A REVIEW AND HARMONISATION OF BIOMASS RESOURCE ASSESSMENTS

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ABSTRACT: The overall objective of the Biomass Energy Europe (BEE) project is to improve the accuracy and comparability of future biomass resource assessments for energy by reducing heterogeneity, increasing harmonisation and exchanging knowledge. First, similarities and differences between the various approaches, methodologies and datasets used in biomass resource assessments are investigated. Particularly the different approaches and methodologies that are used to integrate sustainability criteria into biomass resource assessments are subject of research. Second, a review is carried out of the results of existing biomass resource assessments. The focus is thereby especially on studies that focus on the world and on the EU. Third, a harmonized approach and harmonisation measures for biomass resource assessments are developed. Fourth, the harmonised approach and harmonisation measures are than applied to several case studies. At this moment, phase one and two are nearly completed and in this paper some preliminary results are presented. Phase one and two show that the results of existing biomass resource assessments vary widely. The variation in results is mainly caused by the approaches and methodologies that are applied. Especially the assumptions that are used to determine the future availability of land for energy crop production are crucial. A key parameter is the efficiency of agricultural production systems, which determines the availability of land that is not needed for the production of food. A crucial gap in data and knowledge is related to the availability and productivity of degraded land, which is not investigated in any of the key studies that are included. Further, we concluded that sustainability aspects are inadequately taken into account. Generally, environmental factors are overrepresented whereas social and economic aspects are taken into account far less frequently. Regarding the environmental dimension, biodiversity and climate aspects are included more often than soil and water aspects. Regarding the social dimension, many studies account for the competition of biomass and land with food which always is given priority. Although many studies assess economic aspects, only few calculate the impact of bioenergy production on crop and food prices by integrating bioenergy production in the existing markets. We conclude that none of the approaches and methodologies is ideal, because each approach and methodology has both advantages and disadvantages.
Keywords: potential, assessment, modelling, production, European Union.

1 INTRODUCTION

Policy and decision makers in the EU have put energy policy objectives high on the agenda, including the promotion of the use of biomass as an energy source. European Community policy aims for a strong increase of renewable energy in the EU's overall energy mix (from less than 7% today to 20% by 2020) and a considerable increase of the share of biofuels in the transport sector with a target of 10% of vehicle fuel by 2020 [1].

To achieve these targets it is essential to have resource assessments that are clear, reliable and detailed enough, both for policy, e.g. for the Common Agricultural Policy (CAP), and for industry. This raises the need for reliable knowledge of the biomass potentials for energy in Europe, based on a commonly accepted, EU-wide approach to the assessments. However, biomass resource potential assessments for energy for the same geographic entity differ largely from each other [2-6]. The most important reasons for the considerable variation in the results are:

- The heterogeneity of methodologies and approaches that are used.
- The heterogeneity of datasets that are used.
- The use of different data and assumptions (due to missing empirical data) for certain aspects (e.g. conversion factors, waste fractions, yields).
- The heterogeneity of factors and assumptions

used to consider the production and utilisation of biomass, e.g. sustainability, demand and competition with other sectors.
- The heterogeneity of approaches used for the integration of technological learning curves, both in the production sector of biomass and in biomass-to-energy conversion.

Furthermore, the scope of existing biomass resource assessments vary with regard to the biomass categories considered, e.g. energy crops, forest residues or total potentials (see further Section 2.4), the scale of the analysis (e.g. local, regional and global), the timeframe of the analysis, and the type of potentials considered (see further Section 2.3). Finally, also meeting the criteria of sustainable production, as well as implementation aspects, can further limit usable biomass resources. As a consequence, different nomenclatures and categorizations, and the differing definitions of resource levels from bio-physical to implementation potential, hinder the comparability of the results of various assessments.

The overall objective of the Biomass Energy Europe (BEE) project is to improve the accuracy and comparability of future biomass resource assessments for energy by reducing heterogeneity, increasing harmonisation and exchanging knowledge. In this paper some preliminary results are presented of a review of biomass resource assessments. Specific attention thereby is paid to the impact of the use different approaches, methodologies and datasets. The emphasis is thereby especially on studies that focus on the world and on Europe. More information about the BEE project can be found on http://www.eu-bee.org/.

2 METHODOLOGY

2.1 Project structure

The BEE project consists of four phases.

1. An analysis of the similarities and differences between the various approaches, methodologies and datasets used in biomass assessments is carried out. This also includes an analysis of similarities and differences between the various approaches, the identification of possible synergies by combining various methodologies and datasets and the identification of remaining knowledge gaps and missing data for biomass assessments. The focus is thereby again on Europe, but also studies with other geographical scopes are included.

2. A detailed review is carried out of the results of existing biomass resource assessments. The objective is to provide an in-depth insight into state-of-the-art biomass resource assessments. The analysis includes a selection of biomass resource studies of Europe, but also global, national and regional are included. This analysis results in a documentation and identification of major differences and discrepancies.

3. The results of the previous two phases are used as starting point for phase three. Phase three is the development of a harmonized approach and harmonisation measures for biomass resource assessment. The harmonisation is targeted at the following issues:

- Methodological approaches to determine technical potential.
- Methodological approaches to determine cost-supply curves of biomass resources, economic and implementation potential.
- Integration of supply and demand leading to overall economic potentials.
- Methodologies to define and determine sustainable and implementation potentials.
- Data resources.
- Methodological approaches to determine biophysical and technical potentials are directed to the formulation of best practices for determination of biomass potentials at different spatial scales using earth observations, statistic info, modelling, etc. regarding the data availability (both current and near future) for various geographical scopes.

4. The harmonised approach and harmonisation measures are applied to several case studies. These illustration cases will be carried out at different geographic scales. The main illustration case will be implemented at the European level and will provide estimates both for EU-27 and the Pan-European region. These illustration cases will provide not only information on European and national biomass potentials, but also demonstrate how a biomass resource assessment using a harmonised approach can be performed. Thus, regional differences in data availability and access, as well as the latest methodological achievements or coordinated R&D, will be considered. The single resource studies will be documented using the developed documentation standard allowing a clear classification of biomass categories. The assessment of both single biomass categories and overall assessments including all categories, both at the supranational level (e.g. at the EU level) and at the national and local level, will be subject to that harmonisation. Relevant methodologies and data issues per major estimation steps for each biomass category will be analysed for improvement and harmonisation potential. Both resource assessments aimed at statistical results for an area of interest (e.g. EC-27, a single state), and assessments providing information on the spatial distribution of biomass resources in form of maps or geographic information systems will be studied.

In the remaining of this paper, the focus is the first two phases, which are currently being completed.

2.2 Selection of studies

First, a database of circa 250 bioenergy potential assessments is compiled, out of which 28 studies are selected for detailed analysis. The 28 studies are chosen so that they cover the variability found in the literature with respect to the type of biomass (see further Section 2.3), the type of bioenergy potential (see further Section 2.4) and the approach and methodology (see further Sections 3.1 and 3.2). Other selection criteria are, among others the level of advancement (the selected studies include the current state-of-the-art in the field of bioenergy potential assessments), the integration of demand and supply (studies in which the links between the demand and supply of different biomass categories are investigated are given priority above studies that focus on one type of biomass) and the inclusion of sustainably aspects (special attention is paid to studies that investigate the links between the bioenergy and various sustainability criteria are selected). The selected studies are listed in Table I.

2.3 Type of biomass

The term biomass refers to three types of biomass, which are defined as follows:

- *Forestry and forestry residues.* Forestry biomass refers to harvests from natural forests, plantations (including short rotation forestry (SRF)) and other wooded land and trees outside forests (including orchards, vineyards). Forestry residues include both primary residues, i.e. leftovers from cultivation and harvesting activities (twigs, branches, thinning material etc.) and secondary residues, i.e. those resulting from any processing steps (sawdust, bark, black liquor etc.). Tertiary residues, i.e. used wood (wood in household waste, demolition wood etc.) are considered in the category "organic waste".
- *Energy crops on agricultural land and marginal land.* Energy crops include all crops with the purpose of producing biomass for energy use (including short rotation coppice (SRC)). Marginal land is not well defined in the literature, but the term marginal generally refers to the (low) productivity of the land.
- *Agricultural residues and organic waste.* Agricultural residues is the by-product of agricultural practice (cultivation of farms and harvesting activities), labelled as "primary" and processing of agricultural products, e.g. for food or feed production, labelled as "secondary". Organic waste is divided into materials produced from houses and from industrial and trade activities. Also sludge and biogas from sewage treatment plants as well as landfill gas are considered biomass from organic waste.

Aquatic biomass (algae, seaweed, etc.) is excluded, because the potential of this type of biomass is highly uncertain and data are estimates are scarce. Peat is also excluded, since peat is not a renewable type of biomass within the timeframes that are relevant for climate and energy policies.

2.4 Type of biomass potential

An important difference between existing biomass studies is the potential that is investigated. Four types of biomass potentials are distinguished.

- *Theoretical potential*: the overall maximum amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits. In the case of biomass from crops and forests, the theoretical potential represents the maximum productivity under theoretically optimal management taking into account limitations that result from temperature, solar radiation and rainfall [7-9]. In the case of residues and waste, the theoretical potential equals the total amount that is produced.
- *Technical potential*: The fraction of the theoretical potential which is available under the regarded techno-structural framework conditions and with the current technological possibilities, also taking into account spatial confinements due to competition with other land uses (food, feed and fibre production) as well as ecological (e.g. nature reserves) and other non-technical constraints.
- *Economic potential*: The share of the technical potential which meets criteria of economic profitability within the given framework conditions.
- *Implementation potential*: The fraction of the economic potential that can be implemented within a certain time frame and under concrete socio-political framework conditions, including economic, institutional and social constraints and policy incentives. Studies that focus on the feasibility or on the economic, environmental or social impacts of bioenergy policies are also included in this category.

In theory, a fifth potential can be distinguished, which is the environmentally or ecologically sustainable potential, defined as the fraction of the theoretical potential which meets certain environmental criteria. However, the environmentally or ecologically sustainable potential is not investigated separately in the BEE project, because the environmental criteria are generally included together with other (technical, economic) constraints.

The results of the categorisation of studies are shown in Table I. It should be noted that the definitions of potentials in literature are often not fully consistent with the definitions presented above. Biomass energy assessments that focus on a certain type of potential often also include limitations that, according to the definitions above, are relevant for another type of potential. Further, several studies explicitly, or implicitly, analyse several types of potentials.

3 RESULTS

3.1 Approaches used in biomass resource assessments

Two types of approaches can be distinguished:

- *Resource-focussed assessments* investigate the bioenergy resource base and the competition between different uses of the resources, i.e. the focus is on the biomass energy supply side. Resource-focussed assessments generally investigate the theoretical and technical potentials, taking into account the demand for land and biomass for the production of food and materials as function of among others, population and income growth. Yet, environmental limitations or economic criteria are often also included; particularly the protection of biodiversity is usually included.
- *Demand-driven assessments* analyze the competitiveness of biomass-based energy systems, compared to conventional fossil fuel based energy systems as well as other renewable energy systems and nuclear energy, or estimate the production and use of biomass required to meet exogenous targets on climate-neutral energy supply, i.e. the focus is on the biomass energy demand side. Thus, demand-driven studies typically focus on the economic and implementation potentials, more than on the theoretical and technical potentials. However, some studies start with an evaluation of the feasibility of the projected use of bioenergy, via reference to other studies or by estimating the technical biomass potential. Climate and energy policies are crucial in

Table I. Details of the key studies that are selected for detailed analysis in the BEE project (TT = theoretical or technical; EI = economic or implementation; C = energy crops, F = forest and forestry residues, R = agricultural residues and W = waste).

	Key studies	Type of potential	Methodology	Time-frame	Geographical coverage, geographical aggregation of results	Biomass type	Rationale and remarks
1	Berndes and Hansson [10]	EI	Energy model	2030	EU27, regions	CFR	This study uses the Perspectives on European Energy Pathways (PEEP) model, which is also used within the VIEWLS project.
2	De Vries *et al* [11]	TT-EI	Integrated modelling	2050	World, regions	CF	Based on an IAM, namely the Integrated Model to Assess the Global Environment, which is also used in several other studies [12-14].
3	Dornburg *et al.* [15]	TT-EI	Review	2100	World	C	Particularly the analysis of the links between bioenergy and the use of biomass for food and materials and the food production, wood production for materials, biodiversity and fresh water supplies, but also the review of global biomass potentials are potentially very useful for BEE.
4	EEA [16]	TT	Statistical analysis and spatially explicit analysis	2030	EU25, countries	CFRW	Comprehensive, state-of-the-art assessment. Particularly interesting because of the methodology and approach used to include environmental criteria in biomass potentials. Statistical analysis and spatially explicit analysis are used in combination with several models (e.g. EFI-GTM, EFISCEN, CAPSIM, HECTOR).
5	EEA [17]	TT	Statistical analysis and spatially explicit analysis	2030	EU25, countries	F	Comprehensive, state-of-the-art assessment of forestry biomass potentials. Particularly interesting because of the methodology and approach used to include environmental criteria in biomass potentials. The use of forest biomass for other purposes is modelled using the EFISCEN model of the European Forest Institute (EFI), but several other models are also used. This report includes supporting of EEA [16].
6	EEA [18]	TT	Statistical analysis and spatially explicit analysis, plus several models	2030	EU25, countries	C	Comprehensive, state-of-the-art assessment of potentials from energy crops and agricultural residues and waste. Particularly interesting because of the methodology and approach used to include environmental criteria in biomass potentials and the scenarios related to agricultural land use. Several models are used to model the availability of land for energy crop production. This report includes supporting of EEA [16].
7	Ericsson and Nilsson [4]	TT	Statistical analysis	2040	EU27	FRW	This study is a representative study based on statistical analysis and partially includes a review of biomass energy assessments in Europe.
8	Eickhout and Prins [12]	TT-IE	Integrated assessment	2030	EU27, countries	CFRW	This study describes the technical details of the EURURALIS project. The goal of EURURALIS is, among others, to investigating the integrated impact on socio-economic and environmental indicators as well as on land-use that is assessed for different possible and plausible scenarios. The production and use is thereby one scenario variable. This study uses the Integrated Model to Assess the Global Environment, combined with the economic model LEITAP. See also http://www.eururalis.eu/
9	Gordon *et al* [19-22]	TT-IE	Statistical analysis, spatially explicit analysis, cost supply analysis	2015	USA	CFRW	Detailed state-of-the-art resource-focussed study. Especially interesting because of the many factors that are taken into account when assessing the potentials.
10	Hoogwijk *et al.* [13]	EI	Integrated assessment	2100	World, regions	CFRW	Based on Integrated Model to Assess the Global Environment (IMAGE), which is an integrated assessment model. This study includes the Special Report on Emission Scenarios (SRES) of the IPCC.
11	IEA [23-25]	EI	Energy model	2050	World, regions	CFRW	The World Energy Outlook report series is an influential series of publication.
12	Link *et al.* [26]	TT-EI	Energy model		EU25, countries	C	This study uses the EUFASOM model as described in detail in Schneider and Schwab [27]. See also Kraxner *et al.* [28].
13	Masera *et al.* [29]	TT	Statistical analysis and spatially explicit analysis	2010	National	FR	Wood fuel Integrated Supply/Demand Overview Mapping (WISDOM), a spatially-explicit planning tool which combines resource focused and demand driven approaches to highlight and determine wood fuel priority areas or "wood fuel hot spots".
14	Obersteiner *et al.* (2006)	TT-EI	Integrated assessment	2120	World	FR	This study applied an innovative analytical framework to estimate the joint production of biomass and carbon sequestration from afforestation and reforestation activities. The analysis is based on geographical explicit information in combination with the IPCC-SRES scenarios. This study uses a similar approach and methodology as Hoogwijk *et al.* (2004).

15	OECD (2006)	EI	Energy model	2015	World, regions, major countries	C	This study uses three state-of-the-art economic models, Cosimo, the OECD World Sugar Model and Aglink. Only first-generation biofuels are included.
16	Paustian *et al.* [30]	TT-EI	Review	2015	USA	CR	The comparison of bioenergy with other GHG mitigation strategies in agriculture is very useful, which are partially discussed based on a review of bioenergy potentials and other relevant studies on e.g. carbon sinks.
17	Perlack *et al.* [31]	TT	Statistical analysis, Cost supply assessment	2050	USA	CFRW	Particularly the three scenarios that vary with respect to agricultural production systems are interesting, but also with respect to the general approach and the many factors that are considered.
18	REFUEL [32]	TT-EI	Spatially explicit analysis, Cost supply assessment	2030	EU25, NUTS 2	CFRW	State-of-the-art comprehensive and complex assessment, based on several state-of-the-art models and tools, such as the BioTrans model of the Netherlands Energy Centre, the Agro-Ecological Zones Model of the International Institute of Applied Systems Analysis (IIASA), the Perspectives on European Energy Pathways (PEEP) model of Chalmers University. The assessment also includes an assessment of socio-economics and implementation barriers. Results of the REFUEL project include a final report [32], plus more than 15 supporting reports. See further http://www.refuel.eu/refuel-project/
19	RENEW [33, 34]	TT-EI	Statistical assessment, Cost supply assessment	2020	EU25, countries, regions, NUTS 2	CFRW	The RENEW project includes an assessment of the theoretical, technical and economic potential of woody biomass. Also the environmental effects are investigated. The potential of energy crops is investigated via scenario analysis that varies with respect to the production system. Only lignocellulose biomass is included. EU funded research project. See also http://www.renew-fuel.com/
20	Royityanskiy *et al.* [35]	TT-EI	Integrated assessment	2100	World	FR	This study applies the Integrated Model of Forestry and Alternative Land Use (DIMA) to quantify the economic potential of global forests (i.e. reforestation, deforestation, or conservation and management options) in the case of different IPCC-SRES scenarios.
21	Scenar 2020 [36]	N/A	N/A	N/A	EU25, NUTS 2	C	State-of-the-art scenario analysis of agricultural land use in the EU. Three economic models (LEITAP, ESIM, CAPRI), a more ecological-environmental based model framework (IMAGE) are used, as well as a land use allocation model (CLUE-s) to disaggregate the outcomes to the landscape level. The consumption of biofuels is an exogenous scenario variable. Particularly relevant for modelling agricultural land use. Three reports are available, a final report and a technical report of two volumes. See further http://ec.europa.eu/agriculture/publi/reports/scenar2020/index_en.htm
22	Siemons *et al.* [37]	TT-EI	Statistical assessment, Energy model	2020	EU27, countries	CFRW	Very comprehensive assessment: detailed analysis of technical potentials, followed by analysis of economic potentials, using the SAFIRE energy model, based on scenario analysis, that vary among other with respect to the price of CO2 credits.
23	Sims *et al.* [38]	TT	Statistical assessment	2050	World, regions	C	Review assessment.
24	Thrän *et al* [39]	TT-EI	Statistical assessment,	2020	EU 28, countries	CRFW	Analysis of technical potentials, which are compared with the demand for biomass energy based on policy driven scenarios. Also includes GHG emissions.
25	VIEWLS [40]	TT-EI	Statistical Assessment, Cost Supply Assessment, Energy Model	2030	EU, east and central EU countries only	CFRW	Biomass energy implementation scenarios are compiled based on a.o. the environmental and economic performance of various biomass energy supply chains. See also [41] [42]
26	Von Brown [43]	N/A	Impact assessment	2025	World, countries	C	Assessment of the impact of bioenergy policies on food prices using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model. The International Food Policy Reseach Institute (IFPRI) is a respected research institute that publishes state-of-the-art projections of food production and consumption.
27	Ten Brink *et al.* [15]	N/A	Integrated assessment	2100	Global	C	This study investigates policy options that can have a major positive or negative impact on biodiversity. The use of biofuels is one of the policy options. The innovative element of this study is the analysis of net biodiversity impacts of bioenergy, i.e. the impacts of increased conversion of natural vegetation to agricultural land vs. the impact of reduced biodiversity losses due to reduced GHG emissions. This study incorporates three models, namely an agricultural trade model (Global Trade Analysis Project or GTAP), the Integrated Model to Assess the Global Environment (IMAGE) and a global biodiversity assessment model (GLOBIO). See also Van Vuuren *et al.* (2006) and Section 5 in Dornburg *et al.* (2008).). In Dornburg *et al* (2008), this study is referred to as CBD & MNP (2007).
28	Kline *et al.* [44]	TT-EI	Statistical analysis, Cost supply assessment	2027	Countries	CFR	Detailed, thorough analysis (co-authored by Perlack, so potentially a similar approach and methodology as in Perlack *et al.* (2005).

demand-driven assessments, but also the assumptions about population growth, economic development, technology development and the energy intensity of economic activities are important variables. Population growth and economic development are principal factors behind overall energy end-use. Further, some other studies use agricultural economics models to investigate the economics of the use of conventional agricultural crops for energy production.

- *Integrated modelling assessments* use integrated assessment models (IAMs), which are designed to assess policy options for climate change. IAMs include mathematical correlations between the socio-economic drivers of economic activity and energy use, which lead to emissions and other pressure on the environment leading to environmental changes, which lead to physical impacts on ecosystems, which lead to socio-economic impacts and eventually return to cause changes in the socio-economic drivers. IAMs are unique because they combine information about economic, energy and climate variables across various scientific disciplines, time, and spatial scales. IAMs are particularly useful for the purpose of addressing policy questions, mostly by means of scenario analysis. Often IAMs consist of several linked models and tools.

The approaches used in the 28 selected studies are shown in Table I.

3.2 Methodologies used in biomass resource assessments

In this subsection the methodologies used in the 28 selected studies are categorised, described and discussed. Table I shows categorisation of the 28 studies according to the methodologies that are used. A generalised overview of the different combinations of approaches and methodologies that are found is presented in Table II. The following methodologies are identified:

- *Statistical analysis*. The least complicated studies estimate the energy potential based on assumptions about the yield per hectare, based on expert judgement, field studies or a literate review, in combination with assumptions about the fraction of land available for energy crops or the fraction of forest biomass that is available for energy production to account for the use of land and biomass for other purposes and environmental or social barriers. Often results from other studies are thereby used, but some several other studies use scenario analysis. The potential of residues and waste is generally calculated based on projections of the production of food and wood, multiplied by residue and waste generation coefficients and multiplied by a factor that account for the fact that many residues and wastes can not be collected in practice. Some studies also assess the use of residues for other purposes. This category of analysis is referred to as statistical analysis, because data for this type of analysis start from statistics.
- *Spatially explicit analysis.* The most advanced resource-focussed assessments include spatially explicit data on the availability of land and forests in combination with calculations of the yields of energy crops and forests, based on data on crop growth models that use spatially explicit data on climate, soil type and crop management. The availability of agricultural land for energy crop production is estimated taking into account the use of land for the production of food and other purposes, using scenario analysis that take into account agricultural policies, technological development, population growth, income growth, and so forth. A type of land that has received special attention in our research is degraded and marginal land, because this type of land is partially or not suitable for conventional agriculture. So the use of these types of areas does not lead to competition with food. The same approach is applied when estimating the potential of forestry and forestry residues and agricultural residues and organic waste.
- *Cost-supply analysis.* Cost-supply analysis start from a bottom up analysis of the potential, based on assumptions on the availability of land for energy crop production, including crop yields, or based on assumptions on the availability of forestry and forestry residues. The demand of land and biomass for other purposes and environmental and other (social, technical) limitations are included, ideally by scenario analysis. The resulting bioenergy cost-supply curves are than combined with estimates of the costs of other energy systems or policy alternatives, often with specific attention for policy incentives (e.g. tax exemptions, carbon credits, and mandatory blending targets). A nice examples is the REFUEL project [32].

Table II. An overview of the combinations of approaches and methodologies that are used in existing biomass energy assessments to investigate different types of biomass potentials.

General approach	General methodology	Type of biomass potential	
		Theoretical-technical	Economic-implementation
Resource-focussed	Statistical analysis	Yes	No
Resource-focussed	Spatially explicit analysis	Yes	No
Demand-driven	Cost-supply analysis	No[a]	Yes
Demand-driven	Energy-economics and energy-system model analysis	No	Yes
Integrated assessment modelling	Integrated assessment model analysis	Yes[b]	Yes[b]

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

- *Energy-economics and energy-system model analysis and other economic models.* Several studies use energy-economics and energy-system models, but also other economic models are sometimes applied. Energy-economics and energy-system models mimic the dynamics of the demand and supply of energy, including bioenergy, by means of investigating economic and non-economic correlations. Most energy-economics and energy system models use scenarios, whereby typical scenario variables include the fundamental drivers of energy demand and supply, such as population growth and income growth, as well as technological developments, policy incentives. These variables are often integrated into a coherent set of scenario assumptions. Some models also include greenhouse gas and energy balances for different energy systems, which allows for the optimisation of costs towards greenhouse gas reduction or energy security target.
- *Integrated modelling assessments.* See Section 3.1.

3.3 Energy crops on agricultural land and marginal land

Here a comparison of results for the availability of land for energy crops in the EU15 is presented. More results will be made available in the future. All studies indicate considerable amount of agricultural land potentially available for energy crops in the EU. Figure 1 shows the land available for energy crops in selected studies and scenarios. The comparison shows that variations between results are growing in future projections. The lowest potential is estimated by Thrän *et al* [39] in case of the environmentally oriented scenario and in the RENEW project [33, 34]. Values start from around 4 Mha in 2000 to between 14 and 17 Mha. The highest estimates are given in REFUEL [32], in case of the 'high estimate' scenario. The highest value is about 79 Mha in 2040, which is calculated by Ericsson and Nilsson [4]. This estimate gives extremely high potential also in most countries and is a consequence of the simple assumption that 0.24 ha per capita is needed for food production and rest of land may be managed for energy crops. When the results for the EU27 are disaggregated into two groups, namely the EU15 (old EU member states) and EU12 (new EU member states), the variability in results appears to be different for these two regions. The variability of results is significantly lower for EU15 than for EU12. The estimates by Thrän *et al* [39] for EU15 in 2020 are an exception and the same estimates are rather moderate in results for EU12.

Further, an analysis of national results also reveals interesting results. Thrän *et al* [39] projects no potential for energy crops in case of the environmental scenario in Italy, the Netherlands, Portugal, Slovenia and United Kingdom. However, in EEA [16] opposite trends are projected for some countries. Despite of growing trend in averages in Greece, Finland, Portugal and Sweden the trend of land availability is considerable decreasing. In some countries like Spain, France, Germany, United Kingdom, Poland, Bulgaria and Romania the differences are higher than in other countries.

The assumption made by Ericsson and Nilsson [4] of 0,24 ha per capita for food also gives interesting results. In most countries land availability estimated with this assumption and methodology results in the highest value. There are some exception, countries like Belgium, Germany and the Netherlands, where there is no land available according to this assumption.

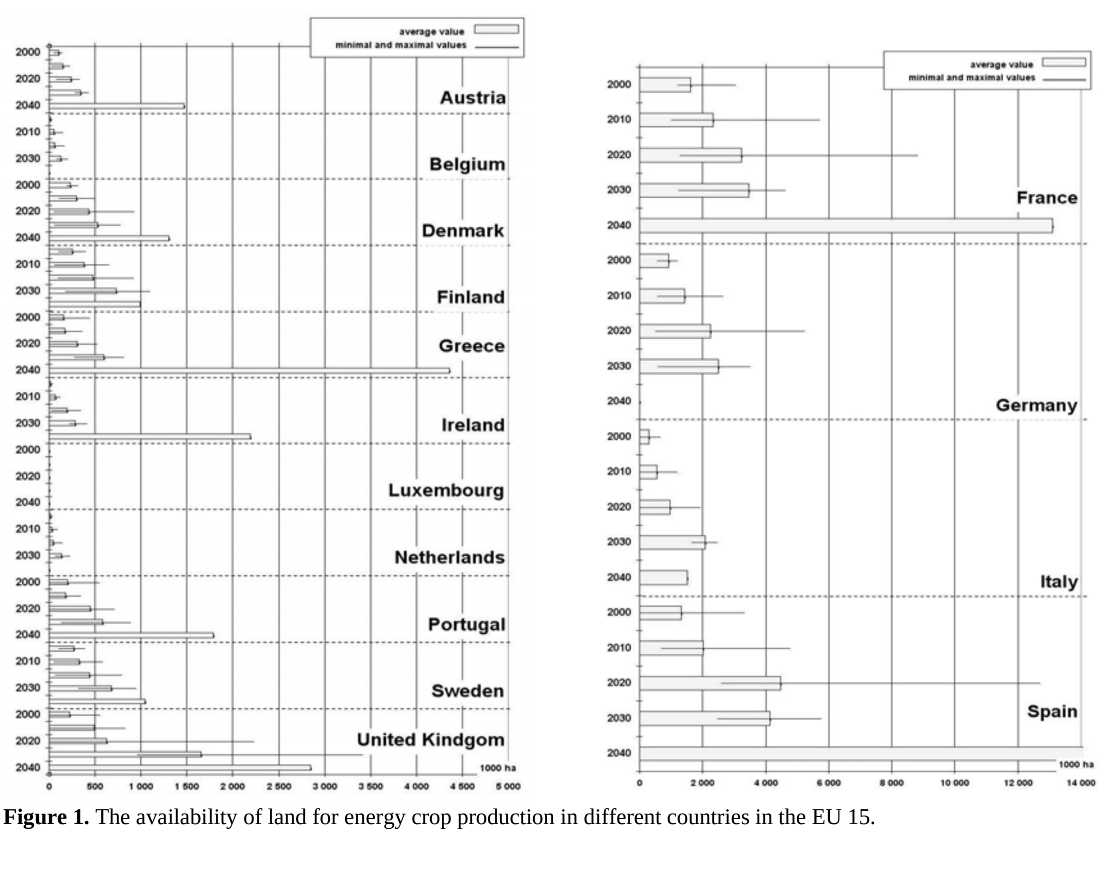

Figure 1. The availability of land for energy crop production in different countries in the EU 15.

3.4 Forestry and forestry residues

Figure 2 provides an overview of biomass potentials of forestry and forestry residues of some of the studies that are investigated. More results will be made available in the future.

These potentials reported by Thrän *et al.* [39] and by Ericsson and Nilsson [4] amount to 2.9 EJ/year for the year 2000, which decreases to 2.2 EJ/year for 2030. The numbers refer to technical potentials which are derived from forest and logging residues as well as additional feelings in the case of Thrän *et al.* [39]. The figure for 2030 given by Ericsson and Nilsson [4] includes forest residues and forest industry by-products under a scenario of high biomass removal. Thrän *et al.* [39] assume that future demand for roundwood will increase stronger than the amount of fellings. This results in a decrease of the estimated bioenergy potential between 2000 and 2030. Ericsson and Nilsson give a further estimate for the technical potential in 2030 under a scenario of low biomass removal which is 0.5 EJ/year lower than the number stated above. Estimates by Ericsson and his colleague for the years 2010 and 2020 are lower than those reported by other studies.

Technical potentials with consideration of environmental sustainability are estimated by EEA [16, 17] and RENEW [33]. When considering complementary fellings (wood balance fraction) based on unused forest growth, the given figures vary between 0.7 EJ/year in the year 2000 [33], 2.2 EJ/year in 2010 [16, 17], 0.8 – 2.1 EJ/year in 2020 [16, 17, 33] and 2.1 EJ/year in 2030 [16, 17]. While the results of RENEW [33] are based on EU27 (excl. Malta and Cyprus), the EEA [16, 17] estimates refer only to 21 EU countries. The given sustainable potentials in RENEW [33] seem low when considering the fact that forest residues, thinnings, roots, stumps and additional fellings (wood balance fellings) are included. However, the study accounts for different factors which reduce the biomass potential considerably. These factors reflect the fraction of woody biomass used for industry and the fraction which cannot be removed for ecological or other reasons. Furthermore, only forest available for wood supply is considered. In contrary, the environmentally sustainable potentials listed in EEA [16, 17] seem rather high which can be explained by the fact that they (at least in the ‘Maximum scenario’) do not only cover regular forestry residues, but also complementary fellings and residues from these fellings. Under a scenario considering protected forest areas and biodiversity, the potentials given by EEA [16, 17] are lower: 1.8 EJ/year in 2010 and 1.6 in 2020 and 2030. Furthermore, without the consideration of complementary fellings the numbers are much lower, equalling only 0.6 EJ/year in 2010 and 0.7 EJ/year in 2020 and 2030. The results of the study represent the average resource potentials per unit of forest area in a pixel based map of the 'environmentally compatible' resource potentials (technical potential). It was then aggregated from 1x1km to NUTS 2 level for 21 EU countries. The estimated potentials by EEA [16, 17] do not differ much in time, depending on scenario the potential is 0.6 – 2.2 EJ in 2010 and 0.7 – 2.1 EJ in 2030.

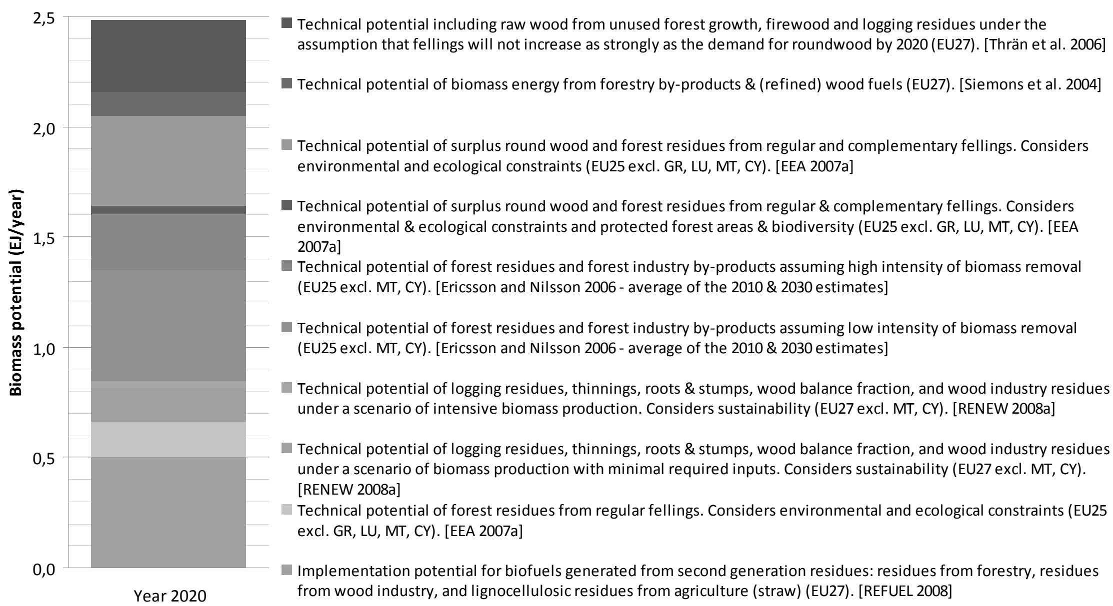

Figure 2. Potentials estimated for year 2020, the potentials should be measured from the x-axis to the upper edge of the respective color.

The implementation potential as reported by REFUEL [32] for the EU27 represents the lowest estimates with 0.1 EJ/year in 2010 and an increase to 0.5 EJ/year in 2020 and 2030. These estimates cover second-generation biofuels not only from forestry residues and wood industry by-products, but also from lignocellulosic agricultural residues such as straw. However, no complementary fellings are considered here. In contrast to REFUEL [32] the implementation potential given by Siemons *et al.* [37] for the EU27 is much higher and amounts to 1.8, 2.0 and 2.2 EUJ/year in the years 2000, 2010 and 2020, respectively. These numbers cover bioenergy derived from forest by-products and wood fuels.

3.51 Agricultural residues and organic waste

Results are currently not available. More detailed results will be made available in the future.

4 DISCUSSION AND CONCLUSIONS

This study also reveals that a large variety of approaches and methodologies are used. Each approach and methodology has specific (dis)advantages, which are summarised in Table II. Statistical analyses only offer very limited possibilities to account for environmental or social needs as they only can be included via a general reduction factor. This factor usually refers to the average and thus cannot reflect specific local conditions. Static spatially explicit analyses are more adequate to reflect a biomass potential that is adapted to local or regional circumstances which makes it much easier to take into account environmental or social aspects. Here, different layers containing relevant local soil, water and climate information can be combined. Static spatially explicit analyses, as statistical analyses, do not offer any possibility to include feedback mechanisms, trade-offs and synergies between the three sustainability dimensions. Furthermore, it is not possible to adequately account for the economic dimension. Several studies use partial or complete equilibrium models to estimate the contribution of biomass energy to the energy supply mix. A key disadvantage of this type of studies is that the results are not validated with data about the availability and productivity of land for energy crop production. Moreover, energy models are especially suitable to investigate the costs and economic potential of biomass energy in relation to other energy sources, but these models do not allow estimates of the impacts on food and fibre markets. For that, agricultural economics models can be used, but these models typically are not linked with energy models and energy crops that are currently not produced on a large scale are usually not included.

In theory, integrated assessment model would be best suited to include all different aspects and facets of sustainability of biomass energy production, including all relevant feedback mechanisms as well as synergies and trade-offs. IAMs thereby allow for the use of multi-dimensional scenarios, whereby a large variety of assumptions for the different parameters (population growth, economic growth, food consumption, environmental policies, trade patterns etc.) are consistent. Integrated assessment models combine bottom up data on land use and productivities with energy models and agricultural economics models. Two examples of this type of models are the forest and agricultural sector optimization (FASOM) model [26] and the Integrated Model to Assess the Global Environment (IMAGE). IAMs thereby provide an appropriate framework to estimate the potential of biomass energy and the impacts on agricultural markets and food security, GHG emissions and land use. An important handicap is the complexity of these models, which makes these models relatively untransparent, expensive to develop and user unfriendly in operation. Moreover, it has to be taken into account that with the integration of separate models, uncertainties due to data gaps or insufficient modelling will be transferred to the IAM.

Further, the review of 28 biomass resource assessments has also shown that sustainability aspects only inadequately are taken into account in existing biomass potential assessments. There is no study that includes all three dimensions of sustainability (environmental, social, and economic) nor is there a study that covers all relevant aspects of one dimension. Generally, environmental factors are overrepresented whereas social and economic aspects are taken into account far less frequently. Regarding the environmental dimension, biodiversity and climate aspects are included more often than soil and water aspects. Regarding the social dimension, many studies account for the competition of biomass and land with food which always is given priority. Although many studies assess economic aspects, only few calculate the impact of bioenergy production on crop and food prices by integrating bioenergy production in the whole market system.

Table II. The advantages and disadvantages of different methodologies used in existing biomass resource assessments.

Methodology	Disadvantages	Advantages
Statistical analysis	No economic mechanisms, no spatially explicit information, no integration, based on crude assumptions, sometimes inaccurate	Simple, transparent, cheap, data are easily available
Spatially explicit analysis	No economic mechanisms, no integration, complex tool	Spatially explicit, transparent, based on data on land use and climate, soil characteristics
Cost-supply analysis	No economic mechanisms, no integration	Cheap, transparent
Energy-economics /energy-system model analysis	No integration with other markets (agricultural markets), not spatially explicit, no integration, no validation based on bottom-up data on land use and climate, soil characteristics, untransparent	Economics mechanisms are included
Integrated assessment model analysis	Complex, untransparent, expensive, results are difficult to interpret, model is user unfriendly, level of details is limited	Integrated/consistent, spatially explicit

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