GREBE

Generating Renewable Energy Business Enterprise

Northern Periphery and Arctic Programme

Resource Assessment Toolkit for Biomass Energy

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July 2018

www.grebeproject.eu

The GREBE Project

What is GREBE?

GREBE (Generating Renewable Energy Business Enterprise) is a €1.77m, 3-year (2015-2018) transnational project to support the renewable energy sector. It is co-funded by the EU's Northern Periphery & Arctic (NPA) Programme. It focuses on the challenges of peripheral and arctic regions as places for doing business, and helps develop renewable energy business opportunities in areas with extreme conditions.

The project partnership includes the eight partners from six countries, Western Development Commission (Ireland), Action Renewables (Northern Ireland), Fermanagh & Omagh District Council (Northern Ireland), Environmental Research Institute (Scotland), LUKE (Finland), Karelia University of Applied Sciences (Finland), Narvik Science Park (Norway) and Innovation Iceland (Iceland).

Why is GREBE happening?

Renewable Energy entrepreneurs working in the NPA area face challenges including a lack of critical mass, dispersed settlements, poor accessibility, vulnerability to climate change effects and limited networking opportunities.

GREBE will equip SMEs and start-ups with the skills and confidence to overcome these challenges and use place based natural assets for RE to best sustainable effect. The renewable energy sector contributes to sustainable regional and rural development and has potential for growth.

What does GREBE do?

GREBE supports renewable energy start-ups and SMEs:

- To grow their business, to provide local jobs, and meet energy demands of local communities.
- By supporting diversification of the technological capacity of SMEs and start-ups so that they can exploit the natural conditions of their locations.
- By providing RE tailored, expert guidance and mentoring to give SMEs and start-ups the knowledge and expertise to grow and expand their businesses.
- By providing a platform for transnational sharing of knowledge to demonstrate the full potential of the RE sector by showcasing innovations on RE technology and strengthening accessibility to expertise and business support available locally and in other NPA regions.
- To connect with other renewable energy businesses to develop new opportunities locally, regionally and transnationally through the Virtual Energy Ideas Hub.
- By conducting research on the processes operating in the sector to improve understanding of the sector's needs and make the case for public policy to support the sector.

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The Toolkit outlines best practice techniques for assessing biomass resource potentials as a foundation for a biomass resource assessment. Biomass resource assessment is indispensable in estimating the bioenergy potential in a given location, the social and environmental impacts accompanying the resources production and the economic viability of biomass utilization scenarios.

The scope of the Toolkit covers:

- Resource potential - theoretical, technical, economic or implementation potential
- Approaches for estimation of resource potential – (resource focused, demand driven or integrated approach)
- General principles, techniques and methods when undertaking a biomass resource assessment
- Forest biomass and methods for resource assessment
- Energy crops and methods for resource assessment
- Agricultural residues and methods for resource assessment
- Organic waste and methods for resource assessment
- Global and country specific tools to make preliminary resource assessment and how to use them

Types of Biomass Potentials

The classification in types of biomass potentials is the first and most important step when undertaking a biomass resource assessment as it provides insight into explicit conditions, assumptions and limitation made in the assessment. The potential of the resource will define the feasibility of the project, return on investments, environmental considerations, coupled with social and political frameworks.

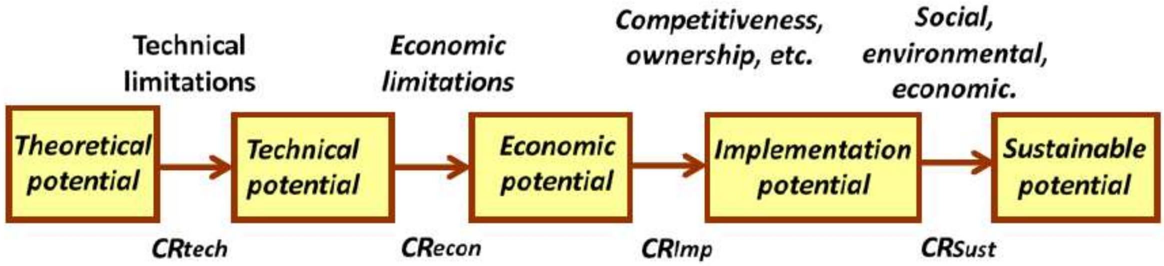

Figure 1. Relation between theoretical, technical, economic, implementation and sustainable potential.[1]

1. Theoretical potential

The theoretical potential of biomass refers to the ultimate resource potential based on calculations of all existing biomass, with no constraints on access or cost-effectiveness.[2] The theoretical potential is expressed in joule (primary energy), as it refers to the energy contained in raw, unprocessed biomass. Afterwards the primary energy is transformed into secondary – electricity, liquid/gaseous fuels, etc. When evaluating the theoretical potential of crops/forests, the maximum yield under a notional optimum running must be considered. However, limitation arising from soil, temperature, solar radiation and rainfall must be taken into consideration when assessing the theoretical potential of crops/forests.

When estimating the theoretical potential of agricultural residues and organic waste, the sum will be equivalent to the total amount produced, with no constraints on access or cost-effectiveness. Whenever theoretical potential is assessed fundamental constraints can be set. For example, when determining the theoretical potential from stemwood, the quantity

[1]https://greengain.eu/platform/feedstock/greengain-biomass-assessment-revealing-hidden-potentials-biomass-landscape-conservation-maintenance-work/
[2] Bioenergy Assessment Toolkit. NREL, 2011.

of wood required for material use is subtracted, as this constraint is considered as fundamental in the forestry sector.[3]

2. Technical potential

The technical potential restricts the theoretical resource potential by taking into consideration elements such as terrain limitations, land use and environmental considerations, collection inefficiencies, and a number of other technical (harvesting techniques, infrastructure and accessibility, processing technique) and social constraints.[4]

- **Location constraints** – include physical challenges of harvesting, gathering and transporting the biomass resources from point of production to the point of end use. The collection and transportation is influenced mainly by distance and terrain (rivers, steep slopes, peatland, etc.). Location limitations have a huge effect of the cost-supply curve for biomass. Distance constraints can be evaluated cartographically by measuring the distance between production site and end users. More detailed terrain constraints may be obtained from detailed cartography data, existing map and/or remote sensing data and analysis. Another option is to conduct a fieldwork where more comprehensive information can be gathered on time required for collecting the biomass resource, distances travelled, when distances start limiting accessibility and terrain limitations.[5]
- **Tenure and land management constraints** – are very country specific and there are three broad categories that can be identified:
  1. Small farms – owned/rented by people from the community and the resources are subject to private property rights.
  2. Communal land – owned by local groups/communities/associations, again subject to private property laws.
  3. Large areas of land – owned/controlled by individual landowners, government/non-government institutions, commercial farms/plantations or state owned land – forest/game reserves.

Tenure constraint mostly affects state land, commercial farming and plantation. If the access to the land is cut off to the local community, information on accessibility should be easily obtainable by the institution controlling the area. However, if the case is that the land is used by different farmers and communities, the task would be more difficult as there will be a lot of people to be contacted before you could start assessing the biomass potential. If detailed analysis is needed, fieldwork could be a useful method for collection of data. [6]

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[3] BEE Best Practices and Methods Handbook 2010.
[4] Ibid 9.
[5] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.
[6] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.

3. Economical potential

To determine the economic potential of biomass, economic limitations are applied to the technical resource potential, resulting in a subcategory of the technical potential, coupled with an evaluation of the cost of biomass resources either at the field or forest edge. The final outcome of this type of assessment is a supply curve (euro/tonne). The economic potential is the portion of the technical potential which meets benchmarks of economic lucrativeness within a given framework of conditions.

4. Implementation potential

The implementation potential is a subcategory of the economic potential, which is defined by a fixed time frame and specific socio/political/economic conditions and limitations. When assessing the feasibility, economic, environmental and/or social impacts of biomass resources, implementation potential should be used.

5. Sustainable Implementation potential

The sustainable implementation potential is the outcome of incorporating social, economic and environmental sustainability conditions in a biomass resource assessment. The three pillars of sustainability are interconnected. The figure below demonstrates some of the key components, links and influences of the three pillars of sustainability.

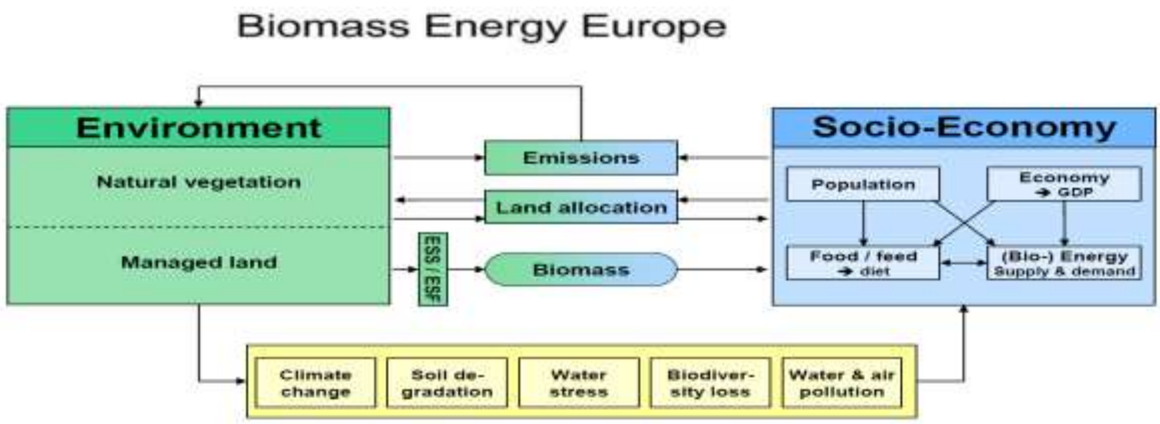

Figure 2. Environmental, social and economic impacts and feedbacks of bioenergy production.[7]

A set of sustainability parameters should be included in every biomass resource assessment in order to decrease the prospective negative impact of bioenergy production. They should

[7] BEE Best Practices and Methods Handbook 2010.

include both direct and indirect effects that might result from bioenergy production. The following list is only an example and it is not exhaustive: [8]

- Environmental sustainability
  - Biodiversity (conservation of land and land management)
  - Climate change
  - Global warming
  - Soil (quality and quantity)
  - Water (quality and quantity)
  - Air quality
  - Forestry
  - Agriculture
  - Resource use (land use efficiency and secondary resources use efficiency)
- Social sustainability
  - Food security (price and supply)
  - Social use of land
  - Labour conditions
- Economic sustainability
  - Bioenergy costs (production and final product)
  - Biomass supply chain
  - Administrative cost (policies, frameworks, etc.)

Taking into consideration sustainability parameters the biomass resource assessment will ensure adherence to the three pillars of sustainable use, renewable and non-renewable resources.

[8] BEE Best Practices and Methods Handbook 2010

Different approaches to biomass resource assessment

The three main approaches to biomass resource assessment are: 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 assessments emphasise the aggregate bioenergy resource base and the competition between different uses of the resource. Demand-driven assessments evaluate the attractiveness of biomass-based electricity and biofuels, or estimate the amount of biomass necessary to meet external targets on climate-neutral energy supply.[9] The integrated approach includes socio-economic drivers and environmental factors.

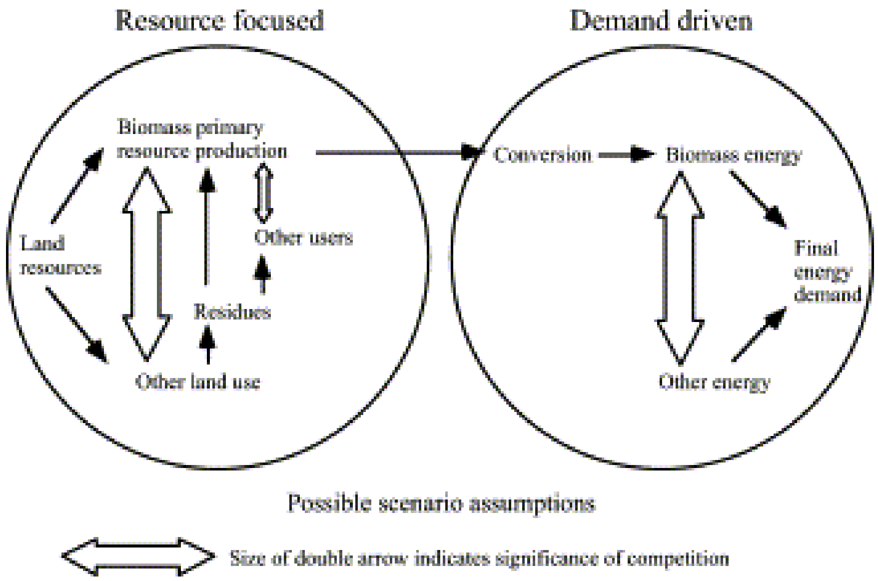

Figure 3. The classification of demand-driven and resource-focused methodologies.[10]

1. Resource focused Approach

The resource focused approach emphasizes the supply of biomass for bioenergy production. A resource-focused assessment evaluates the theoretical and/or technical potential to produce biomass. Thus, its focuses on the demand for food production on land and amount

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[9] G. Berndes, M. Hoogwijk, R. van den Broek The contribution of biomass in the future global energy supply: a review of 17 studies Biomass and Bioenergy, 25 (2003)

[10] BEE Best Practices and Methods Handbook 2010.

of biomass needed to sustain the production. It can also include economic conditions and/or environmental restrictions. Let's take stump extraction for example, it can be in a biodiversity protected area, which would limit the production of biomass, or the cost of extraction could exceed the value. If using the resource-focused approach statistical and spatially explicit methods are important to note[11]:

- **Statistical methods** – are good to be used in combination with a resource focused approach, since they make use of data from statistics gathered through expert services (forest inventories, field studies, literature reviews) on crop yields/production, land use. Furthermore, they can be interlinked with conversion factors, such as residue to crop factors or yields per hectare. In a statistical method, further conditions and limitations could be added – economical, environmental, etc.
- **Spatially explicit methods** – contain data on biomass accessibility in specific locations, such as maps. Area specific data can be on the availability and accessibility of agricultural land and forests, coupled with, calculations of the yields of energy crops and forests, established on growth models that use spatially explicit data (climate, soil type, vegetation type, and management). Spatially explicit methods allow for specific factors to be considered that might affect biomass availability. If static data is available at an in-depth level (municipal, regional, local) they can be transformed and presented in a spatially explicit way. The transportation of biomass can be a fundamental element for assessing the economic viability of a biomass resource. It's vital for the optimisation of biomass production chain good practice to interlink spatially explicit data on availability of biomass with the costs of transportation and location of facilities for conversion of biomass into energy.

2. Demand Driven Approach

The demand driven approach evaluates the competitiveness of a biomass energy system paralleled with fossil fuel based energy systems, renewable energy systems and/or nuclear alternatives. Demand driven approach can also be used when external targets linked with the percentage use of bioenergy required. Therefore, in a demand driven approach the emphasis is on application and economic implementation, rather than technical and theoretical potentials.

If using the demand-driven approach, cost supply methods and energy and/or economic modelling methods are important to note:[12]

- **Cost supply methods** – first step is a bottom-up investigation of the bioenergy potential and associated costs, founded on assumptions on the accessibility of land for energy crop production, including crop yields, forest biomass and forestry

[11] BEE Best Practices and Methods Handbook 2010.
[12] BEE Best Practices and Methods Handbook 2010.

residues. Scenario analysis can be included on other conditions such as technical/environmental constraints, demand of land and biomass. The last step is linking and evaluating the estimates of the cost of other energy systems, with explicit consideration of policy incentives, with the resultant bioenergy cost-supply curves.

- **Energy and/or economic modelling methods** - Energy-economics and energy-system models simulate the underlying forces of the demand and supply of energy, by examining economic and non-economic links. Scenarios are best suited for those models, where the variables are focused on the key influences of energy supply and demand (GDP, population growth, fuel-poverty) along with ever increasing technological advances and ever changing policy incentives. Scenarios can be objective specific, for example reduction of GHG, where different energy systems are compared with a focus on optimising costs towards GHG reductions. A perfect biomass energy scenario should take into competition with other biomass (food, timber, paper, etc.), the other energy markets (oil, gas, coal, other renewables) in order to determine its own economically viable and competitive prices, production and markets.

3. Intergrated Approach

The integrated approach pools data from different sectors (economic, energy, land use, climate, environmental policies, trade patterns etc.) across different time and spatial scales, predominantly by means of scenario analysis. The benefits of the integrated approach over the other approaches/methods are multi-dimensional scenarios, whereby a large variety of assumptions on the different parameters are consistent.

General principles, techniques and methods when undertaking a biomass resource assessment

Establishing the structure of the assessment

Quantifying existing data

It is very important to begin with the collection of data from different resource (national/regional/local data basses, government and NGO's statistics, maps, reports) in order to coordinate, assemble and quantify the available data. Consistent forest statistic data are obtainable from public sources, and different studies. The Food and Agricultural Organization (FAO) is a good place to start as it provides country specific reports on Forest Resource Assessments. However, it is good to bear in mind that they might not reflect reality to the fullest, as statistics mostly reflect commercial applications concerned with the assessment of industrial wood. Most published data does not take into consideration biomass outside forests, dismiss small diameter trees, shrubs and scrub; thus, ignoring large volumes of importance. Accessibility of statistics on these data for wide scales is low and often incorrect due to the methods used in assessments of biomass potentials from trees outside forests.[13]

Determining the methods of assessment

It is crucial to be consistent with measurement and units of biomass while undertaking a resource assessment. Surprisingly, there is no one standard method for measuring biomass used for fuel. There are various techniques for measuring biomass – by volume, weight and in some instances length. In the commercial forestry sector the traditional measure of biomass is by volume; however biomass used fuels is mainly supplied through different shaped biomass (branches, twigs, stalk, etc.) and it is more appropriate to be measured in weight rather than volume. The key element determining the methods of assessment should be the supply–demand dynamics.

Supply and demand analysis

Analysis of both supply available (potential and theoretical), as well as the demand for a production must be carried out. Accurate estimations may be difficult to obtain.

[13] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.

1. Field Surveys – collection of data

Field surveys - are usually costly, time- consuming and multifaceted, so they should be very well structured in order to give a return on the investment. In advance of an official field survey, informal talk with local populations are the preferred method of collecting accurate data, developing a degree of trust and respect, and understanding of social, cultural and economic dynamics. After that it is fundamental to design the survey to ask the right questions by focussing on the essential matters and employing skilled people to undertake it. There are six key questions to be answered if a person has decided to undertake a field survey:[14]

- **What is the aim?** – It is crucial to define the objectives for the biomass assessment and the audience to be addressed.
- **Who is the audience?** – It is recommended to widen the spectrum of the audience, including but not limited to: energy planners, policy makers, regional/local government, community and associations, each of whom will have different insights, which need to be taken into account when conceiving the project idea. Understanding and taking into consideration the audiences' views/opinions/insights will ensure smoothness of the project implementation.
- **How detailed?** – Once the aim of your survey is known and who will be in charge of it, the level of detail for the information can be decided. The first step is to determine the level of detail in the information requirements of the audience chosen to address. The second step is that the data and information must reflect the aims and objectives of the project. It is crucial that the whole process is underpinned by honesty whether or not the audience will agree with the information. The level of detail can be ranging from very general (policy makers) to specific scientific data (project management) and tailored to address diverse audiences.
- **What resources are available?** – The nature of the survey will be determined by the human and financial resources at disposal. The right balance must be struck between what is desirable and what is needed, to make the most efficient use of the available resources and achieve your aims for a value. Time and resources spent on the assessment of a biomass resource should reflect the importance to the end users.
- **Is a field survey necessary?** – Field surveys do produce precise and comprehensive data; however, they usually are costly, time-consuming and multifaceted, particularly in remote areas. A field survey must be undertaken if there are enough resources, no other alternatives (such as existing data, national surveys) and the targeted area is not too large and dispersed.

[14] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.

- **What resources are available?** – Assessment of country/region/locality natural resources - land type, vegetation type, soil composition, water availability and weather patterns.

Remote Sensing – collection of data

While biomass resultants from field data measurements are the most precise, it is not a practical method for broad-scale assessments. This is where Remote Sensing has a strategic advantage. It can deliver data over large areas at a fraction of the cost linked with extensive sampling, allows access to unreachable places and monitoring of areas is repeatedly and consistently done. Data from Remote Sensing satellites are obtainable at different scales, from local to global, from a number of different platforms and in a relatively shorter period compared with other methods of estimating biomass potential. Remote sensing for forestry can analyse and identify location, size, state of degradation and deforestation, fires at forests and plantation areas. There are also different types of remote sensing, such as optical, radar and LiDAR, with each one having certain advantages over the others.[15]

- **Optical Remote Sensing** offers the best alternative to field sampling in biomass assessment, due to its global coverage, repetitiveness and cost-effectiveness. Optical Remote Sensing data is available from a number of platforms, such as IKONOS, Quickbird, Worldview, SPOT, Sentinel, Landsat and MODIS. The spatial resolutions are from less than one metre to hundreds of metres which represent a good opportunity for estimations at any desired scale.
- **Radar Remote Sensing** has achieved a standing for biomass assessment due to its cloud penetration capability and detailed vegetation structural information. While airborne Synthetic Aperture Radar (SAR) systems have been operating for many years, space-borne systems such as Terra-SAR, ALOS and PALSAR have become available since 2000. This has enabled repetitiveness and cost-effectiveness.
- **LiDAR** is a fairly new technology that has the ability to sample the vertical distribution of canopy and ground surfaces, providing comprehensive physical information about the vegetation. This leads to more accurate estimations of basal area, crown size, tree height and stem volume.

Current advances in high resolution space-borne and air-borne satellite data are delivering an opportunity to improve estimates of biomass resources. The use of drones and UAVs has uncovered new roads to refined resolution biomass estimation for targeted uses. Recent sensors, such as the Worldview series, now provide meter level spatial resolution. Furthermore, sensors such as Sentinel and Landsat 8 provide free open data making it accessible to everyone, and data can be used in many different areas, including biomass

[15] Remote Sensing of Above-Ground Biomass. Lalit Kumar and Onisimo Mutanga, 2017.

estimation. Remote sensing is a constantly evolving technology and with new applications and methods being regularly introduced it provides for a novel, cost-effective, timely estimation of biomass resource potentials.

Land use assessment – collection of data

Land use assessment is fundamental in a biomass resource assessment as it determines the actual biomass obtainability. The question in land use assessment is not how much land is physically apt for growing the biomass crop, but on the environmental implications and the competing uses the land may be suitable for. There must be a credible evaluation of the amount of land potentially available for biomass production and the trade-offs involved in using such land for biomass farms.[16] The key objective is to achieve sustainable management of the land resources for the benefit of all affected stakeholders. Land evaluation entails the analysis of data on soils, climate, and vegetation, where the main focus is the land itself with its functions, properties and potential. Whether or not land is appropriate for biomass production depends on the system of production to be employed. Different crops and cultivation systems indicate variances in yields, land requirements, intensity of inputs, and environmental impacts.

Changes in land use over time are very important and need to be taken into account. This can be done by analysing historical remotely sensed data, which is widely available, use of official agricultural data or detailed discussion (survey) with the local population. Changes in land can help understanding the evolution of local biomass resources and assessing future potential and trends of biomass resources. An accurate analysis of agro-cultural climate zones is required if a comprehensive biomass assessment is to be carried out. Biomass yield is dependent on different types/species, agro-climatic region, rainfall, management techniques for biomass production.

Land use assessments is carried out in three steps[17] [18]

- **Step I - Inventory of land utilization types and their ecological requirements**

    1. **Selection of Land Utilization Types (LUT)** - A variety of LUTs should be carefully chosen to mirror current land use and/or land use under an anticipated enhanced condition.
    2. **Compile crop climatic adaptability inventory** - inventory of LUTs requirements in relative to the climatic, soil and landform environments required for the component crops and for the management system. A crop climatic inventory is

[16] Land Use Issues in Biomass Energy Planning, Gerald G. Marten, Resource Policy 8: 65-74. 1982
[17] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.
[18] Agro-ecological Zoning: Guidelines, Issue 73

compiled based on crop phenological requirements, thermal ranges and photosynthetic characteristics.

3. **Compile crop edaphic adaptability inventory** - The agricultural utilization of the climatic potential of crops is contingent on the properties of soil and management of soil. Limitations imposed by landform or by other features of the land surface, such as predisposition to flooding, must also be taken into account.

- **Step II - Compile land resource inventory** - based on merging various layers of data to define agro-ecological cells (AECs) with a unique combination of climate, soil and other related land attributes. Such overlay techniques are most conveniently carried out in a GIS environment. However, alternative methods can be used if a GIS is not available.

1. **Analyse length of growing period (LGP)** - The growing period is the period of the year when both moisture and temperature conditions are favourable for crop growth.
2. **Define thermal zones** -Thermal zones refer to the temperature regime accessible for crop growth during the growing period. They are usually defined based on ranges of mean temperature.
3. **Inventory of climatic resources** - plot the individual station data of temperature, LGP-pattern and mean total dominant LGP derived and construct boundaries of thermal zones, LGP pattern zones, growing period zones and isolines of mean total dominant LGPs. In addition to normal extrapolation techniques, extensive use is frequently made of Landsat images, climatic maps, vegetation maps, land-use maps, topographic maps, and soil maps to guide the delineation of boundaries and isolines. If a GIS is used, the inventory maps should be subsequently digitized. Given the necessary base maps, point data and knowledge on the interpolation of climatic variables between these points, the user can prepare climatic maps in the GIS environment.
4. **Compile soil resources inventory** - derived from existing soil maps, legends and reports. National soil maps at a scale of 1:1000000 or larger are sources from which the required input data can be derived. At more detailed levels of investigation, provincial soil maps may be used or additional data may have to be collected.
5. **Compile present land use inventory** - Compile land resources inventory where overlaying of thermal zones, LGP zones and soil resources inventories. Supplementary information on administrative boundaries, land use and other constraints, such as tsetse fly incidence, may also be overlaid. The output of this procedure is a number of agro-ecological cells. For the overlay of such big amounts of data a GIS is recommended. If a GIS is not accessible, it is possible to allocate data from one inventory to mapping units defined in a separate inventory and to

use the boundaries of these mapping units as the sole spatial framework for the land resource inventory.

- **Step 3 – Assess land suitability** [19]

1. **Agro – climatic suitability and agronomical attainable yields** - inventory of land utilization types and their ecological requirements
   - Matching the features of the temperature regime to the requirements for photosynthesis and phenology of the different crops groups, determining which crops qualify for additional assessment. Evaluation of the temperature necessities of individual crops with the identified thermal zones of the climatic resource inventory allows for a screening exercise which excludes unsuitable crops.
   - Computation of constraint free yields of all qualifying crops, taking into consideration the predominant temperature and radiation.
   - Computation of agronomically achievable yield by appraising yield drops due to agro-climatic restraints, such as moisture, pests and diseases and taking into account the suitability of each crop in each length of the growing period.
2. **Assessment of agro-edaphic suitability** - definition and mapping of agro-ecological zones based on inventories of land resources (including climate, landform and soils)
   - Comparison of the soil requirements of crops with soil conditions of the land
   - Modifications are inferred by limitations imposed by slope, soil texture and soil phase conditions
3. **The results of the land suitability assessment** - a set of land suitability classes for crops grown on different land units or AECs with specified level of inputs. Each land suitability class for each crop under each input level reflects a range of anticipated yields. Knowing the area of each AEC or land unit, estimates of production can be drawn up for more broadly defined agro-ecological zones, or provided administrative boundaries can be related to AEC or land unit boundaries, by province or district.[20]

The figure below illustrates the relationship of these activities and their component procedures.

[19] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.
[20] Agro-ecological Zoning: Guidelines, Issue 73

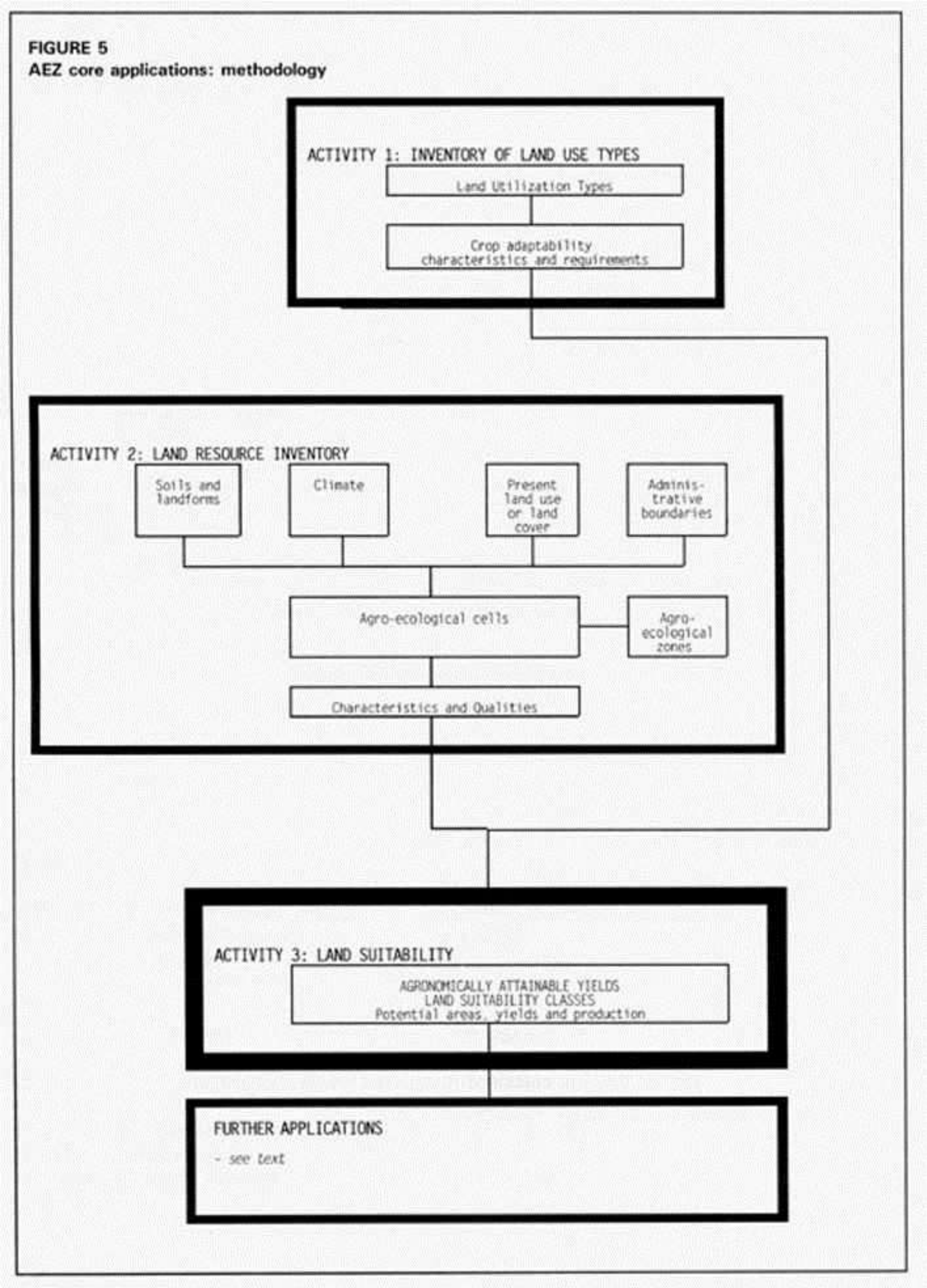


Figure 4. [21]

[21] http://www.fao.org/docrep/w2962e/w2962e-04.htm

Estimating biomass flows – collection of data

A long-lasting objective in data collection is to produce a complete biomass flow diagram for the locality/region/country level. A flow diagram traces biomass resources from production to end use and below you can see a sample flow chart illustrating it.

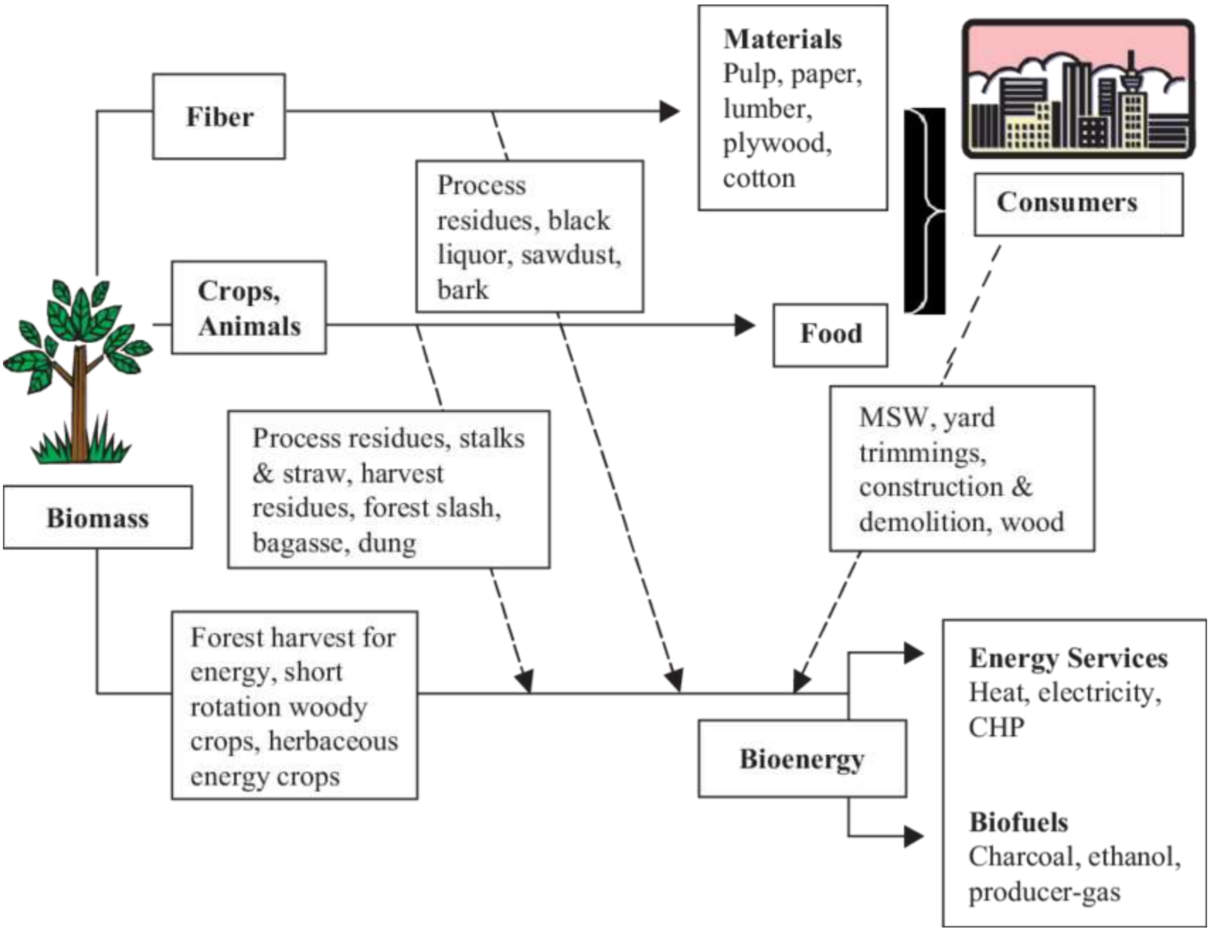


Figure 5. Biomass and bioenergy flow chart [22]

A biomass flow chart ideally should incorporate all form of production (forestry, agriculture, etc.), allow for losses during conversion and provide details of its end uses. In order to be able to create one, data has to be gathered methodically, beginning with aggregate date and working your way down to details. In order for a flow diagram to be precise, there is a requirement for meticulous investigation of biomass supply and consumption. It is worthwhile creating a biomass flow chart, as it a very easy, visual and convenient way of presenting data, while at the same time, it allows an easy means of monitoring alterations in the production and use of biomass resources. [23]

[22] Energy situation and renewables in Turkey and environmental effects of energy use, 2008.
[23] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007.

Biomass charactersticss

Stock and Yield - for the assessment of any biomass resource it is required to measure both stock and yield. Looking at biomass as a renewable energy resource, the annual production and increment is a key factor, as stock become depleted, if the amount of harvested biomass is greater than the increment.[24]

- **Stock** – total weight of biomass as dry matter, for animal's stock if the number of animals is by species.
- **Yield** – increase of biomass in a specific area for a certain period of time, where all biomass removed is included in the calculation. There are 2 ways:
  - Current annual increment **(CAI)** - the total biomass produced for a year. For annual plants this is the total yield for the year. For perennials the CAI will differ according to the season and growing conditions. Thus, for perennials a mean figure has to be calculated every year in the same season.
  - Mean annual increment **(MAI)** – total biomass produced for a certain area divided by the number of years taken to produce it.

When the stock and yield are determined and quantity of biomass is known, next step is to define its energy value which is contingent on the moisture and ash content.

Moisture content (MC) – when burning biomass, part of the energy is used to turn the water that biomass contains into steam; thus, the drier the biomass, the more energy efficient. The moisture content determines the energy value of biomass. Despite woody biomass having higher energy value per se, some agricultural crop or waste might have much lower moisture content; therefore, higher energy value. The energy value of a unit weight of biomass is inversely proportional to the moisture content. In order to get accurate measure of biomass, moisture content must be calculated. There are two ways of calculating moisture content:

- **Dry basis** - the % moisture in the wood is expressed as a percentage of the dry weight of wood. This method is the standard method used to express moisture content for solid wood products. MC% = (weight of water / dry weight of wood) x 100
- **Wet basis** - the percent moisture in the wood is expressed as a percentage of the TOTAL weight of the wood, including both the dry wood material and the water. This method is most commonly used for pulp chips and hogged fuel and this method is generally the method used to determine the MC of woody biomass.
  MC% = (weight of water / weight of water + dry weight of wood) x 100

[24] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007

For example an air-dry wood (15 % MC) has an energy value around 16.00 MJ/kg, while a green wood (100% MC) has energy value of 8.2/kg, proving that removal of MC can double the energy value. The figure below shows the relationship between moisture content and heating value illustrates the correlation between energy and moisture contents. Increased moisture means less energy obtainable.

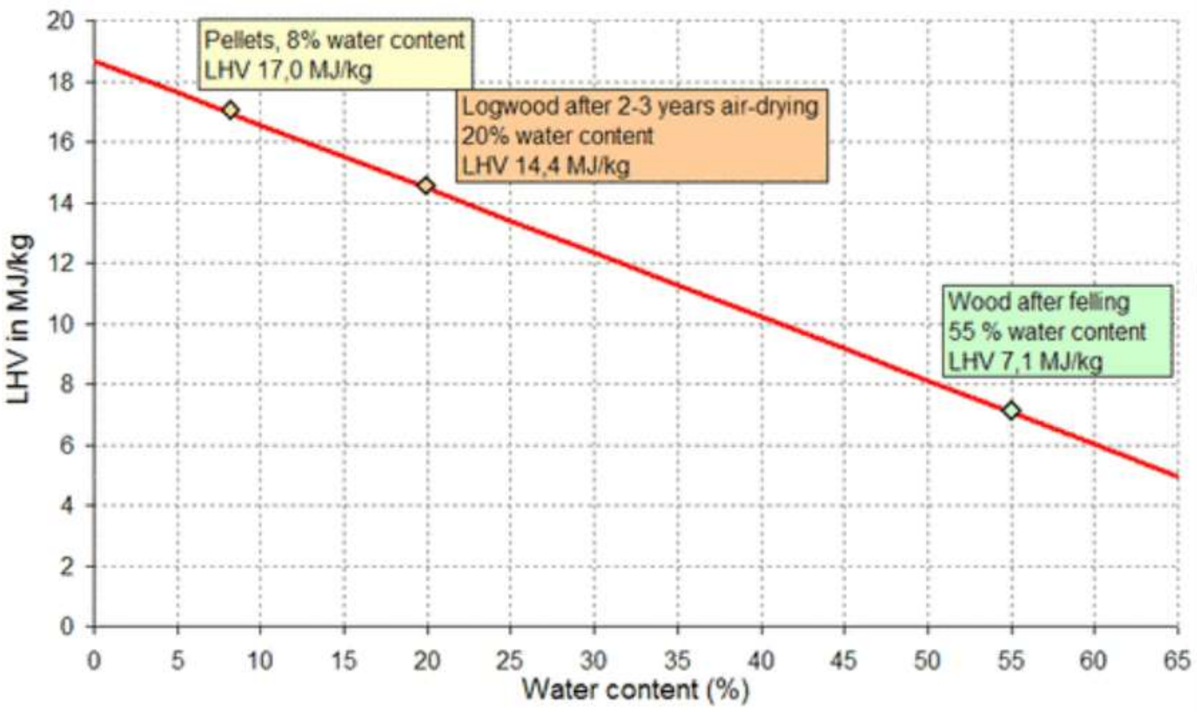


Figure 6. Typical LHV as a function of moisture % content.

- **Ash content** – the higher the ash content the lower the energy value. The ash content is a measure of the mineral content and other inorganic matter in biomass and is used in conjunction with other procedures to determine to total composition of biomass samples. In biomass fuels, the ash content may originate from the biomass itself (materials that the plant absorbed from the water or the soil during its growth,) or from the supply chain (soil collected along with biomass). Structural ash is inorganic material that is bound in the physical structure of the biomass, while extractable ash is inorganic material that can be removed by washing or extracting the material. In any case, after the assembly of a sample the ash content is typically measured by combusting the biomass at a laboratory furnace under controlled conditions. Generally, the ash content of herbaceous biomass is higher than that of woody biomass. While ash weight content (in dry basis) values of less than 1% are expected for wood, different herbaceous biomass types have reported values ranging from less than 2% up to 10% or even up to 25% for rice husks. In waste fractions, the ash content may often be as high as 30-50%

and is only scarcely less than 10%.[25] Ash contents should be compared between biomass samples with the same MC.

Energy value of biomass – The quantity of heat produced per unit mass of the fuel is referred to as the calorific value of the fuel. Different definitions can be used to quantify the calorific heat value of the fuel[26]:

- **Gross calorific value (GCV)** – total energy released through combustion divided by the weight of the fuel. Heat released during combustion per unit mass of fuel, assuming that any water produced during the combustion process is a liquid (any steam produced is condensed to release some further energy). [27]

  Formula:

  $GCV = 0.13491.X_c + 1.1783.X_h + 0.1005.X_s - 0.0151.X_n - 0.1034.X_o - 0.0211.X_{ash}$ [MJ/kg,d.b]

  Where:

  X_c = %wt carbon content (dry basis)

  X_h = %wt hydrogen content (dry basis)

  X_s = %wt sulphur content (dry basis)

  X_n = %wt nitrogen (dry basis)

  X_o = %wt oxygen (dry basis)

  X_{ash} = %wt ash content (dry basis)

- **Net calorific value (NCV)**, a.k.a. low heating value - energy that available for combustion after allowing for energy losses from water evaporation. Heat released during combustion per unit mass of the fuel, assuming that any water produced during the combustion process is steam (this assumes that some energy is used to produce the steam)

  Formula:

  $NCV = GCV \times (1 - (W/100)) - 2.477 \times (W/100) - 2.447 \times (H/100) \times 9.01 \times (1 - (W/100))$

  Where

  NCV = net calorific value (MJ/kg wet basis)

  GCV = gross calorific value (MJ/kg dry basis; for wood usually 20 MJ per oven dry kg)

  W = moisture content of the fuel in wt% (wet basis)

  H = concentration of hydrogen; exmp. Wood biomass fuels (6.00%wt dry basis); herbaceous biomass fuels (5.5%wt dry basis)

For example the difference in petroleum between GCV and NCV rarely would be more than 10%, which however cannot be said for a wide range of moisture content of biomass

[25] The Bioenergy System Planners Handbook – BISYPLAN.

[26] www.rewardinglearning.org.uk/common/includes/microsite_doc_link.aspx?docid.

[27] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007

resources, where differences can be huge. The energy content depends mainly on the water and hydrogen contents.

Weight vs Volume – forest industries use volume as a measure, while biomass fuels are measured in volume. Woody biomass, especially fuelwood, production and consumption are measured by volume. However, it is important to note that the heating value must be measured as a weight, because estimates can be obtained directly from measurements of tree dimensions. Biomass for energy should always be measured by weight. [28]

- Conversion of volume to weight: weight (kg) = volume (m^3) x density (kg/m^3). Density is the density of biomass as it was received, so in order to calculate energy content moisture % needs to be known. Green wood would be normally around 50% moisture; while air dried wood would be around 15%.
- Density: specific gravity is the relative weight per unit volume of a substance when compared to water. Actual density is measure in units of kg per m^3 or g per litre. As volume is influenced by temperature, specific gravity data should be measure under standard room temperature and pressure or stated conditions. Physical state of biomass is important when determining density (stacked wood, chipped wood, pellets, baled straw, etc.). Standard density usually refers to solid biomass volume, estimated by measuring the air voids in a wood stack.

[28] [28] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007

Forest Biomass and methods for assessment

Forest biomass

Below is a map showing the productive forest potential in relation to the total area of the country. Biomass is the world's fourth largest energy source, contributing to nearly 14% of the world's primary energy demand.

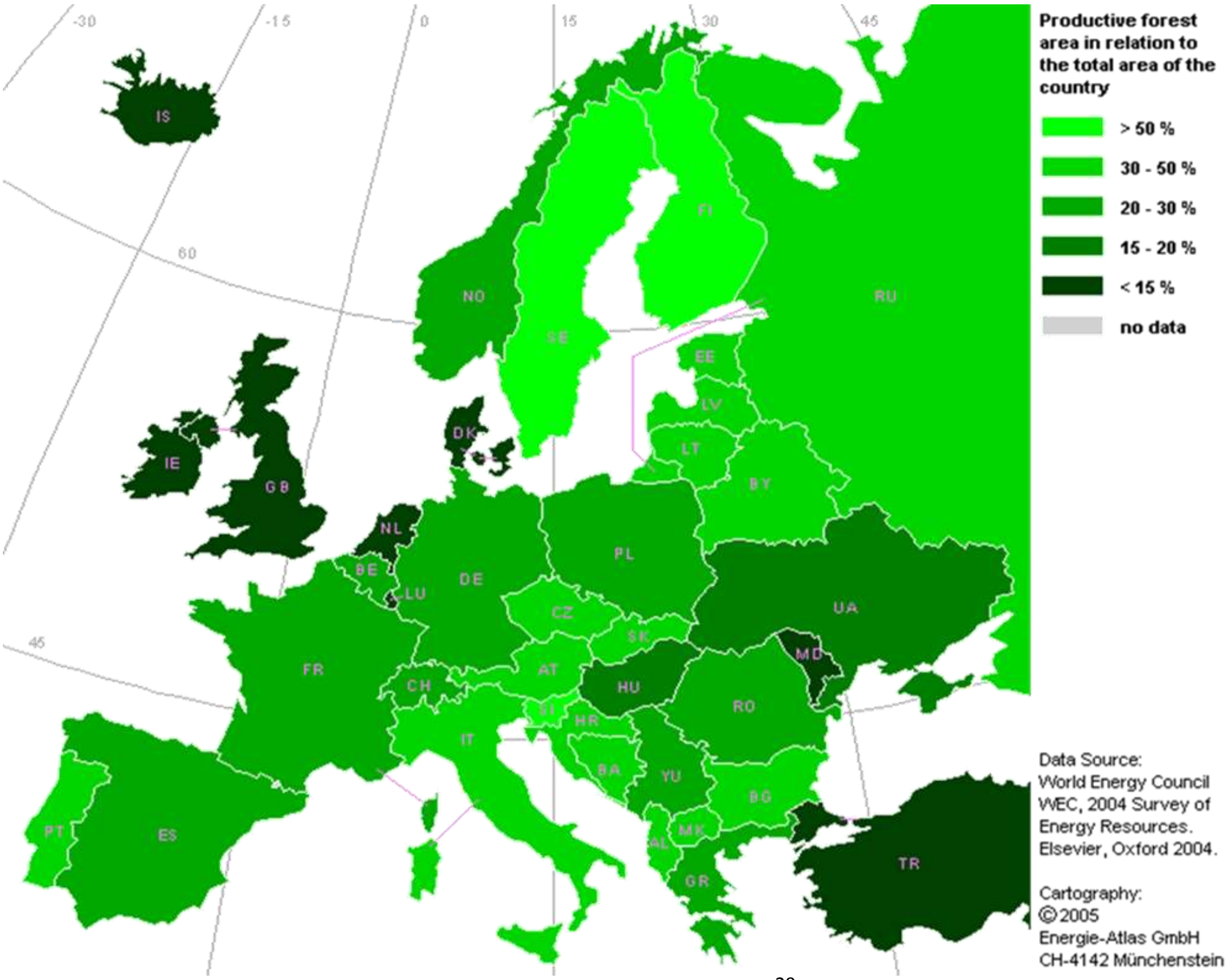


Figure7. Productive forest area in relation to the total area of the country.[29]

[29]http://www.geni.org/globalenergy/library/renewable-energy-resources/world/europe/bio-europe/indexbig.shtml

In the context of bioenergy, forest biomass consists of a number of categories of raw woody materials derived from forests or from processing of timber:

- **Stemwood**: the woody material forming the above ground main growing shoot(s) of a tree or stand of trees. The stem is defined as including all woody volume above ground with a diameter greater than 7 cm over bark.[30] Stemwood is the principal product derived from forests, harvested for material and energy use. The quality of and demand for stemwood are the key factors determining upcoming consumption of wood.
- **Primary forestry residues**: comprises of logging residues (branches, tree tops and leaves or needles), and stumps. Logging residues are very specific because of their low volume per hectare in comparison to stemwood. Recovery rate of logging residues is contingent on local conditions and skills of forest workers. The technical potential of stumps is determined by the general recovery rate consequential from harvesting techniques and the numerous reduction factors for different sustainability criteria decreasing the theoretical potential.
- **Secondary forestry residues**: wood processing industry by-products and residues, like sawdust & cutter chips, bark, slabs, lump wood residues, and black liquor. Secondary forestry residues are a spatially concentrated source – large amounts of the residues can be obtainable from a single factory. Compared to other types of forest woody biomass, all secondary forestry residues are technically accessible. Secondary solid forestry residues typically have lower moisture content than primary forestry residues and; thus, a higher net calorific value. These features considerably assist assembly and the energy use of secondary forestry residues.
- **Woody biomass:** from short rotation plantations on forest lands. [31]

There is a difference between the total potential of wood available as an 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[32]:

$TP\_FWB_{x,y} = TP\_SW_{x,y} + TP\_PFR_{x,y} + TP\ SFR_{x,y}$

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)

TP_PFR x, y = potential of primary forestry residues in country x in year y, (m^3/year)

TP_SFR x, y = potential of secondary forestry residues in country x in year y, (m^3/year)

[30] T.A.R. Jenkins, R.W. Matthews, E.D. Mackie and L. Halsall 2012

[31] BEE Best Practices and Methods Handbook 2010.

[32] Ibid 28

Initial Questions for formulating an assessment strategy [33]

- What type of woody vegetation is present in the chosen area?
    - Planted/natural forest – what are the predominant species?
    - Open woodland
    - Trees outside the planted/natural forest – around the area, in public place
- What is the condition of the vegetation?
    - Well sustained/unkempt
    - Signs of heavy cutting
    - Natural restoration
    - Trimming, pollarding
    - Dead wood collection
    - Litter
    - Erosion
    - Fresh stumps
- Are there any movement/trading of tree products?
    - People transporting woody products or selling them?
    - Heaps of wood around
- Are there any activities for processing/utilization of woody biomass?
    - Sawing/splitting
    - Building
    - Fencing
    - Feeding of farm animals
  - Are there any actions linked to tree management/regeneration?
  - Pruning, clipping, thinning, coppicing, clearing
  - Newly planted trees/young trees
  - Tree nurseries

Wood is mainly grown for other purposes, different from fuel, as they have much higher market value. On the other hand, when trees are produced for other purposes they would only take logs with specific dimension, which means that considerable waste is left behind amounting between 15 – 30% of the above-ground volume. All these are potentially a fuel and should be included in the assessment.

Projecting supply and demand – there are various methods for achieving projections

- **Constant trend-based projections** – assumptions are that demand and consumption go hand in hand with population growth. This useful method to identify resource issues brings demand and supply into a sustainable balance. Nonetheless, with

[33] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007

wood resource decline, cost increase and consumption will have to be reduced and/or substituted with other fuels.

- **Projections with adjusted demand** – the method is beneficial for evaluating demand reductions in per capita and effect of declining wood resource.
- **Projections with increased supplies** – supply can be increased with a range of methods as better use of wastes, forest management, planting etc. The quantity of excess can be estimated by measuring the gap between projected demand and supply. Thus, a plan can be put in place for the additional supplies.
- **Projections including agricultural land** – The grazing and arable land, coupled with commercial forestry, can result in major tree loss. Rather than clearing a land by felling/burning, the wood could be used for fuel and pressure on existing forest stocks can be relieved.
- **Projections including farm trees** – those trees accessible by local consumers with many different uses (shelter, fuel, forage, timber) should also be included in supply and demand projections.

Measuring fuelwood resources and supplies – when evaluating total/actual/potential wood supply, a distinction should be made between standing stocks (what is actually available) and resource flows (rate of wood growth (yield)). Other important circumstances that need to be taken account of when making an energy assessment are: potential competing uses of the wood supply, the actual amount of stock and yield actually obtainable for production due to physical/economical/environmental reasons, amount of yield that can be cut on sustainable basis and amount of wood actually recovered. [34]

- **Estimating stock inventories** – The first step in estimating standing stock of trees is a remote sensing to establish the areas of tree coverage by categories. The next step is merging the data from the remote sensing with the survey and mensuration data. Appraisal of biomass availability will be fairly accurate.
- **Estimating supplies** – Estimation of the amount of wood obtainable from natural forests could be made by depleting the stock and by sustainable harvesting. The technique includes multiplication by the means of which stock and yield quantities are adjusted by loss and accessibility factors.

Forest mensuration[35]

Mensuration stands for the measurement of mass, length and time of forest wood, integrating methods and techniques used by foresters, land surveyors and cartographers. There are many different practices but the parameters are common.

[34] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007
[35] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007

- **Individual tree parameters**
  - Age
  - Diameter of stem (over or under bark)
  - Cross-sectional data (calculated from the above)
  - Length/height
  - Form/shape
  - Taper (rate of change of diameter with length)
  - Volume (over or under the bark)
  - Crown width
  - Wood density
- **Further parameter for forests, woodlands, plantations**, etc.
  - Area – surveyed or estimated by maps/remote sensing
  - Crop structure – age, species, diameter, etc.
  - Total basal area per hectare
  - Total biomass, dry weight per hectare
  - Total energy resource per hectare
- **If the case of a plantation/forest is uniform in terms of species and age, further parameters are** :
  - Average volume per tree
  - Average stem basal area per tree
  - Diameter of tree of average basal area
  - Average height per tree

Comprehensive mensuration data is usually obtainable for very few species, which are commonly cultivated. In the case where data is available it is possible to estimate the biomass resource in a plantation with land use data and biomass table for volume and height of species (rarely available). Presently there is not enough data available for the creation of such tables, however, once the information is in place, surveys could be carried out quite quickly.

Determining the weight of trees[36]

Weight of trees can be measured by many different indicators by using measurements of stem diameter/circumference/basal area, tree crown dimensions, etc. However, given the very diverse nature of trees, comparison between species is challenging. The commercial world is interested in stem volumes and nothing else. Branches, roots, twigs could be a big source of fuel, having in mind they make up over 50% of the tree. When evaluating the biomass resource for energy purposes, calculation should include branches, roots, leaves, twigs. Tree roots can amount to 30-40% of total woody biomass production, however, unless there is a severe deficiency of wood, they are not used for fuel.

[36] The Biomass Resource Assessment Handbook, Frank Rosillo-Calle, 2007

Destructive sampling allows for measurement of those often neglected parts of the tree, by taking samples (leafs, branches, tem, roots volume/weight) for the dominant species in a forest/plantation and estimate the available biomass per unit area. The easiest way to measure the weight of trees is regression between stem basal area and tree weight. This method entails two measurement of the dimeter of each stem. Equipment is easily obtainable and straightforward – callipers, scales, drying apparatus. Sampling is as important as actual measurement. To obtain weight measurements, sample of trees needs to be felled and measurement of green, air-dry and oven-dry density need to be obtained.

Methods for measuring the volume of trees

The parameters needed for the measurement of the volume of a tree are:

- Diameter at breast height (DBH)-
- Total height and crown measurement (diameter + depth) to estimate individual tree volumes
- Mean height
- Basal area at breast height
- Mean crown measurements

Measurement of a single tree

- **Tree Diameter** - the diameter of forest trees is measured in cm at 1.3 m above the ground and is termed the "Diameter at Breast Height" (DBH). Because trees are measured with the bark on this is also called the Diameter at Breast Height Over Bark (DBHOB). When assessing live trees most information is presented as Over Bark proportions. To estimate the depth of the bark (by cutting through the bark to the wood or observing the bark of recently felled trees) and converting DBHOB to the Diameter at Breast Height Under Bark (DBHUB). Trees with a DBH of less than 7 cm are assumed to have no volume and are conventionally classified as 'unmeasurable'.
  DBHUB = DBHOB - (Bark Thickness x 2)
  - **How to measure DBH** - to measure DBH first of all define where "breast height" or 1.3m is on you. Then, wrap the tape around the tree at that height and read the diameter from where the diameter scale starts. Obviously the tape can be used to measure diameter at any point on a tree or log.
- **The height** of young trees (up to 6 metres) is easy to measure with a height-measuring pole or a simple plastic plumbing pipe marked at 0.1 metre intervals. But as trees grow, measuring their heights becomes increasingly difficult. An inexpensive method is MTG tape. The technique: one person, with the tape, stands well back from the tree at a point approximately equal to the height of the tree. The second person stands at the base of the tree. Holding a section of the MTG tape vertically out in front of themselves the first

person moves tape so that the “0” point on the yellow side corresponds to the base of the tree they can then measure the apparent height to the top and calculate 10% of the apparent height. The second person moves their hand up or down the stem to mark a point that corresponds to 10% of the total “apparent” height. Clearly this will correspond to 10% of the total tree height. The first person then returns to the tree and measures the height from the base to the second person’s mark. The total tree height is simply this height multiplied by 10.

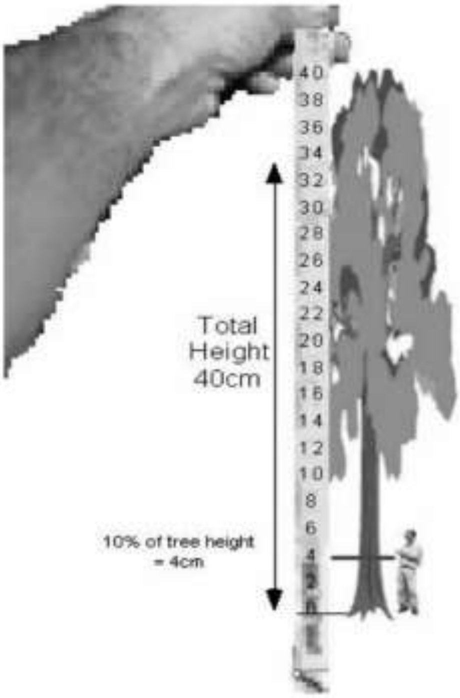
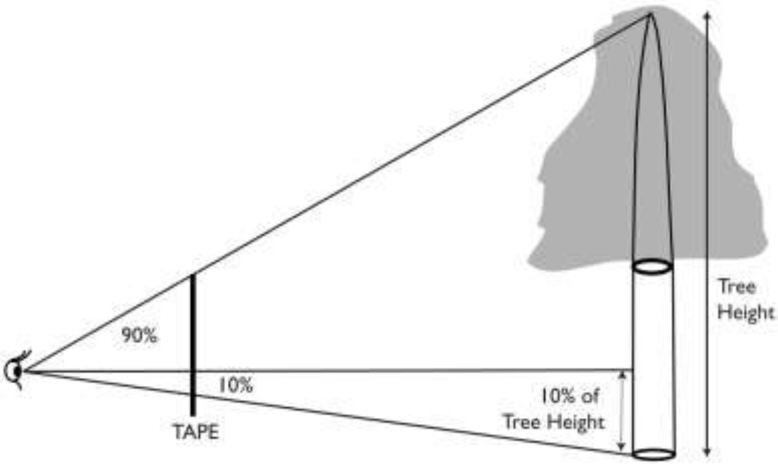


Fig.8. Measuring tree height with the tape. The tree “appears” to be 40cm tall. 10% of 40cm is 4cm. The 2nd person is told to mark the point corresponding to 4cm on the tape. If the distance from the ground to the mark on the tree is 1.4m then the tree is 14m tall.[37]



[37] http://www2.geog.ucl.ac.uk/~mdisney/fieldwork/misc/tree_measurement.pdf

Fig.9 How it works.[38]

- **Tree Basal Area (TBA)** - is the cross-sectional area (over the bark) at breast height (1.3m above the ground) measured in m^2. To define the TBA measure the diameter at breast height in cm (DBHOB) and calculate the basal area (m^2) using the following equation which is simply adapted from the simple formula for the area of a circle (area = πr^2).
  - Formula - TBA = $(DBH/200)^2 \times 3.142\ m^2$
- Total tree volume - By means of a measure of DBH and Ht an estimation of total tree volume can be made by assuming the tree has a particular form: Tree volume (m^3) = TBA x Ht^3 / 3. Please see the figure below for further understanding.

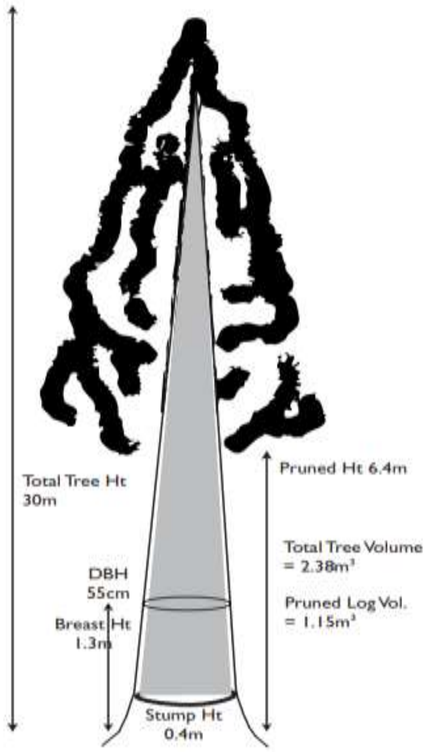


Fig10. Assuming the tree is conical the total tree and pruned log volumes can be estimated using the Basal Area and the formula for a cone.[39]

Another option - The total height of young standing trees can be measured with graduated poles. The total height of other standing trees should be measured with a manual or electronic hypsometer or clinometer, and the instructions supplied with the instrument should be followed. Each tree should ideally be measured from two opposite sides, and the measurements averaged. The distance of the observation points from the tree should be in the region of 1 to 1.5 times the height of the tree. When measuring the heights of trees it is important to remember that accurate use of hypsometers or clinometers requires training, checking, and, most of all, practice.

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[38] http://www2.geog.ucl.ac.uk/~mdisney/fieldwork/misc/tree_measurement.pdf
[39] http://www2.geog.ucl.ac.uk/~mdisney/fieldwork/misc/tree_measurement.pdf

Measurement of a forest/plantation[40]

Using sampling techniques can enable you to reach a good estimate of stocking rate, stand basal area and log volumes by measuring as few as 2 % of the trees in the forest.

- **Classification the Forest** - Develop a map of the area which shows the type of forest, age and past/current management. If growth is altered by topography or soil types these should also be noted on the map. Examine the forest and make a decision as to the different forest blocks. If tree management, performance, provenance, age, soil types or environment are evidently different in parts they should be treated as separate sections on the map. This is important so an accurate representation of the stand's growth can be estimated.
- **Estimating the area** - use a large-scale aerial photograph (1:10,000) and calculate the area using a dot grid/planimeter. Many graphical computer programs can define areas of sporadically shaped polygons drawn over scanned photographs or maps. Extra features such as roads, power lines, water courses, soil types should be also noted on the map.
- **Plot samples** - Measuring trees can be a prolonged and expensive process, therefore only a sample of trees within a stand are measured to deliver an approximation of the stand's growth. A minimum of 3 plots should be established in any section of the forest. For very large uniform forests the total area of all the plots should represent more than 2% of the total forest area.
  - Plot size - between 15 and 30 trees per sample plot is required (12 being the absolute minimum) therefore plot size will depend on stand stocking rates.
  - Calculating Plot area:
    - Rectangular Plots: Plot area (m^2) = Length (m) x Width (m)
    - Circular Plots: Plot area (m^2) = $[\text{Radius (m)}]^2$ x 3.142
- **A plot sheet** - is used to document the data collected. It is valuable to add remarks about the plot/individual trees that may help construe the gathered data. Remarks may include - location of the plot, any unusual features, etc. Once sample plots have been established, trees need to be measured in a systematic way across all plots in the stand. The system illustrated for rectangular and circular plots allows trees to be easily referenced during the measurement exercise.

[40] http://www2.geog.ucl.ac.uk/~mdisney/fieldwork/misc/tree_measurement.pdf

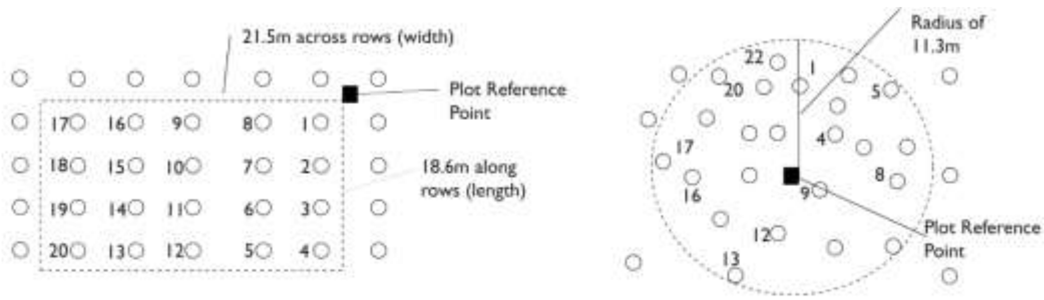

Figure 11 Referencing plots.

- **Plot Measurements**[41]
  - **Stocking rate** - the density/stocking rate of a forest is described as the number of trees per hectare. Calculate as follows:
    Stocking Rate (stems/ha) = Trees in plot / Plot area (ha)
  - **Tree dimensions** - the diameter of every tree in the forest is measured as defined earlier.
  - **Stand height** - Measuring the heights of trees can be challenging and time consuming. In a native forest or plantation, heights of the trees tend to be uniform, so a sample can be selected from every plot. The best choices are the fattest trees of good form - “Mean Dominant Height”.
    - **Mean Dominant Height**- to estimate it select the 3 fattest trees (largest DBH) of good form in each plot and measure their height. The average height of these trees is defined as the Mean Dominant Height for the plot. Where there are more than one species or age class it will be necessary to determine a Mean Dominant Height for each.
  - **Stand Basal Area (SBA)** - the basal area of all the trees at breast height per hectare of forest or plantation (m^2 /ha). SBA can be employed to estimate stand volume. Measuring SBA:
    - Sum of tree basal areas - measure all tree diameters in a plot, calculate individual tree Basal Areas and add these up.
      Basal Area of a tree (m^2) = $(\text{Diameter (cm)}/200)^2 \times \pi$)
      Stand Basal Area (m^2 /ha) = (Sum of the basal area of each tree in the plot) / (area of the plot (ha))
- **Volume Calculations**
  - In plantations/forest with uniform trees a quick estimate of total volume can be made from the SBA = Stand Basal Area (m^2 /ha) and DTH = Dominant Tree Height (m)
    Standing Volume (m^3/ha) = SBA x HT / 3
    Standing Volume (m^3 /ha) = Plot Volume (m^3 /ha) / Plot Area (ha)

41

   - Estimate the crown wood volume from stem volume - where a number of trees are felled to establish ratio of wood in the stem to that in the crown:

     V = G x H x F

     Where:

     G – mean basal area per hectare

     H – mean height

     F – mean reduction factor (allows for the taper on the tree, can range from 0.3 -0.7 and has to be calculated from felling a number of trees and measuring individual logs)

- **Mean Annual Increment (MAI) & Current Annual Increment (CAI)** – biomass production depends on the quality of growing site, rainfall, species, planting, density, rotation age, etc. If there is uniformity across the plantation/forest – trees of the same age and species you can obtain the MAI and CAI:
   - **MAI** – volume increased per tree for a stated number of years, the average volume production per year for a forest

     MAI m^3 /ha/yr = Volume of stand (m^3 /ha)/ Age of Stand (yrs)
   - **CAI -** is the increase in volume at a particular age and is determined by annual measurements of standing volume.

     Example: Current Annual Increment at age 2 (m^3 /ha/yr) (CAI) = (Volume at age 3) - (Volume at age 2)

In compact plantations the CAI will upsurge rapidly in the early years up until competition and limiting light, moisture or nutrients mean that CAI reaches its peak. The decline in CAI can be more rapid than the early rise. In a mature native forest the CAI is often close to zero meaning there is no change in the total wood volume on the site from year to year - for some trees to grow others must die. When the CAI drops to the point that it is the same as the MAI then MAI must fall too since the increase in the next year will be less than the average. Whenever a MAI or CAI figure is quoted the age of the forest must also be known.

For methods statistical methods (basic and advanced), spatially explicit methods (basic and advanced) and cost-supply methods for resource assessment of stemwood, primary forestry residues, secondary forestry residues and woody biomass, including their advantages and disadvantages please visit: http://www.eu-bee.eu/defaulta721.html?SivuID=24158

Energy crops and methods for assessment

Energy Crops

An energy crop is a crop grown explicitly for its energy worth.

Five main types of energy crops can be distinguished, and are further classified as annual (a) and perennial (p) crops[42]:

- **Oil containing crops**: sunflower (a), rape (a), soy (a), oil palm (p), and jatropha (p).
- **Sugar crops**: sugar cane (p), sugar beet (a), and sweet sorghum (a).
- **Starch crops**: corn (a), wheat (a), barley (a), and cassava (a).
- **Woody crops**: poplar (p), and eucalyptus (p).
- **Grassy crops**: miscanthus (p), and switchgrass (p).

However, as shown in the figure below, environmental considerations have to be taken into account when deciding on the mix of energy crops.

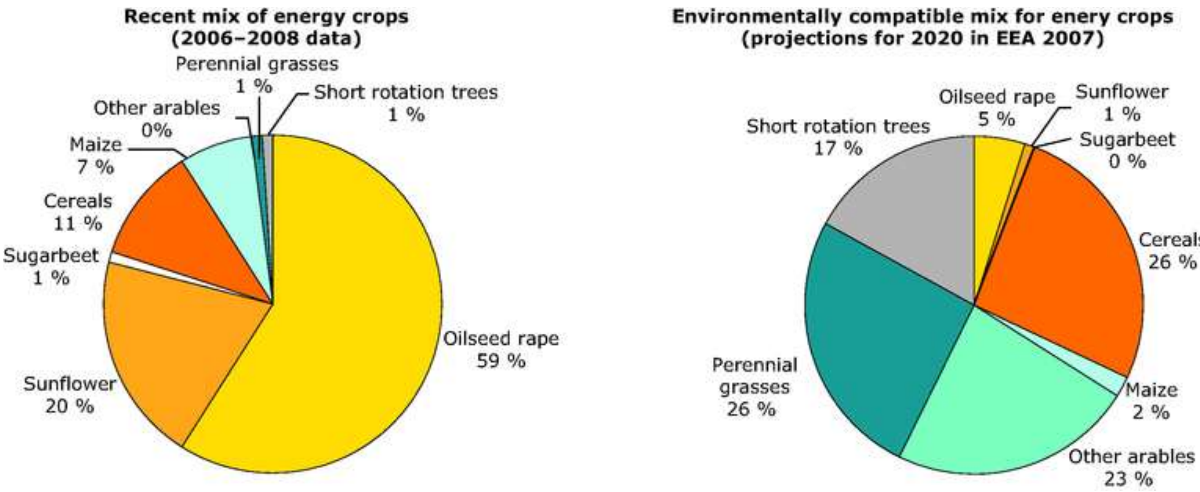

Figure 12. The 'environmentally compatible' energy cropping data and scenario developed by the EEA for 2020.[43]

[42] BEE Best Practices and Methods Handbook 2010.
[43] https://www.eea.europa.eu/data-and-maps/figures/mix-of-energy-crops-200620132008

Areas where energy crops can be produced sustainably in this sense will be within two broad groups:

- Land that is used currently to produce agricultural commodities (including some fallow land)
- A proportion of land that in the recent past has ceased to be cultivated (abandoned land) or has been unavailable or unsuitable for cultivation for specific reasons (contaminated land) see the figure below.

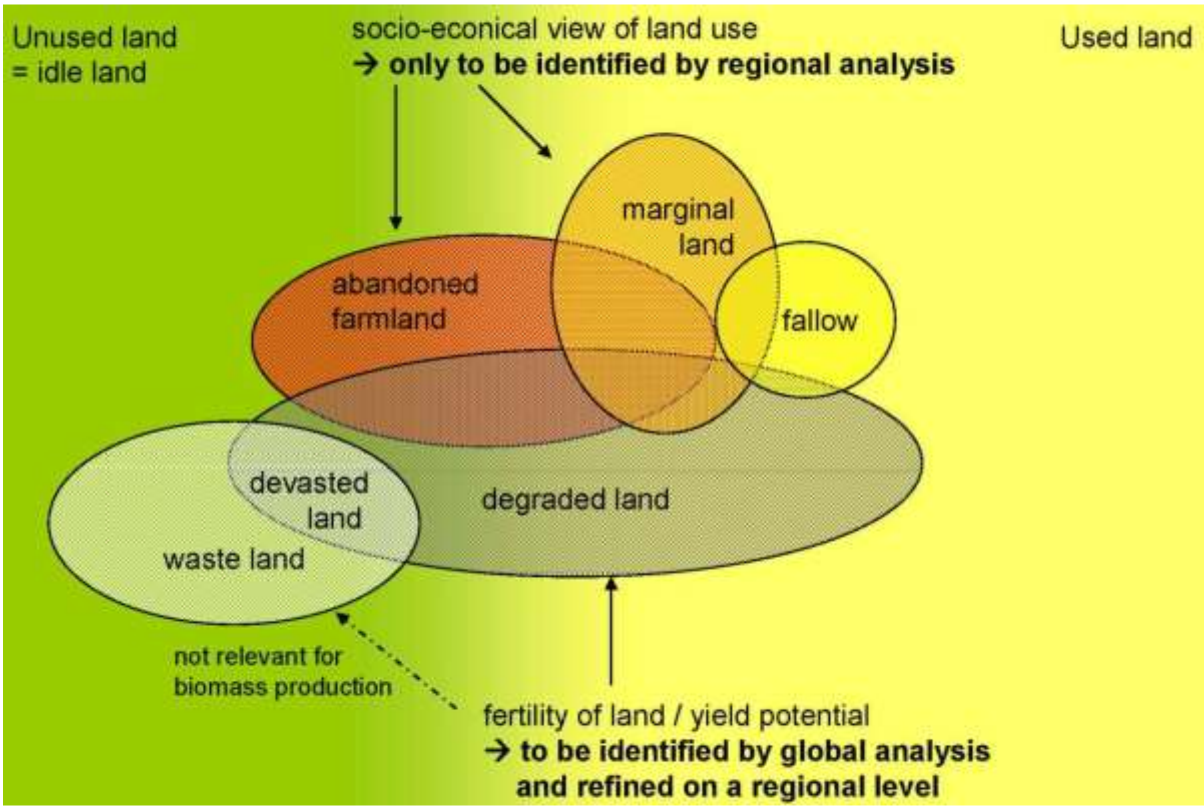

Figure 13. Steps to identify degraded and abandoned farmland for potential bioenergy feedstock production.[44]

Data about the productivity of degraded or low productive types of land are typically not readily available from statistical databases. Preferably, the yield is assessed considering 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.

In the study "Space for energy crops – assessing the potential contribution to Europe's energy future" undertaken by the Institute for European Environmental Policy they provided an estimation as to the potentially available land for energy crops (see below).

[44] BEE Best Practices and Methods Handbook 2010.

	Category of land	Area	Exclusion rationale or data source
Natural and forest land			
A	Existing woodland and forest	Excluded	Covered in IINAS *et al*, 2014
B	Existing non-forest semi-natural habitats (including abandoned grazing land)	Excluded (unless C or D)	Excluded on the basis of its environmental importance
Agricultural land			
C	Recently abandoned cropland (<5 years old)	**~200,000ha**	Data highly limited, estimates based on Corine land use changes ***Corine land cover change (2000 – 2006)****
D	(Recently abandoned) Grassland moving out of agricultural use since 2009, most likely out of production, includes transitions to urban land	**600,000ha**	Some areas excluded on the basis of environmental importance; transition areas unknown, assume most going to urban/forest ***LUCAS land cover data (2009 – 2012)***
E	Current arable land in rotation (including oilseed rape and other industrial crops being utilised as biofuel or other bioenergy feedstocks) excluding fallow (see F)	Excluded	Excluded on the basis of competition with food and feed production
F	Fallow land in agricultural rotation – most of which is needed for agronomic purposes	**200,000ha**	Some areas excluded on the basis of agronomic or environmental importance. ***Farm Structure Survey - Eurostat (2000 – 2012)***
G	Uncropped land within arable farms under environmental agreements or similar eg field corners, buffer strips etc	Excluded	Excluded on the basis of environmental importance. ***No area information***
H	Current grassland under agricultural management (non-arable)	Excluded	Excluded on the basis of competition with food and feed production
I	Other underutilised land within the current UAA but not permanent grassland***	**300,000ha**	n/a
Non-agricultural land			
J	Suitable contaminated sites (excluding areas suited only for afforestation)	**50,000ha**	Excludes areas in use or unsuitable for production or with high biodiversity value. ***JRC 2001 – 2011****
Total			
	Total potentially available land based on optimistic assessments of area		**1,350,000ha**

Figure 14. [45]

Around 1.35Mha of land in the EU has been identified as having potential to be investigated further for the purposes of dedicated energy cropping. The table below shows the potential for the final energy produced from dedicated biomass utilisation and its share of supply.

Assuming all biomass used for:	Lower	Upper	Unit
Biofuel	57	124	*PJ*
Electricity (combustion total)	44	95	*PJ*
- out of which Electricity (co-firing)	*26*	*56*	*PJ*
- out of which Electricity (cogen ST-BP plants)	*18*	*39*	*PJ*
Heat (dedicated)	107	231	*PJ*
Heat uptake (cogen ST-BP plants)	45	98	*PJ*
As a share of *sectoral* EU final energy consumption:			**out of:**
Biofuel	0.5%	1.0%	Road transport (12,021 PJ)
Electricity (combustion total)	0.4%	0.9%	Electricity (10,073 PJ)
+ Heat uptake (cogen ST-BP plants)	*2.2%*	*4.8%*	*Heat (2,022 PJ)*
Heat (dedicated)	5.3%	11.4%	Heat (2,022 PJ)
As a share of total EU *final* energy consumption in 2012 (46,198 PJ):			
Biofuel only	0.12%	0.27%	
Heat only	0.23%	0.50%	
Electricity + Heat (mix of co-firing & cogen)	0.19%	0.42%	

Figure 15. [46]

[45] Space for energy crops – assessing the potential contribution to Europe's energy future", Institute for European Environmental Policy, 2014.
[46] Ibid 44

Energy crops call for land and availability of land is contingent upon competing uses, environmental consideration, and economic viability. The amount of energy to be produced depends on the fertility of the land and the yield of the crops grown upon it. In order to assess the potential for energy crops first there is a need to evaluate the social, environmental and economic barriers and opportunities of growing energy crops for energy production.

Social and environmental barriers and constrains:[47]

- **Food production** - The effect of bioenergy on food production is less ostensible than the impact of biofuels on food production, as bioenergy normally does not use food crops. In order to minimize the impact on food production from growing dedicate energy crops, it is desirable to choose and make use of idle/marginal lands, or somehow unproductive land, as shown in shown in the studies above. However, if other land is targeted that might have competing uses for food production, this might result in land use change and decrease the land available for food, while increasing the prices. Some studies have proved that higher cost in food production can be credited to a combination of reduced food crop yields, market speculation, increasing demand from China for livestock feed, increasing cost of agricultural inputs, etc., rather than growth in bioenergy. [48]
- **Biodiversity** - There is a scarcity of evidence on the biodiversity effects of planting energy crops on idle/unused land, most of the work completed to date has made the comparison with arable production and in many cases annual crops. Thus further research is required into the field. However, if energy crops are to replace woodland or grasslands, this might decrease the biodiversity, and it’s often constrained.
- **Water use** - There is a perception amongst farmers that some of the energy crops can impact drainage ditches and be challenging and costly to remove from the field. However, this is not stayed by scientific evidence since due to the fast growing nature and rate of harvest of the crops much of the plants energy is used to maximise above ground biomass; thus, not allowing deep or thick roots to become established.
- **GHG emissions** - Energy crops tend to reduce GHG emissions, as studies have shown that species grown, its energy conversion route and the land use it displaces, play significant roles in defining the speed at which GHG savings are made. However, studies are frequently based on modelling which has a large degree of potential error. Thus, it’s important to keep in mind that, GHG emissions are also reliant on the efficiency energy conversion; converting biomass to electricity without heat

[47] Domestic Energy Crops Potential and Constraints Review, NNFCC, 2012.
[48] Anatomy of a crisis: the causes and consequences of surging food prices. Headey, D and Fan, S. Agricultural Economics, 2008, Vol. 39 (s1), pp. 375-391.; Urbanchuk, JM. Critique of the World Bank Working Paper "A Note on Rising Food
Prices". LECG LLC, 2008.

recovery will decrease the GHG mitigation potential of the crop. For example, as study found that specific energy crops (Miscanthus and SRC) cultivated for energy, abated more GHG emissions than either grasslands or traditional crop systems, as a result of reduced fossil fuel inputs and augmented carbon sequestration. Nonetheless, the contrary was correct when these same crops were used to substitute broadleaf woodland. Once more, there is a lack of evidence on the impacts of growing energy crops on idle/ unused land.[49]

Economic barriers:[50]

- Cash flow problems between planting and the first harvest are perilous and sustenance during this time is needed.
- Small margins for producers offer little room for error and if an unexpected additional cost appears, this might result in no profit and possibly even a deficit.
- Farmers themselves are often not prepared to contract long term, even if financial gains are substantial.
- Need more support for producers to access end users and secure off-take contracts.

The problems and barriers surrounding energy crops set up a multifarious problem calling for a multi-faceted resolution, which needs further time and research. The benefits of energy crops include their use for energy, ability to store carbon, benefit industrial landscapes, prevent erosion, improve biodiversity in the right location and ensure fuel security.

Methodology for assessing energy crops potential

The proposed method is very general and can be used any type of crops under considerations and any type of utilization foreseen (production of biofuels, of electric power, of thermal energy or co-generation). Land that can be committed to energy crops is identified at local scale through in-depth cartography and datasets, considering morphological, geological and climatic characteristics, administrative borders and current land use. The method is based on the integration of GIS data (spatially continuous) with data resulting from the agricultural census (spatially discrete). GIS based methods consider the spatial distribution of both the availability and the utilization of biomass.

[49] Estimating the pre-harvest greenhouse gas costs of energy crop production. St Clair, S, Hillier, J and Smith, P. 2008, Biomass and Bioenergy, Vol. 32
[50] Domestic Energy Crops Potential and Constraints Review, NNFCC, 2012.

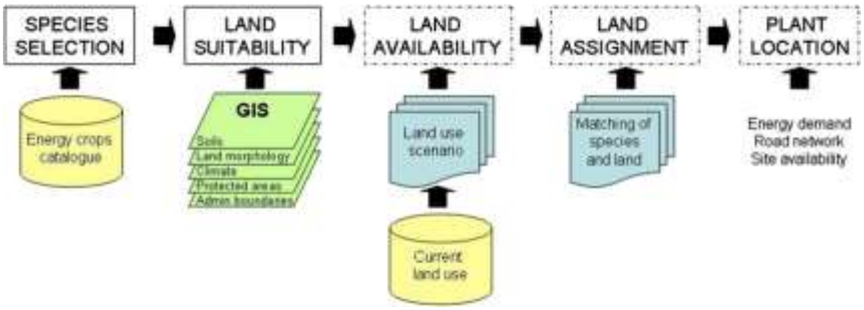

Figure 16. Steps of the proposed method and related databases. [51]

- **Species selection** – entails categorizing favourable crops for the area in question and the associated phytologic characteristics. In order to be able to categorize the crops, database of soil, climatic and geo-morphological preferences for each crop is required, coupled with data about the nature and extent of the agricultural activities required by each considered crop.

	Unit	Willow	Hemp* (spring)	RCG (spring)	Poplar	Soft Wood
Water content at harvest	%	50	10-15	10-15	50-55	50
Dry mass yield	t_{dm}/ha/year	6-10	5-10	4-10	10-20	3-5
Ash content (dry)	%	2.9	1.5	1.0- 8.0	0.5-1.9	1-2
Gross calorific value (dry)	MJ/kg	19.97	18.79	19.20	19.43	20.3
Net calorific value (dry)	MJ/kg	18.62	17.48	17.28 – 18.72	18.10	18.97
Carbon (C)	% DM	49.8	47.3	48.6	39.7	50.6
Hydrogen (H)	% DM	6.26	6.0	6.1	7.7	6.24
Sulphur (S)	% DM	0.03	0.04	0.04 – 0.17	0.2	0.03
Nitrogen (N)	% DM	0.39	0.7	0.3 – 2.0	0.9	0.1
Chlorine (Cl)	% DM	0.03	0.01	0.01 – 0.09	0.04	0.01
Aluminium (Al)	g/kg of ash	2.2	2.1	2.8	16,7	16.0
Calcium (Ca)	g/kg of ash	243.0	240	66.5	189.3	238.8
Potassium (K)	g/kg of ash	123.3	44.7	129.5	28.6	80.7
Magnesium (Mg)	g/kg of ash	23.4	24.0	21.7	42.9	31.4
Sodium (Na)	g/kg of ash	2.5	3.5	7.0	3.6	4.6
Phosphorus (P)	g/kg of ash	36.9	49.3	32.3	17.9	12.4
Silicon (Si)	g/kg of ash	93.3	160	218.3	178	73.9
Ash smelting point, (DT/A)	°C	1490	1610	~1400	1160	1200

Figure 17. Typical values of fuel characteristics.[52]

- **Land suitability** - The next step is to establish a database of land suitability information (cartographic data) of the identified area. This will enable an understanding of soil characteristics; thus, which king of crop can be grown according to its agronomic needs in order to gather data. This database should comprise of data on morphology, soil pedology, climate and all other features that estimate the suitability of the area to cultivate the carefully chosen species. All the data is normally obtainable as digital

[51] A GIS-based approach to evaluate biomass potential from energy crops at regional scale. Giulia Fiorese, Giorgio Guariso, Environmental Modelling & Software, 2010.
[52] Energy from field energy crops – a handbook for energy producers, 2009.

cartography, permitting for uninterrupted representation of data. GIS tools allow users to subdivide areas into parcels which meet the criteria for cultivating energy crops. The specific soil requirements of each species are defined in terms of:

- geo-morphological variables: slope, altitude;
- pedological variables: geotechnical (soil texture and depth, presence of gravels, stability, drainage) and soil (pH, presence of limestone) characteristics;
- climatic variables: temperature and precipitation regimes;
- physical/chemical variables: presence of elements such as organic carbon, nitrogen, carbon to nitrogen ratio, phosphorus and calcium.

All these requirements can be represented on digital, taking off areas unsuitable because of environmental legislation (natural parks, preservation zone, etc.) allowing for an accurate estimation of the available land for energy crops. It is worthwhile to secure compatibility with the administrative borders in the area, where each parcel completely lies within the border of an administrative unit. This necessitates the extra intersection with the layer of administrative borders and splits the areas of equal land characteristics lying across the borders into separate parcels each included only in one administrative unit. As pointed out, land assignment is encountered by environmental barriers that can be defined as continuous on the territory so it may be computed using GIS procedure. Also there are the social barriers, which demand a decision making process at the level of each parcel, which it can be elaborated by using statistical data which are in a way discrete, since they refer to each parcel.[53]

- **Land availability** – even if the land is suitable, the next step is to evaluate the amount of suitable land which can be converted into energy crops. . The land available for biomass production is the residual land base after subtracting the land needed for food, feed and livestock, built areas, and set aside for nature conservation. This step entails current land use data (statistical database) and taking into account political and social constraints. This step involves an evaluating the degree to which existing agricultural practices may be modified, which entails a comparison of the benefits from current agriculture with respect to the possible gains from energy crops. However, it must be noted that a complete formulation of an agricultural plan (including all food and non-food crops, their agricultural practices, land suitability, transportation and utilization costs, etc.) may become very complex and may be challenged by socio-economic conditions of the areas. In order to secure social and political acceptability, it is desirable to choose land which is not currently used for food agriculture, thus only minimally perturbing existing practices.
- **Land assignment/plant location** - the next step involves a decision process whereby is determined which crop to grow in each parcel of suitable land available (land

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[53] A GIS-based approach to evaluate biomass potential from energy crops at regional scale. Giulia Fiorese, Giorgio Guariso, Environmental Modelling & Software, 2010.

assignment) and where to exploit its energy. When more than one crop is suitable for a certain soil, an optimization procedure is required to compute the energy output from biomass utilization and select type, size and location of conversion plants (plant location).

Energy optimization – the last step of the method can be formulated as accounting for the net energy produced in considering energy plants' output (determined by number, size and efficiency of the plants) deducted the energy needed to transport biomass from fields to plants (determined by plant location and on collection basins) and the energy needed to grow and harvest energy crops.

Decision variables:[54]

- x_{ijk}, the area, in hectare (ha), in parcel i-th, grown with species k-th and hauled to plant j-th at a distance d_{ij}, and y_j, a binary variable indicating if the plant is built in parcel j ($y_j = 1$) or not ($y_j = 0$).
- The net energy production, to be maximized, is

$$\max_{\{x_{ijk}, y_j\}} J = \sum_i \sum_j \sum_k \Big[(\eta_j \cdot LHV_k \cdot u_k \cdot x_{ijk}) - (en_{transport} \cdot d_{ij} \cdot u_k \cdot x_{ijk}) - (en_{\mathrm{grow\ k}} \cdot u_k \cdot x_{ijk}) \Big]$$

Where:

u_k - is the annual biomass yield of the k-th species, in dry tons/ha. It does not depend on the specific land parcel *i*, since only the most suitable land for growing crop k has been selected in the previous steps.

n_j - is the j-th plant efficiency.

LHV_k - is the lower heating value of the k-th species, in MJ/dry ton.

$en_{transport}$ - is the annual energy cost, in MJ/dry ton/km, for hauling a unit of biomass over a unit of distance, return trip included.

$en_{\mathrm{grow\ k}}$ - is the annual energy cost, in MJ/dry ton, for growing biomass, again assumed to depend only on the species k.

[54] A GIS-based approach to evaluate biomass potential from energy crops at regional scale. Giulia Fiorese, Giorgio Guariso, Environmental Modelling & Software, 2010.

The objective function is subject to the following limitations

$$\sum_{j}\sum_{k} x_{ijk} \leq A_i \forall \; i$$

(1)

It inflicts that the sum of areas x_{ijk} cultivated with crop k in parcel i, must be at the most as big as the available land A_i (in ha) in the same parcel, identified in the previous steps of the procedure.

$$CAP_j \cdot \xi^L \cdot y_j \leq \sum_{i}\sum_{k} LHV_k \cdot u_k \cdot x_{ijk} \leq CAP_j \cdot \xi^H \cdot y_j \;\; \forall \; j$$

(2) [55]

Confines the supply to each plant in a range, defined by a lower ξ^L and a upper ξ^H bound of the nominal production capacity CAP_j (in MJ/y), when the plant is actually built in location j (y_j = 1), and sets the supply to zero otherwise (y_j = 0). Working around the nominal capacity of the plant, guarantees that the value n_j of the conversion efficiency is eloquent and avoids defining very small plants that may be unjustified from the economical viewpoint.

$$x_{ijk} \geq 0, \;\; y_i = 0,1 \forall i,j,k$$

(3) [56]

Areas for energy crops must be non-negative, while the presence of a plant in the candidate location is a binary value. Here the capacity of each plant is determined by the available biomass, which is also a decision variable. First comes the optimization of land assignment, and the second is optimization plant location with data on biomass availability. For instance, parcels where a plant can be build should have enough land available for its installation. Moreover, if district heating is to be part of a scheme, the parcel should be near and end user populated enough to efficiently exploit the heat supplied by the plant. The solution may include parcels where x_{ij} is zero for all j, if they have a negative energy balance, even when cultivated with the best crop, or if their production is insufficient to justify the construction of an additional plant.

Land assignment for dedicated energy crops should not be devoted only to optimal match between species, land and maximum yield, as this limits the amount of biomass that can be

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[55] A GIS-based approach to evaluate biomass potential from energy crops at regional scale. Giulia Fiorese,Giorgio Guariso, Environmental Modelling & Software, 2010

[56] Ibid 52

produced and utilized. Even land that is not optimal can be devoted to energy crops, but it will accordingly return yields lower than the maximum ones. Thus, as an alternative of having a yes/no (1/0) sharp assignment, the method could be extended by defining a land suitability function to set a value between one (optimal) and zero (unsuitable) to the productivity of each parcel of land with a given set of characteristics.

Agriculture Residues and methods for assessment

Agricultural residues include a wide-ranging diversity of biomass types, and can be separated into three main categories[57]:

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

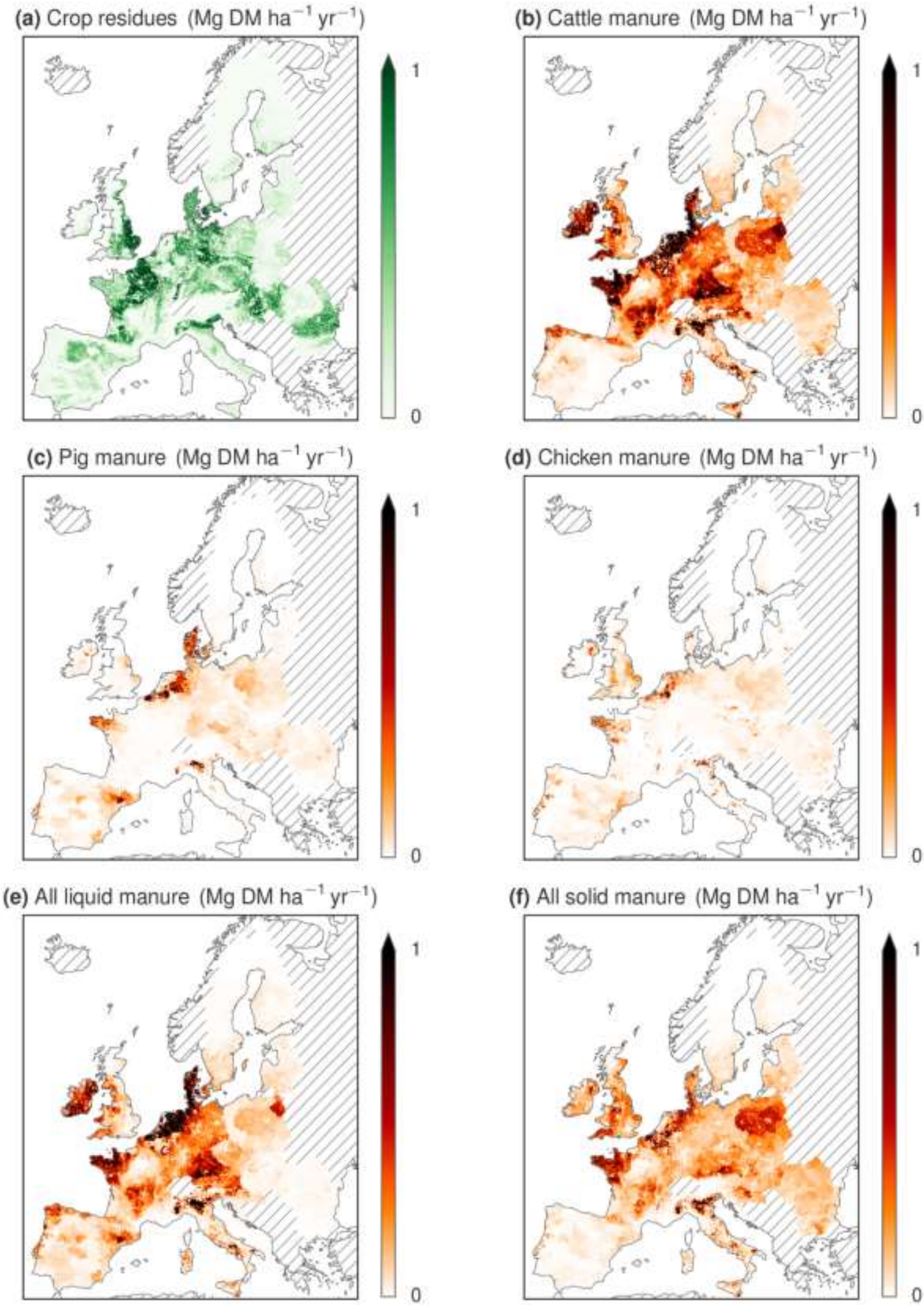
Agricultural residues are the by-products of agricultural practice. A division is made between primary (harvest residues - straw) that are produced in the fields and secondary (processing of the harvested product - bagasse) that are created at a processing facility. Manure is included as a separate category. Secondary residues method of collection is usually straightforward as they are produced at a central processing facility, while primary residues have to be collected from the fields. Manure is organic matter used as organic fertilizer in agriculture. Animal manure can be obtainable as a liquid (farm slurry) or in a solid form. Manure can be gathered from stables if concentrated livestock rearing systems are functional.

There are a couple of causes why only a part of the produced crop residues can be sustainably exploited. Crop residues are a key source of soil organic matter and therefore not all residues can be removed from fields without generating undesirable effects on soil quality. Also, if the weather is very wet after harvest, the quality of the residues may be despoiled and there may be severe soil compaction if heavy machinery is used for removal

[57] BEE Best Practices and Methods Handbook 2010.

of residues. These are both serious apprehensions which farmers reasonably should reflect on before utilizing or selling their crop residues. Overall, there is a lack of data available on the produced quantities of crop residues and how they are managed, but there have been some efforts to estimate how much could be used for energy purposes using national statistics and subnational statistics. [58] Subnational agricultural production statistics are published by Eurostat according to the NUTS classification (Nomenclature of territorial units for statistics).

[58] Analyzing key constraints to biogas production from crop residues and manure in the EU—A spatially explicit model, Rasmus Einarsson, U. Martin Persson, 2017.



[59]

Figure 18.

[59] Ibid 58

The figure above shows the estimated available crop residues and manure in the EU. The panels show estimated available amounts of (a) crop residues, (b) cattle manure, (c) pig manure, (d) chicken manure, (e) sum of liquid manure, and (f) sum of solid manure. The estimates account for the maximum sustainable removal of crop residues, and exclude manure that falls on pastures. Straw used for bedding is excluded from the crop residues density and included in the solid manure densities. Striped areas are not analyzed.

Technical and economic limitations to biogas potential from agriculure residues and manure[60]

Residue-to-crop production ratios

Data on crop yields are easily obtainable, while data on the straw and stover yields is very limited, since the aim of agricultural production was to maximise yields. A wide disparity in residue-to-seed ratios is reported in the literature. The relationship between residue-to-seed production is very specific to the type of crop and plant variety. It is very difficult to make a straightforward estimation of this ratio, since it is influenced by climate and soil conditions and also the farming practices (tillage, density of planting, fertilisation, etc.). Adverse field conditions and crop stress, such as insufficient nutrients and water might reduce the Harvest Index.[61]

Crop residue collection

The residue removal rate fluctuates conditional on a mixture of dynamics, including equipment restrictions, plant variability, the harvest height, yields, environmental requirements and water scarcity. A number of studies deliver approximations on the collection of crop residue from the crop land, largely varying between 30% and 60%, while sustaining soil organic matter, soil organic carbon and protecting it from erosion.[62]

Competitive use of crop residues

In addition to the environmental limitations and economic concerns, the obtainability of crop residues for bioenergy production rest on other competing uses. The main competitive uses of crop residues are for incorporating into soil, animal feed and bedding, mushroom cultivation, surface mulching in horticulture and industrial uses. Straw is often integrated in soil to safeguard against soil erosion, as fertiliser, and soil structure improver. Straw is used for crop security, mainly in cold climates when they are left in the ground during winter. Wheat straw is used as substrate for the mushroom production, together with horse manure or poultry litter. Animal breeding is the most central competitive use of straw and stover for animal feeding and bedding. Straw is commonly used as bedding for cattle, horses

[60] Ibid 59
[61] Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use, Nicolae Scarlata, Milan Martinovb, Jean-François Dallemanda, 2010.
[62] Ibid 61

and pigs and even as fodder. Maize stover is a potential feed for cattle, providing an important share in their diet. The amount of straw used depends on the straw availability, livestock, farming and housing systems, and how long they stay indoors.[63]

Maximum transportation distances for substrates and minimum viable plant size

Bigger biogas plant proportions are usually more economical given an adequate substrate supply. When the biogas is used to produce electricity, calculations indicate substantial returns to scale, perhaps a 30% cost drop going from 150 to 1000 kW HHV. Requiring larger plant sizes is relevant especially if the gas is to be upgraded to vehicle fuel quality. However, larger plant sizes call for lengthier transportation. In areas where substrate density is low, the gathering of substrates and dispersion of digestate may entail inefficiently long transportation distances. An absolute upper limit for transport should be implemented when the net energy balance of the operations turns negative, i.e. when more energy is used than the produced biogas output.

Minimum and maximum Dry Matter (DM) content

Biogas processes can be divided into two main categories: wet and dry fermentation. The DM concentrations in reactors are typically around 10% for wet fermentation and in the range 15–35% for dry fermentation. DM concentration can be higher for the substrate mixture feeding process as DM is constantly disintegrated and removed and there are a number of chemical and physical substrate characteristics that can influence which reactor type, mixing equipment, etc., are most appropriate. To lower the DM concentration you can dilute the substrates with fresh water and recirculate liquids from the reactor effluents. Dilution of very dry substrates may require very substantial amounts of fresh water. Recirculation can aid to lower the DM concentration and rise the methane yields, but it also causes accumulation of both organic and inorganic substances in the reactor which may hinder the digestion process.

Minimum and maximum C:N ratio

Anaerobic digestion necessitates an equilibrium between C and N content. The C:N relation is an important parameter because ammonia inhibition is a potential hurdle to digestion of manure slurries with low C:N ratios. Very high C:N ratios should also be evaded since reactor stability and methane yield may decline if N accessible for microbial growth is deficient. Disparity in reported optimal C:N ratios is foreseeable, in view of the complexity of digestion processes and the many possible confounding variables such as pH, temperature, other nutrient composition, etc.

[63] Ibid 61

The methane yield

The methane yield of substrates is dependent on their physical and biochemical properties and on digestion process parameters such as temperature and retention time. The physical and biochemical properties of substrates can be altered through pretreatment (steam explosion, grinding or extrusion, or biological pretreatment). Pretreatment is beneficial for some lignocellulosic substrates such as straw, which may otherwise be hard to digest.

Primary agricultural residues assement methods.

The most significant type of agricultural biomass available for bioenergy is straw, as it is left after the harvesting of cereals and other annual lignocellulose crops. The parameters that define the straw potential are the area of land covered and the amount of straw produced per hectare or tonne of crop. Constraints include competitive uses 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 tree pruning). The potential of primary residues could be abridged by environmental and sustainability issues.

Basic statistical method – estimate the theoretical potential of annual crop residues, like cereals, on the basis of cultivated area (CA), and agricultural production (AP) in tonnes per hectare, for each specific crop and average product to residue ratios (PtR).[64]

$$THP\_PAR = \sum (CA_i * AP_i * PtR_i * Av_i)$$

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

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

$$THP\_PAR = \sum (CA_i * RY_i * Av_i)$$

[64] BEE Best Practices and Methods Handbook 2010.

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 pruning is based on an average of prunings per tree (Pr) for specific cultivations. The number of trees (TNum) per hectare is recommended to estimate the residues potential per hectare.

$$THP\_PARpr = \sum (TNum_i * \mathrm{Pr}_i * Av_i)$$

Where:

PARpr = primary agricultural residues (pruning's), in tonnes

$TNum_i$ = number of trees per hectare of i crop (n/hectare)

Pr_i = residue yields per tree of i crop, in tonnes (t)

Av_i = availability of residues for i crop according to current harvesting system

Basic statistic method – estimating the *technical potential* of the various primary residues, calculated by taking into account maximum extraction rates to reserve soil quality and alternative uses.

$$TCP\_PAR_i = THP\_PAR_i * EX_i * UF_i$$

Where:

TCP_PAR_i = technical potential of crop i

THP_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)

<u>Advanced statistical method</u> – entail more consideration to the sustainable extraction rates and use factor, as the alternative uses of the crop residues have to be assessed prudently. A humus balance method allows for achieving sustainable extraction rates, by calculating the amounts of primary residues that can be extracted while maintaining sustainable carbon and nitrogen levels in the soil. The "humus saldo" reveals the net effect on humus content, where "humus supply" states the organic matter supply from plant residues and organic fertilizers, and "humus demand" represents the decline 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. The calculation of *hrc* is based on the carbon (C) inputs from biomass in combination with organic fertilizers and nitrogen (N) mineralisation, see the formulas below. [65]

$$hrc = C_H - N_H * k$$

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.

$$C_H = C_R * h_R + C_{RT} * h_{RT} + C_{EX} * h_{EX} + C_{RE} * h_{RE}$$

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.

$$N_H = \left(N_{PB} - N_{dfa} - N_D * wp_D - N_{FERT} * wp_{FERT}\right)/wp_H + \Delta N_{min}$$

Where:
N_{PB} = N in plant biomass as identified by crop yields (kg N/ha)
N_{dfa} = 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)
$Wp_{D,FERT,H}$ = whole plant utilisation rate for N from a defined source pool (factor)
ΔN_{min} = net change of mineral N in soil solution during cropping period (kg N/ha)

[65] BEE Best Practices and Methods Handbook 2010.

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 basic resource-focused statistical method for primary agricultural residues is easy for application, because of the simple equation used and availability of core data on national and international databases. Particularly data for cultivated areas of crops and agricultural production for specific crops are freely available on international databases, like Eurostat and FAOSTAT. The agricultural production could be influenced by market issues, the diet of the population, land use change, and climatic conditions. Only a part of PAR are available for harvesting to evade depletion of organic matter in the soil and guarantee the potential of nutrients in agricultural lands and their yield in the long term.

Cost supply method – provides for cost-supply curves for primary agricultural residues determining how much of the technically available potential of biomass can be exploited at a feasible price. 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).

$$C_{res} = \frac{p_k * \lambda_r * K_r + p_L * \lambda_r * L_r + p_A}{Y_i}$$

Where:
$C_{transport}$ = 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)
λ_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 ($C_{transport}$), is given by the following equation:

$$C_{transport} = \frac{p_{pb} + T + D * \tau * F_r}{B_i}$$

Where:
$C_{transport}$ = the cost of transport (Euro/GJ)
p_{pi} = 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)
τ = the transport cost per litre

F_r = the fuel consumption (liter/km)
B_i = Biomass transported (in GJ)

The cost–supply method can be useful to attain cost-supply curves for any type of bioenergy output (e.g. electricity, heat or ethanol) using agricultural residues as an energy source. Equations are easy to apply and parameters are obtainable through literature or web sources.

Secondary agricultural residues assement methods.[66]

Basic statistics method - the basic statistical method for assessment is appropriate for calculation of the theoretical and technical potential of secondary agricultural residues (SAR) that are produced and gathered at site where harvested portions of agricultural crops for food/feed production are processed. It may be the case that the businesses are obliged to account for the volumes and means of utilisation of their residues to national statistical institutions and statistical data can be obtained from national statistical bodies. If direct statistical data on SAR volumes are not available, the methodology for assessment is the following. First the statistical data on a certain agricultural crop production quantity in tonnes is needed, followed by the same amount multiplied by the product to secondary residue ratio which is specific for each type of product. The obtained result represents the theoretical potential of a certain SAR. The calculation of the theoretical potential can be presented as follows:

$$P_{t_i} = Cr_i \cdot PtSR_i$$

Where:
P_{ti} = 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. SAR are produced and gathered at the enterprises, which process harvested portions of agricultural crops for food/feed production, so the availability factor will normally be equal to one. The Use Factor shows how much collected residues can be used for energy production comparing it with other uses (biomaterial, food, feed, and soil improvement). The Use Factor takes into consideration the availability limitations due to sustainability. The product

[66] BEE Best Practices and Methods Handbook 2010.

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.

The formula:

$$P_{tech\,i} = P_{ti} \cdot Av_i \cdot UF_i$$

Where:

$P_{techn,I}$ = 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*

Cost supply method - concentrates on transportation of biomass as this is a critical aspect for the economic performance. This method starts from evaluation of theoretical and technical potential of SAR (above) and ends with the economic potential. Generally transportation of biomass is considered to be feasible within a distance of up to 100km but because of the low bulk density of SAR, the distance should be reduced to 50km. To check whether utilisation of SAR at a specific plant is economically feasible, the following sub-steps - 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.

(1) Transportation costs of SAR per km per m^3 of a truck or other transportation vehicle (C_v, Euro/km/m^3) is converted into costs per km per kg of the specific SAR (C_{mi}, Euro/km/kg)

$$C_v \cdot \rho_i = C_{mi}$$

Where

C_v = transportation costs of SAR per km per m^3 of a truck or other transportation vehicle

ρ_i = is bulk density of SAR_i

C_{mi} = costs per km per kg of the specific SAR

(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)

$$C_{mi} \cdot Q_i = C_{Q_i}$$

Where:

C_{mi} = costs per km per kg of the specific SAR

Q_i (MJ/kg) = is low heating value of SAR

C_{Qi} = transportation costs of SAR_i per km per kg is converted into costs per km per MJ of energy content

(3) Calculation of costs of SARi transported to a biomass conversion plant n (C_{Qin}, Euro/MJ).

$$C_{Q_i} \cdot S_n = C_{Q_{in}}$$

Where:

C_{Qi} = transportation costs of SAR_i per km per kg is converted into costs per km per MJ of energy content
S_n = is a distance to biomass conversion plant n.

(4) Comparison of fuel costs - Costs of transported SAR are equated to the costs of biomass used at a plant. If SAR is supposed to be co-combusted with a fossil fuel, its costs are compared to the costs of fossil fuels which are the main fuel at the plant. In this case, possible subsidies on the renewable electricity compared to fossil electricity.
(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 defined as economically feasible.

Manure assement methods [67]

Figures on manure management practices in the EU are limited, typically based on expert judgement rather than measurements, and either qualitative or extremely ambiguous. It is extensively acknowledged that manure management practices vary considerably both between and within countries. Moreover, the assessment of different information sources is complicated since no standardized terminology is agreed upon. [68] The table below show assumed excretion and total manure production per animal head for different animals and manure management systems.[69]

[67] BEE Best Practices and Methods Handbook 2010.
[68] Analyzing key constraints to biogas production from crop residues and manure in the EU—A spatially explicit model, Rasmus Einarsson , U. Martin Persson, 2017.
[69] The potential for biogas production from crop residues and manure in the EU, accounting for key technical and economic constraints Rasmus Einarsson and U. Martin Persson.

Animal	Excretion (kg VS head^{-1} d^{-1})	System	Manure incl. bedding (kg VS head^{-1} d^{-1})
Dairy cows	5.1	liquid	5.1
		solid	10.2
Other cattle	2.6	liquid	2.6
		solid	5.2
Breeding pigs	0.5	liquid	0.5
		solid	1.0
Fattening pigs	0.3	liquid	0.3
		solid	0.6
Laying hens	$8 \cdot 10^{-3}$	liquid	$8 \cdot 10^{-3}$
		solid	$8 \cdot 10^{-3}$
Broilers	$5 \cdot 10^{-3}$	liquid	$5 \cdot 10^{-3}$
		solid	$5 \cdot 10^{-3}$

doi:10.1371/journal.pone.0171001.t002

Figure 19.

		DM %	VS/DM %	C/VS %	N/VS %	Methane yield (m^3 CH_4 / Mg VS)
Cattle manure	liquid	8	80	55	7	200
	solid	20	85	"	3.5	"
Pig manure	liquid	6	80	"	10	"
	solid	20	85	"	5	"
Chicken manure	liquid	30	70	"	9	250
	solid	70	70	"	9	250
Crop residues	straw	85	90	"	0.5	200
	maize	"	"	"	"	"
	sunflower	"	"	"	"	"
	sugar beet	13	"	"	2.5	300

doi:10.1371/journal.pone.0171003

Figure 20.

The figure above demonstrates the properties of substrates achieved in a study. Where dry matter (DM) expressed as a fraction of total weight; volatile solids (VS) expressed as fraction of DM, and carbon (C) and nitrogen (N) expressed as fractions of VS. For conversion of methane volume to higher heating value (HHV) the factor 40 MJ m^{-3} was used.[70]

Statistical method - the theoretical manure potential is grounded 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, the total amount of manure produced can be estimated. The above mentioned method is simple and is represented by the following equations:

$$THP\_Manure = \sum NHeads_i * MpH_i$$

[70] Analyzing key constraints to biogas production from crop residues and manure in the EU—A spatially explicit model, Rasmus Einarsson , U. Martin Persson, 2017.

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 used for energy utilization. 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. If combustion is considered, the amount of manure should be multiplied with the lower heating value of the manure instead of using the biogas yield.

$$Energy_{Manure} = \sum NHeads_i * MpH_i * BY_i * GEC_i$$

Where:
BY_i = biogas yields for the i type of livestock manure, in cubic meters (m^3) per tonne
GEC_i = energy content of gas produced from the i type of livestock manure, in joules per cubic meter

Statistical method – in order to calculate the technical potential (only manure that can actually be collected), daily manure production will be multiplied by the number of days per year and the animals. An availability factor Av_i should be recognized replicating the share of manure per year that can be gathered, necessitating literature review/analysis of common agricultural practice in the investigated area. A use factor UF_i could be measured, screening alternative uses of manure. As the manure is still available for other uses after digestion, the use factor is only needed if combustion is considered.

$$TCP\_Manure = \sum NHeads_i * LUs_i * MpU_i * AHD_i * Av_i * UF_i$$

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_i = number of animal housing days per year
i = type of livestock (e.g. cattle, pig, poultry)
Av_i = availability factor (percentage of manure that can technically be collected from stables)
UF_i = use factor (percentage of manure that has no important alternative uses)

The assessment of manure potential calls for comprehensive data on the type of animals, phase of life and function, distinction between male and female, young, adult sowing pigs and possibly between the species of pigs. Agricultural practices can differ substantially between countries, the number of housing days, the availability and alternative use factors need to be determined on a national or regional level. Data collection especially on the animal housing days, availability and use factor based on national and regional practices can be time consuming. On the other hand, the method is straightforward and data about livestock units are available in Eurostat and national statistics.

Organic Waste and methods for assessment

Organic waste (biomass waste or tertiary residues), are the ultimate product of biomass containing products. Examples of organic waste include but are not limited to[71]:

- **Biodegradable municipal waste** - Waste from household and other waste with similar nature/composition, such as food and garden waste, paper and cardboard, that is adept of undergoing anaerobic or aerobic decomposition.
- **Demolition wood** - part of construction and demolition waste which is a by-product from activities such as the construction, total/partial demolition of buildings and civil infrastructure, and road planning and maintenance.
- **Sewage sludge** - can refer to residual sludge from sewage plants treating domestic or urban waste waters and/or residual sludge from septic tanks and other similar installations for the treatment of sewage.

Usually all the different types of organic waste are collected, transported and treated by public and/or private organisations, according to European, national and regional regulations for waste treatment. Organic waste is a by-product produced in significant quantities, as a result from the ever rising economic activity. In order to tackle the negative environmental effects associated with organic waste, and advocate environmental awareness of organic waste processing, government at all levels have enforced policy and legal frameworks for recycling, energy generation and minimisation of organic waste production. Consequently, the obtainability of organic waste will be determined according to the regional/national regulatory framework.

71 BEE Best Practices and Methods Handbook 2010.

The infographic below summarizes the different routes that can be taken when dealing with organic waste.

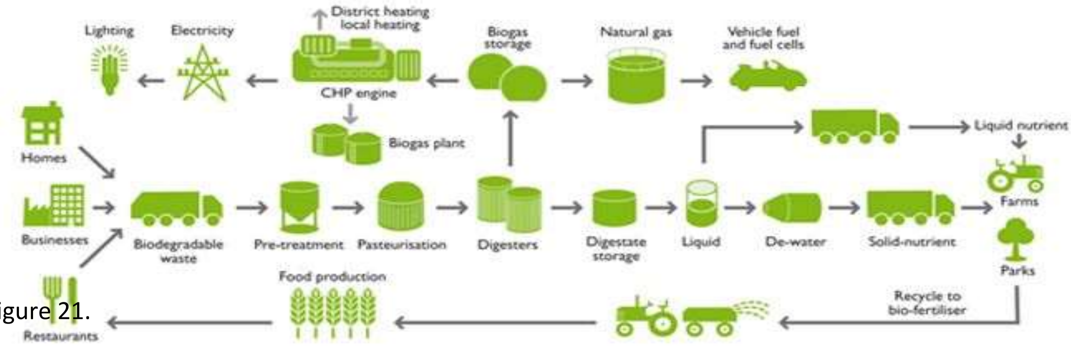


Figure 21.

To minimise negative environmental effects and promote positive environmental effects of (organic) waste processing, policy and legal frameworks must be 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.

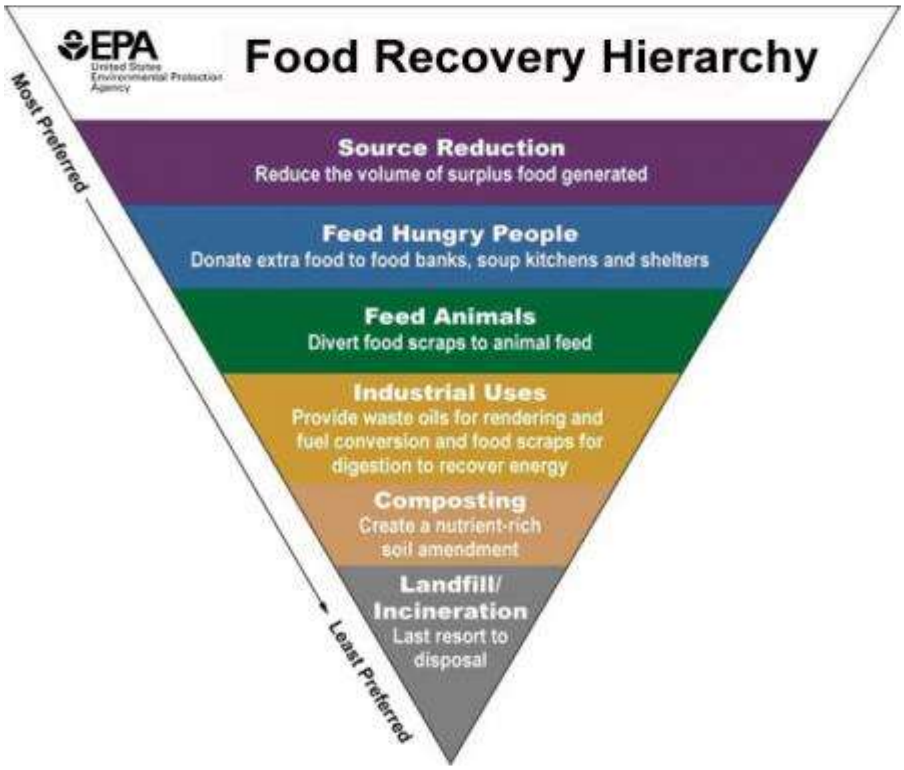


Figure 22. Food recovery hierarchy.[72]

The Food Recovery Hierarchy prioritizes the actions organizations and individuals can take to prevent food waste. From the most to least preferred, each tier focuses on management strategies to tackle food waste. This hierarchy should be born in mind when considering food waste.

[72] http://wastecap.org/press/blog/general/a-walk-through-the-epas-food-recovery-hierarchy

Biodegradable municipal waste

Basic statistical method – evaluation of the theoretical and technical potential of biodegradable municipal solid waste (BMW) based on thermal applications is shown in the equation below :

$$TP\_BMW_{x,y} = MSW_{x,y} * POP_{x,y} * ACC_x * OC_x * LHV_{BMW} * 10^{-6}$$

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)
LHVBMW = lower heating value of BMW (GJ/tonne)
x = country
y = year

In the table below various different outlets of data can be found. [73]

Data item	Data source	Exact location
MSW production per capita (MSWxy)	Eurostat	Eurostat → Statistics database → Tables by themes → Environment and energy → Environment → Waste statistics → Municipal waste generated (tsien120).
The organic content (OC_x) of MSW	OECD	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.
Percentage of the population served by municipal waste services (%)	OECD	OECD Environmental data compendium 2008 (OECD 2008) table 2C provides data on the percentage of the population served by municipal waste services.
Lower heating value of BMW (LHV_{BMW})	2006 IPCC Guidelines for national greenhouse gas inventories, volume 2, energy, (IPCC 2006b)	http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html → section 1.4.1.3, Table 1.2, Municipal wastes (biomass fraction). Composition specific LHVs should be used if available.
The population ($POP_{x,y}$)	Eurostat	Eurostat → Statistics database → Tables by themes → Population and social conditions → Population → Demography → Main demographic indicators → total population (t_popula).

Figure. 23

Advanced statistical method - is similar to the basic method but distinction is made between separately and not-separately collected BMW. Presuming 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

[73] BEE Best Practices and Methods Handbook 2010.

waste. Also the LHV of the BMW should be based on analysis on the average biodegradable waste composition per country. The equations are seen below.

$$TP\_BMW_{x,y,INC} = (MSW_{x,y} * POP_{x,y} * OC_x - BMW_{x,y,compost}) * LHV_{BMW\_INC} * 10^{-6}$$

$$TP\_BMW_{x,y,AD} = BMW_{x,y,compost} * LHV_{BMW\_AD} * 10^{-6} =$$
$$= BMW_{x,y,compost} * LHV_{CH4} * \%_{CH4} * 10^{-6}$$

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

BMW entails of mainly paper and cardboard and kitchen and garden waste, so when calculating the theoretical potential, paper and cardboard is included in OC_x, but when calculating technical potential it's better to be excluded as most of them are being recycled. Some paper and cardboard cannot be recycled due to technical barriers and if data is available, the non-recyclable fractions can be included. The LHV_{BMW} is determined by the composition of waste; i.e. paper has higher LHV than kitchen and garden waste. Since the composition of BMW can vary substantially, this LHV could also differ. The variances in waste management practices between countries results in various practices when defining of municipal waste, surveying methods used, which limits the determination of the amounts of MSW, the organic content (OC_x) of MSW and the calorific value of the BMW. The basic method is straightforward as all essential data can be effortlessly attained from international public accessible literature.

Construction and demolition wood

Statistical method - at European level there is no consolidated data assembly for construction and demolition wood, only data on the total amount available. The waste consists mainly of concrete/bricks/tiles/asphalt, metals, glass, plastics, insulation and wood. The LHV of the wet wood is 12.2 MJ/kg (moisture content 20 %) and weighted average of the wood content in the construction and demolition waste has been calculated based on data is 9.5 %. The equations below show the method.

$$TP\_CDW_{x,y,mass} = CDWa_{x,y} * WC_x$$

$$TP\_CDW_{x,y,energy} = CDWa_{x,y} * WC_x * LHV$$

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

The composition of construction and demolition waste, which serves as a basis for this calculation, varies greatly between countries. This is due to differences in definitions, the design of buildings, which makes the application of one single factor for the share of wood in the construction and demolition waste not an adequate measure. Construction and demolition wood account for a significant energy potential which does not cause any competitions with other use options. Consequently, more detailed and exact data collection should be aimed for at European level in order to tap the full potential of this waste category and establishment of a common definition on what is included in construction and demolition waste.

__Sewage sludge and gas__

Basic statistic method - 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 (sewage gas is produced) or aerobically. Sewage gas and sludge are two different products, so different methods will be applied

- Sewage gas

$$TP\_SeG_{x,y,mass} = \left[\left(SeS_{x,y} * OM\right) + \left(SeS_{industrialx,y} * OM\right)\right] * GY$$

$$TP\_SeG_{x,y,energy} = \left[\left(SeS_{x,y} * OM\right) + \left(SeS_{industrialx,y} * OM\right)\right] * GY * LHV$$

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 (m^3/kg organic dry matter)
LHV = lower heating value of sewage gas (MJ/m^3)
x = country
y = year

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 heating value of sewage gas is 21.6 MJ/m^3 if a methane content of 60 % is assumed (LHV of methane: 35.9 MJ/m^3). For sewage gas there are no other use options than as bioenergy and thus no competition with other applications occurs.

- Sewage sludge

$$TP\_SeS_{x,y,mass} = SeS_{x,y} - SeS\_Agr_{x,y} - SeS\_Landf_{x,y} - SeS\_Comp_{x,y}$$

$$TP\_SeS_{x,y,energy} = \left[SeS_{x,y} - SeS\_Agr_{x,y} - SeS\_Landf_{x,y} - SeS\_Comp_{x,y}\right] * LHV$$

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

For the treated sewage sludge, energy production is by the means of combustion. Before being combusted, sewage sludge needs to be dewatered as it mainly consists of water and therefore has a very low heating value. Mechanical 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.

Global tools and data sources availiable online to make preliminary resource potential assessments

Global data resources

- **Eurostat**
  http://ec.europa.eu/eurostat/web/main/home

  Provide statistical information to the institutions of the European Union (EU) and to promote the harmonization of statistical methods across its member states and candidates for accession as well as EFTA countries. Currently Eurostat data are aggregated at EU-28 level, known as EU-28. While Brexit is planned for 29 March 2019, it is expected that after the Brexit date they will be computed for the EU-27 only as Brexit will make the UK to be a third country. Nonetheless, to avoid confusion with the previous EU-27 group of 27 member state — which was used in series of statistical data before the accession on the member state number 28 — another name for the future EU 27 — without UK — might be defined after, according to Eurostat. Eurostat disseminates its statistics free of charge via its Internet and its statistical databases that are accessible via the Internet. The statistics are hierarchically ordered in a navigation tree. Tables are distinguished from multi-dimensional datasets from which the statistics are extracted via an interactive tool.

- **FAO**
  http://www.fao.org/faostat/en/
  The Food and Agriculture Organization of the United Nations is a specialized agency of the United Nations. FAO is an intergovernmental organization present in over 130 countries. The Organization is comprised of 194 Member States, two associate members

and one member organization - the European Union. It provides time-series and cross sectional data relating to food and agriculture for some 200 countries.

- **Global Forest Resources Assessments**
  http://www.fao.org/forest-resources-assessment/en/
  FAO has been monitoring the world's forests at 5 to 10 year intervals since 1946. The Global Forest Resources Assessments (FRA) is now produced every five years in an attempt to provide a consistent approach to describing the world's forests and how they are changing. The Assessment is based on two primary sources of data: Country Reports prepared by National Correspondents and remote sensing that is conducted by FAO together with national focal points and regional partners.
- **Livestock Sector Brief**
  http://www.fao.org/ag/againfo/resources/en/pubs_sap.html

The purpose of the Livestock Sector Briefs is to provide a concise overview of livestock production in the selected countries through tables, maps and graphs.

- **EARTHDATA**
  https://earthdata.nasa.gov/
  The Earth Observing System Data and Information System (EOSDIS) is a key core capability in NASA's Earth Science Data Systems (ESDS) Program. It provides end-to-end capabilities for managing NASA's Earth science data from various sources – satellites, aircraft, field measurements, and various other programs.
- **European Soil Database v2.0** –
  https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data
  This database (2004) is the only harmonized soil database for Europe, extending also to Eurasia.
- **ECN Phyllis Classification**
  www.ecn.nl/phyllis2/
  A great website to use and is evolving a scheme based on a mixture of plant physiology and practical considerations. Materials are divided into groups that are in turn divided into subgroups. Database content - each data record with unique ID-number shows information (if available) on:
    - classification codes
    - ultimate analysis: carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine, fluorine and bromine
    - proximate analysis: ash content, water content, volatile matter content, fixed carbon content
    - biochemical composition
    - calorific value

  - (alkali)-metal content
  - composition of the ash

- **Corine Land Cover 2006** - http://maps.eea.europa.eu/EEAGalleryBasicviewer/v1/?appid=f9b34d047a154184805687707eb7dfe5&group=9a0c196cb389491ea114eaca9fb07b5e

  CORINE Land Cover (CLC) is a geographic land cover/land use database encompassing most of the countries of Europe.

- **EEA (European environmental agency**) – https://www.eea.europa.eu/data-and-maps

Forest data reources

- **Forest Cover Map 2006**

  http://forest.jrc.ec.europa.eu/activities/forest-mapping/forest-cover-map-2006/; http://fise.jrc.ec.europa.eu/data/efdac/viewer/

  Is a 25m spatial resolution raster Pan-European Forest / Non Forest Map with target year 2006 derived from LISS III and SPOT 4/5 imagery and Corine Land Cover 2006 data.

- **Forest Map of Europe**
  https://www.efi.int/knowledge/maps/forest

  The main aim of the project targets at utilising most effectively both Earth Observation data and recent forest statistical information. It applies a previously developed calibration method to produce a comprehensive and complete European map on forest area at 1 x 1 kilometre resolution.

- **LUCF Sector Good Practice Guidance**
  https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.html
- **GlobAllomeTree**
  http://www.globallometree.org/
  GlobAllomeTree is the first international web platform to share and provide access to tree allometric equations, created in 2013. GlobAllomeTree has extended the data available to tree biomass and volume measurements, wood density data and biomass expansion factors. A unique system of data sharing agreement protects data ownership and gives control to data owners on who they want to share their data with. Data users can look for dataset and may request access to the owner depending on the level of restriction set.
- **Protected Forest Area**
  - **Protected planet**

https://www.protectedplanet.net/
Protected Planet is the most up to date and complete source of information on protected areas, updated monthly with submissions from governments, non-governmental organizations, landowners and communities.

- **EUNIS**
  https://eunis.eea.europa.eu/index.jsp
  The European nature information system, EUNIS, brings together European data from several databases and organisations into three interlinked modules on sites, species and habitat types.

- **Moisture content**: a practical guide for determining moisture content of woody biomass. A Practical Handbook of Basic Information, Definitions, Calculations, Practices and Procedures for Purchasers and Suppliers of Woody Biomass.
  https://dnr.wi.gov/topic/ForestBusinesses/documents/BiomassMoistureContent.pdf
- **Ash content**: Determination of Ash in Biomass by the National Renewable Energy Laboratory method can be found here.
  https://www.nrel.gov/docs/gen/fy08/42622.pdf

Biomass assessment tools

- **Biomass calorific value calculator**
  https://www.eecabusiness.govt.nz/tools/wood-energy-calculators/biomass-calorific-value-calculator/#adv-calculator
- **BIOMASS ENERGY VALUE CALCULATOR**
  https://www.baltpool.eu/en/biomass-energy-value-calculator/
- **Bioenergy simulator**
  https://irena.masdar.ac.ae/bioenergy/
  Free simulator for bioenergy development, allows investigation of numerous of combinations of source, technology and end use.
- **Carbon Trust Initial Assessment tool**
  https://www.carbontrust.com/resources/guides/renewable-energy-technologies/biomass-heating-tools-and-guidance/
  Initial assessment tool (XLS): This tool allows you to make an initial economic assessment of a proposed biomass plant based on site information.

Northern Periphery and Arctic Programme 2014–2020

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Generating Renewable Energy Business Enterprise

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GREBEProject

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Project Partners

GREBE will be operated by eight partner organisations across six regions:

- WDC
- Action Renewables – the future of energy, today
- Luke – Natural Resources Institute Finland
- FPN – Forskningsparken i Narvik
- eri
- Fermanagh & Omagh District Council – Comhairle Ceantair Fhear Manach agus na hÓmaí
- Innovation Center Iceland
- Karelia

About GREBE

GREBE is a €1.77m, 3-year (2015-2018) transnational project to support the renewable energy sector. It is co-funded by the EU's Northern Periphery & Arctic (NPA) Programme. It will focus on the challenges of peripheral and arctic regions as places for doing business, and help develop renewable energy business opportunities provided by extreme conditions.