Advantages
- Information on measured landfill gas production of individual landfills obtained from national data sources can give a good and realistic picture of the actual LFG extraction.

Disadvantages
- Generally only landfill gas that is actually extracted and flared or combusted with energy generation is reported. The true potential of landfill gas not collected is unknown when using this method.
- Information on individual landfills might be difficult to find.

Future biomass potentials
- The future landfill gas potential is difficult to assess if only statistic information is used. Its potential depends on the historic and future amounts of waste deposited. This could be modelled using the advanced method. See next section.

Sustainability aspects
- Please refer to section 6.2.1 for a discussion on the sustainability aspects of landfill gas utilisation.

Key uncertainties and future research needs
- In general literature sources do not provide details on the amounts of landfill gas currently not being extracted. This requires a more detailed assessment as described in the next section.
6.3.3 Landfill gas - advanced spatially explicit method

Method

The methane emissions of individual landfills can be estimated using the CDM ‘Tool to determine methane emissions avoided from dumping waste at a solid waste disposal site’ (UNFCCC 2008). This CDM tool uses a similar method as described in the IPCC Good Practice Guide (IPCC 2006c) as used in the statistical method, but is focused on individual waste disposal sites. Updates of the methods and tools can be found on the CDM website1. The tool is primarily designed to estimate methane emission reductions, but can be used to estimate the total emissions of a landfill, called Solid Waste Disposal Site (SWDS) as well. Equation 6.3.3.1 shows the main equation of the tool.

\[
BE_{CH4,SWDS,y} = \varphi \times GWP_{CH4} \times (1 - OX) \times \frac{16}{12} \times F \times DOC_f \times MCF \times \sum_{x=1}^{y} \sum_{j} W_{j,x} \times DOC_j \times e^{-k_j(y-x)} \times (1 - e^{-k_j})
\]

(Equation 6.3.3.1)

In order to obtain the methane emissions expressed in tonnes methane, instead of tonnes of CO₂-equivalent, the GWP_{CH4} should be removed and the equation be rewritten as:

\[
BE_{CH4} = \varphi \times (1 - OX) \times \frac{16}{12} \times F \times DOC_f \times MCF \times \sum_{j} W_{j,x} \times DOC_j \times e^{-k_j(y-x)} \times (1 - e^{-k_j})
\]

(Equation 6.3.3.2)

Where:

- \(BE_{CH4,SWDS,y}\) = Methane emissions from the landfill (in tonnes CO₂-equivalent)
- \(BE_{CH4}\) = Methane emissions from the landfill (in tonnes methane)
- \(\varphi\) = Model correction factor to account for model uncertainties (0.9)
- \(GWP_{CH4}\) = Global Warming Potential (GWP) of methane (25)
- \(OX\) = Oxidation factor (reflecting the amount of waste from SWDS that is oxidised in the soil or other material covering the waste)
- \(F\) = Fraction of methane in the SWDS gas (volume fraction) (0.5)
- \(DOC_f\) = Fraction of degradable organic carbon (DOC) that can decompose (0.5)
- \(MCF\) = Methane correction factor
- \(W_{j,x}\) = Amount of organic waste type \(j\) prevented from disposal in the SWDS in the year \(x\) (tonnes)
- \(DOC_j\) = Fraction of degradable organic carbon (by weight) in the waste type \(j\)
- \(k_j\) = Decay rate for the waste type \(j\)
- \(x\) = Year during the existence of the SWDS: \(x\) runs from the start year (\(x=1\)) to the year \(y\) for which avoided emissions are calculated (\(x=y\))
- \(y\) = Year for which the methane emissions are calculated

The model takes into account waste disposed in start year \(x=1\) until the year \(y\) for which the emissions need to be estimated. Different methane correction factor (MCF) exists for:

- Anaerobic managed SWDS (1.0)
- Semi-aerobic managed SWDS (0.5)
- Unmanaged SWDS with deep and/or high water table (0.8)
- Unmanaged-shallow SWDS (0.4)

For further information, please refer to (UNFCCC 2008).

---

1 http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html?searchon=1&searchmode=advanced
Data sources

Table 48 Data sources landfill gas - advanced spatially explicit method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ, OX, F, DOC, MCF, k, j, k, j,</td>
<td>(UNFCCC 2008)</td>
<td>CDM-Home → Methodologies → Methodologies for CDM project activities → Methodological tools → Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site.</td>
</tr>
<tr>
<td>are model parameters, described in the tool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount of organic waste</td>
<td>To be obtained from landfill owner</td>
<td>Various</td>
</tr>
<tr>
<td>sent to landfill</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remarks

- Most parameters are model parameters that can be determined by general characterization of the SWDS, and selection of the right value using the Tool (UNFCCC 2008).
- More challenging is to acquire data on the amount of organic waste that has been sent to landfills over the years. This information may be obtained from literature, but very probably direct interviews with landfill owners will be necessary.

Advantages

- The method is internationally recognised and used in many CDM projects. Furthermore, the method is updated regularly.

Disadvantages

- The method requires detailed input on current and historic amounts of waste that were brought to each individual landfill. These amounts will not always be available, since weighing waste before dumping it in a landfill has not always been obligatory.

Future biomass potentials

- Realistic estimates of future quantities of waste sent to landfills need to be obtained. In general, it is expected that amounts of waste for landfill will decrease, but this is not necessarily the case for the landfill involved.

Sustainability aspects

Please refer to section 6.2.1 for a discussion on the sustainability aspects of landfill gas utilisation.

Key uncertainties and future research needs

Please refer to section 6.2.1 for a discussion on the sustainability aspects of landfill gas utilisation.

6.3.4 Landfill gas - cost-supply method

Method

- The costs of BMW collection and disposal are not taken into account since these tasks need to be carried out anyway. Also, the biomass supply costs consisting of the installation of a piping system for methane recovery from the landfill do not need to be taken into account: according to Annex I of the Landfill directive (art. 4.2), landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used.
- The conversion of electricity or upgraded biogas from landfill gas is not covered, as it is outside the scope of this report.
- By performing of a feasibility study (calculation of IRR and NPV) it can be assessed at which costs the landfill gas can be made available, and whether flaring or energy generation is the most financially feasible option.
Data sources
- For case specific calculations, offers of technology suppliers can be used.
- For a general assessment of the contribution of LFG to the energy supply of a country, standardised investment costs and operational costs need to be determined using literature, or by comparing costs information of different landfills (if available).

Remarks
- A generic costs-supply curve can be produced, showing the costs of the raw landfill gas extraction. Local conditions will however play an important role in landfill gas recovery, as well as subsidy programmes for electricity and gas generation from landfill gas.

Advantages
- The method is straightforward.

Disadvantages
- The piping system and its costs will be site specific.

Future biomass potentials
Please refer to section 6.3.1.

Sustainability aspects
Please refer to section 6.3.1.

Key uncertainties and future research needs
- While costs of extraction can be estimated quite well, the landfill gas yield remains dependent on various site specific conditions.
6.4 Construction and demolition wood

For assessment of the availability of construction and demolition wood only the statistical method is available, since no spatially explicit data are available on construction and demolition wood. Therefore, also the cost supply method is not presented.

6.4.1 Construction and demolition wood - statistical method

Method

\[ TP_{CDW, x,y, mass} = CDW_{a, x,y} \times WC_{x} \]  
(Equation 6.4.1.1)

\[ TP_{CDW, x,y, energy} = CDW_{a, x,y} \times WC_{x} \times LHV \]  
(Equation 6.4.1.2)

Where:

- \( TP_{CDW, x,y, mass} \) = theoretical biomass potential of construction and demolition wood of country \( x \) in year \( y \) (tonnes/year)
- \( TP_{CDW, x,y, energy} \) = theoretical biomass potential of construction and demolition wood of country \( x \) in year \( y \) (PJ/year)
- \( CDW_{a, x,y} \) = amount of construction and demolition waste in country \( x \) in year \( y \) (tonnes/year)
- \( WC_{x,y} \) = wood content of construction and demolition waste in country \( x \) (percent)
- \( LHV \) = lower heating value of construction and demolition wood (GJ/tonne)
- \( x \) = country
- \( y \) = year

Data sources

Table 49 Data sources construction and demolition wood - basic statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of demolition and construction wood</td>
<td>EEA</td>
<td>(Brodersen et al. 2002); only Belgium, Denmark, Germany, Finland, Spain, Ireland, Netherlands, Sweden.</td>
</tr>
</tbody>
</table>

Remarks

- Since at European level there is no centralised data collection for construction and demolition wood, only data on the total amount of construction and demolition waste is available. The waste consists mainly of concrete/bricks/tiles/asphalt, metals, glass, plastics, insulation and wood.
- For the basic approach, a weighted average of the wood content in the construction and demolition waste has been calculated based on data provided by (Brodersen et al. 2002), which is 9.5 %. A more detailed approach has been developed by the EEA project “Projections of construction and demolition waste arisings and GHG emissions”. Here, countries are grouped into four groups based on their geographical and waste management characteristics in order to gain at least a one-year complete data set with information on the waste fractions.
- The lower heating value of the wet wood is 12.2 MJ/kg (moisture content 20 %) (IEA 2007).
- More advanced studies should refer to national sources for the exact share of wood contained in the construction and demolition waste. Alternatively, there might be direct data available on the amount of construction and demolition wood. Additionally, national data should be drawn on regarding the share of CDW that is allowed to be incinerated; in some countries, certain parts cannot be incinerated due to the contamination of the wood.
Advantages
- The methodology is simple and for most European countries there are data on the total amount of construction and demolition waste available.

Disadvantages
- Data on the potential of construction and demolition wood derived with this methodology are not exact. The composition of construction and demolition waste, which serves as a basis for this calculation, varies greatly between European countries. Firstly, this is due to differences in definitions. For instance, in Austria and Germany also excavated soil and stones belong to this waste category and account for a large amount. Secondly, the design of buildings differs between countries. In Finland and Sweden buildings are mainly made up of wood whereas in Germany, Ireland and the Netherlands, concrete, bricks, tiles, etc. dominate. As a result, in Sweden and Finland, wood accounts for around 27% of the waste, whereas in Germany, Ireland and the Netherlands, it is only around 1.7%. Therefore, the application of one single factor for the share of wood in the construction and demolition waste does not adequately reflect the differences between countries.

Future biomass potentials
- The future potential of construction and demolition wood mainly depends on the population growth, the activities in the construction and demolition sector as well as on architectural trends; more wood might be used for a certain period of time, which will become waste long after. (Skovgaard and Moll 2005) have developed a model to estimate future amounts of waste in the construction sector within the EU-15 countries. The model is based on the analysis of past trends regarding population growth, economic activities in the construction and demolition sector and the amount of waste produced. If the links have been reliable in past, they have been used for projections regarding the development of the amounts of waste in the future.
- As a result, waste from the construction and demolition sector in the EU-15 is estimated to increase by approximately 30 - 35% by 2020 in the Baseline scenario. In the Low growth scenario, increases are more moderate with 15 - 20%. These figures are related to waste from the construction and demolition sector as a whole. However, provided that there is no change in the composition of the waste, the factors can also be applied to construction and demolition wood.
- The amounts of waste generated per capita differ greatly between countries and over time, mirroring differences and changes in structure and technology used within the building and construction sector, but also differences regarding what has been categorised as construction and demolition waste.
- A similar approach is used in the EEA project “Projections of construction and demolition waste arising and GHG emissions”.

Sustainability aspects
- Construction and demolition waste (including construction and demolition wood) has a recycling target in the waste directive 2008/98/EC, which incentivises the recycling of wood (at least 70% by weight shall be recycled). However, it has to be noted that a large part of this wood category has been painted and/or treated, which prevents its use as biomaterial (e.g. as chip board). In this case, there is no competition with alternative uses.
- It has to be noted that the incineration of treated wood requires special measures for preventing air pollution. Some European member states (e.g. Denmark) do not allow the incineration of certain parts of construction and demolition wood due to contamination. In those cases, national regulations have to be taken into consideration.
- For further aspects regarding sustainability, please refer to chapter 8 as well as Annex 2 and Annex 3.

Key uncertainties and future research needs
- Since there is no central data collection on this waste category neither on national nor on European level, the exact composition of demolition and construction waste and therefore the potential of
construction and demolition wood is not clear. Construction and demolition wood accounts for a significant energy potential which does not cause any competitions with other use options. Therefore, more detailed and exact data collection should be aimed for at European level in order to tap the full potential of this waste category.

- Part of the data collection should also be the establishment of a common definition on what is included in construction and demolition waste. For instance, sometimes excavated soil and stones are part of the waste and account for large amounts.
- Future predictions are difficult to make as economic activities in this sector among other factors depend on the economic development and consumer behavior which are difficult to predict. Moreover, the composition and weight of CDW depends mainly on demolition activities. The changes in use of wood in construction are reflected on waste after the buildings’ demolition. So it is difficult to predict when and how much CDW wood will be generated.

6.5 Sewage sludge and gas

Sewage sludge is produced from the treatment of wastewater. First, a raw primary sludge is obtained that needs to be further stabilized for transportation. The treatment is done either anaerobically or aerobically. In the first case, sewage gas is produced that consists mainly of methane.

6.5.1 Sewage sludge and gas - statistical method

Since sewage gas and sewage sludge are two different products, they will be dealt with separately.

Method - Sewage gas

\[
TP_{SeG_{x,y,mass}} = \left(SeS_{x,y} \times OM\right) + \left(SeS_{industrial,x,y} \times OM\right) \times GY
\]

(Equation 6.5.1.1)

\[
TP_{SeG_{x,y,energy}} = \left(SeS_{x,y} \times OM\right) + \left(SeS_{industrial,x,y} \times OM\right) \times GY \times LHV
\]

(Equation 6.5.1.2)

Where:

- \(TP_{SeG_{x,y,mass}}\) = technical biomass potential of sewage gas of country \(x\) in year \(y\) (tonnes/year)
- \(TP_{SeG_{x,y,energy}}\) = technical biomass potential of sewage gas of country \(x\) in year \(y\) (PJ/year)
- \(SeS_{urban,x,y}\) = amount of sewage sludge treated in urban sewage plants in country \(x\) in year \(y\) (tonnes/year)
- \(SeS_{industrial,x,y}\) = amount of sewage sludge produced in industrial sewage plants in country \(x\) in year \(y\) (tonnes/year)
- \(OM\) = organic dry matter of sewage sludge in urban & industrial sewage plants (percent)
- \(GY\) = gas yield (m³/kg organic dry matter)
- \(LHV\) = lower heating value of sewage gas (MJ/m³)
- \(x\) = country
- \(y\) = year

Method - Sewage sludge

\[
TP_{SeS_{x,y,mass}} = SeS_{x,y} - SeS_{Agr_{x,y}} - SeS_{Landf_{x,y}} - SeS_{Comp_{x,y}}
\]

(Equation 6.5.1.3)

\[
TP_{SeS_{x,y,energy}} = \left(SeS_{x,y} - SeS_{Agr_{x,y}} - SeS_{Landf_{x,y}} - SeS_{Comp_{x,y}}\right) \times LHV
\]

(Equation 6.5.1.4)

Where:

- \(TP_{SeS_{x,y,mass}}\) = technical biomass potential of sewage sludge of country \(x\) in year \(y\) (tonnes/year)
- \(TP_{SeS_{x,y,energy}}\) = technical biomass potential of sewage sludge of country \(x\) in year \(y\) (PJ/year)
- \(SeS_{x,y}\) = amount of sewage sludge of country \(x\) in year \(y\) (tonnes/year)
- \(SeS_{Agr_{x,y}}\) = amount of sewage sludge used in agriculture in country \(x\) in year \(y\) (tonnes/year)
SeS_Landf\(_{x,y}\) = amount of sewage sludge disposed in landfills in country \(x\) in year \(y\) (tonnes/year)\(^4\)

SeS_Comp\(_{x,y}\) = amount of sewage sludge used as compost in country \(x\) in year \(y\) (tonnes/year)

LHV = lower heating value of sewage sludge (PJ/tonne)

\(x\) = country

\(y\) = year

### Data sources

#### Table 50 Data sources sewage sludge and gas - statistical method

<table>
<thead>
<tr>
<th>Data item</th>
<th>Data source</th>
<th>Exact location</th>
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<tbody>
<tr>
<td>Total sewage sludge production from urban waste water</td>
<td>Eurostat</td>
<td>Eurostat → Statistics → Environment → Water → Total sewage sludge production from urban waste water</td>
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<tr>
<td>Total sewage sludge production from industrial waste water treatment</td>
<td>National data</td>
<td>(Nitsch et al. 2004); (Fritsche et al. 2004)</td>
</tr>
<tr>
<td>Agricultural use of sludge production from urban waste water</td>
<td>Eurostat</td>
<td>Eurostat → Statistics → Environment → Water → Agricultural use of sludge production from urban waste water</td>
</tr>
<tr>
<td>Landfill of sewage sludge production from urban waste water</td>
<td>Eurostat</td>
<td>Eurostat → Statistics → Environment → Water → Landfill of sewage sludge production from urban waste water</td>
</tr>
<tr>
<td>Composting of sewage sludge production from urban waste water</td>
<td>Eurostat</td>
<td>Eurostat → Statistics → Environment → Water → Composting of sewage sludge production from urban waste water</td>
</tr>
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<td>Eurostat</td>
<td>Eurostat → Statistics → Environment → Water → Population connected to urban wastewater treatment</td>
</tr>
<tr>
<td>Population</td>
<td>Eurostat</td>
<td>Eurostat → Statistics → Population → Demography → Main demographic indicators → Total population</td>
</tr>
</tbody>
</table>

### Remarks

- Anaerobic digestion is a common technology to treat raw primary sewage sludge for reducing the volume and mass. Sewage gas is produced as a by-product and frequently used to cover own energy needs. The average gas yield is 0.5 m\(^3\)/kg organic dry matter for untreated sludge. The figures available at Eurostat concerning the amount of urban waste water refer to treated sewage sludge. A factor of 2.3 has been derived to calculate the amount of organic dry matter of raw sludge. The factor is based on the following assumptions (all numbers based on (Leible et al. 2003)):
  - Treated sludge: 50 % of the dry matter is organic → 0.015 is the mineral fraction that does not change during fermentation
  - Untreated sludge: 70 % of the dry matter are organic, 30 % are mineral → the amount of organic matter in the untreated sludge is \(\frac{0.015 \times 0.7}{0.3} = 0.035\)
  - To derive the organic matter for untreated sludge based on the treated sludge, a factor of \(\frac{0.035}{0.015} = 2.3\) has to be applied

For sewage sludge derived from industrial waste water treatment, the factor to be applied depends on whether data on treated or untreated sludge are available.

- Beside sewage sludge from urban wastewater treatment there is also sewage sludge production from industrial wastewater. However, these wastewaters are mostly treated in own sewage plants and the sludge is combusted on-site. In case energy is produced it is used internally. Therefore, currently no data are available on the amount of industrial sewage sludge.

\[^4\] SeS_Landf\(_{x,y}\) is subtracted from the potential of sewage sludge that is available for combustion. Of course, the sludge in landfills still produces gas which can be used, but this potential should be included in the potential of landfill gas.
• The heating value of sewage gas is 21.6 MJ/m³ if a methane content of 60 % is assumed (LHV of methane: 35.9 MJ/m³).
• For the treated sewage sludge, the most frequently used method for energy production is combustion. Before being combusted, sewage sludge needs to be dewatered as it mainly consists of water and therefore has a very low heating value. Mechanic dewatering results in a heating value of 0.9 MJ/kg (25 % dry matter).
• The heating value of the sludge could be increased to 9.7 MJ/kg if the sludge is dried thermally (90 % dry matter). Drying is an option only if waste heat is available that cannot be used otherwise. Otherwise, thermal drying would use more energy than is generated during combustion. The assessment of such a potential, however, can only be realised with a spatially explicit method (see section 6.5.2).
• Please note that the above mentioned amount of sewage sludge only refers to the amount of sludge that has been treated in sewage plants, i.e. the amount already includes the rate of connection to urban wastewater treatment. Whereas in some countries over 90 % of the population is connected to urban waste water treatment, in many countries still less than 50 % are connected.

Advantages
• The method is simple and there is a good data availability on European and (if required) national level.

Disadvantages
• In the basic approach it has been assumed that all sewage sludge is treated with anaerobic digestion. In reality this is not the case as only big sewage plants have digesters whereas in smaller plants, the final treatment is done aerobically. Whether anaerobic digestion is used depends on the economic viability, which is different in each country. Moreover, it is questionable whether the use of sewage gas for energy production is standard in all countries. Therefore, no generalised figure can be given and the resulting potential will be overestimated.
• In contrast, the fact that the – rather low – heating value of mechanically dehydrated sewage sludge is taken as a basis leads to an underestimation of the potential. The derivation of a more exact potential based on the use of surplus waste heat has to be realised with spatially explicit methodologies (see section 6.5.2).
• Currently no data are commonly accessible on the amount of industrial sewage sludge and gas. Data sources, though, might be available on national level.

Future biomass potentials
• The future potential of sewage gas and sludge depends among others on the amount of treated urban waste water and thus on the development of the number of households and on the connection rate of households to sewage treatment. Although many of the European countries have reached the (economically possible) maximum connection rate, many countries still have possibilities to increase it. For industrial wastewater treatment, the future potential depends on future building activities.
• When considering to change the connection rate, it has to be taken into account that the above mentioned sewage sludge potential already includes current connection rates. Therefore, the 100 % sewage production has to be extrapolated first based on the current amount of sludge and the current connection rate. After that, the connection rate can be adapted to the respective scenario. For the amount of sludge produced per capita, the total amount of sewage sludge has to be divided by the population size.
• Regarding the further use of sewage sludge, there are different options. Currently, part of the sludge is disposed of in landfills or used in agriculture and therefore is no longer available for energy production via combustion as presented in the above described methodology. Sludge that is disposed of in landfills contributes to the production of landfill gas. For the potential of landfill gas, see section 6.3.
• In the future, probably less sewage sludge will be disposed of in landfills as the landfill directive (1999/31/EC 1999) aims at reducing the disposal of biodegradable waste by 35 % until 2016. The
directive has led to the implementation of rather strict regulations in many member states reducing the amount of biodegradable waste in landfills.

- The use of sewage sludge in agriculture is strongly promoted on European level and the threshold limits in the sewage sludge directive (86/278/EEC 1986) are set rather loosely. However, in different European countries there are opposing trends and the use of sewage sludge in agriculture is inhibited more and more by restrictive regulations.
- Therefore, for future scenarios, the regulations in the European member states need to be taken into account. Whereas in some countries, it is likely that the whole amount of sewage sludge will have to be combusted, in other states large quantities will be applied to the fields.
- Moreover, the energy potential of both gas and sludge, will likely be influenced by the future development of technologies. These will likely lead to a reduction of sewage sludge and to an increase in energy efficiency (in the combustion of the gas and the sludge). Research is ongoing regarding the drying of sewage sludge without using external energy carriers (e.g. with solar power) which would increase the amount of energy that can be saved.

Sustainability aspects

- For sewage gas there are no other use options than as bioenergy and thus no competition with other applications occurs.
- As due to the landfill directive (1999/31/EC 1999) the disposal of sewage sludge in landfills is likely to be reduced in the future, the most relevant competition will occur between the use of the sludge in agriculture and its combustion for energy production.
- From a sustainability point of view, the use of biomass as biomaterial should be given priority as of all renewable energy carriers, only biomass can be used as a source of sustainable materials (see chapter 8). The use of sewage sludge in agriculture could replace mineral fertiliser, especially phosphate which is an increasingly scarce non renewable resource. However, the application of sludge on fields results in the accumulation of organic and inorganic (heavy metal) pollutants in soil and water, and should therefore not be promoted. Moreover, high ammonia emissions contribute to acidification and eutrophication of ecosystems, which has been identified as one of the major threats to biodiversity (see chapter 8).
- These problems do not occur if the sludge is combusted. As many life cycle assessments have shown, the combustion of sewage sludge would also be the better option from a climate protection and fossil energy saving point of view – provided that the drying could be realised with waste heat. An exception is phosphate as non renewable resource. However, there are already technologies available to extract phosphate from the ashes.
- The achievement of higher connection rates to sewage treatment facilities not only leads to higher energy potentials but also implies a significant improvement of the living standard and substantially mitigates the contamination of water and soils due to untreated waste water.
- For further aspects regarding sustainability, please refer to chapter 8 as well as Annex 2 and Annex 3.

Key uncertainties and future research needs

- Since industrial sewage sludge is mostly used internally, there are no data available on exact amounts of sludge production. However, it probably accounts for a great potential as often there is surplus waste heat available for drying the sludge in industrial plants. For Germany, (Fritsche et al. 2004) derived a potential of 1.45 million tonnes of industrial sewage sludge and 2.48 million tonnes from urban wastewater treatment.
- Further uncertainties concern the amount of energy that can be produced combusting sewage sludge. If external energy carriers are used for drying, more energy might be needed than can be saved. Therefore, only waste heat or other heat sources (solar power) should be used for drying. However, there are big differences between European countries concerning such technologies. In Germany and Scandinavia there is a long tradition of combusting (biodegradable) waste and thus an infrastructure has been developed that can be used for drying and combusting sewage sludge. In contrast, in southern European countries, such an infrastructure is not yet well established and
thus likely lower energy efficiencies will be achieved. If possible, biomass potential assessments should take into consideration these differences.

6.5.2 Sewage sludge and gas - basic spatially explicit method

Method

- For the mass and energy potentials of sewage sludge and gas, the same equations can be used as presented in section 6.5. Two elements of the equations should be regionalised for spatially explicit results: information on the distribution of industry that produces sewage sludge and gas as well as information on the population distribution in Europe and on the population connected to urban wastewater treatment.
- This methodology is mainly applied to sewage sludge and sewage gas potentials derived from urban wastewater treatment as well as sewage sludge from industrial wastewater treatment. For sewage gas from industrial waste water treatment, a spatially explicit presentation would not increase knowledge since the energy produced from the gas is directly used on site. Therefore, information on the distribution of plants producing energy from sewage gas is not needed.

Data sources

<table>
<thead>
<tr>
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<th>Exact location</th>
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</thead>
<tbody>
<tr>
<td>Sewage sludge production from industrial wastewater treatment</td>
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<td>Eurostat → Statistics → Environment → Water → Population connected to urban wastewater treatment</td>
</tr>
</tbody>
</table>

Remarks

- As described in section 6.5.1, the sewage gas yield is 0.5 m³/kg organic dry matter and 70 % of the dry matter is organic dry matter. The heating value of sewage gas is 21.6 MJ/m³ (with 60 % methane content).
- The lower heating value of mechanically dewatered sewage sludge is 0.9 MJ/kg (20 % dry matter).
- For further remarks, refer to section 6.5.1.

Advantages

- Regionalised information on the amount of sewage sludge and sewage gas available for energy production will be available. These can serve as input for more detailed analyses as described in the following section (6.5.2).
- Moreover, future potentials on sewage sludge and gas from urban wastewater treatment can be derived more exactly since trends in population distribution and migration can be taken into account. This is important since only larger communities are likely to build sewage treatment plants. Remote and sparsely populated rural areas are more likely to apply decentralised treatment methods. Moreover, anaerobic digestion where sewage gas is produced as a by-product is only applied in larger sewage plants.
Disadvantages
- Currently, there is no commonly accessible database for spatially explicit data regarding the connection rates to urban waste water treatment. Therefore, own assumptions have to be made based on population distribution.
- Moreover, there are no commonly accessible spatially explicit data on industrial wastewater production. These data have to be derived from national sources.

Future biomass potentials
- In addition to the factors described in section 6.5.1, the development of the population distribution should be taken into consideration, i.e. trends in population migration. If necessary, the connection rates for wastewater treatment should be adapted to the demographic development. For instance, in remote areas with a clear migration trend into cities, the population will probably only gradually connected to wastewater treatment, or not at all.
- Moreover, future industry building activities should be taken into account.

Sustainability aspects
- Apart from the topics mentioned in section 6.5.1, no further aspects need to be taken into consideration.

Key uncertainties and future research needs
- See section 6.5.1.

6.5.3 Sewage sludge and gas - advanced spatially explicit method

Method
- This method is only applicable for the use of sewage sludge which should be dried before being combusted. For sewage gas, there are no further changes compared to section 6.5.2.
- Add information on plants with waste heat available (e.g. electric power plants, biogas plants, concrete factories, etc.) based on the regionalised information concerning the availability of sewage sludge per capita from urban waste water treatment as well as regarding the amount of sewage sludge from industrial wastewater treatment (section 6.5.1). This waste heat can be used for drying the sewage sludge and thus increase its heating value.
- In the surroundings of these plants, take into account an increased heating value of sewage sludge and thus an increased energy potential. In other areas, refer to the heating value of mechanically dewatered sewage sludge.

Data sources
- There are no commonly accessible spatially explicit data bases on the plants with waste heat available. There might be data available on national level. For the statistical information concerning the potential of sewage sludge, see section 6.5.1.

Remarks
- Sewage sludge contains large amounts of water and thus a low heating value. Mechanical dewatering would be a minimum pre-treatment and results in a lower heating value of 0.9 MJ/kg (20 % dry matter). Drying the sludge would increase the heating value to 9.7 MJ/kg (90 % dry matter). However, from an energy saving and climate protection point of view, drying only makes sense in case enough surplus waste heat is available as otherwise the thermal drying process would require more energy than the combustion of sewage sludge could produce.

Advantages
- Using the heating value of mechanically dewatered sewage sludge would lead to a very conservative energy potential. It can be increased by taking into account surplus waste heat available for drying the sewage sludge.
Disadvantages
- There is no commonly accessible data base available for industrial plants and their amount of surplus waste heat. Data have to be collected based on national information.

Future biomass potentials
- Beside the factors described in section 6.5.1, the development in population distribution will play an important role as it influences the sewage sludge catchment areas. The drying of sewage sludge will be economically viable and thus realisable only if there is a rather high population density in the catchment area. Furthermore, future plans for building plants that are potential waste heat sources as well as the alternative use options for this heat will influence the potential.

Sustainability aspects
- Apart from the aspects mentioned in section 6.5.1, no further aspects need to be taken into consideration.

Key uncertainties and future research needs
- Apart from the uncertainties mentioned in section 6.5, the lacking data base regarding the amount of waste heat available is a major obstacle within this methodology. Only with these data, a realistic potential of energy produced from sewage sludge can be derived since only with waste heat the heating value of sewage sludge can be increased.

6.5.4 Sewage sludge - cost-supply method

Method
For both sewage sludge and sewage gas, the technical potential is calculated following the statistical methodology described in section 6.5.1.

The costs of both raw materials are set to zero since they are produced as residues in wastewater treatment and since there is no market.

Data sources
- For the data sources related to the quantities of sewage sludge and gas, please refer to section 6.5.1.

Advantages
- The method is quite simple since – apart from data for calculating the technical potential – no further data are necessary.

Disadvantages
- It is questionable whether it makes sense to derive a cost-supply curve from a product that has no production costs. For real cost-supply curves, the inclusion of the bioenergy generation costs would be necessary.

Future biomass potentials
- Future technical potentials of sewage sludge and gas are described in section 6.5.1.

Sustainability aspects
- For sustainability aspects related to sewage sludge and gas potentials, see section 6.5.1.

Key uncertainties and future research needs
- The main uncertainty is related to the exact future amount of sewage sludge and gas. For this, please refer to section 6.5.1.
6.6 Future research needs

Biodegradable municipal waste
- Since the definition of municipal waste and surveying methods used vary from country to country, comparability of data is limited. However, most uncertainty is related to the determination of the organic content and the energy value of the wastes. Further harmonisation of methods between countries is needed to improve data quality.
- Because the amount of organic waste generated, and the share diverted from landfill are important parameters for verification of whether the requirements of article 5 of the landfill directive (1999/31/EC 1999) are met, it is expected that Eurostat and DG Environment will develop a methodology for determination of these parameters (Kloek 2000). This method will generate official data on BMW quantities. It is therefore advisable to observe, and if relevant, implement this upcoming method.

Landfill gas
There are two areas of uncertainty in the estimate of methane emissions from solid waste disposal sites: (i) the uncertainty attributable to the method; and (ii) the uncertainty attributable to the data (activity data and parameters). Both are described in section 3.7.2 of (IPCC 2006c). The following main observations regarding the method are made below:
- The used First Order Degradation (FOD) model takes into account historic waste volumes, which is an improvement compared to the default (Tier 1) method in previous versions of the IPCC guidance, like (IPCC 1996), which assumed that all methane would be released in the same year that the waste was deposited. However, it is important to remember that the FOD method is a simple model of a very complex and poorly understood system.
- Decay of carbon compounds to methane involves a series of complex chemical reactions and may not always follow a first-order decay reaction. Higher order reactions may be involved, and reaction rates will vary with conditions at the specific SWDS. Reactions may be limited by restricted access to water and local variations in populations of bacteria.
- SWDS are heterogeneous. Conditions such as temperature, moisture, waste composition and compaction vary considerably even within a single site, and even more between different sites in a country. Selection of ‘average’ parameter values typical for a whole country is difficult.
- Use of the FOD method introduces additional uncertainty associated with decay rates (half-lives) and historical waste disposal amounts. Neither of these are well understood or thoroughly researched. Further research is needed in the determination of some parameters such as the oxidation factor, which is heavily discussed.

Further research is needed to understand the process better and to assess whether more complex models will provide more accurate results, given the mentioned heterogeneities in the composition of the waste, moisture content, etc. Such an assessment should be combined with a large scale landfill gas monitoring program to obtain measured data. Since its interest in methane emission reduction, it is expected that IPCC will remain a good source of information on the current state of the art in modelling landfill gas production.

Construction and demolition wood
- Only limited methods were presented for construction and demolition wood, mainly because of lack of data. The most important research need is the establishment of a common definition on what is included in construction and demolition waste in order to allow proper data collection. For instance, sometimes excavated soil and stones are part of the waste and account for large amounts. This leads to a major overestimation of the potential. The introduction of a separate waste class for woody construction and demolition wood, on the level of Eurostat and to be implemented in all member countries, would improve the data availability considerably.
- Also with common definitions and European wide data collections, future predictions are difficult to make as economic activities in this sector and the composition of construction and demolition waste among factors depend on the economic development and consumer behaviour which are
difficult to predict. Only when sufficient base data become available is it worthwhile to put considerable effort in the prediction of future availability of construction and demolition wood.

**Sewage sludge and gas**
- The most relevant research need concerns efficient options for drying the sludge in order to increase the energy content. Thermal drying of the sludge considerably increases the heating value of the sludge and therefore the energy output. However, if external energy carriers are used for drying, more energy might be needed than can be saved. Therefore, only waste heat or other heat sources (solar power) should be used for drying. However, there are big differences between European countries concerning such technologies. In Germany and Scandinavia there is a long tradition of combusting (biodegradable) waste and thus an infrastructure has been developed which can be used for drying and combusting sewage sludge. The refinement of the existing infrastructure and the development of new and innovative logistical concepts would further enhance the energy output from sewage sludge. In contrast, in southern European countries such an infrastructure still needs to be developed and established.

### 6.7 Improvement of data sources

**Biodegradable municipal waste**
- In many countries there is uncertainty about the organic content of not separately collected municipal waste. Efforts should be made to make existing waste composition analyses available in an internationally accepted format.
- In case these analyses are not available at all, they should be carried out using relevant surveying methods. Based on waste analyses, country specific lower heating values of BMW could be determined.

**Landfill gas**
- The used First Order Degradation (FOD) model requires data on the amounts and quality of organic waste that has been sent to landfill over the years. This information may be obtained from literature, but very probably direct interviews with landfill owners will be necessary.

**Demolition wood**
- Construction and demolition wood accounts for a significant energy potential which does not cause any competition with other use options. In order to tap the full potential of this waste category, more detailed and exact data collection should be aimed for at a European level.
- So far, there is no central data collection on this waste category, neither on national nor on European level. Data that are available are incomplete – both in terms of time scale as well as geographical coverage. At the same time, the composition of construction and demolition waste greatly differs between countries so that wood fractions cannot be transferred. As a result, the exact composition of demolition and construction waste and therefore the potential of construction and demolition wood is not clear.
- The introduction of a separate waste class for woody construction and demolition wood on the level of Eurostat and to be implemented in all member countries, would improve the data availability considerably.

**Sewage sludge and gas**
- Currently, the sewage sludge and sewage gas potentials can only be derived for urban waste water, ignoring the potential of industrial sewage sludge and gas. Due to its mostly internal use, there is no exact data available on the amount. However, it probably accounts for a great potential. (Fritsche, Dehoust et al. 2004) derived a potential for Germany of 1.45 million tonnes of industrial sewage sludge and 2.48 million tonnes from urban wastewater treatment. Moreover, in many industrial plants there is surplus waste heat available for drying the sludge which further increases the heating value and therefore the energy output. The improvement of the data base would lead to a more realistic estimation of sewage sludge and gas potential.
Further data gaps concern the size of sewage plants, more exactly the share of sewage plants that use anaerobic digestion. Only with anaerobic digestion, sewage gas is produced. Moreover, it is questionable whether the use of sewage gas for energy production is standard in all countries. A more detailed data base on this issue would prevent the overestimation of the sewage gas potential.
7 Total resource assessments

7.1 Scope and definitions

Scope
This chapter describes the approaches and methods that are used for estimating the total biomass energy potential of different types of biomass (forest biomass, energy crops, agricultural residues and organic waste).

Resource-focused assessments typically focus on the present and future availability of surplus agricultural land and low productive land for energy crop production and of land under forest cover for the production of forest biomass (see section 7.2 and 7.3). The potential of residues can usually be calculated based on the present and future agricultural production. However, the total biomass energy potential is not just the sum of the potential of different biomass types.

Ideally, the total biomass energy potential is estimated taking into account competition between biomass resource uses, as well as competition between alternative energy technologies and primary energy sources. Therefore, this section is focused on demand-driven assessments, i.e. energy and economic modelling methods that analyse the competitiveness of biomass-based electricity and biofuels, and estimate the amount of biomass required to meet exogenous targets on climate-neutral energy supply. The ideal study would therefore take into account the whole chain, from potential supply of biomass to demand for food, materials, wood products and energy carriers and their various inter-linkages and dynamics.

It should be noted that energy and economic modelling methods as well as integrated assessment models can also be used to evaluate the potential of different types of biomass separately. These methodologies are not discussed in the previous discussions to avoid overlap between the different sections in this handbook.

Definitions
The definitions of the different types of biomass are already given earlier in this report. The total biomass energy potential is the aggregate (but not necessarily the sum) of the different biomass energy types.

7.2 Total resource assessments using statistical and spatially explicit methods

A detailed description of statistical and spatially explicit methods is already provided in the previous chapters. The total potential of biomass energy can be estimated using statistical and spatially explicit methods by summing up the potential of the different types of biomass. It is important that double counting is prevented, by ensuring that the definitions of different land use types do not overlap and by ensuring the consistency of the scenarios.

7.3 Total resource assessments using cost-supply methods

A detailed description of statistical and spatially explicit methods has already been provided in the previous chapters. The total cost-supply curve of biomass energy can be estimated by adding the cost-supply curves of different types of biomass. With that it is essential that double counting’s are prevented, by ensuring that the definitions of different land use types do not overlap and by ensuring the consistency of the scenarios. Such an aggregated cost-supply curve provides important insight into the cost-effectiveness of the various biomass-to-energy chains. These cost-supply curves can also be used as input for economic models.
7.4 Demand driven energy and economic modelling methods

7.4.1 Description of method

Method
Energy-economics and economic modelling methods mimic the dynamics of the demand and supply of energy, including bioenergy, by means of investigating economic and non-economic correlations. Note that in this method the definition ‘surplus agricultural land’ is not applicable, because in economic terms agricultural land is only surplus when the price is zero, which is never the case. The ideal energy-economics and energy-system model includes the following characteristics:

1. It takes the fundamentals of energy demand into account, i.e. population growth, GDP development, and relates global energy demand to these factors in a way that deals with the possibility of improving energy efficiency by technological and other innovations.
2. It includes all energy-related sectors and applications of feedstock, i.e. power generation, transport, heating (domestic as well as industrial) as well as feedstock applications for materials.
3. It encloses all options for supplying energy-related services, i.e. conventional and advanced fossil options and all kinds of renewable options.
4. It fills in projected energy demand per sector by economic rules, i.e. by choosing least-cost options at given (external) constraints. Such constrains can be specific policies or explicit CO₂ reduction targets, but other constraints will be inherent to the energy system (e.g. no unlimited introduction of intermittent power generation technologies without addressing costs for net balancing measures).
5. Costs of the different energy supply options are assessed with dynamic and (e.g. as for biomass applications) interrelated cost-supply curves.
6. These curves also take into account technological learning of innovative options in particular.
7. It contains extensive analysis of the sensitivity of the outcomes to different scenarios or differences in the key assumptions on e.g. costs.

Scenarios are used for the fundamental drivers of energy demand and supply, such as population growth and income growth, as well as technological developments, policy incentives. These variables are integrated into a coherent set of scenario assumptions. Some models also include greenhouse gas and energy balances for different energy systems, which allows for the optimisation of costs towards greenhouse gas reduction or energy security targets.

Other economic models focus on the integration of bioenergy and materials markets and agricultural economics models. An ideal agricultural economics model takes into account the effects on prices, production, and markets of all other crops. The ideal study compares the net-return of all possible crops that a farmer can grow. The competition with other markets (food, feed) - determining the output prices of competing markets and crops - is decisive for the economic feasibility of biofuels. The ideal study is able to deal with the competing claims of food, feed and fuel on production factors in order to estimate a real economic feasible production of biomass for fuel.

An example of a demand-driven model is the PEEP (Perspectives on European Energy Pathways) model that is described in the box below.

Data sources
Building an energy-economics and economic model can be very resource demanding. Price-demand and price-supply correlations can be estimated based on historic data and projections of technological developments. The data sources that are used are the same as those used in cost-supply assessments. The models are fed with exogenous policy targets and scenarios, oil price assumptions or other assumptions on the development of prices of means of production and technology development. For further references see also the ‘Data Sources Handbook’.
Advantages
A crucial advantage is that dynamic economic correlations are included that take into account various underlying factors that influence the economic viability. This makes these models especially suitable for evaluating (financial) energy policies and carbon prices. Also, technical learning is a crucial factor that can be included in this type of analysis.

Disadvantages
A disadvantage of this type of studies is however, that the results are not validated with bottom-up information about the availability and productivity of agricultural land. Furthermore, the correlations included in these models are based on historic data and expert judgement, which makes that the results are non-transparent and subject of debate. The most important handicap is that energy, agriculture and forest models are usually not integrated or linked with other models. This means that the dynamics of bioenergy markets are potentially not accurately depicted.

Further, partial of full equilibrium models are often inaccurate with respect to evaluating indirect land-use changes, for not taking into account the impact of co-products on land use. The production of first-generation biofuels results in the production of protein rich feed, which can be used as animal feed and thus replaces the use of land for the production of feed crops. These effects are typically not included in existing studies.

Future biomass potentials
Future biomass potentials are calculated by the model based on exogenous assumptions for certain parameters.

Sustainability aspects
Sustainability aspects are usually not evaluated in this type of models. Although this type of models can be expanded to evaluate the impact of energy crop production on food security, food prices, employment and trade balance. The possible integration of sustainability aspects in energy and economic modelling methods is further elaborated on in section 8.4.3.

Key uncertainties and future research needs
The impact of technological learning is not effectively taken into account. Further, some models work with constant costs for biomass, while it can be expected that this feedstock will generally show increasing costs with increasing demand. Another issue is that these models usually only focus on forest biomass or crops, while residues and waste are usually excluded. Also the indirect land use change effects are uncertain, whereby also the production of animal feed should be included.

7.4.2 Example: the PEEP model

The example of a demand driven energy systems model: PEEP (Perspectives on European Energy Pathways) is based on (Berndes and Hansson 2007)

To understand the development of energy systems in the EU in a quantitative manner, a regionalized energy and transport model, the PEEP model, was developed. The model operates with an optimisation algorithm that decides which primary energy sources, energy-conversion technologies, and energy carriers should be used to meet the energy demand for the studied time periods at the lowest energy system cost (net present value costs over the modelling period), while meeting specific targets.

The energy-system costs include costs for fuel, capital, operation and maintenance, distribution and infrastructure as well as costs for transportation of biomass and biofuels, and additional vehicle costs for gas-fuel vehicles. The optimization algorithm represents the market mechanisms in an ideal market where all actors always have access to perfect information and act rationally. The model is driven by energy demand which is defined externally. Additional exogenously defined parameters include
primary energy supply potentials and costs, energy-conversion characteristics, the initial energy-system capital stock, trade parameters and CO₂ emissions for the included fossil energy sources and related conversion/end-use technologies. The policy targets are also defined exogenously.

The PEEP has three main parts: (i) the supply of primary energy sources; (ii) the supply of energy-conversion technologies producing energy carriers; and (iii) the final energy demand. The energy demand is subsequently subdivided into three end-use sectors: (i) electricity, (ii) transportation and (iii) heat and other fuel use.

**Primary energy sources**
The availability and costs of fossil fuels are given at EU level. The costs for oil, coal and natural gas are taken from (EC 2003) and reflect an optimistic view of the development for fossil fuels that implies that no major supply constraints are likely to apply in the period leading up to 2030. The electricity supply potential for renewable resources (in addition to biomass) are given at country level and represent what is estimated to be practically (rather than theoretically) possible to reach within the time period considered. Also, a maximum share (20%) of the total electricity demand can be met with intermittent energy sources (i.e., solar and wind power).

**Future biomass potentials**
The costs and potentials for the different biomass types change over time and are set based on estimates of relevant country and biomass type specific parameters for residues in forestry and agriculture as well as for energy crops (Van Dam et al. 2005); (Wakker et al. 2005). Four types of energy crops are considered: lignocellulosic, starch, oil and sugar crops. The land availability is defined based on scenario assessments of availability of land for energy crops (i.e. land not used for food production that could support energy crop production). Economic mechanisms that consider the competition between biomass production for energy purposes with other land uses are not employed in the model.

**Energy conversion technologies**
The energy conversion technology data are, in general, country specific and include investment as well as operation and maintenance costs, lifetime, efficiency, and load factors. The data represent technologies that exist at present or are estimated to be available in the near future.

**Final energy demand**
The energy-demand scenarios are exogenously defined at country level and for each of the three end-use sectors, based on the baseline projection for the period of 2000–2030 in European energy and transport trends to 2030 (EC 2003).

The model is run with three different scenarios: (i) CO₂ emission and transport fuel policy scenario (CTP), (ii) CO₂ emission policy scenario (CP) and (iii) no policy scenario (NP). CTP includes an exogenously defined CO2 emission limit for the EU as a whole and country-level targets for the introduction of biofuels and other alternative fuels in the transportation sector. The CO₂ emission target places an upper limit on the total accumulated emission from fossil fuel use during the studied time period. The limit is estimated assuming a reduction of CO₂ emission by 35% in 2020 and 40% in 2030 compared to the baseline which is then applied to the model. In the transport sector respectively 8%, 20% and 30% of the petrol and diesel use has to be replaced with alternative fuels in 2010, 2020 and 2030, with biofuels and other renewable fuels contributing at least 5.75%, 11.5% and 17.25% these years. CP includes the CO₂ emission target only and NP includes no policies. There are two mechanisms for CO₂ emissions abatement in the model; CO₂ emissions can be reduced by switching fuel or by switching to an energy conversion technology with a higher efficiency.
### 7.5 Integrated assessments

#### 7.5.1 Description of method

**Method**

Integrated assessment models include correlations between the socio-economic drivers of economic activity and energy use. Economic activities and energy use lead to emissions and other pressure on the environment resulting in environmental changes, which in turn lead to physical impacts on societies and ecosystems and to socio-economic impacts and eventually return to cause changes in the socio-economic drivers. This type of models also allows using complex scenarios, whereby a scenario consists of a consistent set of parameters. Furthermore, this type of models can be expanded with many other datasets and tools. Particularly the combination of data of different dimensions of sustainable development make the integrated assessment modelling approach extremely suitable for evaluating the sustainable potential of biomass energy from crop production. In addition, this type of models integrates bottom up data on various issues, e.g. land use and productivity data are combined with energy models and agricultural economics models and thereby provide an appropriate framework to estimate the potential of biomass energy and the impacts on agricultural markets and food security, GHG emissions, land use, biodiversity and other sustainability indicators. This is particularly important when considering the impact of land use changes on e.g. biodiversity, GHG emissions, and fresh water balance that are induced by the production of biomass energy.

**Data sources**

A wide variety of data is used in integrated assessment models, depending on the parameters and factors that are considered. Basically, all data source described in the other sections and in the ‘Data Sources Handbook’ are potentially useful for integrated assessments.

**Advantages**

The complexity and integrated nature of these models is a big plus and allows for the use of storylines and a large number of variables. IAMs offer internally consistent and globally comprehensive analysis of impacts. They provide “vertical integration” (i.e., cover the entire “causal chain” from socioeconomic activities giving rise to GHG emissions to concentration, climate, impacts, and adaptations), and “horizontal integration” (i.e., account for inter-linkages between different impact categories, adaptations, and exogenous factors such as economic development and population growth), and allow for consistent treatment of uncertainties. IAMs thereby provide an appropriate framework to estimate the potential of biomass energy and the impacts on agricultural markets and food security, GHG emissions and land use.

**Disadvantages**

An important handicap of IAMs is the complexity of these models, which gives these models relatively lower transparency, makes them expensive to develop and user-unfriendly in operation. Moreover, the integration of separate models and the uncertainties due to gaps in knowledge and data are often problematic in IAM. This goes especially for the usefulness of IAMs for addressing climate change, in the light of the huge uncertainties and unresolved scientific question. Therefore, better insight into IAM models, the uncertainties, the sensitivities and the assumptions is prerequisite. This is especially important because IAMs rely on reduced-form equations to represent the complexities of more detailed models. Their usefulness is highly dependent on how well they are able to capture the complexities of more disaggregated approaches.

**Future biomass potentials**

Future biomass potentials are either estimated by the model or are included as exogenous scenario variables.
Sustainability aspects
IAMs are typically well-suited to evaluate the impact of bioenergy crop production and use on various sustainability criteria, especially climate change. This is further elaborated in section 8.4.4.

Key uncertainties and future research needs
Key uncertainties and future research needs should focus on increasing the accuracy and resolution of integrated assessment models. Also, the accuracy of the correlations needs to be improved and validated in more detail.

7.5.2 Example: the EUFASOM model
The European Forest and Agricultural Sector Optimization Model (EUFASOM) has been developed as an integrated assessment scientific tool for the comprehensive economic and environmental analysis of land use and land use change in forest and agriculture sectors of the European Union (but also includes commodity supply and demand functions for non-EU regions covering the entire globe). EUFASOM estimates the likely response of land use sectors to structural changes related to climate, bioenergy, biodiversity, soil, water and food that are brought about by political, environmental, technical, socioeconomic and market changes. The likely land use impacts are determined through constrained welfare maximization.

Model computations are executed using the General Algebraic Modeling System (GAMS) Software as a conceptually non-linear program (which is linearly approximated). Subject to compliance with a set of constraining equations, EUFASOM maximizes the net present value of all agricultural and forestry sector activities and includes the impacts of policy incentives and disincentives. Technological opportunities, physical resource endowments, production capacities, inter-temporal relationships, and political regulations form important constraints while cost coefficients for land use and commodity processing alternatives, adjustment costs for major land use changes, commodity market price changes and production factors, trade costs, transportation costs, revenues and political incentives and disincentives contribute to the net economic surplus of all markets. The solution of EUFASOM identifies the equilibrium levels for all agricultural and forest sector activities under given economic, political and technological conditions. These consist of optimal land use allocations and associated management intensities, related environmental impacts, regional resource usage, commodity supply, equilibrium market prices, and trade volumes of the agricultural and forest commodities covered in the model (Schneider et al. 2008a). A succinct schematic representation of the model components and structure is illustrated in Figure 10.

Figure 10 The EUFASOM model structure
Data and methodology
Agricultural production involves two commodity groups - food and dedicated energy crops, while forest biomass comes from both wood felling and wood residues. Land is the only explicit resource involved. The model has an initial distribution of agricultural land to arable land, forest land, wetland, grassland and energy crop land. Arable land is taken as the proportion of the total land available for agriculture or the utilized agricultural area. Wetlands include peatland, wet forests and wet grassland (Schleupner and Schneider 2010). Grassland area comprises both temporary and permanent grassland areas where permanent grassland covers about 8% of the total European land surface and 35% of the total utilized agricultural area. On average, temporary grassland equals about 10% of the total grassland area except for certain Scandinavian countries, where the proportion can be substantially higher (Smit et al. 2008). The initial distribution of land available for growing dedicated energy crops in Europe is defined to be about 4% of total land and about 8% of agricultural land (EURURALIS 2008).

Indicators including arable and forest land use data quantities and the current production, consumption, detailed trade matrix (import and export flows), and price data for agricultural and forest commodities are taken from the public statistics database of the Food and Agricultural Organization of the United Nations (FAOSTAT) and from the report ‘The State of Food and Agriculture 2006’ of the FAO (FAO 2006b) (FAO 2008). The aggregated traditional arable commodities include soft wheat, hard wheat, barley, cotton, oats, rye, rice, corn, soya, sunflower, rape, sugarcane, sugar beet, potato, pulses, tobacco and flax. Biomass yields of dedicated energy crops such as willow, poplar, miscanthus and reed canary grass are taken from EPIC model simulations using homogenous response units (HRU) (Schmid et al. 2007); (Schneider et al. 2008b) while the production and demand quantities of biomass and bioenergy products are consistent with 2009 PRIMES datasets. The initial wetland distribution data used was from the existing wetland areas from SWEDI (Schleupner and Schneider 2010) while the European statistical bureau, Eurostat, provided the regional grassland data used in the study (Smit et al. 2008).

Model development
The EUFASOM model depicts the impact of socio-economic drivers on land use activities and agricultural markets. Mathematically, this is accomplished through the following major equations:

1. the objective function equation;
2. the commodity balance equation for food, forest and energy crops;
3. the resource balance equation for the supply and demand relationships for agricultural and forest production factors;
4. the crop mix equation; and
5. the land use change equation.

The mathematical structures of these equations are represented below.

The objective function maximizes the net present value of the total economic surplus of the agricultural and forest sectors subject to a set of constraining equations, which define a convex feasible region for all endogenous land use decision variables. The following important decision variables form the model constraints:

(a) resource endowment constraints, which limit the available land area for each land use category;
(b) biomass production and supply constraints, which limit the biomass production based on the yield of energy crops;
(c) trade constraints, which restrict the import and export volumes of commodities between the regions;
(d) demand constraints, which force the model to supply a certain quantity of commodities for domestic use;
(e) land use change constraints, which restrict the total permissible land use change between different land use categories; and
(f) policy constraints, which enforce incentives related to land use, processes and demand quantities.

Technically, the economic surplus is computed as the sum across time, space, commodities and resources of total price endogenous goods, constant price goods, exports and governmental net payments to the agricultural/forestry sector (or the areas underneath all demand curves known as the consumers’ surplus, producers’ or resource owners’ surplus) minus the total costs of production, transportation, processing and exports (areas underneath all supply curves). Information on the various aspects and dimensions of the different constraints and components (markets, energy, trade, processes, land use and resources) are combined in an integrated manner. The objective function is presented in Equation 7.5.2.1 (see next page). Note that policy (p) coefficients can either be added or subtracted depending on whether it is an incentive/subsidy or tax/tariff. In this case, incentives are applied in Equation 7.5.2.1.

Equation 7.5.2.2 presents the commodity balance equation for all regions and products. The technical coefficient, $\alpha$, presents the input requirements for each of the variables involved. Table 52 and Table 53 explain the major indices and variables used in the model. Specifically, for each region ($r$) and product ($y$) at a specific period ($t$), the total amount allocated to domestic consumption (DEMD), processing (PROC) and exports (TRAD$_{r_1,r_2}$) cannot exceed the total supply through crop production (CROP), bioenergy plantations (PERE), grasslands (GRAS), nature reserves (WETL), forest (FORE) or imports (TRAD$_{r_2,r_1}$).

Equation 7.5.2.3 presents the resource balance equation for the supply and demand relationships for agricultural and forest production factors. The resource input requirements per unit of production are represented by the resource use coefficients, $\alpha$, for each region ($r$), soil type ($j$), altitude ($h$), slope ($s$), land use type ($c, b, g, w, f$) and technology ($m$) for each of the variables (CROP, PERE, GRAS, WETL, FORE, PROC).
Maximize WELF = \sum_{t} \partial_{t}

\begin{align*}
\sum_{r, y} \left( \int \varphi_{r, t, y}^{DEMD} (DEMD_{r, t, y}) \, d(\mathbb{I}) \right) \\
+ \sum_{r, y} \left( \int \varphi_{r, t, y}^{EXP} (\sum_{t_{i}} TRAD_{r, t_{i}, y}) \, d(\mathbb{I}) \right) \\
+ \sum_{r, y} \left( \psi_{r, t, y}^{DEMD} \cdot DEMD_{r, t, y} \right) \\
+ \sum_{r, y, p} \left( \psi_{r, t, x, y, p}^{PROC} \cdot PROC_{r, t, x, y} \right) \\
+ \sum_{r, j, h, a, m, p} \left( \psi_{r, j, h, a, m, p}^{CROP} \cdot CROP_{r, j, h, a, m} \right) \\
+ \sum_{r, j, h, a, b, m, p} \left( \psi_{r, j, h, a, b, m, p}^{PERE} \cdot PERE_{r, j, h, a, b, m} \right) \\
+ \sum_{r, j, h, a, g, m, p} \left( \psi_{r, j, h, a, g, m, p}^{GRAS} \cdot GRAS_{r, j, h, a, g, m} \right) \\
+ \sum_{r, j, h, a, w, m, p} \left( \psi_{r, j, h, a, w, m, p}^{WETL} \cdot WETL_{r, j, h, a, w, m} \right) \\
+ \sum_{r, j, h, a, f, m, p} \left( \psi_{r, j, h, a, f, m, p}^{FORE} \cdot FORE_{r, j, h, a, f, m} \right) \\
\end{align*}

\begin{align*}
\sum_{r, y} \left( \int \varphi_{r, t, y}^{SUPP} (SUPP_{r, t, y}) \, d(\mathbb{I}) \right) \\
\sum_{r, y} \left( \int \varphi_{r, t, y}^{RESR} (RESR_{r, t, y}) \, d(\mathbb{I}) \right) \\
\sum_{r, y} \left( \int \varphi_{r, t, y}^{IMP} (\sum_{t_{i}} TRAD_{r, t_{i}, y}) \, d(\mathbb{I}) \right) \\
\sum_{r, y} \left( \tau_{r, t, y}^{TRAD} \cdot TRAD_{r, t, y} \right) \\
\sum_{r, j, h, a, s, n_{1}, m_{1}, n_{2}} \left( \tau_{r, j, h, a, s, n_{1}, m_{1}, n_{2}}^{LUCH} \cdot LUCH_{r, j, h, a, s, n_{1}, m_{1}, n_{2}} \right) \\
\sum_{r, x, y} \left( \tau_{r, x, y}^{PROC} \cdot PROC_{r, x, y} \right) \\
\sum_{r, j, h, a, c, m} \left( \tau_{r, j, h, a, c, m}^{CROP} \cdot CROP_{r, j, h, a, c, m} \right) \\
\sum_{r, j, h, a, b, m} \left( \tau_{r, j, h, a, b, m}^{PERE} \cdot PERE_{r, j, h, a, b, m} \right) \\
\sum_{r, j, h, a, g, m} \left( \tau_{r, j, h, a, g, m}^{GRAS} \cdot GRAS_{r, j, h, a, g, m} \right) \\
\sum_{r, j, h, a, w, m} \left( \tau_{r, j, h, a, w, m}^{WETL} \cdot WETL_{r, j, h, a, w, m} \right) \\
\sum_{r, j, h, a, f, m} \left( \tau_{r, j, h, a, f, m}^{FORE} \cdot FORE_{r, j, h, a, f, m} \right) \\
\end{align*}

(Equation 7.5.2.1)

Where: \varphi = price, \tau = cost, \psi = incentives or taxes
The total use of resources, RESR, over all agricultural and forest activities is always restricted to the total resource endowments, \( \beta \), for all regions (r), time periods (t) and all i which represents the resource items for arable land, forest land, wetland, grassland and energy crop land.

\[
RESR_{r,t,i} \leq \beta_{r,t,i} \quad \text{(Equation 7.5.2.4)}
\]

The relative crop area mix equation is presented in Equation 7.5.5. Note that t- refers to past time periods for which data of crop areas exist.

\[
\sum_m CROP_{r,t,j,h,s,c,m} = \sum_{t-} (\alpha_{r,t,c,m}^{CROP} \cdot CROPMIX_{r,t,c-}) \quad \text{(Equation 7.5.2.5)}
\]
Land use change occurs when there are changes in land allocation between forests, crop production, bioenergy plantations, and nature reserves. Changes to the preceding periods are subject to adjustment costs in the objective function (Schneider et al. 2008b). Land use change is constrained to the maximum permissible transfer between different land use categories Equation 7.5.2.8. The land use change accounting and aggregation equations are presented in Equations 7.5.2.6 and 7.5.2.7. Note that the variable LUCH is an unrestricted variable.

\[
\begin{bmatrix}
+ \sum_{m,p} \left( CROP_{r,t,j,h,a,s,m,p} - CROP_{r,t-1,j,h,a,s,m,p} \right) \\
+ \sum_{m,p} \left( PERE_{r,t,j,h,a,s,m,p} - PERE_{r,t-1,j,h,a,s,m,p} \right) \\
+ \sum_{m,p} \left( GRAS_{r,t,j,h,a,s,m,p} - GRAS_{r,t-1,j,h,a,s,m,p} \right) \\
+ \sum_{m,p} \left( WETL_{r,t,j,h,a,s,m,p} - WETL_{r,t-1,j,h,a,s,m,p} \right) \\
+ \sum_{m,p} \left( FORE_{r,t,j,h,a,s,m,p} - FORE_{r,t-1,j,h,a,s,m,p} \right)
\end{bmatrix} \cdot \tau_{r,t,j,s} = LUCH_{r,t,j,h,a,s} \quad \text{(Equation 7.5.2.6)}
\]

\[ LUCH_{r,t,j,h,a,n} = \sum_{i=1}^{n} LUCH_{r,t,j,h,a,s} \quad \text{(Equation 7.5.2.7)} \]

\[ LUCH_{r,t,j,h,a,n} < LUCH_{r,t,j,h,a,n}^{max} \quad \text{(Equation 7.5.2.8)} \]

Critical assumptions and uncertainties

It should be noted that the accuracy of the model depends on the quality of data input and the specified boundary conditions for which it is calibrated. All input data that are obtained empirically are subject to certain uncertainties, which are then transferred to the model. Model results are therefore only valid in the context of the settings applied.
### Table 52 Major indices used in the biomass module

<table>
<thead>
<tr>
<th>Index</th>
<th>Symbol</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>r</td>
<td>27 EU member states</td>
</tr>
<tr>
<td>Period</td>
<td>t</td>
<td>time period</td>
</tr>
<tr>
<td>Resources</td>
<td>i</td>
<td>land</td>
</tr>
<tr>
<td>Species</td>
<td>s</td>
<td>all individual and aggregate species categories</td>
</tr>
<tr>
<td>Crop</td>
<td>c(s)</td>
<td>soft wheat, hard wheat, barley, cotton, oats, rye, rice, corn, soya,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sunflower, rape, sugarcane, sugar beet, potato, pulses, tobacco and flax</td>
</tr>
<tr>
<td>Forest</td>
<td>f(s)</td>
<td>forest felling, forestry residues</td>
</tr>
<tr>
<td>Wetland</td>
<td>w(s)</td>
<td>wetland</td>
</tr>
<tr>
<td>Grassland</td>
<td>g(s)</td>
<td>grassland</td>
</tr>
<tr>
<td>Perennial</td>
<td>b(s)</td>
<td>miscanthus, reed canary grass, willow, poplar</td>
</tr>
<tr>
<td>Product</td>
<td>y</td>
<td>bioenergy, bioelectricity, bioheat, biofuel, pellets, biomass</td>
</tr>
<tr>
<td>Process</td>
<td>x</td>
<td>refer to the table on processing pathways (see Table 54)</td>
</tr>
<tr>
<td>Environmental qualities</td>
<td>e</td>
<td>food impacts, land use management options</td>
</tr>
<tr>
<td>Soil types</td>
<td>j(i)</td>
<td>sand, loam, clay, bog, fen, 4 soil depth classes</td>
</tr>
<tr>
<td>Altitude levels</td>
<td>h</td>
<td>&lt; 300, 300 – 600, 600 – 1100, &gt; 1100 meters</td>
</tr>
<tr>
<td>Slope</td>
<td>a</td>
<td>7 slope types (0-3, 3-6, 6-10, 10-15, 15-30, 30-50, &gt;50), any slope</td>
</tr>
<tr>
<td>Technologies</td>
<td>m</td>
<td>alternative tillage, irrigation, fertilization, thinning, animal housing and manure management choices</td>
</tr>
<tr>
<td>Policies</td>
<td>p</td>
<td>taxes or tariffs, subsidies or incentives, targets</td>
</tr>
<tr>
<td>Community</td>
<td>n</td>
<td>aggregated species belonging to a community (arable, pasture, forest, wetlands, perennials)</td>
</tr>
</tbody>
</table>

\(n_1\) denotes old community, \(n_2\) denotes new community

Sources: (Schneider et al. 2008b) and (Ramos and Schneider 2010)

### Table 53 Major variables used in the biomass module

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROP</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Arable crops</td>
</tr>
<tr>
<td>GRAS</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Grassland/ Pasture</td>
</tr>
<tr>
<td>PERE</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Biomass crop plantations for bioenergy</td>
</tr>
<tr>
<td>WETL</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Wetland ecosystem reserves</td>
</tr>
<tr>
<td>FORE</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Forest yields</td>
</tr>
<tr>
<td>LUCH</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Land use changes</td>
</tr>
<tr>
<td>RESR</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Factor and resource usage</td>
</tr>
<tr>
<td>PROC</td>
<td>mixed</td>
<td>≥ 0</td>
<td>Processing activities</td>
</tr>
<tr>
<td>SUPP</td>
<td>1E3 t</td>
<td>≥ 0</td>
<td>Supply</td>
</tr>
<tr>
<td>DEMD</td>
<td>1E3 t</td>
<td>≥ 0</td>
<td>Domestic demand</td>
</tr>
<tr>
<td>TRAD</td>
<td>1E3 t</td>
<td>≥ 0</td>
<td>Trade</td>
</tr>
<tr>
<td>EXP</td>
<td>1E3 t</td>
<td>≥ 0</td>
<td>Exports</td>
</tr>
<tr>
<td>IMP</td>
<td>1E3 t</td>
<td>≥ 0</td>
<td>Imports</td>
</tr>
<tr>
<td>CROP MIX</td>
<td>1E3 ha</td>
<td>≥ 0</td>
<td>Crop mix areas</td>
</tr>
<tr>
<td>WELF</td>
<td>1E6 €</td>
<td>Free</td>
<td>Economic Surplus</td>
</tr>
</tbody>
</table>

Source: (Schneider et al. 2008b) and (Ramos and Schneider 2010)

### Table 54 Bioenergy processing pathways used in the biomass model

<table>
<thead>
<tr>
<th>Land use biomass options</th>
<th>Technological Processes</th>
<th>Non-food product options</th>
<th>End Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>Combustion</td>
<td>Bioelectricity, Bioheat</td>
<td>Bioenergy</td>
</tr>
<tr>
<td>Red canary grass</td>
<td>Pelletizing</td>
<td>Pellets</td>
<td>Fuel for combustion, co-firing, bioenergy</td>
</tr>
<tr>
<td>Willow</td>
<td>Combustion, CHP</td>
<td>Bioelectricity, Bioheat</td>
<td>Bioenergy</td>
</tr>
<tr>
<td>Maize, Sugar beet, Sugar cane</td>
<td>Fermentation process (Oilseeds)</td>
<td>Bioethanol</td>
<td>Biofuel</td>
</tr>
<tr>
<td>Rape, Sunflower</td>
<td>Esterification process</td>
<td>Biodiesel</td>
<td>Biofuel</td>
</tr>
</tbody>
</table>

Source: (Ramos and Schneider 2010)
7.6 Future research needs

Future research needs that are relevant for the statistical method, spatially explicit method and for the cost-supply method are already discussed in the previous sections.

In the case of energy and other economic models, the impact of technological learning is often not effectively taken into account. Furthermore, some models work with constant costs for biomass, while it can be expected that this feedstock will generally show increasing costs with increasing demand. Another issue is that these models usually focus only on forest biomass or crops, while residues and waste are usually excluded.

7.7 Improvement of data sources

Future improvements of data sources are needed as already discussed in the previous section about the statistical method, spatially explicit method, cost-supply method and energy and economic modelling methods.
8 Sustainability

8.1 Scope and definitions

8.1.1 Scope

Different definitions exist to describe the term ‘sustainability’, the most common of which has been established by the Brundtland Commission, formally the World Commission on Environment and Development (WCED). In 1987, the Brundtland report ‘Our common future’ has been published containing a definition of sustainable development which today is widely used and cited (WCED 1987):

*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

Sustainability can be conceptually broken down into three constituent parts: environmental sustainability, social sustainability and economic sustainability – also referred to as the ‘three pillars’ of sustainability (see Figure 11).

![Figure 11 The three pillars of sustainability](image)

The three dimensions are connected via feedback mechanisms, trade-offs and synergies. The production of biomass for the use of bioenergy mainly influences the environmental dimension, but also the social and economic dimensions. It uses land for cultivation, energy, water and nutrients and at the same time has an impact on air, soil, water, biodiversity, and landscapes. The fact that agricultural land is needed to obtain biomass for bioenergy production influences agricultural markets as well as food and energy prices. The impact of bioenergy production on environmental, social, and economic aspects and on the linkages inside each dimension results in a complex system that is difficult to adequately cover and integrate in biomass resource assessments. Figure 12 shows some of the most important elements, linkages and impacts and gives a rough idea of the complexity of the system.
In order to reduce potential negative impacts of bioenergy production, a set of sustainability parameters has been developed to be included in biomass resource assessments. They aim at covering direct and indirect effects of bioenergy production on factors such as human beings, fauna and flora; soil, water, air, climate and the landscape; material assets and cultural heritage. At the same time, including the parameters in biomass resource assessments will help to achieve sustainability goals such as the sustainable use of renewable and non-renewable resources, usage of the environment as a carbon sink, as well as guaranteeing intra- and inter-generational justice.

The following aspects are covered by the set of sustainability parameters developed in this handbook:

- Environmental sustainability
  - Biodiversity
  - Climate change
  - Soil (quality and quantity)
  - Water (quality and quantity)
  - Air quality
  - Resource use
- Social sustainability
  - Competition with the demand for food, feed, fibres
  - Labour conditions
- Economic sustainability
  - Bioenergy costs

Further explanation regarding these elements and the derivation of the sustainability parameters will be provided in section 8.3. In Annex 2.4, additional socio-economic aspects are discussed that at the moment cannot be integrated in biomass potential assessment but that should be kept in mind.

### 8.1.2 Definitions

The analysis of existing biomass potential assessments has shown that the lack of common definitions for certain terms is one of the reasons for the huge deviation of results. The following definitions shall provide a common ground for methods presented in this handbook.

**Surplus land**

In this handbook, surplus land is a simplified construct that describes the agricultural area available for bioenergy production, i.e. land that is not demanded for the production of food, feed, and biomaterial. For the derivation of surplus land, the area needed for food and non-food purpose, i.e. for food, feed and biomaterial production is subtracted from the total agricultural area. The demand for food and feed...
is dependent on market prices, income and income distribution, population, and dietary preferences. Together with crop yields, livestock intensity and self-sufficiency it determines the food-related land demand. The amount of surplus land may change over time in both directions.

It has to be noted that from a strict economic point of view, this kind of surplus land does not exist. As soon as prices enter the analysis, there is no surplus land since this term refers to land that has no value i.e. that is not scarce. However, this simplification is necessary for doing simpler statistical and spatially explicit analyses that are based on a certain amount of land allocated to biomass for energy production. More advanced modelling approaches and integrated assessment models are needed to include market prices and mechanisms and thus to reflect land allocated to different uses (including energy crops) in a more realistic way.

Surplus land includes set-aside land and abandoned agricultural land and is sometimes used in relation to the terms degraded, marginal or low productive land. For the definitions of these terms, see section 4.2. The use of such land categories might be wise from a food production point of view since it often accounts for a high biodiversity. Therefore, the identification of areas for energy crop cultivation should not rely on such categories and their biodiversity value should be checked carefully.

Biodiversity

In the Convention of Biological Diversity (CBD), biodiversity is described as ‘variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems’ (CBD 1992, Article 2). Biodiversity can be divided into three levels:

- Genetic diversity
- Species diversity
- Ecosystem diversity

A multitude of concepts and indicators exist to describe and measure each level of biodiversity. (Lysen et al. 2008) give a short overview on different indicators and discusses their advantages and disadvantages in the context of different key questions. Due to the complexity of biodiversity, one single indicator will never adequately describe a situation, but complementary ones need to be chosen. This makes it difficult to directly include biodiversity indicators in biomass potential assessments. Therefore, an indirect approach is applied, i.e. environmental criteria are included in a way that indirectly supports biodiversity on all three levels. For instance, areas with high biodiversity value are excluded from biomass production.

Habitats of high biodiversity value

According to Article 17 (3) of the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009) ‘biofuels and bioliquids shall not be made from raw material obtained from land with high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status’:

- undisturbed primary forest and other wooded land;
- areas designated for nature protection purposes or for the protection of rare, threatened or endangered ecosystems or species recognized by international agreements;
- natural and non-natural highly biodiverse grassland.

In designated areas and non-natural highly biodiverse grassland, management is allowed (i.e. biomass may be used) if it does not interfere with nature protection purpose or – for grasslands – if it is necessary to preserve the grassland status. At this background it has to be noted that many high-value ecosystems originate from old management traditions which are discontinued today. Therefore, management of such ecosystems is often required to preserve their high-value status. In this case, there might a win-win situation with biomass utilisation leading to an increase of the biomass potential.
Most certification systems and sustainability schemes include the prevention of biodiversity loss in their sets of sustainability criteria or parameters. At present, there is no consistent global dataset with High Biodiversity Value areas. As a minimum approach, all areas that are currently protected should be taken into account in biomass potential assessments. In the past years, a European wide ecological network of protected areas has been established – the Natura2000 network. It is legally based on the Birds (79/409/EEC 1979) and the Habitats (92/43/EEC 1992) Directives and covers two of the three biodiversity levels named in the Convention of Biological Diversity (CBD): ecosystem and species diversity (see the definition of biodiversity above). However, the network only covers EU member states. Besides the Natura2000 network, other legally protected areas exist. They comprise national protected areas such as nature reserves or protected landscapes and areas that are recognized by international agreements (e.g. Wetlands of International Importance (Ramsar)).

However, protected areas comprise only part of the areas with high biodiversity value and the Natura2000 network only covers European member states. Therefore, further areas should be identified taking into account different methodologies and data sets. (Stewart et al. 2008) developed a comprehensive guideline on how to identify High Conservation Value (HCV) forest areas. Initially, it was used for the certification of sustainable produced wood under the Forest Stewardship Council (FSC), however, it is now also applied for agricultural certification. Further approaches are Key Biodiversity Areas (KBA), which integrates Endemic Birds Areas (EBA), Important Plant Areas (IPA) as well as the Alliance for Zero Extinction (AZE). All these data are included in the Integrated Biodiversity Assessment Tool (ibat). Conservation International developed a “Rapid Assessment” method for a fast analysis of an area’s biodiversity status. Within Europe, High Nature Value (HNV) areas have been identified (see definition below). For an overview on approaches and datasets, see (Hennenberg 2008).

High Nature Value (HNV) farmland

The agro-environmental indicator ‘High Nature Value (HNV) farmland’ is one of 35 EU-indicators that have been established in the European IRENA project (Indicator reporting on the integration of environmental concerns into agriculture policy) (EEA 2005a). HNV farmland is defined as “those areas in Europe where agriculture is a major (usually the dominant) land use and where agriculture sustains or is associated with either a high species and habitat diversity, or the presence of species of European conservation concern, or both” (Andersen et al. 2003).

The HNV farmland indicator according to (Andersen et al. 2003) distinguishes the following types of high nature value farmland:
- Type 1: Farmland with a high proportion of semi-natural vegetation.
- Type 2: Farmland dominated by low intensity agriculture or a mosaic of semi-natural and cultivated land and small-scale features.
- Type 3: Farmland supporting rare species or a high proportion of European or World populations.

At the moment, there is no database on HNV farmland. Therefore, a simple indirect approach is applied. As agriculture in those areas is usually extensive, all areas under agro-environmental support, extensively managed areas as well as areas under organic farming should be regarded as potential HNV farmland. The status quo regarding these cultivation categories should be preserved. It has to be taken into account that also here, significant overlaps might exist as for instance extensively or organically managed areas are likely to be under agro-environmental support. If national data sources are available on HNV farmland, they should be drawn on.

Areas under agro-environmental support

Agro-environmental measures aim at integrating environmental goals into the European Common Agricultural Policy (CAP). Farmers commit themselves, for a five-year minimum period, to adopt environmentally friendly farming techniques that go beyond good farming practice (GFP). In return for their commitment, they receive financial assistance that compensates for additional costs and loss of income that occurs as a result of altered farm management practices. Agro-environmental measures can be designed at national, regional or local level and thus can be adapted to local or regional farming and environmental conditions (EEA 2005c).
The baseline for agri-environmental measures are minimum sustainability requirements which are covered by cross compliance (Council Regulation (EC 73/2009 2009)). Since 2005, all farmers that receive direct payments are subject to cross-compliance. This means that they have to fulfill certain requirements in the field of environment, food safety, animal and plant health as well as animal welfare. Furthermore, they have to keep land in ‘good agricultural and environmental conditions’ with regard to soil protection, maintenance of soil organic matter and structure, avoidance of habitat deterioration, and water management. Good farming practice as included in cross compliance is also mandatory for European Member States under the Renewable Energy Directive (2009/28/EC 2009).

Wetland/peatland
Wetlands are lands that are permanently covered with or saturated by water or for a significant part of the year (2009/28/EC 2009). Peatlands are wetlands that are covered with a thick organic soil layer (peat). The preservation of wetlands and peatlands is important from a climate protection as well as from a biodiversity preservation point of view.

Continuously forested areas and wooded land
To prevent high carbon stock losses, according to the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009) biofuels and bioliquids should not be produced on continuously forested land, i.e. land spanning more than one hectare with trees higher than five meters and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ. Furthermore, land spanning more than one hectare with trees higher than five meters and a canopy cover of between 10 % and 30 %, or trees able to reach those thresholds in situ shall be excluded from biofuel production. The exclusion of forested land for biofuel production is related to its conversion. This means, as long as the forest remains forest, woody biomass can be used for bioenergy production (including biofuels and bioliquids).

Grassland
According to the the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009) liquid biofuels should not be produced on natural and non-natural highly biodiverse grassland, i.e. its conversion is excluded. The cultivation of grassland is allowed as long as it is necessary for preserving the grassland status. According to the Directive, the Commission is responsible for establishing respective criteria and geographic ranges. For this purpose, there has been a public consultation that ended in February 2010. In the course of this consultation, (Lübbeke and Hennenberg 2010) presented suggestions on how to define grassland, on how to distinguish natural and non-natural grassland and on how to identify highly biodiverse grassland (see also (Hennenberg et al. 2009)).

Beside biodiversity conservation, grassland protection has a further dimension: since it often accounts for high carbon stocks, its conversion should generally be minimised from a climate protection point of view. At least within the European Union, large scale pasture conversion is not allowed: according to the European regulation on direct support schemes under the common agricultural policy (Council Regulation (EC 73/2009 2009) the member states shall ensure that “land, which was under permanent pasture at the date provided for the area aid applications for 2003 is maintained under permanent pasture” (for new member states, the reference year is 2004). However, member states may derogate from this rule, provided that they take action to “prevent any significant decrease” in its total permanent pasture area. The regulation is implemented in the member states in different ways.

8.2 Political framework

The production and use of bioenergy has caused increased discussion in recent years regarding the impact on environmental, economic and social aspects. These discussions have resulted in efforts on international, European and national level to develop biomass production systems in a more sustainable way. Furthermore, efforts on all levels are under way to mitigate climate change, preserve
natural resources such as biodiversity, water and soil and to enforce human rights. As a result, in order to achieve sustainability goals, institutional systems such as regulations, agreements and conventions have been established. Even if these systems do not particularly focus on bioenergy production, their implementation still has an indirect influence on it. In addition to the institutional systems, sustainability assessment systems have evolved aiming at monitoring and assessing sustainability issues.

**Conventions and agreements** on international level are the Convention on Biodiversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), the United Nations Framework Convention on Climate Change (UNFCCC) and the Conventions of the International Labour Organisation (ILO). The signing parties – among them the EU and its member states – have put in place legislation for implementing these conventions.

Apart from these conventions, sustainability criteria have been integrated in European and national legislation that are either directly linked to bioenergy production or in sectors indirectly influencing biomass production. In this context, an important regulation on European level is the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009) which has been passed in April 2009. Besides setting national targets for the share of renewable sources in the energy and transport sectors, it currently is the only legally binding legislation that defines sustainability criteria for biomass that is used for bioenergy purposes, more exactly for the use of biofuels and bioliquids. The criteria set up in Article 17 are to be applied to imported biomass as well as to biomass produced within the European Union. The most important criteria are:

- 35 % minimum greenhouse gas emission savings (50 % from 2017 and 60 % from 2018);
- No biomass production on primary / undisturbed forests and wooded land nor on highly biodiverse natural grassland;
- Restricted biomass production on protection areas (legally protected areas on national level, further areas designated for the protection of rare, threatened or endangered ecosystems or species on international level) as well as on highly biodiverse non-natural grassland; production of raw material is allowed as long as it does not interfere with protection purposes and if it is necessary for preserving the grassland status;
- Restricted biomass production on land with high carbon stocks (forests, wetlands, peatlands);
- The cultivation in the European Union has to comply with the minimum requirements for good agricultural and environmental conditions (as referred to in the Council Regulation (EC 73/2009 2009) on common rules for direct support schemes for farmers under the common agricultural policy).

The cultivation of protected areas, forests and non-natural grasslands is allowed under certain restrictions: the production of raw materials should not interfere with nature protection purposes, forest use is allowed as long as forest is not converted into arable land and grassland may be used if the biomass use is necessary to preserve its grassland status. Biofuels and bioliquids produced from waste and residues (other than agricultural, aquaculture, fisheries and forestry residues) only need to fulfil the sustainability criteria regarding the 35 % minimum greenhouse gas savings.

Furthermore, the Commission shall report to the European Parliament and the Council on

- The impact on social sustainability in the Community and in third countries of increased demand for biofuel;
- The impact of Community biofuel policy on the availability of foodstuffs at affordable prices, in particular for people living in developing countries;
- The respect of land-use rights;
- Whether the country has ratified and implemented each of the following Conventions of the International Labour Organisation: 29, 87, 98, 100, 105, 111, 138, 182;
- Whether the country has ratified the Cartagena Protocol on Biosafety and the Convention on International Trade in Endangered Species of Wild Fauna and Flora.
All the latter criteria are not binding since they only need to be reported to the Commission. However, they give a hint on which aspects are regarded as important by European member states in the field of bioenergy production.

The sustainability criteria defined in the EU Renewable Energy Directive are only applied to biofuels and bioliquids and not for solid and gaseous biomass sources. To fill this gap, the European Commission has compiled a report on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling (COM (2010)11 2010). It defines most relevant sustainability issues for this type of biomass, but refrains from proposing any binding criteria at EU level due to considerable differences in feedstock and since no sustainability risks are expected for domestic biomass production from wastes and residues. However, it recommends to follow the sustainability schemes laid down in the Renewable Energy Directive if single Member States want to introduce national sustainability schemes for solid and gaseous biomass used in electricity, heating and cooling.

Whereas the EU Directive on the promotion of the use of energy from renewable sources (2009/28/EC 2009) directly focuses at biofuel and bioliquid production, the inclusion of sustainability criteria in European environmental, waste and water policies indirectly influences the production of biomass for bioenergy purposes. Examples are the establishment of an ecological network of special areas for conservation (the so-called Natura2000 network) or the prioritisation of waste avoidance and recycling in waste policies. These directives and policies have to be implemented on national level leading to own national goals regarding the share of renewable energy and the decrease of greenhouse gas emissions. Furthermore, national regulations exist for the establishment of protected areas, management practices in agriculture (e.g. the share of grassland that can be converted) and regarding other sustainability aspects. For further information on relevant legislation within Europe see (Vesterinen et al. 2010).

One possibility to preserve biodiversity is the establishment of a global network of protected areas that would reduce the area potentially available for biomass for bioenergy production. Currently, there are about 30,000 protected areas covering 13,250,000 km². The most important international network of protected areas expertise is the World Commission on Protected Areas (WCPA) administered by the IUCN’s Programme on Protected Areas. It helps governments and others to plan protected areas and promotes the establishment and effective management of a world-wide representative network of terrestrial and marine protected areas.

Conventions also result in the establishment of protected areas such as the Ramsar Convention and its Wetlands of International Importance and the World Heritage Convention with the UNESCO world heritage sites. The latter include both natural and cultural sites. Also part of the UNESCO are biosphere reserves covered under the ”Man and the Biosphere Programme”. The 564 sites aim at demonstrating approaches to link conservation and sustainable development. As a regional platform serves the ASEAN Centre for Biodiversity that established a number of protected areas in Southeast Asia. Also within Europe, a regional network has been established; the Natura2000 areas aiming at protecting endangered plant and bird species. Beside these areas, on national level many protected areas have been established.

In addition to existing protected areas there is constant international effort going on to detect areas that are of importance in terms of biodiversity and thus for identifying conservation priority. Examples are the identification of Biodiversity Hotspots by Conservation International, the Centers of Plant Diversity by IUCN and WWF-US, the selection of Important Bird Areas (IBAs) by Birdlife International or the Prime Butterfly Areas by Butterfly Conservation as well as the concepts of High Conservation Value (HCV) or High Nature Value (HNV) farmland. In future, these efforts will partly also be translated into protected areas.

Besides binding legislation, certification systems have been established that shall ensure a sustainable production of agricultural and forestry biomass in general but also biomass specifically produced for
bioenergy purposes. The entry is voluntary; however, once being a member, the rules have to be followed. Examples of certification systems are the Roundtable on Sustainable Biofuel (RSB), the Forest Stewardship Council (FSC) for forestry, the Roundtable on Sustainable Palm Oil (RSPO), the Roundtable in Responsible Soy (RTRS), the better Sugarcane Initiative (BSI) and the International Federation of Organic Agriculture Movements (IFOAM). Whereas RSPO, RTRS, BSI and IFOAM have common, international standards, FSC has national branches with own national rules. For a comprehensive overview and comparison of certification systems see (Fehrenbach et al. 2008), (Vis et al. 2008) and (van Dam 2010).

Various sets of sustainability indicators and criteria have been developed either specifically for bioenergy production systems or in sectors that are related to biomass production. They for instance serve the purpose to measure the impact of bioenergy production on environment, economy and/or society. Currently, two analytical frameworks are under development by the FAO. The Bioenergy Environmental Impact Analysis (BIAS) allows assessing the influence of bioenergy production systems on environmental factors such as climate, biodiversity, soil and water (Fritsche et al. 2008). The Bioenergy and Food Security project (BEFS) also develops an analytical framework for analysing the impact of national and sub-national bioenergy developments in developing countries on food security. The Global Bioenergy Partnership (GBEP) has been established in 2005 in order to support a biomass and biofuel deployment. It currently establishes a set of criteria and indicators regarding the sustainability of bioenergy. It aims at guiding any analysis undertaken of bioenergy at the domestic level with a view to informing decision making and facilitating the sustainable development of bioenergy.

On European level several indicator sets have been developed for measuring the progress towards certain goals related to biodiversity or nature protection. Being a signer of the Convention on Biological Diversity (CBD), the European Union set itself the target to halt the loss of biodiversity and restore habitats and natural systems by 2010 in its 2001 Strategy for Sustainable Development (CEC 2001). In this context, the SEBI project (Streamlining European 2010 Biodiversity Indicators) developed a set of 26 indicators that shall help monitor the progress towards the 2010 target (EEA 2007c). In 2004, a core set of indicators (CSI) has been developed comprising agriculture, biodiversity, climate change and water (EEA 2005b). Furthermore, 35 agro-environmental indicators (AEI) have been defined during the IRENA project (Indicator reporting on the integration of environmental concerns into agricultural policy) in 2005 in order to integrate environmental concerns into Common Agricultural Policies (CAP) (EEA 2005a). In the field of forestry, the Ministerial Conference on the Protection of Forests in Europe (MCPFE) is a pan-European policy process for the sustainable management of European forests. Beside several guidelines on sustainability issues in European forests in 2002, a set of criteria and indicators has been developed for sustainable forest management (MCPFE 2002). In view of recent developments addressing sustainability of biomass production, the emerging focus on the role of forests and sustainable forest management related to climate change and energy and the implementation of the European Renewable Energy Directive, a working group has been established on sustainability criteria for forest biomass production, including bioenergy. Based on a gap analysis of existing MCPFE tools recommendations have been developed on minimum requirements on sustainable forest management, with special focus on bioenergy and climate mitigation (MCPFE 2010).

Sustainability criteria related to the forestry sector are also developed and used in the EU EFORWOOD project. It developed a quantitative decision support tool assessing sustainability aspects of the European Forestry-Wood Chain (FWC) and subsets thereof (e.g. regional), covering the whole chain, i.e. forestry, industrial manufacturing, consumption and recycling. The ToSIA (Tool for Sustainability Impact Assessment) is a dynamic sustainability impact assessment model that is analysing environmental, economic, and social impacts of changes in forestry-wood production chains, using a consistent and harmonised framework from the forest to the end-of-life of final products. The results do not only give a holistic picture on the current status of a region’s forest value chains in terms of e.g. employment figures, production costs or CO₂ emissions, but also make it possible to evaluate the impacts on sustainability of potential developments in future as a consequence
of increasing demand for forest bio-energy. The difference between ToSIA and other similar, already existing, tools is that none of those addresses all three sustainability dimensions (environmental, economical and social) along the whole FWC in a balanced way (Lindner et al. In press).

Last but not least, guidelines and handbooks have been published on how to establish bioenergy systems in a sustainable way. Examples are the framework for decision makers on sustainable bioenergy (UN 2007) and the sustainability standards for bioenergy published by WWF (Fritsche et al. 2006).

World-wide, many approaches and activities are underway that address sustainability within agriculture and in bioenergy production. Especially the development of sustainability criteria showed strong progress in recent years, however, up to now there is no set of internationally accepted criteria and derived indicators. The criteria defined within the European Renewable Energy Directive (2009/28/EC 2009) are currently the only legally binding criteria and only cover part of the bioenergy (liquid biofuels). These are to be seen as a minimum approach that does not cover sustainability with all its relevant aspects. Therefore, within this handbook, the RED criteria have been complemented by those currently developed in certification systems, guidelines and initiatives.
8.3 Set of sustainability parameters to be included in biomass resource assessments

8.3.1 General remarks - Establishment of a set of sustainability parameters

Based on an extensive literature research covering the current activities related to sustainability (see section 8.2), a set of sustainability parameters has been established to be included in biomass resource assessments. Sustainability criteria and indicators that are applied and implemented on international, European and national level have been implemented in order to assess the current state or to measure the progress towards a certain goal. Thus, it is not possible to directly include them as limiting factors in biomass resource assessments. However, they give hints which aspects are currently discussed in the field of bioenergy and sustainability. For the parameter set developed in this handbook, only those aspects have been taken into consideration that influence the technical biomass potential in one way or another. Since basically, the biomass potential is derived by combining the area and the yield achieved, mostly environmental aspects are taken into consideration. For instance, excluding conservation areas to account for biodiversity decreases the area available for biomass production and thus the potential. In contrast, the inclusion of social or economic parameters is mostly difficult and not feasible since they neither influence the area available nor the yields. For instance, good labour conditions or job creation do not directly affect the amount of biomass produced. These topics can only be included with the help of very complex modelling systems.

All criteria listed in the EU Directive on the promotion of the use of energy from renewable sources ((2009/28/EC 2009); see section 8.2) have been integrated in this set since they are currently the only legally binding sustainability criteria related to bioenergy. However, the Directive has to be seen as a minimum consensus among the European member states. It is far from ensuring an overall sustainable provision and use of bioenergy. Some of the criteria are not restrictive but only need to be reported (e.g. the ratification and implementation of the Conventions of the International Labour Organisation). Therefore, many more parameters have been added aiming at integrating sustainability as comprehensively as possible. Furthermore, as with all sustainability criteria and indicators, also those in the Renewable Energy Directive had to be “translated” into parameters that can be included in biomass resource assessments. As a result, these criteria are not explicitly stated in the set developed in this handbook but are indirectly included. All parameters that include elements of the Renewable Energy Directive will be marked with an asterisk in the following schemes and tables. This enables the application of a minimum approach where at least requirements defined by the Renewable Energy Directive can be taken into account.

The set of sustainability parameters has been allocated to the three dimensions as described in section 8.1.2. In order to simplify the complex system, a hierarchy has been established following the approach described in (Fehrenbach et al. 2008). The three sustainability dimensions are regarded as themes. Within each theme, principles are postulated describing certain areas of concern from a general point of view, like: biodiversity shall be conserved, or climate change shall be mitigated. Criteria are needed for clarifying the fulfilment of the rather general principles. A criterion might be: The loss of habitats of high biodiversity value shall be prevented. The criteria are further broken down into different parameters that describe clear quantitative or qualitative sustainability aspects to be included in biomass potential assessments. This hierarchy is displayed in Figure 13.
In Table 55 the set of principles, criteria and parameters developed in this handbook are displayed. The following references have been taken into account: (Fehrenbach et al. 2008), (PEFC 2007), (EEA 2005a), (EEA 2007c), (FSC 1996), (Fritsche et al. 2006), (MCPFE 2002), (UN 2007), (2009/28/EC 2009), (Hennenberg 2005), (EC 73/2009 2009), (BSI 2010), (Cramer and al. 2006), (RSB 2009), (GGL 2005b; GGL 2005a), (RSPO 2007; SAN 2010), (IUCN 2008), (Gallagher 2008), (Hennenberg 2010).

All criteria and parameters that are derived from the European Renewable Energy Directive (2009/28/EC 2009) are marked with an asterisk (*; note that the wording might be different from the directive). If these criteria are included in biomass potential assessment, the potential derived will be in compliance with the Directive.

Please note that this handbook – and thus all sustainability criteria – only refer to the production of biomass and not to the subsequent steps of converting it into energy. For a detailed description of the criteria and parameters please refer to Annex 2:

- Annex 2.1 for the theme ‘environment’
- Annex 2.2 for the theme ‘society’
- Annex 2.3 for the theme ‘economy’ and
- Annex 2.4 for other socio-economic parameters.

In section 8.4 a summary is provided which parameters can be included in which biomass resource assessment method (statistical, spatially explicit, cost-supply curves, etc.). Annex 3 gives detailed instructions on how to include the parameters into the different biomass resource assessment methods. In Table 55 and Annex 2, only the parameters are presented. Numbering the parameters shall help to allocate them within the presented hierarchy. It has to be noted that not all parameters can be included in all types of biomass resource assessments. More information on this is given in section 8.4.
Table 55 Themes, principles, criteria and parameters to be included in biomass resource assessments  
* parameters based on RED (2009/28/EC 2009)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Principle</th>
<th>Criterion</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The loss of biodiversity shall be prevented</td>
<td>1</td>
<td>The loss of habitats of high biodiversity value (HBV) shall be prevented *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN *</td>
</tr>
<tr>
<td></td>
<td>Direct land cover change shall be prevented</td>
<td>4</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
</tr>
<tr>
<td></td>
<td>Indirect land cover change shall be prevented</td>
<td>6</td>
<td>Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>Allow afforestation of permanent grassland if it is compatible with the environment (exclusion of highly biodiverse grassland)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
</tr>
<tr>
<td></td>
<td>Support forest and agro-biodiversity</td>
<td>9</td>
<td>Preference of using surplus land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>Restrict use of genetically modified organisms (GMO)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13</td>
<td>Minimum number of crop species and varieties as well as structural diversity within the cropping area</td>
</tr>
<tr>
<td></td>
<td>Protection of High Nature Value (HNV) farmland</td>
<td>14</td>
<td>Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>Adapt management practices (i.e. crop choices and yields) on extensively cultivated areas</td>
</tr>
<tr>
<td></td>
<td>There has to be a significant contribution to greenhouse gas mitigation</td>
<td>17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19</td>
<td>Avoid a massive conversion of permanent grassland into arable land *</td>
</tr>
<tr>
<td></td>
<td>Indirect land cover change shall be prevented</td>
<td>20</td>
<td>Preference of using surplus land</td>
</tr>
<tr>
<td>Theme</td>
<td>Principle</td>
<td>Criterion</td>
<td>Parameter</td>
</tr>
<tr>
<td>-------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>Negative impacts on soil shall be minimized</td>
<td>8 Minimise soil erosion</td>
<td>21 Maximum slope limits for cultivation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22 Only perennial crops on sites susceptible to soil erosion</td>
</tr>
<tr>
<td></td>
<td>Negative impacts on water shall be minimized</td>
<td>9 Protect soil quality</td>
<td>23 Maximum extraction rates for primary agricultural and forestry residues</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24 Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 Minimisation of harmful contamination of surface and ground water</td>
<td>25 Maximum extraction rates for primary agricultural and forestry residues</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>26 Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 Prevent overexploitation of water resources</td>
<td>27 Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions (especially for rain fed agriculture)</td>
</tr>
<tr>
<td></td>
<td>Resource use shall be minimized</td>
<td>12 Minimization of emissions of air pollutants</td>
<td>28 For irrigation, adapt water consumption to regional resources; if no data are available, exclude irrigation as a precautionary principle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 Resource efficiency should be increased</td>
<td>29 Adapt management practices (i.e. crop choices and yields) to local bio-physical conditions</td>
</tr>
<tr>
<td></td>
<td>Food security shall be ensured</td>
<td>14 Avoid competition with food production</td>
<td>30 Recycle before waste is used for energy production</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>31 Ensure a sustainable use of renewable resources</td>
</tr>
<tr>
<td><strong>Society</strong></td>
<td>The production of biobased materials shall be ensured</td>
<td>15 Avoid competition with the production of biomaterials</td>
<td>32 Preference of using surplus land</td>
</tr>
<tr>
<td></td>
<td>Adequate labour conditions shall be ensured</td>
<td></td>
<td>33 Preference of using surplus land</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16 Labour rights shall be complied with *</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>34 Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182) *</td>
</tr>
</tbody>
</table>
8.4 Inclusion of sustainability parameters in biomass resource assessments

8.4.1 How sustainability parameters influence biomass potentials

The following sections give detailed guidelines to which extent sustainability parameters can be included in biomass resource assessments. In Annex 3 detailed instructions can be found on how the parameters can be included in statistical, spatially explicit and cost-supply assessments. Although this handbook aims at being applicable at a global level, the main focus of the parameters covers European aspects and conditions (e.g. by referring to Natura2000 areas). As can be seen in the case of the Natura2000 areas, even at European level it is not possible to include all parameters in detail due to a lack of data. At global level, this problem is even more severe. Generally, also parameters have been included that currently can not be taken into consideration due to a lack of data. Nevertheless, they are listed presuming that in many cases data sources will be developed in the next years.

Not all parameters can be included in all resource assessment methods. Generally, the more complex the methods, the more possibilities there are for covering sustainability aspects. However, all biomass resource assessment should strive for including sustainability as comprehensively as possible by not only focusing on climate change. Due to the strong presence of climate change in the media and in public discussion, there is a risk that other aspects such as biodiversity or soil and water quality are neglected.

The inclusion of sustainability parameters in biomass resource assessments often decreases the resulting potential by limiting either the area available (e.g. through area dedicated to conservation and therefore withdrawn from bioenergy use), the yields (e.g. through less intensive management methods in sensitive areas) or the share of the potential that can finally be exploited (due to economic and social constraints). However, sustainability also may increase biomass potentials, e.g. if biomass from landscape conservation activities is included or if economic constraints are overcome by subsidies or other incentives.

8.4.2 Sustainability in statistical, spatially explicit and cost-supply assessments

Table 56 to Table 58 show a summary of which sustainability criteria can be included in which type of biomass resource assessment. The parameters are sorted by biomass categories in order to facilitate the search. For categorization, see section 8.3. Several parameters describe more than one criterion. For example, the parameter ‘No drainage / use of land that was wetland (including peatlands) in January 2008’ is used to specify Criterion 1 (‘The loss of habitats shall be prevented’) and Criterion 5 (‘Areas with high carbon stocks shall be excluded from conversion’). The numbers indicate where the parameters can be found in the hierarchy presented in Table 55.

More detailed information on the implementation of each sustainability parameter in the respective biomass resource assessment method can be found in Annex 3:
- For resource focused statistical methods see Annex 3.1
- For resource focused spatially explicit methods see Annex 3.2
- For demand driven assessments see Annex 3.3

A general introduction on sustainability parameters for energy and economic models and integrated assessments can be found in section 8.4.3 and 8.4.4 below.
### Forestry and forestry residues

Table 56 Sustainability parameters to be included in the different types of biomass resource assessments for forestry and primary forestry residues

*parameters based on RED (2009/28/EC 2009)*

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Statistical</th>
<th>Spatially explicit</th>
<th>Cost-supply</th>
</tr>
</thead>
</table>
27 Adapt management (i.e. crop/tree choices and yields) to local bio-physical conditions, especially for rain fed agriculture

28 For irrigation, adapt water consumption to regional resources; if no data are available, exclude irrigation as a precautionary principle

30 Recycle before waste is used for energy production

31 Ensure a sustainable use of renewable resources

34 Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182) *

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Statistical</th>
<th>Spatially explicit</th>
<th>Cost-supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td>X x x x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td>X x x x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN *</td>
<td></td>
<td>X x x x</td>
<td></td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>X x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
<td></td>
<td>X x</td>
<td></td>
</tr>
<tr>
<td>6, 19</td>
<td>Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland *</td>
<td></td>
<td>X x x</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Allow afforestation of permanent grassland if it is compatible with the environment (exclusion of highly biodiverse grassland)</td>
<td></td>
<td>X x</td>
<td></td>
</tr>
<tr>
<td>8, 18</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
<td>X x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9, 20, 32, 33</td>
<td>Preference of using surplus land</td>
<td>X x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10, 24, 26, 29</td>
<td>Adapt management practices (i.e. crop / tree choices) to local bio-physical conditions</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Restrict use of genetically modified organisms (GMO)</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td>X x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Minimum number of crop species and varieties as well as structural diversity within the cropping area</td>
<td></td>
<td>X x</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support</td>
<td>X x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Parameter</td>
<td>Statistical analyses</td>
<td>Spatially explicit analyses</td>
<td>Cost-supply analyses</td>
</tr>
<tr>
<td>----</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>----------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>16</td>
<td>Adapt management practices (i.e. crop choices and yields) on extensively cultivated areas</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>Maximum slope limits for cultivation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>22</td>
<td>Only perennial crops on sites susceptible to soil erosion</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Adapt management (i.e. crop/tree choices and yields) to local bio-physical conditions, especially for rain fed agriculture</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>For irrigation, adapt water consumption to regional resources; if no data are available, exclude irrigation as a precautionary principle</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Recycle before waste is used for energy production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Ensure a sustainable use of renewable resources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182)</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Waste

Table 58 Sustainability parameters to be included in the different types of biomass resource assessments for waste

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Statistical analyses</th>
<th>Spatially explicit analyses</th>
<th>Cost-supply analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6, 19</td>
<td>Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Allow afforestation of permanent grassland if it is compatible with the environment (exclusion of highly biodiverse grassland)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8, 18</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9, 20, 32, 33</td>
<td>Preference of using surplus land</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10, 24, 26, 29</td>
<td>Adapt management practices (i.e. crop / tree choices) to local bio-physical conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Restrict use of genetically modified organisms (GMO)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Minimum number of crop species and varieties as well as structural diversity within the cropping area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.4.3 Sustainability in demand driven energy and economic modelling methods

As described in section 7.4, economic modelling methods mimic the dynamics of demand and supply in different sectors by means of investigating economic and non-economic correlations. Economic models are used to simulate the economic impacts of political decisions at national, European or international level, e.g. to estimate the consequences of different policy options. If an entire national economy (or the entire global economy) is covered, this is called a general equilibrium model. It searches for a simultaneous equilibrium on all relevant markets. In contrast, if only selected markets (at least one) are considered, this is called a partial equilibrium model.

In a partial equilibrium model, either the energy, agriculture or forestry sector is dealt with separately without fully taking into account interrelations between the sectors. The bioenergy potential is approached from the demand side and the biophysical basis is not directly modelled but aggregated to supply functions. Therefore, mostly social and economic sustainability parameters can be included whereas many environmental parameters can only be dealt with at a very crude level.

Energy models, i.e. partial equilibrium models for the energy sector, deal with the demand and supply in the energy sector – including bioenergy. For a detailed description, refer to section 7.4. Choices between energy options are made based on energy prices and external restrictions such as mandatory biofuel quotas. Energy prices, i.e. production costs, can be calculated by means of dynamic cost-supply curves. Here, all parameters that are listed in Annex 3.3 can be taken into account. Additionally, sustainability can be included indirectly via applying respective regulations and / or restrictions such as subsidies or tax reductions. For example, carbon taxes aiming at mitigating climate change considerably influence the production costs of energy and thus the whole energy market structure. In this respect, greenhouse gas balances derived from life cycle assessments help to identify the most advantageous products and thus to orientate policies and (fiscal) regulations towards maximising greenhouse gas reductions.

The same applies to partial equilibrium models for the agriculture and forestry sector: the costs of biomass production are based on cost-supply curves, therefore all sustainability parameters that have been described for cost-supply curves (Annex 3.3) can be included. Again, mainly social and economic sustainability is considered. Also here, legislation needs to be taken into account since it influences prices. Examples are mandatory biofuel quotas that require a certain level of biofuel production as well as subsidies and tax exemptions. For agriculture, ideally the whole sector is regarded – including food, feed, biofuel and biomaterial production. This allows monitoring the impact of bioenergy production on food prices and taking into consideration the need for biomaterials. By integrating all biomass uses, market feedbacks affecting the equilibrium allocation of these uses...
can be considered. In addition, market distortions should be accounted that arise from governmental regulations supporting certain fields of biomass applications. A further important aspect is the by-products from biofuel production. Often, they can be sold on markets thus influencing the demand, for example for animal feed and respective prices. Moreover, by-products affect land use and land-use change. Many by-products can be used as animal feed thus replacing conventionally produced animal feed and releasing the respective agricultural land which in turn has implications for their sustainability.

Generally, indirect land use change caused by the production of biofuels can have two opposite effects. Firstly, biofuel production may replace existing crops to new areas where the transformation of natural vegetation into agricultural land is caused. Depending on the vegetation, this can have strong negative impacts on climate change. Secondly, as described above, the by-products of biofuel production may have alleviating effects by releasing agricultural land previously used for feed production. Economic models are theoretically able to capture these indirect land use changes caused by changes in trade flows of certain commodities if energy models are linked with agriculture and forestry models. However, so far none of the existing models covers by-products from biofuel production in a satisfactory way. Furthermore, economic models allow for analysing the effects of bioenergy production on climate change in a much more comprehensive way than statistical and spatially explicit models. For these analyses the models have to be connected to a database on emission factors which can be obtained by means of life cycle assessment (LCA). Regarding land use change, the models have to be linked to a database on carbon stocks or to a biophysical model covering this issue. Moreover, results can only be obtained in a linear (non-dynamic) way, i.e. the impact of climate change on bioenergy production cannot be taken into consideration. This is only possible in integrated assessments.

8.4.4 Sustainability in integrated assessments

Integrated assessments combine several methodologies and models often involving multiple disciplines (for a more detailed description, see section 7.5). In the case of bioenergy, these assessments potentially cover a) biophysical production potentials across heterogeneous land qualities, management regimes, and climate zones, b) biomass production economics, market restrictions, and market adjustments, and c) multiple non-market impacts on society and environment including their feedback on a) and b). This type of models is able to mirror the complexity of interactions between society, economy and environment: they include socio-economic drivers of economic activity and energy use that lead to emissions and other pressure on the environment resulting in environmental changes, which in turn lead to physical impacts on societies and ecosystems and to socio-economic impacts and eventually return to cause changes in the socio-economic drivers.

The combination of economic and biophysical models allows for a quite comprehensive inclusion of sustainability parameters. In principle, all sustainability criteria listed in section 8.4 can be taken into consideration. In addition, feedback mechanisms can be included which allow for reproducing the complexity of sustainability in a more realistic way. Examples of such feedback mechanisms are:

- Linkage between bioenergy production and climate change: on the one hand, the use of bioenergy may mitigate climate change. On the other hand, climate change may influence the production of biomass and thus the bioenergy potential.
- Interaction between bioenergy production, climate change and biodiversity: the production of bioenergy may threaten biodiversity (see Annex 2.1) and other ecosystem services especially if dedicated energy crops are used. On the other hand, bioenergy may mitigate climate change which in turn decreases pressure on biodiversity. Only integrated assessment models are able to reflect this trade-off
- Land use change: The effect of bioenergy production on land use change is increasingly addressed in public and scientific discussion. As described in the previous chapter, indirect land use changes include advantageous and disadvantageous effects. Integrated assessment models allow capturing these effects.
Sustainability aspects of bioenergy potentials are complex by nature and involve not only different land uses but also different sectors. Because of their complexity, integrated assessment models are theoretically well suited to capture sustainability aspects in a very comprehensive way. However, the inclusion of all relevant aspects, feedback mechanisms and correlations in such models is challenging. Model combinations are error-prone and require great caution and experience, as interfaces have to be clearly defined and harmonised. As described in section 7.5, increasing complexity of models results in lower transparency, higher costs of model development, and reduced user friendliness. Problems are also caused by data and knowledge gaps and the reliance on a single or limited number of universal measures of impacts. Therefore, it is essential to choose the level of complexity of models carefully according to the modelling purposes.

8.5 Future research needs

In the course of the analysis of biomass resource assessments and sustainability the following future research needs have been identified:

Amount of surplus land
In biomass resource assessments focusing on energy crops, great deviations exist between the different results. This is partly due to differences in the amount of land that has been identified as being available for energy crop cultivation. This has several reasons. First, there are no transparent and commonly accepted definitions for land use categories. This will be dealt with further below (‘Definition gaps’). Second, different scenarios regarding population growth and consumption patterns / diets (especially the amount of meat that is consumed) have a great influence on the area needed. Third, there are weaknesses in the modelling of inter-linkages between biomass production for feed, food, biomaterial and bioenergy needs and the respective area needed. In the production of bioenergy (but also of biomaterials), many co-products occur that can be used as feed replacing conventionally produced feed. For instance, in biodiesel production, rapeseed meal is obtained that can replace soy meal. The conventionally produced feed does not need to be produced any more and thus the respective area is released. This again can be used for other purposes. Although these effects can have quite an impact on the amount of land used, up to now there is no general or partial equilibrium model that takes them into account.

Definition gaps
As has been mentioned above, the lack of common definitions has been identified as one of the reasons for deviating results in biomass resource assessments. Especially concerning land use categories, definitions and terms often differ greatly. As a consequence, different terms are used that describe areas that can be used for bioenergy production. Examples are ‘surplus land’, ‘marginal land’, ‘degraded land’, ‘land that is no longer needed for food production’, ‘underused land’, ‘non-productive land’ or ‘rest land’. This makes it impossible to derive biomass potentials that are comparable with each other. Also FAO and IPCC use different land use categories. FAO divides the land area into ‘agricultural area’, ‘forest area’ and ‘other land’ of which the latter includes built-up areas, barren land and other wooded land for instance. IPCC uses the categories ‘forest land’, ‘cropland’ and ‘grassland’, i.e. agricultural area is already divided into two categories at the highest level. Moreover, there is a separate category for ‘wetlands’ and ‘settlements’, respectively. In order to create a common ground for discussions and analyses, there is a need to find common definitions for all land use categories.

Inter-linkages and feedback mechanisms within the environmental dimension
Research is needed for greater understanding of the inter-linkages between climate change, land-use and land-use change, biodiversity and the consequences thereof for bioenergy production. Two issues are briefly presented here: soil degradation/desertification and biodiversity. Through soil degradation and desertification, high amounts of carbon dioxide that has been stored in the vegetation and soil organic matter is released into the atmosphere contributing significantly to
climate change. Especially dryland soils have lost a significant amount of carbon due to degradation and desertification. It is estimated that desertification has caused a carbon loss of 20–30 Gt (billion tonnes) up to now, and that a further 0.23–0.29 Gt of carbon are lost to the atmosphere from drylands every year as a result of desertification and related vegetation destruction, through increased soil erosion and the reduced carbon sink. However, it remains difficult to quantify the feedbacks between the land surface and the atmosphere, and projecting the potential outcomes of future climatic effects due to land-cover change remains challenging. However, the large surface area of drylands makes soil carbon sequestration globally significant. Under a range of assumptions, dryland soils could annually accumulate 0.9–1.9 Gt C (3.3–6.97 Gt CO₂) if desertification control and land restoration practices are adopted (GTZ 2009). The establishment of bioenergy crops such as Jatropha could be one possibility for soil restorations. However, also the possibilities to establish bioenergy crops on degraded soils need further investigation.

Another issue is the role of biodiversity. In this context, the following factors play an important role:

- **Chances and risks of bioenergy production:** Bioenergy production can have a negative impact on biodiversity. Since the agricultural area is restricted, the introduction of bioenergy production in existing agricultural systems can lead to intensification of cultivation and to land cover changes for gaining additional arable land. In this respect, also indirect land cover changes need to be considered. Both aspects influence biodiversity inside and outside agricultural systems. On the other hand, bioenergy also bears certain chances for enhancing biodiversity. For example, the introduction of bioenergy crops in Europe, such as perennial grasses and short rotation forestry, can add to the habitat diversity and thus also biodiversity if conventional crops and rather monotonous landscape structures are replaced. Bioenergy production also is a good opportunity for using biomass from landscape management, which is important for preserving certain habitats. For a comprehensive picture on bioenergy, models need to include both advantageous and disadvantageous impacts.

- **Climate change:** Not much is known about the linkages between climate change, bioenergy production and biodiversity. On the one hand, bioenergy helps mitigating climate change which in turn helps saving biodiversity. On the other hand – as has been described above – an increased bioenergy production bears risks for biodiversity through intensification in agriculture, cultivation of marginal (and thus highly biodiverse) soils and land use change. Up to now, these interlinkages, feedbacks and drawbacks have not been adequately included in bioenergy modelling.

**Greenhouse gas savings**

Many greenhouse gas balances have been prepared that can be used to quantify the potential impact of bioenergy production on the climate. However, the following problems remain unsolved:

- **Integration of indirect land use changes:** The introduction of bioenergy production in existing agricultural systems might cause so-called indirect land use changes: if food production is not given priority it can be displaced to other areas and eventually to non-agricultural land where land use changes of natural or semi-natural ecosystems occur. Resulting emissions from changes in above- and below ground carbon stock have to be allocated to the bioenergy system and significantly influence the outcomes of the respective greenhouse gas balances. In extreme cases, the use of bioenergy can lead to additional greenhouse gas emissions instead of GHG savings. However, up to now, no sound and comprehensive methodology has been developed for quantifying the impact of indirect land use changes.

- **The impact of nitrous oxide (N₂O) emissions:** In most greenhouse gas balances, default emission reduction values are included based on the IPCC Tier 1 approach for direct emissions. However, these factors could lead to an underestimation of the contribution of nitrogen fertiliser to global warming. A study by (Crutzen et al. 2007) reveals that nitrous oxide emissions caused by fertiliser use might be three to five times higher than has been assumed by IPCC. This implies that the production and use of bioenergy leads to increases of greenhouse gas emissions rather than to their savings.

- **Inclusion of impacts on biodiversity, water use and soil quality:** Within the current life cycle assessment methodology as defined in the ISO standards 14040 and 14044, there is no methodology to include aspects such as impact on biodiversity, the use of water resources as well as water and soil quality. However, the production and use of bioenergy use greatly influences...
these aspects. Therefore and since LCA results are widely accepted in policy making, development of applicable and commonly accepted methodologies should be focused on. Otherwise there is a risk that these impacts do not gain the attention they deserve in public discussion.

Beside the mentioned research needs, (Lysen et al. 2008) have identified a range of research needs based on an analysis of several global biomass resource assessments. In the following, those needs are listed that are of importance in this handbook:

- Integration of modelling efforts of the various arenas included in this assessment, in particular macro-economic/market models that are interlinked with integrated assessment tools and bottom-up analyses of agricultural, livestock and biomass production systems;
- Impact of policy incentives (such as subsidies, trade policies, climate policies) on agriculture, livestock, land-use and, ultimately, biomass resource availability;
- Impacts of land use change and changes in vegetation patterns on biodiversity including improved indicator systems for quantifying biodiversity;
- Impacts of changed land use and vegetation patterns on water use, including an improved understanding of ways to limit water use;
- Inter-linkages between climate change, agricultural productivity, land-use change, biodiversity and subsequent consequences for biomass resource potentials;
- Improved understanding of marginal and degraded lands and potential biomass production systems with their respective performance and impacts;
- Improvement of agricultural management and efficiency;
- Case studies on the full range of impacts (ecological and socio-economic) and performance (production levels, costs) of biomass production (and supply) systems in concrete settings, in particular covering more difficult circumstances such as by using degraded lands.

8.6 Improvement of data sources

Depending on the methodology, there are different needs for improving the data sources. Therefore, they will be dealt with separately in the following. All data gaps mentioned in the following are related to publically available data at EU or global level. Of course, respective data might be available at national level and / or only accessible for research institutes.

Statistical analyses

Major data gaps have been identified with regard to protected areas. It is for example not possible to indicate whether Natura2000 and other legally protected areas are established on cropland or grassland. Moreover, there are no statistical data on the suitable management level in different zones – no management, extensive or intensive management. Therefore, excluding all protected areas would lead to a significant underestimation of the biomass potential. For instance, in Spain 23% of the terrestrial area belongs to the Natura2000 network. Therefore, management is not excluded within this methodology, however, at a reduced yield level. If the application of a reduced yield level is not possible, Natura2000 areas should be excluded from use following the precautionary principle. Also, the fact that it is not possible to detect overlaps between protected areas adds to the underestimation. For example, in Germany, about one third of all nature reserves are part of the Natura2000 network. Regarding protected areas other than Natura2000 areas, there are no aggregated statistical data but data are given only for each site. This makes it quite time-consuming to come to an overall figure.

Regarding wetlands and peatlands, at global level there are only figures for areas under the Ramsar Convention. Furthermore, there are no global or European level statistical data on certified forest areas, on extensively managed areas as well as on slope gradients. Respective data, however, might be available at national or sub-national level.
Spatially explicit analyses

In spatially explicit analyses, it is possible to allocate Natura2000 areas to different land uses if the data are combined with land cover data (e.g., Corine Land Cover). However, the level of cultivation cannot be identified. Data related to management in Natura2000 areas will only be available on European level in a few years when management plans will have been established for all Natura2000 areas. For other legally protected areas that are listed in the Ramsar databases, there are no spatially explicit data available containing the borders but only spot data. Therefore, it is not possible to locate these areas and detect overlaps with Natura2000 and other legally protected areas.

Further data gaps concern the identification of ‘High Nature Value (HNV) farmland’. It is one out of 35 EU-indicators that have been established in the European IRENA project (Indicator reporting on the integration of environmental concerns into agriculture policy) (EEA 2005a). HNV farmland is defined as “those areas in Europe where agriculture is a major (usually the dominant) land use and where agriculture sustains or is associated with either a high species and habitat diversity, or the presence of species of European conservation concern, or both” (Andersen et al. 2003). Three types of HNV farmland have been established:

- Type 1: Farmland with a high proportion of semi-natural vegetation;
- Type 2: Farmland dominated by low intensity agriculture or a mosaic of semi-natural and cultivated land and small-scale features;
- Type 3: Farmland supporting rare species or a high proportion of European or World populations.

HNV farmland is estimated to make up 15-25% of the utilized agricultural area in EU-15 (EEA 2004). They comprise hot spots of biodiversity in rural areas and are often characterized by extensive farming practices.

However, up to now, there are no data available to identify HNV farmland at an overall European scale, let alone the different types. They can only be detected based on an indirect approach. For example, the first type is identified based on land cover data combined with agronomic farm level data (EEA 2004). Also areas under agro-environmental support, certified forest areas, extensively cultivated areas and areas under organic farming cannot be located on a spatially explicit base due to a lack of respective data.

Furthermore, on European level there are no data on areas under agro-environmental support and organic farming, certified forest areas, extensively cultivated areas as well as data on slope gradients and the amount of water available for irrigation. The latter data would need to be modelled taking into account renewable water resources of an area as well as water needs of other sectors such as food production, industries or domestic use. Depending on the scale of the study, respective data at national or sub-national level might be available.
9 Conclusions and recommendations

9.1 Conclusions

With the Methods Handbook and Data Sources Handbook, a comprehensive description of biomass methods and data sources is available for national and EU level biomass resource assessments. It provides a description of methods and provides recommendations for the use of data sources to determine the cascade of potentials from the theoretical potential over the technical potential, the economic potential, and the implementation potential towards the sustainable implementation potential.

The Methods Handbook includes the description of various methods to determine this cascade of potentials:

- basic and advanced statistical methods;
- basic and advanced spatially explicit methods;
- cost-supply methods;
- energy and economic modelling methods;
- integrated assessments.

Furthermore, it covers several biomass types within the following major biomass categories:

- forestry and forestry residues;
- energy crops;
- agricultural residues;
- organic waste.

In total, 40 detailed descriptions of methods, necessary data sources to assess the current and future potentials are provided, together with the necessary formulae and a description of data sources needs. For each method, future research needs have been identified as well as needs to improve the data sources to reduce the uncertainty behind the assessments. General recommendations for methodology development, data development and further development of the Methods Handbook are given in the next sections.

9.2 Recommendations for methodology development

Six important areas have been identified that should be addressed in future research on methodology development:

i. integrated modelling of biomass potential and use;
ii. advanced integration of remote sensing and earth observation data;
iii. improved methodology for estimating net climate benefits of bioenergy;
iv. improved methodology for estimating the environmental effects of intensive and large-scale bioenergy systems;
v. increased understanding of the social acceptance of large-scale bioenergy systems;
vi. conflicts between different goals for bioenergy use.

These areas are described further below:

Integrated modelling of biomass potential and use

Although existing studies still lack a full consideration of environmental aspects, the methodologies to assess the technical potentials are essentially already well developed and described in the Methods Handbook. One of the major challenges is the assessment of the economically realisable biomass
potential. Economic aspects need to be analysed and better integrated in biomass resource assessments in future research. Also, trade flow and market aspects like the competition with material use as well as the consideration of implementation issues in potential assessments require more investigation.

Indirect land use changes are much more difficult to model than direct land use changes. To do so adequately, estimates have to be based on economy-wide models (e.g. general equilibrium models) that take into account the supply and demand of agricultural commodities, land use patterns, and land availability (all at the global scale), among many other factors. To achieve this, an extensive analysis and review of the various approaches, methods and tools that can be used for an integrated assessment of the bioenergy potential is needed.

The multitude of interlinkages, correlations and parameters relevant to evaluating biomass potentials for energy requires an integrated treatment. This goes especially for, and is especially relevant to, estimating future trends in the use of land for food production, and the use of residues, waste and forest biomass for food and materials. The same is also relevant to the limitations due to water, soil and food security constraints as well as maintaining biodiversity, whereby indirect land use and other indirect impacts are crucial. These issues are at the core of the current discourse on the role of bioenergy in the global energy supply, but are only treated in general terms in the Method Handbook and further method development is urgently needed.

Advanced integration of remote sensing and earth observation data
Approaches and methodologies that locate and quantify biomass with high spatial resolution are already utilized in existing studies. The methods are described in the Methods Handbook and may be even more thoroughly analysed in the CEUBIOM project. However, recent and future sensor technology developments and improved availability of earth observation data necessitates:

- Further development of methods for using earth observation data in bioenergy potential assessments with focus on a high integration with in-situ monitoring systems.
- Development of methods for the assessment of spatially explicit net annual increment levels and yield levels using earth observation data.
  - Approaches using net primary production (NPP) need further attention.
- Further integration of economic and implementation issues in spatially explicit estimates of bioenergy potential.
- Method development for the integration of airborne remote sensing data, specifically LIDAR data that offer the opportunity to identify and quantify biomass resources for which currently data are missing, e.g. on the potential from trees and other woody biomass outside forests.
- A study that demonstrates the benefits of a remote sensing assisted study on the assessment of the bioenergy potential on all kinds of land use including forestry, agricultural residues and energy crops at national and regional level.

Improved methodology for estimating net climate benefits of bioenergy
Since climate change mitigation is a major justification for promoting bioenergy, there is an obvious need to accurately assess the net greenhouse gas mitigation benefits of bioenergy in biomass resource assessments. There is need for:

- Development of standardised methods for calculating CO₂ avoidance in biomass resource assessments;
- Development of a framework for verification of CO₂ avoidance;
- Development of methods and data to include direct land use change (dLUC), including changes in soil carbon levels;
- Development of methods and data to include also indirect land use change (iLUC) both inside and outside the EU.

These methods can make use of activities going on under the Clean Development Mechanism of UNFCCC and Good Practice Guidance provided by IPCC.
**Improved methodology for assessing the environmental effects of intensive and large-scale bioenergy systems**
- Increase the understanding of the environmental effects of intensive forest biomass utilisation options (e.g. stump harvesting, whole tree energy wood thinning on different site conditions).
- Assessments of the environmental effects of large scale and intensive biomass for energy production on agricultural land.
- Increase the understanding of the environmental effects of intensive utilisation of agricultural residues.
- Assessments of constraints on and effects of the use of natural resources, for instance water, mineral fertilizers, etc.

**Increased understanding of the social acceptance of large-scale bioenergy systems**
- Assess to what degree an increased production of biomass for energy on agricultural cropland is socially acceptable.
  - Would society object large scale and intense production of biomass for energy on agricultural land?
  - What are critical thresholds of acceptance?
- Assess to what degree an increased mobilization of forest biomass is socially acceptable.
  - Would society object to a high mobilization of the forest biomass potential?
  - What are critical thresholds of acceptance?
- Can the acceptance be influenced with appropriate information to the public?
- Methodology to include these findings in biomass resource assessments

**Increased understanding of conflicts between different goals for bioenergy use**
- Develop methodologies that can be used to increase the understanding of conflicts between different goals for biomass use, i.e. climate change mitigation, energy security, rural development, etc;
- Assess to what extent large-scale bioenergy production will affect food security and nutrition for poor people;
- Assess to what extent large-scale bioenergy systems will affect small-scale farmers;
- How to design economically viable sustainable biomass resource utilization chains?
- How to develop policy instruments that would avoid unsustainable development (such as direct burning of woody biomass that is suitable as well for material use) and support cascade use of woody biomass with energy conversion at the end of the chain?

### 9.3 Recommendations for data development

There is a strong need for further development of data for biomass resource assessments, as well as data on current biomass use to facilitate the identification of biomass resources still available for a further increase of the use of biomass for energy. Three levels of data development needs have been identified:

i. data assessing the current production and use of biomass and bioenergy;
ii. data needed to perform assessments of the current and future potential of biomass for energy;
iii. data development pertaining to Earth Observation (EO) techniques.

Three overarching areas of data pertaining to biomass and bioenergy need to be augmented and improved:

i. supply: including forestry, agriculture and organic waste and biomass processing industries;
ii. demand: including the main demand sectors, i.e. heat and power generation (both domestic and large scale), saw mills and the pulp and paper industry and biofuel production;
iii. trade: including imports and exports of all kinds of biomass and biofuels.
Below, general recommendations on data development are given per biomass category. Detailed recommendations are found at the end of the chapters on these biomass categories.

**Forestry**
The following is necessary for further data development:
- Countries that do not yet have a continuous sample based national forest inventory are encouraged to implement such inventory that provides a solid basis for potential assessments.
- Further harmonisation of national level definitions of stem wood and residues.
- Natura2000 areas cover considerable forest areas but harvesting and management restrictions need to be identified.
- Recovery rates and restrictions due to environmental constraints in forestry need to be refined either via integration of a recovery rate and restrictions assessment in national forest inventories or via dedicated studies.
- Data on removals and current use of stemwood and primary forest residues for energy generation.

**Energy crops**
Further data development is needed on:
- The extent of degraded and low productive soils; as a basis a commonly accepted definition of these areas is needed.
- The current use of degraded and marginal soils and the ownership of such lands, as well as their role from a biodiversity point of view.
- The dynamics and feasibility of changes in the efficiency of the agricultural production system.
- The efficiency and biomass turnover in the animal production system.
- The use and carrying capacity of pastures in the animal productions system.
- Inclusion of future plans on national level with respect to energy crop production together with a characterisation of the envisage land resource and the current use in NREAP or dedicated EUROSTAT data to enable impact modelling on both potential estimates and planned area increase.
- Current land management intensities including tillage, fertilization, water, plant protection, labour intensities by crop.
- Current crop rotation.
- Current land owner distribution.
- Current soil states.
- Current water uses and water needs in sectors other than agriculture.

**Agricultural residues and organic waste**
The following is necessary for further data development:
- Product to residue ratios based on empirical data.
- Spatial explicit data on (1) quantities of straw that should remain on site due to environmental limitations, (2) spatial distribution of straw needed for uses other than bioenergy.
- Construction and demolition wood accounts for a significant energy potential that does not cause any competition with other use options. In order to tap the full potential of this waste category, more detailed and exact data collection should be aimed for at a European level.
- Data on the percentage of the population served by municipal waste services are lacking in the recommended data source for some countries in, and that consequently the method cannot be strictly applied for those countries.
- Data on the organic content of municipal solid waste was not available for eight countries of the EU27. In addition, for some countries the available data proved to be rather old.
- The location of High Nature Value (HNV) farmland and associated restrictions need to be identified.
- Natura2000 areas can yield considerable amounts of biomass, but sustainable harvesting and management restrictions need to be identified before they can be regarded as part of the sustainable biomass resources.
 Availability and potentials of residues from food industry, landscape management and marine biomass.

Earth observation data
The data made available via the increased capacity of satellite based earth observation for environmental policies via the European GMES (Global monitoring for environment and security) programme, national level programmes and from initiatives from outside Europe in this sector are of high relevance. These programmes should be continued including both high resolution optical and SAR data. A possible future space borne LIDAR system of high resolution would strongly increase the capability to assess biomass quantitatively.

9.4 Recommendations for further development of the Methods Handbook

The utilisation of the methods described in the Methods Handbook can contribute to a harmonisation of future biomass resource assessments. It is now possible to refer to the Methods Handbook with respect to methods, assumptions and data sources, highlighting options chosen and if necessary highlighting differences in the methods applied and data sources used. This promotes an increased comparability of future studies.

The Method Handbook can serve as a first step towards a development to a reference work of biomass resource assessment at EU and national level. Several measures to achieve this will be necessary:

- As soon as readers start to use the Methods Handbook, various detailed comments can be expected. This was already the case when applying the methods in the illustration cases within the BEE project, which lead to a considerable improvement of the Methods Handbook versus the initial draft version. The authors of the Methods Handbook would therefore like to encourage its users to provide their comments to enable, when appropriate, adjustments in a next version of the Methods Handbook.
- Few biomass categories are not yet included, mainly because they are generally not covered in biomass resource assessments due to a lack of adequate data, for instance: waste from the food industry (covering slaughterhouse waste, used oils and fats, spills, etc.) and wood from landscape management, or marine biomass. Although it takes more effort, it will be very useful to include them in future assessments and display this generally unknown potential that can be of a considerable size.
- Furthermore, the need for further development of methods and for improvements of data sources has been identified throughout the 40 single method descriptions of the handbook. Thus, as soon as new methods are developed and improved data sources are available, these need to be integrated in the handbook to achieve and maintain the status of a reference work for biomass resource assessment methods.

It is recommended to establish permanent links between entities working on national and EU level biomass resource assessments in a dedicated network. This could lead to a standardisation of national level potential studies, e.g. in the context of updates of the national renewable energy action plans and would strongly support the comparability of national and EU level studies. The Methods Handbook could serve as a baseline handbook for such a network, that could initiate and steer the development towards a reference book.
Annex 1  Use of spatial data from remote sensing in biomass resource assessments

Introduction
This annex intends to give a brief overview of options that arise from the integration of Remote Sensing (RS) in biomass resources assessments and makes reference both to existing applications and to the integration of RS approaches describes in various chapters of this handbook.

In recent years, Remote Sensing (RS) techniques became a very efficient tool for monitoring the earth’s surface due to increasing accuracy and availability of the RS data products. With those data products, meaningful interpretations can be made about the Earth’s biological conditions and resources, geologic and hydrologic processes and resources, and human dynamics (CEOS 2008). Remote Sensing data usually is categorized according to the sensor type and the platform respectively. Platforms are either airborne (at airplanes, helicopters, balloons e.g.) or space borne (satellites or space shuttle). The sensors are categorized into active sensors and passive sensors, and within these categories the sensors are specified according to their spectral and geometrical resolution and regarding the used electromagnetic spectrum. Due to the increasing number and quality of sensors (accuracies in the Ground Sampling Distance (GSD), which means a higher geometrical resolution, repetition cycles, radiometric resolution), space borne sensors satellite remote sensing became more and more developed towards operational services important for RS techniques in recent years. Within the next 15 years, for example, the CEOS (committee on earth observation satellites) agencies are operating around 240 satellites with more than 385 different instruments or sensors (CEOS 2008). The different instruments may be considered under the following categories that are relevant for biomass assessments:

- High and very high resolution optical and multispectral sensors
- Medium-resolution multi-spectral radiometers (VIS/IR)
- Radars (Radio detection and ranging)
- Lidars (Light detection and ranging)

The most common sensor types for biomass assessment are high resolution optical and multi-spectral sensors (passive sensors) as well as microwave Radar and Lidar sensors (active sensors). Following these categories, a broad classification of sensors used for biomass assessments is given as follows (Rosillo-Calle 2007):

- Photographic camera (air)
- Spectral Scanner (air and space)
- Radar (air and space)
- Lidar (air and space)

The spectral resolution discriminates between sensors in panchromatic or single band (e.g. black and white film), multispectral (like RGB colour film, colour-infrared film or multispectral scanners like e.g. LandSat ETM+ with 8 bands), hyperspectral scanners (e.g. HYMAP with 128 bands), active Laserscanner or Lidar systems and active microwave or Radar sensors (e.g. TerraSAR-X). An overview of currently used satellite missions and sensors useful for biomass assessments is given in Table 59.
### Table 59 Satellite Missions and Sensors useful for biomass assessments

<table>
<thead>
<tr>
<th>Mission (Sensor)</th>
<th>Sensor Type</th>
<th>Sensor</th>
<th>Resolution spatial</th>
<th>Resolution spectral</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medium Resolution multispectral sensors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Envisat</td>
<td>MS</td>
<td>MERIS</td>
<td>300m</td>
<td>15 bands</td>
<td>Envisat</td>
</tr>
<tr>
<td>AVHRR</td>
<td>MS</td>
<td>AVHRR3</td>
<td>1000m</td>
<td>6 bands</td>
<td>NOAA16,17</td>
</tr>
<tr>
<td>LandSat TM</td>
<td>MS</td>
<td>TM</td>
<td>30m</td>
<td>7 bands</td>
<td>Landsat 4,5</td>
</tr>
<tr>
<td>LandSat ETM</td>
<td>MS</td>
<td>ETM+</td>
<td>30m</td>
<td>8 bands</td>
<td>Landsat 7</td>
</tr>
<tr>
<td>LandSat MSS</td>
<td>MS</td>
<td>MSS</td>
<td>79m</td>
<td>4 bands</td>
<td>Landsat 1-3</td>
</tr>
<tr>
<td>IRS1</td>
<td>MS</td>
<td>AWIFS</td>
<td>56m</td>
<td>2 bands</td>
<td>IRS-1c/d</td>
</tr>
<tr>
<td>OrbView</td>
<td>MS</td>
<td>OrbView-2</td>
<td>1100m</td>
<td>8 bands</td>
<td>OrbView-2</td>
</tr>
<tr>
<td><strong>High resolution optical sensors (HR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRS1</td>
<td>MS</td>
<td>LISS-3</td>
<td>25m</td>
<td>3 bands</td>
<td>IRS-1c/d</td>
</tr>
<tr>
<td>IRS-P6</td>
<td>MS</td>
<td>LISS-4</td>
<td>6m</td>
<td>3 bands</td>
<td>ResourceSat-1</td>
</tr>
<tr>
<td>JERS</td>
<td>MS</td>
<td>JERS-1</td>
<td>18m</td>
<td>7 bands + 1 Stereo</td>
<td>JERS-1</td>
</tr>
<tr>
<td>SPOT</td>
<td>MS</td>
<td>HRVIR</td>
<td>20m (pan 10m)</td>
<td>4 bands</td>
<td>Spot 4</td>
</tr>
<tr>
<td>SPOT</td>
<td>MS</td>
<td>HRG</td>
<td>10m (pan 5m)</td>
<td>5 bands</td>
<td>Spot 5</td>
</tr>
<tr>
<td>ALOS</td>
<td>MS</td>
<td>AVNIR-2</td>
<td>10m</td>
<td>4 bands</td>
<td>ALOS</td>
</tr>
<tr>
<td><strong>Very high resolution sensors (VHR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IKONOS</td>
<td>MS</td>
<td>Ikonos</td>
<td>3m (pan 1m)</td>
<td>4 bands</td>
<td>IKONOS</td>
</tr>
<tr>
<td>GeoEye</td>
<td>MS</td>
<td>GeoEye-1</td>
<td>1.65m (pan 0.4m)</td>
<td>5 bands</td>
<td>GeoEye-1</td>
</tr>
<tr>
<td>FormoSat</td>
<td>MS</td>
<td>FormoSat-2</td>
<td>8m (pan 2m)</td>
<td>5 bands</td>
<td>FormoSat-2</td>
</tr>
<tr>
<td>Quickbird</td>
<td>MS</td>
<td>BGIS2000</td>
<td>2.5m (pan 0.6m)</td>
<td>5 bands</td>
<td>Quickbird</td>
</tr>
<tr>
<td>ERS</td>
<td>MS</td>
<td>ATSR-2</td>
<td>1m</td>
<td>7 bands</td>
<td>ERS-2</td>
</tr>
<tr>
<td>RapidEye</td>
<td>MS</td>
<td>RapidEye</td>
<td>6.5m</td>
<td>5 bands</td>
<td>5 RapidEye Satellites</td>
</tr>
<tr>
<td>IRS</td>
<td>PAN</td>
<td>Cartosat 1,2</td>
<td>(Pan 1m)</td>
<td>1</td>
<td>IRS cartosat 1,2</td>
</tr>
<tr>
<td></td>
<td>PANstereo</td>
<td></td>
<td>Stereo 2.5m</td>
<td>1+1</td>
<td></td>
</tr>
<tr>
<td><strong>Active Sensors (Radar and Lidar)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RadarSat</td>
<td>Radar</td>
<td>Radarsat2</td>
<td>3-100m</td>
<td>c-band</td>
<td>Radarsat 2</td>
</tr>
<tr>
<td>TSX</td>
<td>Radar</td>
<td>TerraSar-X</td>
<td>1m,3m,18m</td>
<td>x-band</td>
<td>TerraSAR-X</td>
</tr>
<tr>
<td>SRTM2000</td>
<td>Radar</td>
<td>SRTM1 SRTM3</td>
<td>Ca. 1 ArcSec</td>
<td>x-band + c-band</td>
<td>Space Shuttle</td>
</tr>
<tr>
<td>ALOS</td>
<td>Radar</td>
<td>PALSAR</td>
<td>&gt;7m</td>
<td>L-band</td>
<td>ALOS</td>
</tr>
<tr>
<td>Envisat</td>
<td>Radar</td>
<td>ASAR</td>
<td>30-100m</td>
<td>c-band</td>
<td>Envisat</td>
</tr>
<tr>
<td>JERS</td>
<td>SAR</td>
<td>SAR</td>
<td>18m</td>
<td></td>
<td>JERS-1</td>
</tr>
<tr>
<td>ERS</td>
<td>Radar</td>
<td>AMI</td>
<td>30m</td>
<td>c-band</td>
<td>ERS-2</td>
</tr>
<tr>
<td>ICESat</td>
<td>Lidar</td>
<td>GLAS</td>
<td>70m / 170m</td>
<td>2 Lidar wave lengths</td>
<td>ICESat</td>
</tr>
</tbody>
</table>

For a complete overview of current satellite missions, see also:
Data sources
The data sets obtained from remote sensing sensors can be further classified regarding the level of processing:

- Primary Remote Sensing products
- Secondary Remote Sensing products

The processing level increases from raw or primary data (e.g. spectral reflection intensity) to secondary data products with a high level of pre-processing (e.g. land cover maps, net primary production, and digital elevation models).

An overview on examples where primary and secondary remote sensing products have been used in biomass assessments is given in Table 60.

Table 60 Primary and Secondary remote sensing products

<table>
<thead>
<tr>
<th>Product</th>
<th>Based on Dataset/Sensor</th>
<th>Resolution spatial</th>
<th>Information used in biomass energy assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Landcover and Land use products (secondary RS products)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGBP Landcover USGS 2003</td>
<td>Spaceborne multispectral imagers</td>
<td>1000m</td>
<td>17 Land cover classes used e.g. in: (Obersteiner 2007) (Rokityanskiy et al. 2007)</td>
</tr>
<tr>
<td>GLOBCOVER, Global Land Cover 2000 (GLC2000)</td>
<td>Spaceborne multispectral imagers</td>
<td>300m</td>
<td>JRC provides this bottom up approach for identification of ecosystems used e.g. in: (Ten Brink et al. 2007)</td>
</tr>
<tr>
<td>National topographic information systems (e.g. ATKIS in Germany, Natura 2000)</td>
<td>Aerial images, Optical satellite images</td>
<td>1:50000</td>
<td>Topographic information system of Germany, e.g. to discriminate forest types and land use types, used in: (Kappler et al. 2008) (Scenar2010 2006) (Eickhout and Prins 2008)</td>
</tr>
<tr>
<td>Forest Map of Europe, JRC forest map 1990, 2000, 2006</td>
<td>NOAA-AVHRR, CLC IMAGE 2006, Landsat 7</td>
<td>1km raster</td>
<td>Forest classes (deciduous, coniferous and mixed forest) were used e.g. in: (EEA 2007a)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Based on Dataset/Sensor</th>
<th>Depending on sensor, from 1m to 1000m</th>
<th>Information used in biomass energy assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation and terrain models (primary RS products)</td>
<td>Aerial images, ALOS PRISM, Shuttle Radar Topography Mission or Lidar campaigns</td>
<td>High accurate digital elevation models are used to derive the terrain slope and height to assess the suitability for forestry biomass extraction or to evaluate the soil erosion, e.g. in: (Dieter et al. 2001) (Kappler et al. 2008) (Fritsche et al. 2004) (EEA 2007a) (EEA 2006) (EEA 2007b) (Obersteiner 2007) (Rokityanskiy et al. 2007) (Hoogwijk et al. 2005)</td>
<td></td>
</tr>
</tbody>
</table>
A number of global and regional land cover mapping efforts, using Earth observation data from satellites, have been undertaken over the past decade by utilizing sensors such as AVHRR, MODIS and SPOT Vegetation. A new, 300 m resolution global land cover map (Globcover) has been released by the POSTEL Service Center that uses the MERIS sensor aboard the Envisat satellite. A number of national and regional land cover data sets, including e.g. the National Land Cover Database (NLCD) for the USA, CORINE for Europe have been developed at the 30 m resolution range. Via global and European initiatives such as the European GMES both up to data land cover data and improved digital elevation data will be available for utilization in future for biomass assessments.

Methods
Remote sensing data can be utilized in many ways. The major general options are to use remote sensing data sources for one of the four following purposes:

a) Providing information on the spatial distribution of land use/cover classes that cover specific biomass resources such as forest or land cover classes that are subject to agricultural activities or potential areas for the cultivation of energy crops. It also provides information on area coverages per land use/cover class that can be utilized as regional level or national level statistics.

b) In assessing parameters that are closely correlated with biomass and thus can provide high spatial resolution information on the physical potential, when this information is calibrated using ground reference data biomass (e.g. spectral information from multispectral satellites, vegetation height from SAR or LIDAR, NPAR from MODIS).

c) In assessing constraints related to topography by providing e.g. remote sensing based digital terrain models.

d) Once physical or technical potentials have been spatially assessed based on remote sensing data, other GIS data sets can be utilized to identify restrictions, e.g. by overlay of data on protected areas with specific utilization restrictions, or to assess harvesting or supply costs or for spatial modelling of supply and demand.

The major challenge in using remote sensing data is the combination with other information that is required in potential assessments but that is of different spatial resolution, or not directly spatially linked to mapped land cover classes.

Given the different properties of biomass major categories and subcategories, very specific approaches are necessary and are described in this handbook both for supranational to national level assessments, and for national to regional level studies. In Table 61 reference is made to the chapters where the specific approaches that use remotes sensing data are described.

<table>
<thead>
<tr>
<th>Biomass category</th>
<th>Approach</th>
<th>Geographic scope</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stemwood and primary forestry residues</td>
<td>Basic spatially explicit method</td>
<td>Supranational to national</td>
<td>3.4.1</td>
</tr>
<tr>
<td>Stemwood and primary forestry residues</td>
<td>Advanced spatially explicit method</td>
<td>National to regional</td>
<td>3.4.2</td>
</tr>
<tr>
<td>Stemwood and primary forestry residues</td>
<td>Cost supply method</td>
<td>Regional</td>
<td>3.5.4</td>
</tr>
<tr>
<td>Energy crops</td>
<td>Basic &amp; advanced spatially explicit method</td>
<td>Supranational, national to regional</td>
<td>3.4.2</td>
</tr>
<tr>
<td>Primary agricultural residues</td>
<td>Basic spatially explicit method</td>
<td>Supranational, national to regional</td>
<td>5.2.2</td>
</tr>
<tr>
<td>Primary agricultural residues</td>
<td>Advanced spatially explicit method</td>
<td>Regional to local</td>
<td>5.2.3</td>
</tr>
</tbody>
</table>
PRINCIPLE: THE LOSS OF BIODIVERSITY SHALL BE PREVENTED
For the definition of biodiversity, see section 8.1.2. As described there, biodiversity is complex and difficult to measure. Therefore, parameters that directly aim at protecting a certain level of biodiversity are hard to define and an indirect approach is applied here. This means that sustainability parameters aim at regulating bioenergy production and used in a way that biodiversity is indirectly supported.

This is realized in two ways: by restricting the area available for bioenergy production and by defining certain management practices that in turn influence yields. First of all, areas are excluded from bioenergy production that might have a high biodiversity value, i.e. legally protected areas as well as areas that are of importance for the protection of biodiversity but that are currently not protected (e.g. wetlands, which often have a high biodiversity value). Secondly, management practices and the protection status (e.g. no residue harvest in buffer zone) are adapted to local biophysical conditions. By covering both elements, the biomass potential is restricted in twofold: via the area available as well as via yield levels.

A special emphasis needs to be put on the intensification of ‘underused’, ‘marginal’ or ‘non-productive’ land. This might be wise from a food production point of view. However, these land use types often account for a high biodiversity. Therefore, such areas should only be intensified if there is no risk for biodiversity. However, up to now there is no data base that would allow identifying such areas. The lack of common definitions for these land use categories further hinders their clear allocation (see also section 8.5 on future research needs). Since a great share is part of the agricultural area, they at least are partly covered by Criterion 4 on the High Nature Value (HNV) farmland.

Biodiversity is linked to the principles soil, water and climate change. Preserving soil and water quality helps to protect biodiversity. Climate change poses a great threat to biodiversity. An increased use of bioenergy could mitigate climate change and thus decrease pressure on biodiversity. However, – beside an increased need for agricultural land – most life cycle assessments of bioenergy have shown that the greenhouse gas savings of bioenergy are associated with an increase in acidification and eutrophication. Both environmental categories are among the main causes of biodiversity loss. These linkages are usually not addressed in biomass resource assessments and addressed as future research needs (see section 8.5).

Criterion 1: The loss of habitats of high biodiversity value (HBV) shall be prevented
For the definition of high biodiversity value (HBV), see section 8.1.2. To date, there is no globally comprehensive data base, however, different approaches and single data bases exist that cover at least part of these areas (section 8.1.2). As a minimum approach, all legally protected areas (either on international, European or national level) are taken into consideration. Furthermore, wetlands are included since they often are highly biodiverse.

Parameters:
1. Adapt management in Natura2000 areas (based on Birds (AFB Network 2002) & Habitats (92/43/EEC 1992) Directives); in countries not covered by the Natura2000 network, identify areas of high biodiversity value from national legislation / data sources. At the moment, there is no data related to Natura2000 areas that allows differentiating between different management zones (totally protected zones and zones where cultivation is still allowed or even required). However, often, the ecosystems captured by the Natura2000 network evolve from management and would change without further management. Therefore, management and thus biomass for bioenergy production in Natura2000 areas is allowed in this methodology at a reduced yield level. If the application of reduced yields is not feasible,
Natura2000 areas should be excluded from use following the precautionary principle. The second difficulty is that overlaps with other legally protected areas can not yet be captured in the statistical assessments leading to an underestimation of the potential. For further details on data gaps, see explanations on the tables in Annex 3.

2. Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites). The same difficulties as for Natura2000 areas apply here: there is no information on different management zones and regarding overlaps with Natura2000 areas. For further details on data gaps, see explanations on the tables in Annex 3.

3. Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN. Since only part of these ecosystems is currently covered by protected areas, further relevant areas should be identified. There is no overall methodology or database, but various approaches and concepts (e.g. HCVs, HNVs, KBAs, IPAs, etc.). An overview is given in (Hennenberg 2008). For identifying high nature value grassland, see the Excursus below.

4. No drainage / use of land that was wetland (including pristine peatlands) in January 2008. For the definition of wetlands and peatlands see section 8.1.2.

5. Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands). The size of the buffer zones should be adapted to the size of the protected areas / wetlands.

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**Excursus: Identification of high biodiversity value grasslands**

Currently, only part of high biodiversity value grassland is covered by protected areas. Therefore, in the following, a selection of methods for their identification is presented (after White et al. 2000)).

- a. The IUCN and WWF-US have identified 234 “Centers of Plant Diversity (CPDs)” out of which 40 are found in grassland areas. They represent areas with high biological value where nature protection could preserve a great amount of characteristic grassland species. However, GIS data are not available for free.
- b. 23 out of 217 “Endemic Bird Areas (EBAs)” that have been identified by Birdlife International comprise grassland as key habitat. Also here, there are no GIS data available.
- c. The WWF-US established a “Global 200 Ecoregions Database”. 35 are grassland regions, which comprises some of the most important grassland biodiversity. The GIS data can be ordered at WWF.
- d. The database of “Important Plant Areas” can be searched for grassland habitats. Their database also specifies under which convention such habitats are listed.
- e. Among the “Prime Butterfly Areas (PBAs)” in Europe, no specific search for grasslands can be done, however, most of these areas are grassland areas. Butterfly species are often used as proxy indicators for the condition of grassland.
- f. The “Red List of Threatened Plant Species” of the IUCN can be searched for species that appear in grassland habitats. However, spatially explicit data are available only for part of the species.

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**Criterion 2: Direct land cover change shall be prevented**

Land cover changes only occur if future biomass potentials are derived. Therefore, the following parameters are not relevant for the current biomass potential.

**Parameters:**

6. Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland. According to the European regulation on direct support schemes under the common agricultural policy (Council Regulation (EC 73/2009 2009) the member states...
shall ensure that “land, which was under permanent pasture at the date provided for the area aid applications for 2003 is maintained under permanent pasture” (for new member states, the reference year is 2004). However, member states may derogate from this rule, provided that they take action to “prevent any significant decrease” in its total permanent pasture area. The regulation is implemented in the member states in different ways. For instance, in Germany the proportion between arable land and grassland that existed in 2003 should not change significantly. If grassland is reduced by more than 5 % proportionately to arable land, permission is needed for further conversion. If the proportion has decreased by more than 10 %, grassland has to be re-established. Other regulation might be applicable in different member states. Therefore, in the basic approaches the conversion of grassland should be excluded. In more advanced assessments, regulations in the member states should be taken into account. Although it is not a common rule, grassland that is part of the Natura2000 network or of other legally protected areas should be excluded from conversion for biodiversity reasons. Furthermore, highly biodiverse grassland should be identified (for an approach, see Excursus) and excluded from conversion.

7. Allow afforestation of permanent grassland if it is compatible with the environment (exclusion of highly biodiverse grassland). European regulation on direct support schemes under the common agricultural policy (Council Regulation (EC) 73/2009 2009) grassland may be afforested if it is ‘compatible with the environment’. Therefore, grassland that is part of protected areas (Natura2000 or others) or that is highly biodiverse should be excluded from afforestation to prevent biodiversity losses. For the identification of highly biodiverse grassland, see the Excursus above.

8. Exclude continuously forested areas and wooded land from conversion into arable land. For the definition, see section 8.1.2. The definition has been developed to account for carbon storing ecosystems. However, it can also be applied in this case since forests potentially are highly biodiverse.

**Criterion 3: Indirect land cover change shall be prevented**

Indirect land use changes occur if biomass for energy is produced on agricultural land that is currently used for food and feed production. Since the demand for food and feed still needs to be satisfied, food and feed production is relocated to another area where unfavourable land-use changes might occur. Land use changes are critical, both from a biodiversity and a climate change point of view.

**Parameters:**


The use of surplus land for energy crop production prevents the competition with feed and food production and thus eventually its displacement causing the conversion of natural ecosystems. For the definition of surplus land, see section 8.1.2.

**Criterion 4: Support of forest and agro-biodiversity**

**Parameters:**

10. Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions.

11. Restrict the use of genetically modified organisms (GMO). Within the European Union regulations regarding GMO are quite heterogeneous. They range from a total ban of commercial cultivation of GMO to a long-time commercial cultivation of single GM crops (e.g. maize in Spain) (GMO Compass 2007). Future biomass resource assessments need to take into account the various regulations that exist in each country in order to adapt yield increases accordingly.

12. Maximum extraction rates for primary agricultural and forestry residues. Agricultural residues are the food source for soil biota and micro organisms. They transform the residues into humus, which in turn is important for soil fertility (see Criterion 7). Forestry residues (including dead wood) are important for above-ground animals such as beetles and birds (as
food source and as habitat). Slowly, the wood becomes part of the soil ecosystem and serves as a food source for soil biota and microorganisms.

13. Minimum number of crop species and varieties as well as structural diversity within the cropping area.

**Criterion 5: Protection of High Nature Value (HNV) farmland**

For the definition of High Nature Value (HNV) farmland, see section 8.1.2. Up to now, there is no regular database with spatially explicit data on HNV farmland. Therefore, an indirect approach is applied here. As generally biodiversity increases if intensity of farming decreases, all areas under agro-environmental support, extensively managed areas as well as areas under organic farming should be regarded as potential HNV farmland. The status quo regarding these cultivation categories should be preserved. Significant overlaps between the categories exist as for instance extensively or organically managed areas are likely to be under agro-environmental support. If national data on HNV farmland are available, they should be drawn on.

**Parameters:**

14. Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support.
   *For the definition of agro-environmental support, see section 8.1.2.*

15. Adapt management practices (i.e. crop/tree choices and yields) on agricultural areas under organic farming and in certified forestry areas. *Certified forestry areas usually are not subsumed under HNV farmland. However, they are included here, since they thematically fit to organic farming.*

16. Adapt management practices (i.e. crop choices and yields) on extensively cultivated areas.

**PRINCIPLE: THERE HAS TO BE A SIGNIFICANT CONTRIBUTION TO GREENHOUSE GAS MITIGATION**

Climate change is one of the most important reasons for bioenergy production and use and at the same time strongly influences biomass potentials – both directly and indirectly. First of all, climate change influences yields: depending on the region and ecosystem, yields either increase (due to higher temperatures, higher CO₂ concentrations) or decrease (due to unfavourable changes in growing conditions). Secondly, it influences area availability: salinisation and desertification might require the abandonment of cultivation, but in northern latitudes, new areas could become available for agriculture. Indirect influences are caused by the use of bioenergy itself. On the one hand, an increased use of bioenergy might mitigate climate change; on the other hand, land use changes and increased fertilizer production and use might contribute to climate change. These aspects are addressed as future research needs (see section 8.5) since to date they are not adequately covered in biomass resource assessments. Regarding other sustainability principles, climate change influences biodiversity, the availability of water as well as the competition of land for food and biomaterial production via land availability.

**Criterion 6: Areas with high carbon stocks shall be excluded from conversion**

**Parameters:**

17. No drainage / use of land that was wetland (including peatlands) in January 2008.
   *For the definition of wetlands and peatlands, see section 8.1.2.*

18. Exclude continuously forested areas and wooded land from conversion into arable land.
   *For the definition of continuously forested areas and wooded land, see section 8.1.2.*

19. Avoid a massive conversion of permanent grassland into arable land.

**Criterion 7: Indirect land use change shall be prevented**

Indirect land use changes occur if biomass for energy is produced on agricultural land that is currently used for food and feed production. Since the demand for food and feed still needs to be satisfied, food and feed production is displaced to another area where unfavourable land-use changes might occur. Land use changes are critical, both from a biodiversity and a climate change point of view.
Parameters:

20. Preference of using surplus land

The use of surplus land for energy crop production prevents the competition with feed and food production and thus eventually its displacement causing the conversion of natural ecosystems. For the definition of surplus land, see section 8.1.2.

**PRINCIPLE: NEGATIVE IMPACTS ON SOIL SHALL BE MINIMIZED**

Regarding soil, two aspects are important: soil function and soil quality. Soil function is related to the risk of erosion, i.e. the loss of soil volume. Increased soil erosion leads to the loss of nutrients, carbon, as well as the leakage of chemicals to water bodies. This will decrease soil fertility, contribute to climate change as the soil carbon is released into the atmosphere, as well as negatively influence water quality. Soil erosion can be prevented by excluding areas with high erosion risk (i.e. areas with steep slopes) and by adapting crop choices to soil and topographic conditions.

Soil quality mainly refers to soil fertility, which is influenced by soil erosion but also by the direct input of nutrients and fertilizer. Furthermore, it is indirectly affected by volatilisation and deposition of nitrogen and pollutants contained in fertilizers and pesticides. The removal of a high share of forestry and agricultural residues negatively influences soil fertility as they play an important role for soil structure and organic matter content.

**Criterion 8: Minimize soil erosion**

Parameters:

22. Only perennial crops on sites susceptible to soil erosion.

Annual crops require regular tillage operations, which increases the erosion risk.
23. Maximum extraction rates for primary agricultural and forestry residues

Agricultural and forestry residues are transformed into humus, which is important for a stable and porosite rich soil. This in turn helps to prevent soil erosion.

**Criterion 7: Protect soil quality**

Parameters:

24. Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions.
25. Maximum extraction rates for primary agricultural and forestry residues

Agricultural and forestry residues are humus sources that improve soil quality and stores soil organic carbon. Applying a maximum percentage of straw that can be used for bioenergy production is a simplification that only partly reflects real conditions. First, the corn: straw ration changes over time, which means that every year, different total straw amounts are produced. Since the soil requires a minimum amount of straw (depending on the soil type and other factors), rather an absolute amount of straw should remain on the field. As a result, in bad years there might be no straw available for energy production. Moreover, straw that is used for bedding and later returned to the fields – either before or after fermentation for biogas production – has to be part of the balance since it still is able to restore the humus content. If data are available on the soil type and the amount of straw that is required for sustainable humus balancing, more detailed and exact assumptions should be made in the calculations.

**PRINCIPLE: NEGATIVE IMPACTS ON WATER SHALL BE MINIMIZED**

Here also two aspects are important: water quantity and water quality. Water quantity is influenced by crop choices, i.e. their specific need for water. If irrigation is applied, the water availability in a region is important. In this context, the competition for water resources with other sectors such as industry, agriculture (food and feed production) and the domestic use of water need to be taken into account. Water availability is influenced by climate change as rainfall patterns as well as water transpiration
and evaporation will change. Areas susceptible to water shortages will increase. Such areas will require special crop choices or – in the worst case – the abandonment of cultivation. Regarding water quality, the leakage of agro-chemicals (fertilizers, pesticides) to ground and surface water bodies causes most pollution. The degree of water pollution among others depends on the carrying capacity of the water, i.e. on the water availability, which differs between regions. Leakage occurs if the amount of agro-chemicals is not adapted to actual needs or if soil erosion occurs. Both risks can be mitigated by adapting the crop choices (and yields) to local soil, topographic and climate conditions. Water bodies are also indirectly affected by volatilisation and deposition of nitrogen and other pollutants contained in fertilizers and pesticides.

**Criterion 10: Minimization of harmful contamination of surface and ground water**

**Parameters:**

26. Adapt management practices (i.e. crop choices and yields) to local bio-physical conditions. If crop choices are made based on the local bio-physical conditions, the risk of an inappropriate fertiliser and pesticide input and thus leakage and volatilisation of pollutants is mitigated.

**Criterion 11: Prevent overexploitation of water resources**

**Parameters:**

27. Adapt management (i.e. crop choices and yields) to local bio-physical conditions (especially for rainfed agriculture). This makes sure that the crop specific water needs are adapted to local water resources. For example, in dry climates only crops with high water use efficiencies and / or low water needs should be grown.

28. For irrigation, adapt water consumption to regional resources; if no data are available, exclude irrigation as a precautionary principle. If crops are irrigated it should be made sure that the water use rate in a region is lower than the water regeneration rate. Competition with other water consumers (industry, agriculture for food and feed production, domestic use, other ecosystems) needs to be taken into account.

**PRINCIPLE: NEGATIVE IMPACTS ON AIR SHALL BE MINIMIZED**

Air quality influences ecosystems via the deposition of pollutants (e.g. acidifying or eutrophying substances) but also human health, e.g. via the deposition of nitrogen oxides. Agriculture, i.e. the cultivation of bioenergy crops is an important contributor to air pollution due to the production and application of fertilizers. Especially acidification and eutrophication are caused by nitrogen fertilizer application. To minimize negative impacts on air quality, the fertilizer input should be as low as possible. This can best be achieved if crop choices are adapted to local bio-physical conditions.

**Criterion 12: Minimization of emissions of air pollutants**

**Parameters:**

29. Adapt management practices (i.e. crop choices and yields) to local bio-physical conditions. If crops are perfectly adapted to the local bio-physical conditions, fertilizer and pesticide inputs can be minimized and thus the risk of harmful field emissions can be mitigated.

**PRINCIPLE: RESOURCE USE SHALL BE MINIMIZED**

The minimization of resource use, i.e. the increase of resource efficiency is an element in many sustainability strategies. Usually, this principle is applied to the production of goods, i.e. to the use of non-renewable resources. In this case, the potential of most biomass categories is not directly influenced. However, the principle can also be applied to the waste category. To preserve resources, waste (e.g. paper) should not directly be used for energy production but recycling should be prioritized. Only if no more recycling is possible, energy production should be an option. Generally, in the overall bioenergy system, the use of residues and waste should be given priority over a use of
energy crops. The principle can also be applied to renewable resources. In forestry, the most basic rule is that wood extraction should not be higher than forest growth rates.

**Criterion 13: Resource efficiency should be increased**

Parameters:
- 30. Recycle before waste is used for energy production.
- 31. Ensure a sustainable use of renewable resources.

**Annex 2.2 Theme: Society**

**PRINCIPLE: FOOD SECURITY SHALL BE ENSURED**

As the area globally available for agriculture is restricted, an expansion of biomass cultivation inevitably leads to an increased competition, above all with food production. There is a consensus that food security has to be given priority. The domestic food demand depends on two aspects: population growth and dietary preferences (i.e. the share of meat). Also the level of self-sufficiency needs to be considered, at least in studies on European and national level. Theoretically, all food needed in Europe could be imported, which would free all agricultural land within Europe for biomass production. However, it has to be taken into account that importing food likely leads to indirect land use changes in other countries: if food production on existing (and restricted) agricultural land is not given priority, the production of energy crops will lead to a displacement of food production to non-agricultural land, which may result in land use changes of natural or semi-natural ecosystems. The same can of course happen in Europe if food production is not given priority and if the conversion of forest or grassland is not strictly excluded. These land use changes are to be seen as critical from a climate change and biodiversity point of view. The prioritization also helps keeping food prices affordable – an issue that is especially relevant in developing countries.

**Criterion 14: Avoid competition with food production**

Parameters:

For the definition and derivation of surplus land see section 8.1.2.

**PRINCIPLE: THE PRODUCTION OF BIOBASED MATERIALS SHALL BE ENSURED**

Although it is discussed less fiercely than the competition with food production, there is also a strong competition for biomass used for the production of biomaterials such as wood as building material. This demand should also be given priority. In the construction sector and in the chemical industry, biomass is the only alternative renewable source, whereas for energy, other renewable sources are available such as solar or hydro power.

**Criterion 15: Avoid competition with the production of biomaterials**

Parameters:

For the definition and derivation of surplus land see section 8.1.2.

**PRINCIPLE: ADEQUATE LABOUR CONDITIONS SHALL BE ENSURED**

**Criterion 16: Labour rights shall be complied with**

Parameters:
- 34. Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182).

This parameter needs to be considered only in those countries that have not yet ratified and implemented the listed Conventions since only here, the implementation of the parameter
influences the (economic) biomass potential. For example, if child labour is present in a specific country, the implementation of the Convention that prohibits child labour would increase the production costs of biomass. For biomass resources analyses in countries within the European Union – having ratified and implemented the mentioned Conventions – this parameter is not relevant and does not need to be taken into consideration.

**Annex 2.3  Theme: Economy**

As with social parameters, it is difficult to include economic parameters in biomass resource assessments since they do not influence the technical biomass potential. Rather complex models are needed to include the interlinkages between food or energy prices and bioenergy production. Cost-supply assessments are the only ones that inherently take into account economic aspects. Here, economic sustainability in terms of economic viability is included per se since it refers to the amount of bioenergy that can be produced at a certain price level. Therefore, no additional parameters need to be defined.

**Annex 2.4  Excursus: Other Socio-economic parameters**

The emphasis of the sustainability parameters developed in this handbook is on environmental aspects. This is due to the different nature of environmental and social criteria in terms of their measurability: environmental criteria refer to (relatively) stable states that are quantifiable with scientific methods, i.e. they can be measured objectively. In the past, objective thresholds and institutional rules have been commonly agreed on that now help to include these aspects in biomass potential assessments. In contrast, social aspects are much more difficult to capture. There is consensus on certain aspects such as good labour conditions, job creation or welfare increase that have partly been transformed into regulations such as the conventions of the International Labour Organisation. But even if official regulations exist, they usually do not provide any strict rules that could be integrated in resource assessments. In most cases, however, no regulations exist at all. For example, there is no rule that defines the number of jobs that should be created by bioenergy production or the percentage of welfare increase that should be achieved. Finally, when it comes down to single actors and their individual wishes and needs, perceptions become very subjective and might change quite rapidly. For example, the perception of the impact on landscape by biomass for bioenergy production can change from negative to positive and vice versa depending on a number of subjective factors and issues that can sometimes be difficult to identify and let alone to predict. Such views are also weighed differently in different locations and circumstances and between local, regional and larger scale levels. Since social criteria are subjective, they are at best difficult to measure and quantify and it is hard to find objective benchmarks for comparison, which could be included in biomass resource assessments. Their assessment has to be done on local level based on local consultations, which usually are difficult and quite costly.

At the present time, there is still relatively limited literature that focuses on social sustainability in comparison to environmental sustainability, and in general a comprehensive study of the concept of social sustainability within the biomass potential assessment area is still missing. Furthermore, practical approaches to the social sustainability concept have not been based on theory but rather on the common sense and current political agendas.

Despite the difficulty to measure them, social aspects influence biomass potentials quite considerably. They come into play during the cultivation of biomass (e.g. noise disturbances during harvesting) and if the supply chain is taken into consideration (e.g. biomass transport to the conversion plant). For many social criteria (e.g. employment, social cohesion, rural diversification, etc.), their inclusion in biomass resource assessment procedure and methodology will not have an impact on the total area available for biomass production. However, there are exceptions to this like the perception of the impact on landscape related to energy crops production, in which case this is directly related to the available area. In these cases, social aspects can have impacts on the implementation potential of biomass, more exactly on which fraction of the technical potential can be tapped. For example, if the population has strong objections (e.g. against a biogas plant due to worries regarding odour nuisance),
the technical potential cannot be exploited. Further examples of how social aspects influence biomass potentials are the influence society has on the management level of forests as well as the structure of forest ownership. Especially the latter is one reason why large wood potentials remain unused. This is mainly due to a high fragmentation of privately owned forests, which makes accessing the potential quite cost-intensive. Private forest owners often decide differently from state owners and sometimes are reluctant towards cooperation that would help to make the potential accessible. For example, in cooperations the use of machinery such as harvesters could be shared making it less expensive or the collection of woody residues could be bundled.

In practical terms, some of the most important socio-economic parameters cannot be included in biomass resource assessments procedures without considering the local context and implications of utilising biomass for energy purposes on the local level. For example, the issue of landscape impact related to the cultivation of energy crops can in some cases be an important issue and have a considerable impact on the available area, i.e. the technical potential. However, it is also possible that in some cases this issue does not have any impact on the available area, and it is not possible to determine the exact amount without obtaining feedback from local stakeholders. The necessity of including the local context (stakeholders) in the definition of social sustainability criteria and parameters that will be taken into consideration is confirmed by major relevant experts on the subject (Fehrenbach et al. 2008), (Vis et al. 2008), (Domac et al. 2005), (Thornley et al. 2009), (Buchholz et al. 2009), (Haberl et al. 2009), (Haughton et al. 2009), and (O’Connell et al. 2009)).

In general, the procedure for including socio-economic parameters in the assessment of biomass potential (technical, economic, social) mostly has to be based on:
- analysing the potential impacts of both biomass production and consumption,
- obtaining feedback from stakeholders regarding the importance of the identified impacts, and
- structuring this feedback into appropriate criteria to be included in the analysis.

An important consideration to keep in mind is that a strict distinction between social and economic impacts and benefits of a bioenergy project is in most cases not possible and such an analysis would provide only partial results at best. A summary of some of the socio-economic impacts associated with local bioenergy production is listed in Table 62 (Domac et al. 2005).

<table>
<thead>
<tr>
<th>Table 62 Impacts associated with local bioenergy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimension</strong></td>
</tr>
<tr>
<td>Social Aspects</td>
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<tr>
<td>Macro Level</td>
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<tr>
<td>Supply Side</td>
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<tr>
<td>Demand Side</td>
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</table>

The specified impacts represent a general overview of possible criteria that could be included in the sustainability aspects of biomass resource assessments from the socio-economic point of view.
However, the definition of specific socio-economic criteria to be included in the analysis dependents on the particular project and its background.

For illustration purposes, a selection of some of the most widely discussed socio-economic issues is presented in the following.

- **Food costs**
  One issue often discussed in relation to biomass production for energy purposes is the right of food at affordable prices, in particular for people living in developing countries. This right is also laid down in the EU Directive on the promotion of the use of energy from renewable sources (Article 17; (2009/28/EC 2009)). Partly, rising food prices can be prevented by avoiding competition with food production and by prioritising food production as it is done in criterion 12. However, in a globalised world, claiming 100 % food self-sufficiency in a country for guaranteed affordable food prices is not a realistic option. Moreover, food prices are not only affected by bioenergy production but are a part of the complex and interactive world market and are thus difficult to model and to predict. Factors that add to a great variability of harvests and thus food prices are crop failures due to droughts, floods, soil salinization as well as due to climate change.

- **Creation of new employment (especially in rural areas)**
  Rural income generation and job creation are widely used arguments for enhancing bioenergy. The introduction of bioenergy as an employment and income-generating source can help to stem adverse social cohesion and stability trends in rural areas (e.g. high levels of unemployment, rural depopulation, etc.). It is evident that rural areas are often suffering from significant levels of outward migration, which may – in some countries – endanger population stability. As bioenergy plants are often deployed at rural locations they may have positive effects on rural labour markets by, firstly, introducing direct employment and, secondly, by supporting related industries and the employment therein (e.g. the farming community and local/regional renewable energy technology providers, installers and service providers). However, it has to be noted that the taxation need for subsidies leads to job losses elsewhere so that net employment effects are close to neutral or neutral (Edwards et al. 2008).

- **Impact on landscape**
  The introduction of bioenergy crops such as short rotation coppice (SRC) often creates new and visible features in a landscape. It can have either a beneficial or negative impact on the landscape, depending on where and how it is grown. The actual impact will depend upon the character and quality of the recipient landscape, the extent of physical change involved, and the ability of the landscape to accommodate this change. For example, in structured landscapes with a lot of forests, the cultivation of short rotation coppice would not be an added value. Here, visual axes are already limited and thus very important to be preserved. In contrast it could add some structure to very flat and field-dominated regions.

- **Land use rights**
  Land use rights are generally defined as the rights of private persons, legal persons or other organizations to use land rights for a fixed period of time. The issue of land use rights has been identified as an important aspect with regard to the assessment of the social sustainability of biofuels production. The reporting commitment on land use rights is also laid down in the EU Directive on the promotion of the use of energy from renewable sources (Article 17; (2009/28/EC 2009)). In many countries and regions land use rights are not implemented or guaranteed. This is especially true for common laws since no written contracts exist. As a result, the production of biomass for bioenergy purpose can aggravate this situation if the local population is displaced by the establishment or expansion of plantations. The implementation of land use rights should be a prerequisite for bioenergy production. Especially common laws need to be identified and discussed. As an input for biomass resource assessments, only those areas should be available for biomass for bioenergy production where land use rights are clearly defined and observed.
Annex 3  Sustainability parameters in specific biomass resource assessments methods

Annex 3.1  Sustainability in resource-focused statistical assessments

Resource-focused statistical assessments are simple assessments that are based on assumptions about the total area of land available for energy crop cultivation in combination with assumptions on the (usually average) yield per hectare or the fraction of forest biomass that is available for energy production. Usually, statistical data are combined with different average factors such as harvest ratios, crown-to-stem ratios for the amount of woody residues or corn-to-straw ratios.

Statistical assessments offer only very limited options to include sustainability aspects and fail to cover all aspects. Mostly, sustainability criteria are included as limiting or reduction factors. Only aspects can be included that directly limit the area or the yield achieved on the areas. For instance, from the total agricultural area available for energy crop production the following area sizes should be subtracted: area needed for food / feed / biomaterial production (at a given rate of self-sufficiency) as well as protected areas.

In Table 63 to Table 70, all sustainability parameters that can be considered in statistical analyses are listed. The parameters are ordered by biomass categories in order to facilitate the search. For categorization, detailed explanations and references, see section 8.3. Several parameters serve to describe more than one criterion. For example, the parameter ‘No drainage / use of land that was wetland (including peatlands) in January 2008’ is used to specify Criterion 1 (‘The loss of habitats shall be prevented’) and Criterion 5 (‘Areas with high carbon stocks shall be excluded from conversion’). The numbers indicate where in Table 55 the parameters can be found.
Forestry and forestry residues

Table 63 Sustainability parameters to be included in statistical analyses for forestry and primary forestry residues; * parameters based on RED (2009/28/EC 2009)

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Forestry</th>
<th>Primary forestry residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td>Only forests available for wood supply are considered as a source of woody biomass; apply a reduction factor to account for reduced yields in Natura2000 forests; if yield reduction is not feasible, exclude Natura2000 forests from use (by subtracting the area of Natura2000 forests from total forest area)</td>
<td>Only forests available for wood supply are considered as a source of woody biomass and therefore of primary forestry residues; apply a reduction factor to exclude Natura2000 areas from primary residue extraction (by subtracting the area of Natura2000 forests from total forest area)</td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas – national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td>Only forests available for wood supply are considered as a source of woody biomass; apply a reduction factor to exclude all protected forestry areas (by subtracting the area of protected forests from total forest area)</td>
<td>Only forests available for wood supply are considered as a source of woody biomass and therefore of primary forestry residues; apply a reduction factor to exclude protected areas (by subtracting the area of protected forests from total forest area)</td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>For future biomass potentials, no afforestation of areas that were wetland or peatland in January 2008</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Allow afforestation of permanent grassland if it is compatible with the environment (exclusion of highly biodiverse grassland)</td>
<td>For future biomass potentials, allow for afforestation of grasslands; exclude grassland that is part of the Natura2000 network and of other legally protected areas</td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td>Reduction factor for primary forestry residue yields: 65 % of branches etc. are available; 33 % of stumps are available</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>Apply a reduction factor to account for reduced harvesting levels in certified forestry areas</td>
<td>Apply a reduction factor to account for reduced harvesting levels in certified forestry areas</td>
</tr>
<tr>
<td>21</td>
<td>Maximum slope limits for cultivation</td>
<td>Apply a reduction factor to account for forests not available for harvesting due to steep slopes</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Ensure a sustainable use of renewable resources</td>
<td>Wood extraction rates should be lower than forest growth rates</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Preference for using surplus land</td>
<td>Only use harvested wood that does not satisfy the requirements of the wood processing industry, e.g. specific size and shape of stem</td>
<td></td>
</tr>
</tbody>
</table>
Energy crops and agricultural residues

Table 64 Sustainability parameters to be included in statistical analyses for energy crops and agricultural residues;
* parameters based on RED (2009/28/EC 2009)

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Energy crops</th>
<th>Primary residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td>Only use surplus arable land for energy crop cultivation; apply a reduction factor to account for reduced yields in Natura2000 areas on arable land; if yield reduction is not feasible, exclude Natura2000 areas from use (by subtracting the size of Natura2000 areas that cover arable land from total arable land)</td>
<td>Apply a reduction factor to exclude Natura2000 areas from primary residue extraction (by subtracting the size of Natura2000 areas that cover arable land from total arable land)</td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td>Only use surplus arable land for energy crop cultivation; apply a reduction factor to account for reduced yields in Natura2000 areas on arable land; if yield reduction is not feasible, exclude Natura2000 areas from use (by subtracting the size of Natura2000 areas that cover arable land from total arable land)</td>
<td>Apply a reduction factor to exclude protected areas from primary residue extraction (by subtracting the total size of protected areas that cover arable land)</td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>For future biomass potentials, no conversion of areas that were wetland or peatland in January 2008</td>
<td></td>
</tr>
<tr>
<td>6, 19</td>
<td>Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland *</td>
<td>For future biomass potentials take into account national regulations for grassland conversion into arable land; do not allow conversion of grassland that is part of the Natura2000 network and other legally protected areas; if no regulations are available, do not allow grassland conversion</td>
<td></td>
</tr>
<tr>
<td>8, 18</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
<td>For future biomass potentials exclude the conversion of forests/wooded land into arable land</td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td>Apply maximum extraction rates for primary agricultural residues (straw, vineyards); for straw only 30 % should be used after subtraction of the amount for other use purposes (livestock)</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support</td>
<td>Apply a reduction factor to account for reduced harvesting levels on areas under agro-environmental support</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>Apply a reduction factor to account for reduced harvesting levels in areas under organic farming</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Adapt management practices (i.e. crop choices and yields) on extensively cultivated areas</td>
<td>Apply a reduction factor to account for reduced harvesting levels on extensively managed areas</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Maximum slope limits for cultivation</td>
<td>Apply a reduction factor to account for arable land not available for harvesting due to steep slopes</td>
<td></td>
</tr>
<tr>
<td>20, 32, 33</td>
<td>Preference for using surplus land</td>
<td>Subtract area size needed for food and feed production (based on population growth, consumption patterns and the rate of self-sufficiency) as well as for biomaterial production from total arable land</td>
<td></td>
</tr>
</tbody>
</table>
Waste

Table 65 Sustainability parameters to be included in statistical analyses for waste

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Recycle before waste is used for energy production</td>
<td>Prioritize recycling over the use for energy production</td>
</tr>
</tbody>
</table>

Table 66 shows the data sources currently available for covering sustainability aspects in statistical resource assessments.

Table 66 Data sources for statistical analyses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data source/ Data item</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natura2000 forests</td>
<td>(Eurostat 2009)</td>
<td>Table 1.2.2 (‘Protected and protective areas’), p.30</td>
</tr>
<tr>
<td>Protected areas</td>
<td>World Database on Protected Areas (WDPA)</td>
<td>WDPA (<a href="http://www.wdpa.org">http://www.wdpa.org</a>) → Search</td>
</tr>
<tr>
<td>Wetlands and peatlands</td>
<td>Ramsar database, only for Ramsar sites</td>
<td>Ramsar (<a href="http://ramsar.wetlands.org">http://ramsar.wetlands.org</a>) → Database</td>
</tr>
<tr>
<td>Forests available for wood supply</td>
<td>Eurostat</td>
<td>Eurostat → Statistics Database → Agriculture, forestry and fisheries → Forestry</td>
</tr>
<tr>
<td>Arable land</td>
<td>Eurostat</td>
<td>Eurostat → Statistics Database → Agriculture, forestry and fisheries → Agro-environmental indicators → Agricultural production systems → Main agricultural land types</td>
</tr>
<tr>
<td>Grassland</td>
<td>Eurostat</td>
<td>Eurostat → Statistics Database → Agriculture, forestry and fisheries → Agriculture → Other farmland → Permanent grassland: Number of farms and areas by size of farm and size of cereal area</td>
</tr>
<tr>
<td>Area under agro-environmental support</td>
<td>Eurostat</td>
<td>Eurostat → Statistics Database → Main tables → Environment and Energy → Environment → Area under agro-environmental commitment</td>
</tr>
<tr>
<td>Area under organic farming</td>
<td>Eurostat</td>
<td>Eurostat → Statistics Database → Agriculture, forestry and fisheries → Agriculture → Organic farming → Organic crop area / Area under organic farming</td>
</tr>
<tr>
<td>Certified forest areas</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Extensively managed areas</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Areas with steep slopes</td>
<td>n.a.</td>
<td></td>
</tr>
</tbody>
</table>

Currently, there is an insufficient data base concerning Natura2000 and other legally protected areas. Regarding Natura2000 areas, only data on the complete size as well as on forestry areas are available – an allocation to grassland and arable land is not possible. This makes it difficult to identify impacts on biomass potentials for energy crops. Moreover, in many parts of the areas under the Natura2000 network, cultivation and forest management is allowed and even required in order to preserve certain habitats. Thus, the exclusion of all Natura2000 areas would lead to an underestimation of the biomass potential. Therefore, a reduced management is allowed within this methodology. However, wherever the application of reduced yield levels is not feasible, Natura2000 areas should be excluded from use following the precautionary principle. More detailed national data should be drawn on where available. It has to be noted that only the net area size of Natura2000 should be taken into account. There are great overlaps between the areas under the birds and the habitats directives. However, statistical data that are currently available take into account these overlaps.

Moreover, there are no aggregated statistical data on all legally protected areas in European countries. Data are given only for each site, which makes it quite time-consuming to come to an overall figure.
Furthermore, there is no possibility to detect overlaps between Natura2000 sites and other legally protected areas, which further adds to the underestimation of the biomass potential.

Regarding wetlands and peatlands, there are only area sizes for areas under the Ramsar Convention. Furthermore, there are no statistical data on certified forest areas, on extensively managed areas as well as on slope gradients. These data have to be evaluated on national level.

**Annex 3.2  Sustainability in resource-focused spatially explicit assessments**

Compared to statistical assessments, spatially explicit assessments – even static ones – offer much more possibilities to include sustainability aspects. Different spatial layers can be integrated that account for different information. In doing so, sustainability can be covered to a large extent apart from feedback mechanisms and linkages. Scenario analyses also offer the opportunity to include various external effects.

In Table 67 to Table 69, all sustainability aspects are listed that can be included in spatially explicit analyses. The parameters are ordered by biomass categories in order to facilitate the search. For categorization, detailed explanations, and references, see section 8.3. Several parameters serve to describe more than one criterion. For example, the parameter ‘No drainage / use of land that was wetland (including peatlands) in January 2008’ is used to specify Criterion 1 (‘The loss of habitats shall be prevented’) and Criterion 5 (‘Areas with high carbon stocks shall be excluded from conversion’). The numbers indicate where in the hierarchy presented in Table 55 the parameters can be found.

**Forestry and forestry residues**

**Table 67 Sustainability parameters to be included in spatially explicit analyses for forestry and forestry residues**

<table>
<thead>
<tr>
<th>No</th>
<th>Parameters based on RED (2009/28/EC 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
</tr>
<tr>
<td></td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biome reserves (UNESCO MAB), Ramsar sites) *</td>
</tr>
<tr>
<td>2</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by international agreements</td>
</tr>
</tbody>
</table>

* parameters based on RED (2009/28/EC 2009)
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>intergovernmental organisations or the IUCN *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>Identify wetlands and peatlands (baseline: 2008) for exclusion from use; exception: harvesting is possible during winter</td>
</tr>
<tr>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
<td>Identify protected areas (Natura2000 and others) and wetlands; include appropriate buffer zones that are based on the size of the protected areas; adapt management methods (reduced harvesting levels)</td>
</tr>
<tr>
<td>7</td>
<td>Allow afforestation of permanent grassland / pasture if it is compatible with the environment (exclusion of highly biodiverse grassland)</td>
<td>For future biomass potentials, allow for afforestation of grasslands; exclude grassland that is part of the Natura2000 network and of other legally protected areas. Additionally: identify high biodiversity value grassland and exclude from conversion</td>
</tr>
<tr>
<td>10, 24, 26</td>
<td>Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions</td>
<td>Adapt tree choices to local biophysical conditions (e.g. agro-ecological zones, soil type, climate) No below ground residue harvesting (stumps, roots) around water bodies (buffer size 10 m)</td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td>Extraction rates for primary forestry residues (including stumps) are adapted to local soil conditions based on slope, soil type, soil depth, soil compaction risk; no harvesting if slopes &gt; 35%; adapt harvesting to soil fertility based on a nitrogen deposition map; maximum extraction rate for above-ground residues at 65%, for below-ground residues at 33%; see also Table 13. Additionally: exclude foliage from harvesting</td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>Adapt harvesting levels on certified forestry areas Adapt residue extraction levels on certified forestry areas</td>
</tr>
<tr>
<td>21</td>
<td>Maximum slope limits for cultivation</td>
<td>No harvesting if slopes &gt; 35 %; no harvesting on soils with high compaction risks (Histosols, Fluvisols, Gleysols, Andosols, undrained (permanently wet) peatlands); exceptions where harvest can be realised during winter on frozen soils</td>
</tr>
<tr>
<td>27</td>
<td>Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions (especially for rainfed agriculture)</td>
<td>Adapt tree choices and harvesting levels to local bio-physical conditions (e.g. climate, water availability); no clear cuts</td>
</tr>
<tr>
<td>31</td>
<td>Ensure a sustainable use of renewable resources</td>
<td>Wood extraction rates should be lower than forest growth rates</td>
</tr>
<tr>
<td>33</td>
<td>Preference of using surplus land</td>
<td>Wood removals for industrial use are subtracted from the aggregated stemwood increment raster to exclude wood that is utilized for other purposes from the increment potentially available for energy For primary and secondary residues, take into account and prioritize alternative use options</td>
</tr>
</tbody>
</table>
**Energy crops and agricultural residues**

**Table 68 Sustainability parameters to be included in spatially explicit analyses for energy crops and agricultural residues**

* parameters based on RED (2009/28/EC 2009)

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Energy crops</th>
<th>Primary agricultural residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td>Identify Natura2000 areas (based on Birds &amp; Habitats Directive) and apply a reduced yield level; no SRC in bird protection areas; in non member states identify high biodiversity value areas from national legislation / data sources and exclude from use or apply a reduced yield level. Additionally: differentiate between core zones (no management) and other areas (management allowed); exclude core zones from use and adapt management in other areas (crop choices, yields, harvesting levels); mind overlaps with other legally protected areas (see parameter 2)</td>
<td>Identify Natura2000 areas (based on Birds &amp; Habitats Directive) and exclude from residue use; in non member states identify high biodiversity value areas from national legislation / data sources and exclude from residue use. Additionally: differentiate between core zones (no management) and other areas (management allowed); exclude core zones from use and adapt management in other areas (harvesting levels); mind overlaps with other legally protected areas (see parameter 2)</td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td>Identify protected areas and exclude from use. Additionally: differentiate management intensity based on IUCN categories, exclude all areas with category I (core zones); adapt management on other areas (harvesting levels); mind overlaps with Natura2000 areas</td>
<td>Identify protected areas and exclude from residue use. Additionally: differentiate management intensity based on IUCN categories, exclude all areas with category I (core zones); adapt management on other areas (harvesting levels); mind overlaps with Natura2000 areas</td>
</tr>
<tr>
<td>3</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN *</td>
<td>Identify areas with rare, threatened or endangered species and adapt management; mind overlaps with protected areas</td>
<td>Identify areas with rare, threatened or endangered species and exclude from residue use; mind overlaps with protected areas</td>
</tr>
<tr>
<td>4-17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>For future biomass potentials, no conversion of areas that were wetland or peatland in January 2008</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
<td>Identify protected areas (Natura2000 and others) and wetlands; include appropriate buffer zones that are based on the size of the protected areas; adapt management methods (crop choices, yields)</td>
<td></td>
</tr>
<tr>
<td>6-19</td>
<td>Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland *</td>
<td>For future biomass potentials take into account national regulations for grassland conversion into arable land; do not allow conversion of grassland that is part of the Natura2000 network and of other legally protected areas. Additionally: identify high biodiversity grassland and exclude from conversion; if no regulations are available do not allow grassland conversion into arable land</td>
<td>For future biomass potentials no conversion of forests / wooded land for energy crop cultivation</td>
</tr>
<tr>
<td>8-18</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
<td>For future biomass potentials no conversion of forests / wooded land for energy crop cultivation</td>
<td></td>
</tr>
<tr>
<td>10, 24, 26, 29</td>
<td>Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions</td>
<td>Adapt crop choices and yields to local bio-physical conditions (e.g. agro-ecological zones, soil types, climate); consider atmospheric deposition of nitrogen loads; no cultivation around water bodies (buffer zone 30 m)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Restrict use of genetically modified organisms (GMO)</td>
<td>Take into consideration national regulations regarding GMOs; if GMOs are banned, adapt future yield increases</td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td>Maximum extraction rates for primary agricultural residues (straw, vineyards); for straw only 30% should be used after subtraction of the amount for other use purposes (livestock); no harvesting at steep slopes; adapt harvesting to soil fertility based on a nitrogen deposition map</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Minimum number of crop species and varieties as well as structural diversity within the cropping area</td>
<td>Adapt crop choices and related yields</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support</td>
<td>Adapt crop choices, assume lower average yields on areas under agro-environmental support; mind overlaps with areas under extensive and organic farming!</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>Adapt crop choices and yields on areas under organic farming; mind overlaps with area under agro-environmental support and extensively managed areas!</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Adapt management practices (i.e. crop choices and yields) on extensively cultivated areas</td>
<td>Adapt crop choices and yields in extensively cultivated areas; mind overlaps with area under agro-environmental support and organic farming!</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Maximum slope limits for cultivation</td>
<td>Maximum slopes limits for energy crop cultivation</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Only perennial crops on sites susceptible to soil erosion</td>
<td>Perennial crops on areas with erosion risk based on slope &amp; soil type</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Adapt management practices (i.e. crop/tree choices and yields) to local bio-physical conditions (especially for rainfed agriculture)</td>
<td>Adapt crop choices and yields to local bio-physical conditions (e.g. climate, water availability)</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>For irrigation, adapt water consumption to regional resources; if no data are available, exclude irrigation as a precautionary principle</td>
<td>Adapt irrigation to local renewable water resources under consideration of competing water consumers; if no data are available, exclude irrigation as a precautionary principle</td>
<td></td>
</tr>
<tr>
<td>32, 33</td>
<td>Preference of using surplus land</td>
<td>Subtract area size needed for food production (based on population growth, consumption patterns and the rate of self-sufficiency) as well as the area needed for biomaterial production from total arable area</td>
<td></td>
</tr>
</tbody>
</table>

For primary and secondary residues, take into account and prioritize alternative use options, e.g. the use of straw as bedding material.
Waste

Table 69 Sustainability parameters to be included in spatially explicit analyses for waste

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Recycle before waste is used for energy production</td>
<td>Prioritize recycling over the use for energy production</td>
</tr>
</tbody>
</table>

Table 70 shows data sources currently available for covering sustainability aspects in spatially explicit assessments.

Table 70 Data sources for spatially explicit analyses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data source / Data item</th>
<th>Exact location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natura 2000 Areas (Birds and Habitats Directives)</td>
<td>European Environment Agency (EEA)</td>
<td>EEA (<a href="http://ec.europa.eu/environment/index_en.htm">http://ec.europa.eu/environment/index_en.htm</a>) → Data and Maps → Biodiversity → Natura2000 data</td>
</tr>
<tr>
<td>National and international legally protected areas</td>
<td>n. a. (only statistical data)</td>
<td></td>
</tr>
<tr>
<td>Protected areas in Europe</td>
<td>Common Database on Designated Areas (CDDA)</td>
<td>EEA (<a href="http://www.eea.europa.eu/">http://www.eea.europa.eu/</a>) → Data and maps → Biodiversity → Nationally designated areas</td>
</tr>
<tr>
<td>Wetland / peatland</td>
<td>Ramsar database, only statistical data for Ramsar sites</td>
<td>Ramsar (<a href="http://ramsar.wetlands.org">http://ramsar.wetlands.org</a>) → Database</td>
</tr>
<tr>
<td>Adapt management to local bio-physical conditions</td>
<td>IIAASA: Global Agro-Environmental Zones (GAEZ)</td>
<td><a href="http://www.iiasa.ac.at/Research/LUC/GAEZ/index.html">http://www.iiasa.ac.at/Research/LUC/GAEZ/index.html</a></td>
</tr>
<tr>
<td>High nature value (HNV) farmland</td>
<td>Nitrogen deposition</td>
<td>EMEP modelled air concentrations and depositions: <a href="http://webdab.emep.int/Unified_Model_Results/AN/">http://webdab.emep.int/Unified_Model_Results/AN/</a></td>
</tr>
<tr>
<td>Area under agro-environment support</td>
<td>n. a. (only statistical data)</td>
<td></td>
</tr>
<tr>
<td>Area under organic farming</td>
<td>n. a. (only statistical data)</td>
<td></td>
</tr>
<tr>
<td>Certified forestry areas</td>
<td>n. a.</td>
<td></td>
</tr>
<tr>
<td>Extensively cultivated areas</td>
<td>n. a.</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>European Soil Portal - European Soil Database of the European Soil Bureau Network, resolution 1km, European coverage; Data for instance on soil types, soil quality (organic carbon content), erosion risk; suitability for agriculture</td>
<td>EC Joint Research Centre, <a href="http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDB">http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDB</a> B/index.htm</td>
</tr>
<tr>
<td>Slope gradients</td>
<td>n. a.</td>
<td></td>
</tr>
<tr>
<td>Adaptation of water consumption to regional resources</td>
<td>Amount of surplus water available for irrigation</td>
<td>n. a.</td>
</tr>
</tbody>
</table>

As with the statistical analyses, also for the spatially explicit analyses there are data missing related to Natura2000 and other legally protected areas. The spatially explicit analyses allow allocating Natura2000 areas to different land uses if the data are combined with land cover data (e.g. Corine Land Cover). However, it is still not possible to identify the level of cultivation that is allowed in a certain area: intensive, extensive or no cultivation at all. Data related to management in Natura2000 areas will only be available in a few years when management plans will be established for all Natura2000 areas. Among others, they will include information on the management level.

Other protected areas are listed in the CDDA and WDPA data bases. For the CDDA data base, data are gathered by EEA via EIONET. These data are then forwarded to WDPA / Eurostat. Thus, both
data bases should contain the same level of information. However, this is not the case. Therefore, both data bases should be drawn on in order to guarantee a complete coverage of protected areas. For all protected areas, information on IUCN categories is available so that management practices can be adapted accordingly. There are partial overlaps between Natura2000 areas and other legally protected areas which need to be considered.

For wetlands, the Ramsar database exists. However, there are no spatially explicit data available containing the borders but only spot data. Therefore, it is not possible to locate these areas and detect overlaps with Natura2000 and other legally protected areas.

Further data gaps concern areas under agro-environmental support and organic farming, certified forest areas, extensively cultivated areas as well as data on slope gradients and the amount of water available for irrigation. The latter data would need to be modelled taking into account renewable water resources of an area as well as water needs of other sectors such as food production, industries or domestic use.

**Annex 3.3  Sustainability in demand driven cost supply assessments**

Cost-supply analyses contain two elements: first, the technical biomass potential is assessed by using either statistical or spatially explicit approaches. Second, this potential is combined with the results from cost accounting that evaluated the costs of biomass production in order to create a cost-supply curve.

Sustainability parameters can be integrated twofold. First, they can be integrated into the assessment of the technical potential. Depending on whether a statistical or a spatially explicit approach is used, the parameters as described in Annex 3.1 and Annex 3.2 can be used. In addition to the technical potential, also the production costs are influenced by integrating sustainability the following parameters:

**Environmental parameters** influence the production costs in two ways. First, they restrict the area available for the production of energy crops as well as for wood and residue extraction. The size and distribution of the catchments area for wood, crops and residues significantly influences transportation costs, which are often decisive for the economic viability of bioenergy. For statistical analyses, mean transportation costs should be applied, while for spatially explicit approaches they can be modelled exactly based on the distances. Second, at farm level, certain practices influence the production costs of energy crops. For conventional farming systems, cultivation in compliance with the minimum requirements for good agricultural and environmental conditions as referred to in the Council Regulation (EC) No 73/2009 is taken as granted. Here, no further restrictions are applied and thus costs are not influenced. However, they should be adapted in extensive or organic farming systems for energy crops and in certified forests. In some cases additional costs for certification may occur. Moreover, additional income due to agro-environmental support might have to be taken into account. These elements, however, can only be covered by detailed spatially explicit analyses.

**Social parameters** that could influence production costs are mainly related to working conditions. However, as described in Annex 2.2, for European studies it can be assumed that regulations related to labour conditions are implemented and regulated. Hence, there would be no need to apply additional criteria. On global level, however, the integration of labour conditions such as the ban on child labour or minimum wages could lead to increased production costs if compared to the current costs.

**Economic parameters**

As the amount of biomass produced is connected to the respective price levels, the resulting potentials are per se sustainable from an economic point of view. Further parameters cannot be included.

In Table 71 to Table 73 all sustainability aspects are listed that can be included in cost-supply analyses. For the parameters related to the technical potential, please refer to Annex 3.1 and Annex
3.2. The parameters are ordered by biomass categories in order to facilitate the search. For categorization, detailed explanations and references, see section 8.3. Several parameters serve to describe more than one criterion. For example, the parameter ‘No drainage / use of land that was wetland (including peatlands) in January 2008’ is used to specify Criterion 1 (‘The loss of habitats shall be prevented’) and Criterion 5 (‘Areas with high carbon stocks shall be excluded from conversion’). The numbers indicate where in the hierarchy presented in Table 55 the parameters can be found.
Forestry and forestry residues

Table 71 Sustainability parameters to be included in cost-supply analyses for forestry and forestry residues

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Forestry</th>
<th>Primary forestry residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adopt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td>Adapt transportation costs to account for reduced yield levels in certain areas (depending on data availability, either reduced yield levels are applied to whole protected areas or it is differentiated between core zones and other areas)</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for residue extraction (depending on data availability, either complete protected areas are excluded or only core zones)</td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for wood extraction (depending on data availability, either complete protected areas are excluded or only core zones)</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for residue extraction (depending on data availability, either complete protected areas are excluded or only core zones)</td>
</tr>
<tr>
<td>3</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN *</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for wood extraction (depending on data availability)</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for wood extraction (depending on data availability)</td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>For future potentials, adapt transportation costs to area size available</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
<td>Identify protected areas (Natura2000 and others) and wetlands; include appropriate buffer zones which are based on the size of the protected areas; adapt management methods and related production costs</td>
<td>Identify protected areas (Natura2000 and others) and wetlands; include appropriate buffer zones that are based on the size of the protected areas; exclude foliage and stumps from harvesting in the buffer zones; adapt transportation costs to account for the fact that harvesting area is reduced</td>
</tr>
<tr>
<td>7</td>
<td>Allow afforestation of permanent grassland / pasture if it is compatible with the environment (exclusion of highly biodiverse grassland)</td>
<td>For future potentials, adapt transportation costs to area size available</td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td></td>
<td>Adapt transportation costs to the level of harvest and therefore the area size needed</td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>Adapt production costs to certified forest management; take into account fees for certification</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182)</td>
<td>Adapt labour costs accordingly; take into account national regulations, e.g. regarding minimum wages</td>
<td>Adapt labour costs accordingly; take into account national regulations, e.g. regarding minimum wages</td>
</tr>
</tbody>
</table>
### Energy crops and agricultural residues

**Table 72 Sustainability parameters to be included in cost-supply analyses for energy crops and agricultural residues**

*parameters based on RED (2009/28/EC 2009)*

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Energy crops</th>
<th>Primary agricultural residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adapt management in Natura2000 areas (based on Birds &amp; Habitats Directive); in states not covered by the Natura2000 network, identify high biodiversity value areas from national legislation / data sources *</td>
<td>Adapt transportation costs to account for reduced yield levels in certain areas (depending on data availability, either reduced yield levels are applied to whole protected areas or it is differentiated between core zones and other areas)</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for residue extraction (depending on data availability, either complete protected areas are excluded or only core zones)</td>
</tr>
<tr>
<td>2</td>
<td>Exclude other legally protected areas - national (e.g. nature reserves, national parks) and international (e.g. Biosphere reserves (UNESCO MAB), Ramsar sites) *</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for energy crop cultivation (depending on data availability, either complete protected areas are excluded or only core zones)</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available (depending on data availability, either complete protected areas are excluded or only core zones)</td>
</tr>
<tr>
<td>3</td>
<td>Adapt management on areas designated for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the IUCN *</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available for energy crop cultivation (depending on data availability, either complete protected areas are excluded or only core zones)</td>
<td>Adapt transportation costs to account for the fact that certain areas are not available (depending on data availability, either complete protected areas are excluded or only core zones)</td>
</tr>
<tr>
<td>4, 17</td>
<td>No drainage / use of land that was wetland (including peatlands) in January 2008 *</td>
<td>For future potentials adapt transportation costs to account for the fact that certain areas are not available</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Buffer zones between cultivated land and areas of high biodiversity value (protected areas and wetlands)</td>
<td>Identify protected areas (Natura2000 and others) and wetlands; include appropriate buffer zones that are based on the size of the protected areas; adapt management methods and related production costs due to more extensive farming practice</td>
<td></td>
</tr>
<tr>
<td>6, 19</td>
<td>Avoid a massive conversion of permanent grassland to arable land; no conversion of highly biodiverse grassland *</td>
<td>For future potentials, adapt transportation costs to account for the fact that certain areas are excluded</td>
<td></td>
</tr>
<tr>
<td>8, 18</td>
<td>Exclude continuously forested areas and wooded land from conversion into arable land *</td>
<td>For future potentials, adapt transportation costs to account for the fact that certain areas are excluded</td>
<td></td>
</tr>
<tr>
<td>12, 23, 25</td>
<td>Maximum extraction rates for primary agricultural and forestry residues</td>
<td>Adapt transportation costs to the level of harvest and therefore the area size needed</td>
<td>Adapt transportation costs to the level of harvest and therefore the area size needed</td>
</tr>
<tr>
<td>13</td>
<td>Minimum number of crop species and varieties as well as structural diversity within the cropping area</td>
<td>Adapt production costs to the specific crop choices</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Adapt management practices (i.e. crop choices and yields) on areas under agro-environmental support</td>
<td>Adapt production costs to extensive farming levels; take into account subsidies</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Adapt management practices (i.e. crop / tree choices) on agricultural areas under organic farming and in certified forestry areas</td>
<td>Adapt production costs to organic farming levels; take into account fees for certification</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Adapt management practices (i.e. crop choices and yields) on extensively cultivated areas</td>
<td>Adapt production costs to extensive farming levels; take into account subsidies</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Maximum slope limits for cultivation</td>
<td>Adapt transportation costs to</td>
<td></td>
</tr>
</tbody>
</table>
Only perennial crops on sites susceptible to soil erosion

Adapt production costs accordingly

For irrigation, adapt water consumption to regional resources; if no data are available, exclude irrigation as a precautionary principle

If irrigation is applied, take into account the respective costs

Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182) *

Adapt labour costs accordingly; take into account national regulations, e.g. regarding minimum wages

Adapt labour costs accordingly; take into account national regulations, e.g. regarding minimum wages

**Waste**

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Compliance with labour standards according to the conventions of the International Labour Organisation (Nr. 29, 87, 98, 100, 105, 111, 138, 182) *</td>
<td>Adapt labour costs accordingly; take into account national regulations, e.g. regarding minimum wages</td>
</tr>
</tbody>
</table>
Annex 4 References


Dieter, M., H. Englert and M. Klein (2001). Abschätzung des Rohholzpotenzials für die energetische Nutzung in der Bundesrepublik Deutschland (Estimates of the potential of roundwood for the production of energy in Germany). Hamburg, Germany, Institut für Ökonomie, Bundesforschungsanstalt für Forst- und Holzwirtschaft, Universität Hamburg: 31 + Appendices.


EOBEM (2001). EOBEM (Earth Observation for grassland, shrubland and woodland biomass estimate and management), ENV4-CT98-0754,E, EOBEM D3002, “Algorithm, Design & Implementation”.


GTZ (2009). Running dry? Climate change in drylands and how to cope with it, Bonn, Oekom.


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