



Global Potential of Sustainable Biomass for Energy

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ABSTRACT

There is no doubt now that energy is fundamental to our development. Global energy trends such as higher energy demand and prices, big differences across regions, structural changes in an oil and gas industry increasingly dominated by national companies, the prospect of irreversible climate change, as well as demand for energy security all highlight the need for a rapid transition to a low-carbon, efficient and environmentally benign energy system. The search for energy alternatives involving locally available and renewable resources is one of the main concerns of governments, scientists and business people worldwide.

As researchers tackle problems according to global trends, an overwhelming body of research focusing on bioenergy in relation to other types of renewable energy might illustrate the role bioenergy has as the most important renewable energy source for the near and medium-term future. Thus, analyzing the amount of existing research, we found that about 50% (4,911 records) of 9,724 renewable energy records available were bioenergy records. We also found that publications on each of the four main sources of biomass (agriculture, forest, waste and other) represent about one quarter of the 4,911 bioenergy records retrieved.

Biomass – the fourth largest energy source after coal, oil and natural gas - is the largest and most important renewable energy option at present and can be used to produce different forms of energy. As a result, it is, together with the other renewable energy options, capable of providing all the energy services required in a modern society, both locally and in most parts of the world. Renewability and versatility are, among many other aspects, important advantages of biomass as an energy source. Moreover, compared to other renewables, biomass resources are common and widespread across the globe.

The sustainability potential of global biomass for energy is widely recognized. For example, the annual global primary production of biomass is equivalent to the 4,500 EJ¹ of solar energy captured each year. About 5% of this energy, or 225 EJ, should cover almost 50% of the world's total primary energy demand at present. These 225 EJ are in line with other estimates which assume a sustainable annual bioenergy market of 270 EJ. However, the 50 EJ biomass contributed to global primary energy demand of 470 EJ in 2007, mainly in the form of traditional non-commercial biomass, is only 10% of the global primary energy demand. The potential for energy from biomass depends in part on land availability. Currently, the amount of land devoted to growing energy crops for biomass fuels is only 0.19% of the world's total land area and only 0.5-1.7% of global agricultural land. Although the large potential of algae as a resource of biomass for energy is not taken into consideration in this report, there are results that demonstrate that algae can, in principle, be used as a renewable energy source.

From all of these perspectives, the evidence gathered by the report leads to a simple conclusion: Biomass potential for energy production is promising. In most cases, shifting the energy mix from fossil fuels to renewables can now be done using existing technology. Investors in many cases have a reasonably short pay-back because of good availability of low-cost biomass fuels. The latter is of course dependant on local incentives, however. Overall, the future of bioenergy is also to a large extent determined by policy. Thus, an annual bioenergy supply covering global energy demand in 2050, superseding 1,000 EJ, should be possible with sufficient political support.

¹ 1 EJ = 10¹⁸ J

Global production of biomass and biofuel is growing rapidly due to the increasing price of fossil fuels, growing environmental concerns, and considerations regarding the security and diversification of energy supply. There are many scenarios that predict a high potential for biomass in the future. There have also been many studies performed in recent decades to estimate the future demand and supply of bioenergy. Overall, the world's bioenergy potential seems to be large enough to meet the global energy demand in 2050. The current stock of standing forest is a large reservoir of bioenergy and in line with the theoretical potential of biomass energy. However, most of the research studies on biomass potentials ignore existing studies on demand and supply of wood, despite the extensive literature and data on the subject. Taking into account data from a variety of international sources, rough estimates of the energy production potential of woody biomass from forestry show that, in theory, the demand for wood fuel and industrial roundwood in 2050 can be met, without further deforestation, although regional shortages may occur.

However, the shift in the energy mix requires much more investment in infrastructure, equipment and in some cases R&D. Moreover, a prerequisite for achieving bioenergy's substantially high potential in all regions is replacing current inefficient and low-intensive management systems with best practices and technologies.

EXECUTIVE SUMMARY

Bioenergy is the most important renewable energy option, both at present, as well as in the near- and medium-term future. It will therefore play a crucial part in integrated systems of future energy supply and will be a valuable element of a new energy mix. Biomass has the potential to become the world's largest and most sustainable energy source and will be very much in demand.

This report is a synthesis of information and its relative distribution in the bioenergy field, obtained through a review of global data and literature. The report contains two main sections organized around bioenergy issues, including an information survey and a literature review. The overwhelming amount of research focused on bioenergy compared to all other renewable energy types illustrates the role of bioenergy as the most important renewable energy source for the near- and medium-term future. Based on existing literature, the review seeks to identify some key trends and shifts in bioenergy topics related to the sustainable potential of global biomass.

Global energy trends, the prospect of irreversible climate change and demand for energy security highlight the need for a rapid transition to an energy system that is low-carbon, sustainable, efficient and environmentally benign. The search for energy alternatives involving locally available renewable resources is one of the main concerns of governments, scientists and business people worldwide. Bioenergy is attractive at all stages of development due to its potential integration with a wide range of development strategies around the world. Moreover, bioenergy is based on resources that can be utilized on a sustainable basis all around the world and can thus serve as an effective option for the provision of energy services. In addition, the benefits accrued go beyond energy provision, creating unique opportunities for regional development. Biomass – the fourth largest energy source after coal, oil and natural gas - is the largest and most important renewable energy option at present and can be used to produce different forms of energy carriers, thus providing all the energy services required in a modern society, both locally and in most parts of the world. Renewability and versatility are, among other things, important advantages of biomass as an energy source. Moreover, compared to other renewable resources, biomass is common and widespread across the globe.

The annual global primary production of biomass is equivalent to the 4,500 EJ of solar energy captured each year. The potential of global biomass as a sustainable energy source is widely recognized. Thus, at present, a bioenergy supply of 270 EJ, possible on a sustainable basis, can cover almost 50% of the world's total primary energy demand. Moreover, this amount of bioenergy can be achieved by only 6% of the annual global primary production of biomass. The potential for energy from biomass depends in part on land availability. Currently, the amount of land devoted to growing energy crops for biomass fuels is only 0.19% of the world's total land area and only 0.5-1.7% of global agricultural land. A mere 10% increase in the efficiency of biomass production through irrigation, manuring, fertilizing and/or improved management through the cultivation of idle land, would create energy equivalent to the total current global energy demand. The current forest standing stock is a large reservoir of bioenergy and in line with the theoretical potential of biomass energy. Furthermore, the world has access to a huge amount of unutilized biomass through harvesting algae. Currently, there is no algae exploitation taking place. However, this report doesn't deal with potential of algae as a source of bioenergy. From all of these perspectives, the evidence gathered by the report leads to a simple conclusion: the potential of biomass for energy production is promising. Shifting the energy mix from fossil fuels to renewables can now in most cases be done using best practices and existing technologies. Investors in many cases have a reasonably short pay-

back because of good availability of low-cost biomass fuels. The latter is of course dependant on local incentives, however.

There are a number of scenarios predicting the future potential of biomass. There have also been many studies performed in recent decades to estimate the future demand and supply of bioenergy. However, if we compare an upper limit of the total global bioenergy production potential in 2050 of 1,135 EJ, that can come available as energy supply without affecting the supply of food crops, with the highest scenarios on the global primary energy demand in 2050 of 1,041 EJ, we see that the world's bioenergy potential is large enough to meet global energy demand in 2050. Unfortunately, this information is not part of the public consciousness. Supplying the public with important information about bioenergy can equip them to then put pressure on politicians to create a framework for increasing the speed with which bioenergy solutions are implemented.

The sustainable use of biomass as an energy source requires comprehensive management of natural resources such as land and water. Unsustainable biomass production would erode the climate-related environmental advantage of bioenergy. It's more important than ever to reliably demonstrate that the advantages of biofuels exceed the cost of the potential environmental damage caused by their production. Therefore, sustainable development of biomass and biofuels is the major challenge in increasing the production of biomass and biofuels. Criteria to ensure the sustainable production of biomass are urgently needed.

There are international efforts underway to regulate the production and trade of bioenergy by establishing sustainability criteria. Sustainability can be supported by certification of substrates' origin. Certification is judged to be the most suitable instrument for the development of sustainable bioenergy systems and further development and implementation of certification systems will be an important tool.

PREFACE

This report is a synthesis of information and its relative distribution in the bioenergy field, obtained through a review of global data and literature. The report contains two main sections, organized around bioenergy issues including an information survey and references (comprehensive list of records that share factors of “Certification” and “Certification and Sustainability” within renewable bioenergy results) and a literature review of bioenergy potential. Based on a review of existing literature, the report will seek to identify some key trends and shifts in bioenergy topics related to global potential of sustainable biomass supplies. As different references used in this report sometimes use different data sources and system limits, figures from separate sources are not always compatible and comparable.

The “WORLD BIOENERGY ASSOCIATION PROJECT ON BIOENERGY, CERTIFICATION CRITERIA, QUANTIFYING AND SUSTAINABILITY CRITERIA & BIOENERGY VERSUS FOOD, LAND-USE, AND WATER SUPPLY” makes up the framework for this report. The project partners are the Swedish University of Agricultural Sciences, Department of Energy and Technology and the World Bioenergy Association (WBA). The original project structure was changed somewhat along the way in order to be more efficient. The upgraded project structure was agreed upon in a document dated October 9th, 2009.² The updated structure of the project encompasses three position papers and related background material. The three papers are entitled “Global potential of sustainable biomass for energy”; “Certification criteria for sustainable biomass for energy”; and “Biomass for energy versus food and feed, land use analyses and water supply”.

Much of the improvement in this opening report has been the result of constructive discussions with Mr. Kent Nyström, President of WBA. Important comments on the manuscript have also helpfully been provided by other members of the WBA board, including Mr Andrew Lang, SMARTtimbers Cooperative Ltd. The Wood Energy Group, Australia; Mr. Douglas Bradley, Canadian Bioenergy Association (CanBio) & Climate Change Solutions, Canada; Dr Heinz Kopetz, European Biomass Association & Austrian Biomass Association, Austria; Mrs Jennipher Handoondo, Zambia National Farmers Union’s Oil Seed Commodity Unit; Prof. Judi W. Wakhungu, African Centre for Technology Studies (ACTS), Kenya; Mr Kai Johan Jiang, Dragon Power Group, Co., Ltd., P.R. China; Prof. S.C. Bhattacharya, International Energy Initiative, India; Dr Tetsunari Iida, ISEP - Institution for Sustainable Energy Policies, Japan; and Mr William Holmberg, ACORE, USA. Important comments have also come from Assistant Prof. Pål Börjesson, Environmental and Energy Systems Studies, Department of Technology and Society, Lund University, Sweden; Mr Marcos Martin, AVEBIOM, Spain; Mr Kjell Andersson and Ms Karin Haara both Svebio, Sweden. The authors furthermore wish to thank SLU department colleagues Dr Serina Ahlgren, Prof. Tord Johansson, Ms Sofia Bryntse and Mr Gunnar Larsson for sharing photographs for the cover and Mr Olle Olsson for providing important data.

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² Structure for the project “WBA Bioenergy Project on Criteria, Quantification and Land Use” – an agreement made between the partners

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I. INTRODUCTION

Everything, in essence, is about energy. There is no doubt now that energy is fundamental for our development (e.g., Dias et al., 2004). Energy is vital for the internal and external security of a country and energy issues are at the core of social, environmental and economic security challenges.

However, the economic implications of energy shortage are not well understood. The key role that natural resources, energy and environmental services play in determining economic growth has been underestimated within neoclassical economy. Moreover, the quantification of a direct link between energy use and economic and social development can be elusive (e.g., Giampietro, 2008). At least since the 1950s, it has been clear that factors other than capital and labor must be responsible for most economic growth (Ayres R.U. in Barbir & Ulgiaty, 2008). Cleveland et al. (2000) suggest that only accounting for energy quality reveals a relatively strong relationship between energy use and economic output. However, the “quality” of energy sources and energy forms is not substantive and this entails that different forms of energy cannot be easily substituted for each other or aggregated into an overall index (Giampietro, 2008).

The search for energy alternatives involving locally available renewable resources is one of the main concerns of governments, scientists and business people worldwide. Biomass – the fourth largest energy source after coal, oil and natural gas - is currently the most important renewable energy option.

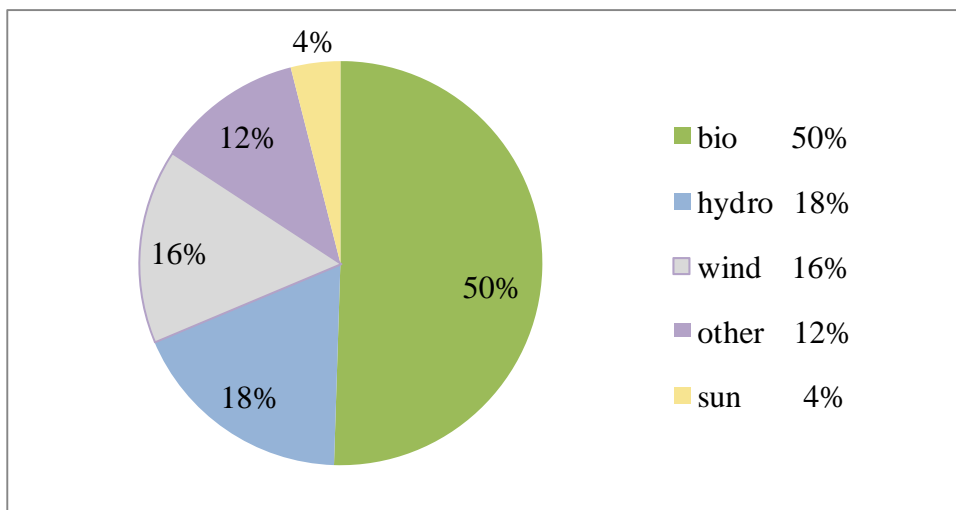
II. INFORMATION SURVEY

“How well is bioenergy represented, as well as different criteria, within scientific literature on renewable energy?” In order to answer this question, we used the ISI Web of Knowledge research databases.

ISI Web of Knowledge products are high-quality research databases. ISI Web of Knowledge covers 256 disciplines and delivers access to journals, conference proceedings, patents, websites, chemical structures, compounds and reactions in a unified platform for access to objective content that integrates all data and search terms together allowing users to find all relevant items with one search - regardless of which database in which it originated. Fully indexed and searchable, it turns raw data into powerful knowledge by combining renowned multidisciplinary databases with content-specific selections and tools. High standard of content assures users of superior results that cannot be matched by a free search engine or less selective database.

The bibliography found using the ISI Web of Knowledge All Databases (ISIWOKAD) contains materials collected in August 2009 while reviewing the literature connecting bioenergy with environmental sustainability and certification schemes. We have followed all applicable search rules when creating search queries. The bibliography is designed to help answer the question “How well are different criteria represented within scientific literature on renewable energy and bioenergy?” We used the Analyze Tool to discover trends and patterns graphically.

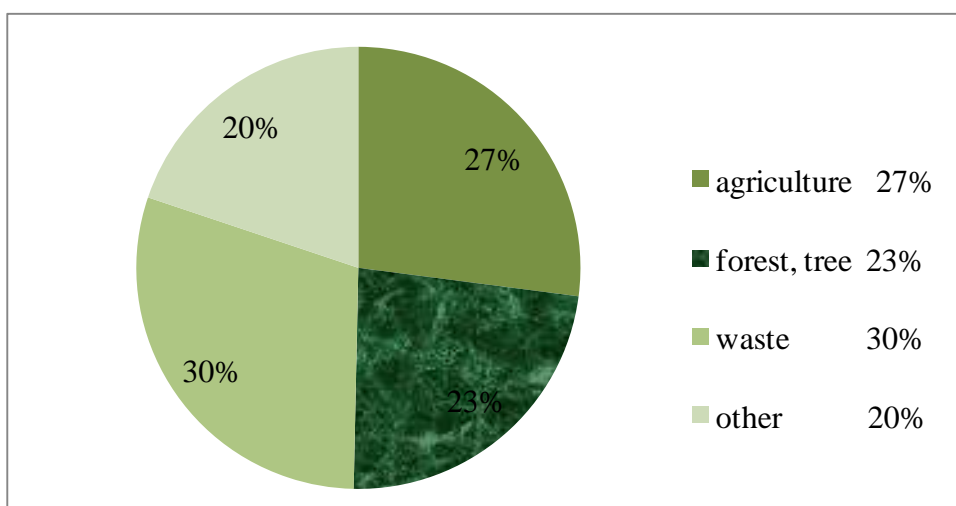
The growing interest in bioenergy is reflected in the large number of energy articles published. We found that more than 50% (4,911 records) of 9724 renewable energy records available within ISIWIKAD have bioenergy as their subject (Figure 1).



Notes: See notes for Figure 3

Figure 1. Relative distribution of 9,724 renewable energy records from ISI WEB of Knowledge All Databases refined by different energy source (Source: renewable energy Topic^a in all databases of ISI Web of Knowledge refined by energy source Topics^b, available at 2009-08-04).

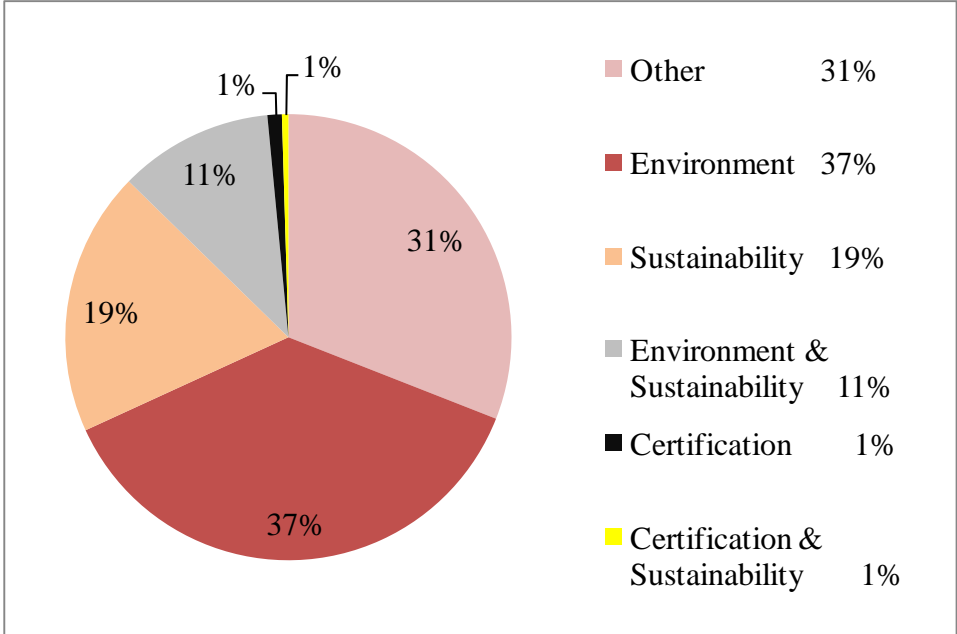
Scientific research is among the most important of human activities and considered central to a knowledge-based society. Publications are the concrete result of scientific research. As research problems are adjusted to changing global trends, the overwhelming research activity focused on bioenergy compared to all other renewable energy types illustrates the role of bioenergy as the most important renewable energy source in the near- and medium-term future. Analyzing the amount of existing research, we also found that publications on each of the four main biomass sources (agriculture, forest, waste and other) represent about one quarter of the 4,911 bioenergy records retrieved (Figure 2).



Notes: See notes for Figure 3

Figure 2. Relative distribution of 4,911 renewable bioenergy records from ISI WEB of Knowledge All Databases refined by different biomass source (Source: renewable energy Topic^a in all databases of ISI Web of Knowledge refined by bioenergy Topic^c and biomass source Topics^d).

However, refining the bioenergy records using different criteria reveals that sustainability and certification are not issues which figure prominently in existing literature on bioenergy, despite the public attention both topics receive from various stakeholders and policymakers. Of the 4,911 bioenergy records retrieved, relatively few discuss certification criteria (51 records) and certification and sustainability criteria (23 records), (Figure 3).



- Notes:
- ^a renewable energy Topic: Topic=(renew* SAME energ*)
 - ^b energy source Topics: Topic=(hydro*) OR Topic=(wind*) OR Topic=(sun*) OR Topic=(bio*)
 - ^c bioenergy Topic: Topic=(bio*)
 - ^d biomass source Topics: Topic=(agric*) AND Topic=(forest* OR tree*) AND Topic=(wast*)
 - ^e environment, sustainability, certification and certification & sustainability criteria Topics: Topic=(environ*) OR Topic=(sustain*) OR Topic=(certif.*)

Figure 3. Relative distribution of records of different criteria within 4,911 renewable bioenergy records (Source: renewable energy Topic^a in all databases of ISI Web of Knowledge refined by bioenergy Topic^c as well as different criteria Topics^e).

The results identified one strategic issue: as we need a quality system that efficiently operates and supports the management, one that will influence the firm's economic results, we need more research on sustainability and certification and other topics that could form the basis for a credible and comprehensive system of sustainability standards for bioenergy.

III. SELECTION AND REVIEW OF LITERATURE ON GLOBAL BIOMASS POTENTIAL AND SUSTAINABILITY CRITERIA

1. Global energy consumption

The world’s energy demand in 2006 amounted to about 490 EJ (11,703 MTtoe³) and was made up of about 81% fossil fuels (oil, gas and coal), about 10% biomass, about 6% nuclear and about 2.2 and 0.5% hydropower and other energy respectively (Figure 4, IEA 2008).

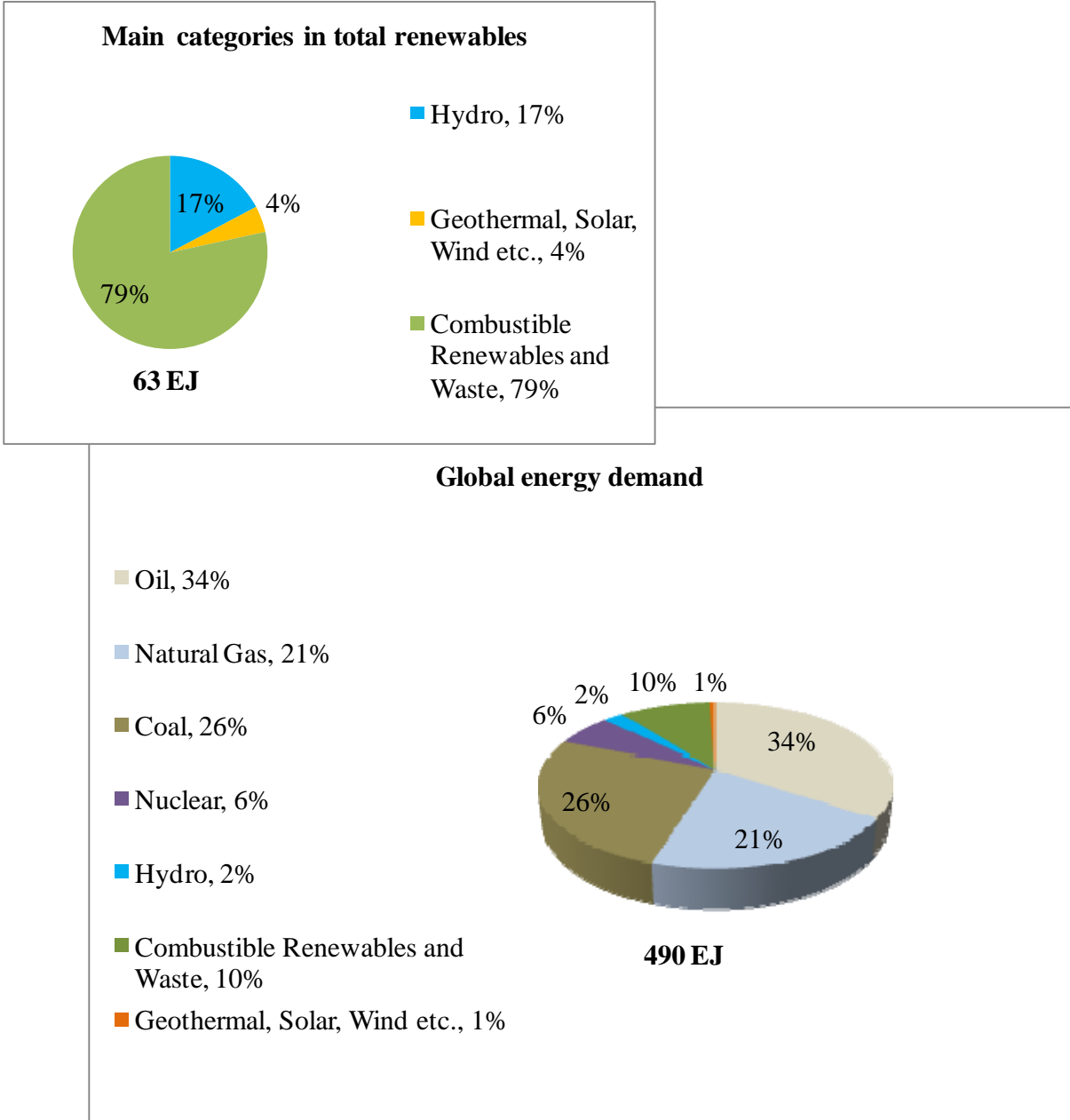


Figure 4. Constitutes of the global energy demand and share of the main categories in total global renewables in 2006. (Source: IEA, 2008).

³ Million tons of oil equivalent; 1 toe = 41.9 GJ

However, taking into account the growing concern among scientists and economists, business people and managers, governments and people regarding shortages of energy and material resources (Ulgiaty et al., 2008; Krstulovic & Barbiar, 2008) and the increasing importance of environmental issues, it is obvious there is an urgent need to change the current situation. At the UN Climate Change negotiations in December 2003, the International Energy Agency (IEA) reported that “climate change mitigation will require profound modification in energy production and use worldwide”. The search for alternatives is one of the main concerns of governments, scientists and business people worldwide. As a result, there is a general trend to search for energy alternatives based on locally available renewable resources, while at the same time pursuing increased energy efficiency throughout the economy (Silveira, 2005).

2. Renewable energy

Renewable energy sources that can be either replenished continuously or within a moderate time frame through natural energy flows include solar energy (heat and electricity), bioenergy, wind power, hydropower, and geothermal power. There is also a strong commitment to financing sustainable development and renewable energy generation (Skambracks, 2007). Given that renewable energy sources are expected to play a key role in the near future, the production of renewable energy worldwide is also expected to grow quickly, increasing its share of the global energy mix.

Many countries have already adopted the goal of enhancing the role of renewable sources in their energy supplies. The EU has set ambitious targets to raise the share of renewable energies, particularly biofuels. Thus, the European Commission proposed a directive on the use of energy from renewable sources in January 2008 (Rosch & Skarka, 2008). Moreover, at a European level, there is a strong commitment to produce 20% of energy from renewables by 2020 (Marchal et al., 2009). The exploitation of renewable energy sources can help the European Union meet many of its environmental and energy policy goals, including its obligation to reduce greenhouse gases under the Kyoto Protocol (EC, 2002a) and the aim of securing its energy supply (EC, 2002b; EC, 2005).

Liquid fuels made from biomass are attracting growing interest in EU and worldwide. Three principal factors drive the growing interest in liquid biofuels: 1) concerns about energy security; 2) environmental considerations that focus on GHG emissions, primarily in industrial countries, and on tailpipe emissions in developing countries that have relatively lenient vehicle emission and fuel quality standards; 3) to maintain and create jobs and economic development in rural areas – based on e.g. Kojima et al. (2007).

3. Bioenergy

Bioenergy is attractive at all stages of development due to its potential integration with all possible development strategies worldwide. The potential of bioenergy is widely recognized and bioenergy offers opportunities to address questions other than energy. Thus, bioenergy can be a solution for matters relating to economic, national, environmental and political security (Roberts, 2007). Moreover, bioenergy is based on resources that can be utilized on a sustainable basis all around the globe and can provide an effective option for the provision of energy services from a technical perspective. In addition, the benefits accrued go beyond energy provision, creating unique opportunities for regional development (Silveira, 2005).

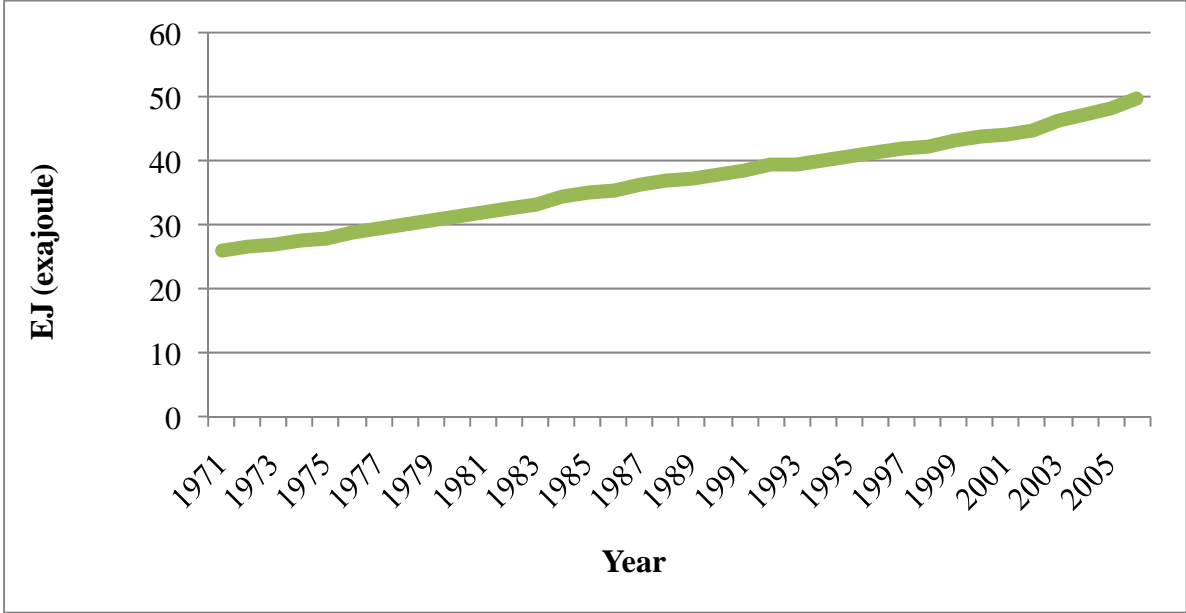
Bioenergy production generally has a higher capital cost than fossil fuel alternatives, however the lower cost of the wood fuel provides a quick commercial payback and increasing savings

over the longer term. Energy policies in Europe can potentially affect prices for wood raw materials and can create markets for such materials as well (Hashiramoto, 2007). Unfortunately, many potential investors in bioenergy projects do not have a solid understanding of all the technical, social and environmental issues involved (Sims et al., 2006).

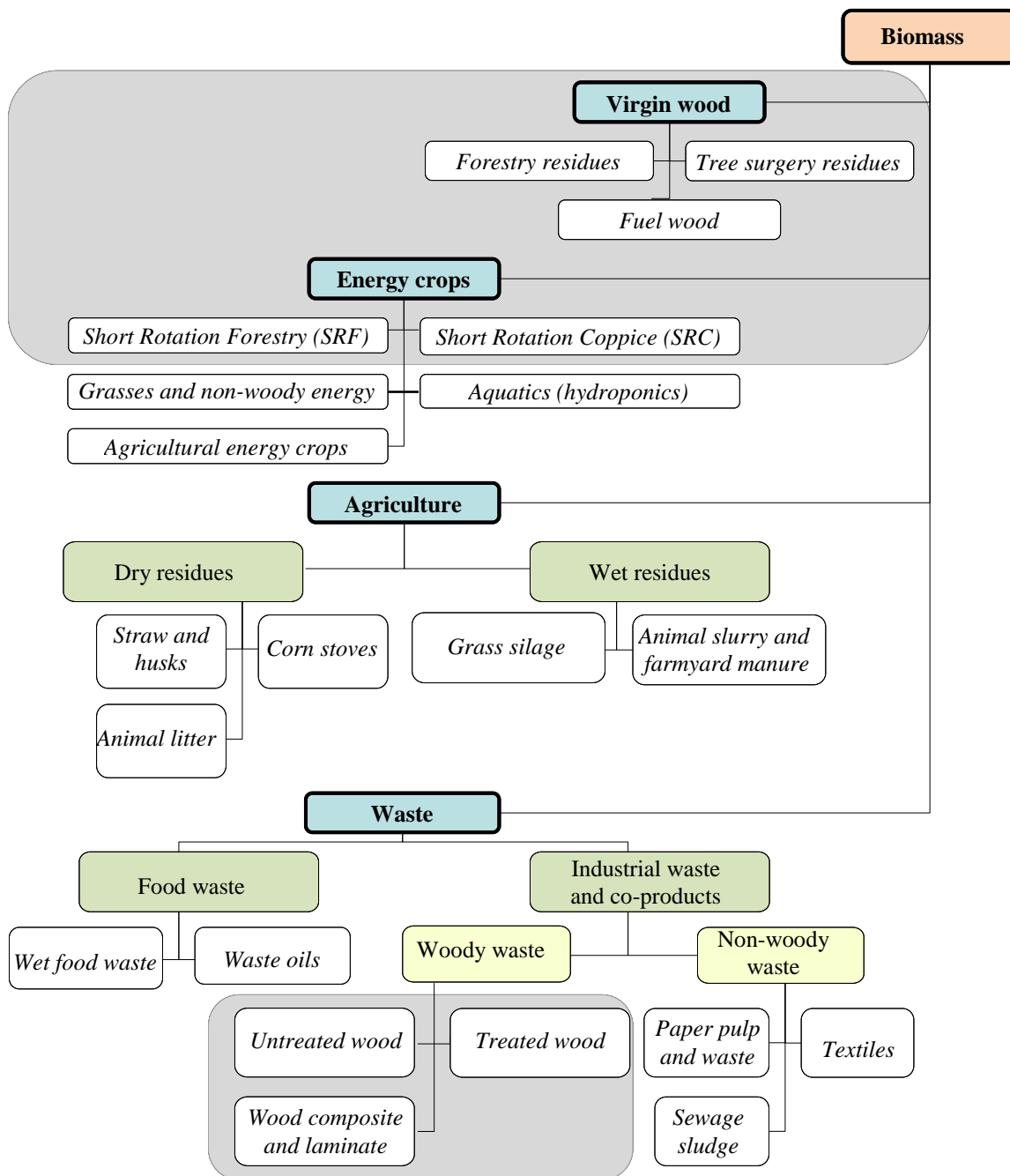
4. Biomass as a renewable energy source

Since the beginning of civilization, biomass has been a major source of energy throughout the world. Biomass is the primary source of energy for nearly 50% of the world’s population (e.g., Karekezi & Kithyoma, 2006) and wood biomass is a major renewable energy source in the developing world, representing a significant proportion of the rural energy supply (Hashiramoto, 2007). In the past decade, the number of countries exploiting biomass opportunities for the provision of energy has increased rapidly, and has helped make biomass an attractive and promising option in comparison to other renewable energy sources. The global use of biomass for energy increases continuously and has doubled in the last 40 years (Graph A). This according to the World Bank (2009) who uses IEA electronic files.

Concerns about sustainable energy supplies, commitments to the Kyoto Protocol (i.e., the additional cost of carbon imposed through carbon trading increases the cost of fossil fuels and therefore makes “carbon-lean” biomass more competitive, increasing prices for fossil fuels and availability of stocks of wood raw material) have been major influences on the promotion of wood energy policies (e.g., Hashiramoto, 2007; Sims, 2003). Renewability and versatility are among many other important advantages of biomass as an energy source. The biomass resources currently available come from a wide range of sources (Figure 5).



Graph A. World use of combustible renewables and waste 1971 – 2006. (Source: World Bank, 2009)



Note: Biomasses from woody materials are in the shaded areas.

Figure 5. Classification of sources of biomass for production of energy.

These can be classified into woody biomass, agricultural sources and wastes. Biomass can be used in several fields (heat, power, liquid biofuels and biobased products), Figure 6.

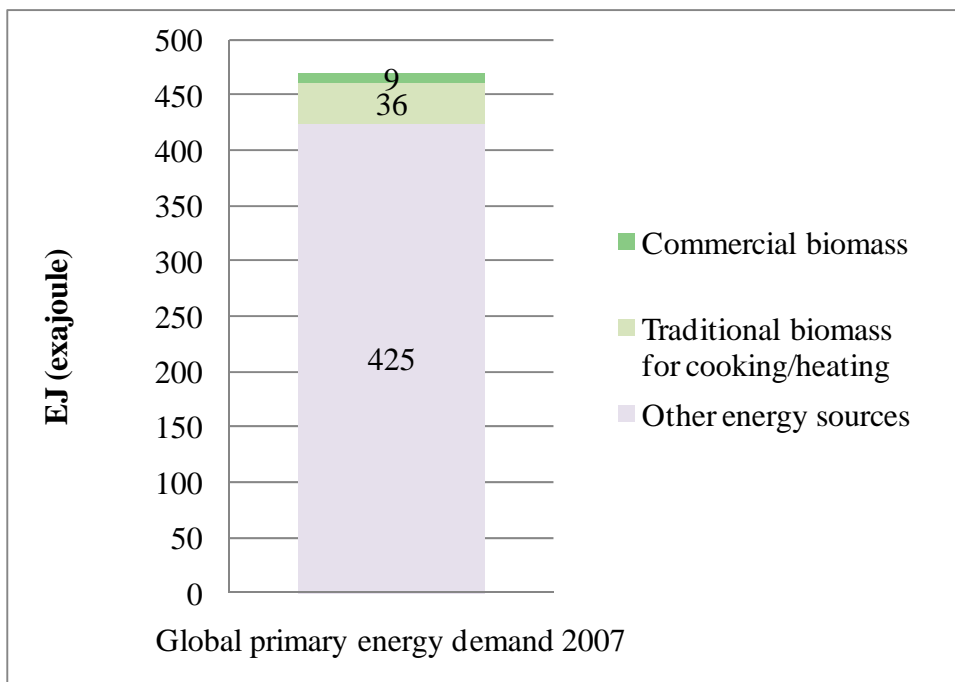


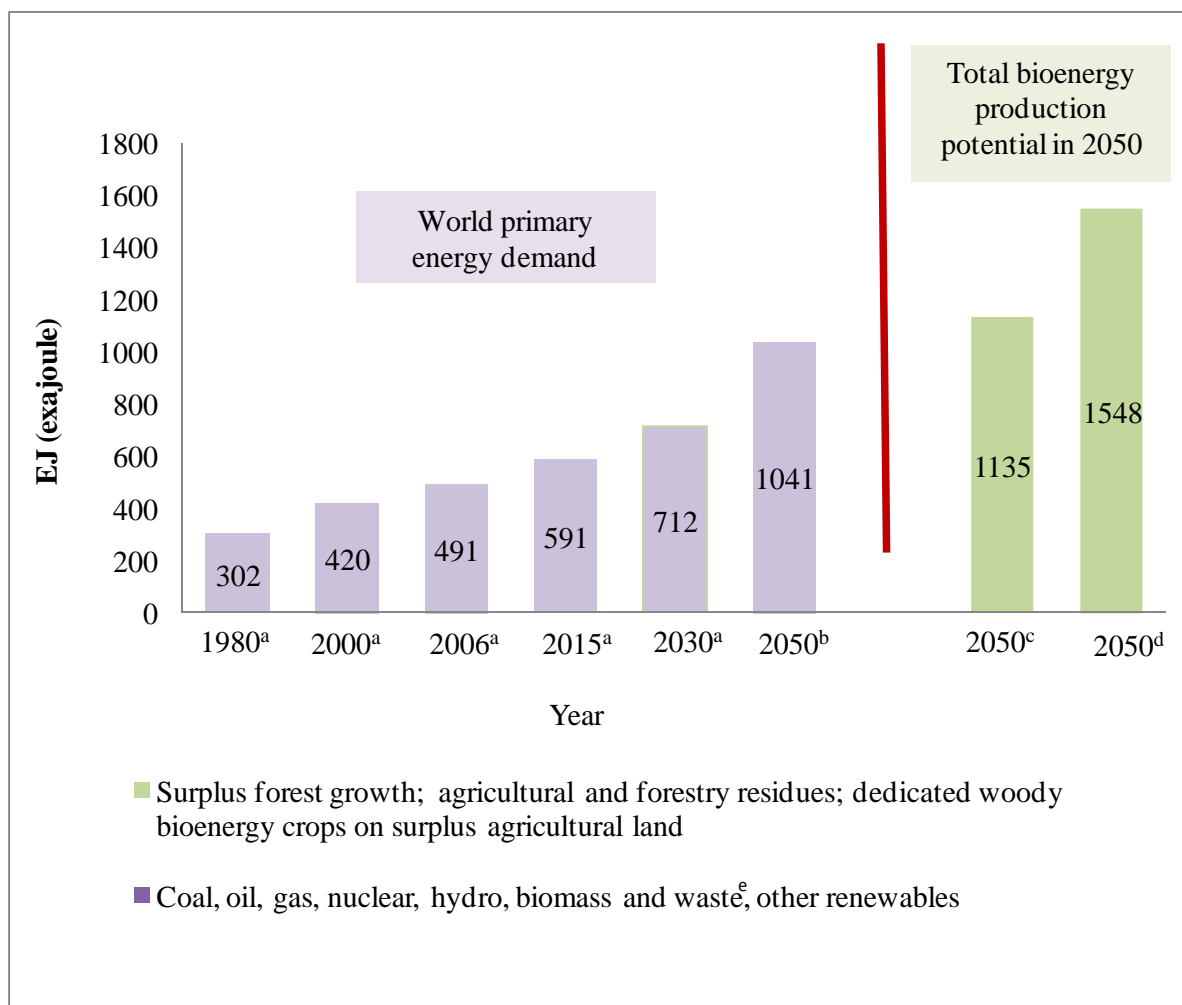
Figure 6. Contribution of biomass to global primary energy demand of 470 EJ in 2007. (Source: Faaij, 2008).

Contribution of biomass to the global energy demand of 470 EJ in 2007 is only 10%, mainly in the form of traditional non-commercial biomass (Figure 6). Figures 4 and 6 show how much biomass is used today. Moreover, we know that biomass can be used to produce different forms of energy, thus providing all the energy services required in a modern society. Furthermore, compared to other renewables, biomass is one of the most common and widespread resources in the world (WEC, 2004). Thus, biomass has the potential to be a source of renewable energy, both locally and in large parts of the world. Worldwide, biomass is the fourth largest energy resource after coal, oil, and natural gas - estimated at about 10% of global primary energy (and much higher in many developing countries) (Figure 4). Compared to other renewables, biomass is currently the largest renewable energy source (Figure 4).

About 90% of bioenergy in the EU is used for heating applications, while the remainder is used for electricity generation, transportation fuel, and chemical applications. Any decision on which fuel energy carrier (ethanol, biodiesel, biohydrogen or electricity) should be produced from biomass as a renewable energy source cannot be based solely on the efficiency or economics of the processes. As other criteria should be considered, various multicriterial analyses are needed, such as “well-to-wheels”, “life-cycle”, “energy analysis”, etc., in order to evaluate the sustainability of different options (Krstulovic & Barbiar, 2008).

5. Biomass potential and resources on a global scale

The annual global primary production of biomass is equivalent to the 4,500 EJ of solar energy captured each year (Sims, 2004). About 5% of this energy, or 225 EJ, would have covered almost 50% of the world’s total primary energy demand in 2006, as shown in Figure 7. These 225 EJ are in line with other estimates based on models which assume an annual sustainable bioenergy market of 270 EJ (Hall & Rosillo-Calle, 1998).



Notes: ^a IEA, 2008

^b Highest consumption scenario (Smeets et al., 2004)

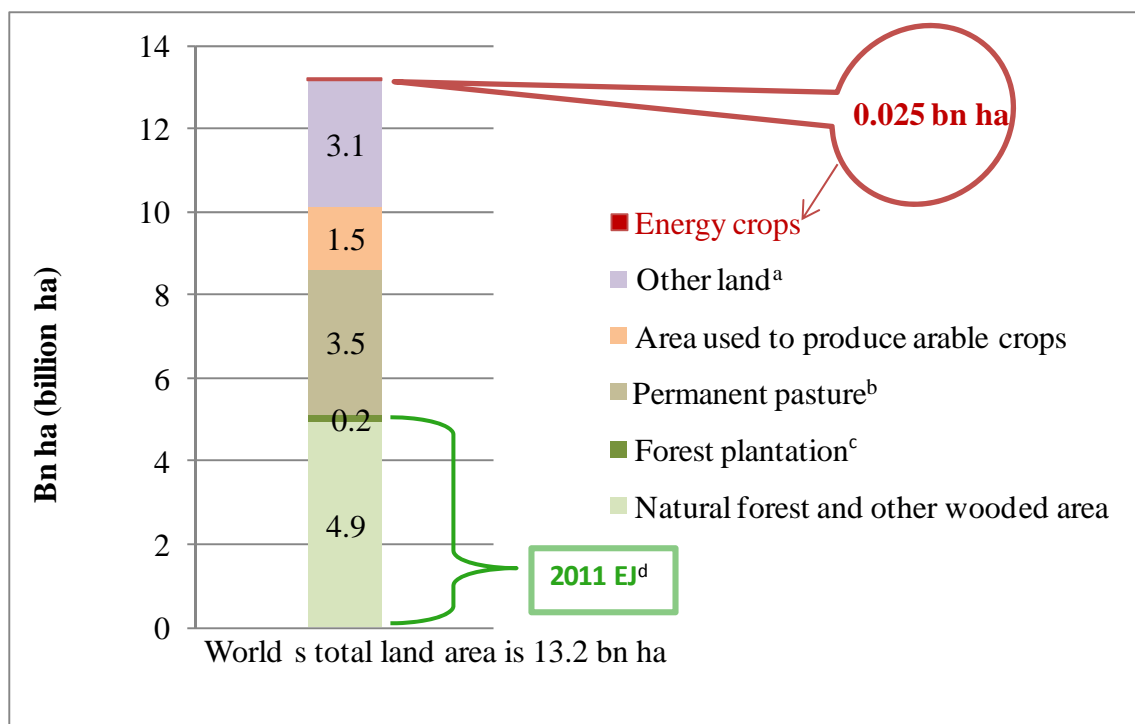
^c Based on an upper limit of the amount of biomass that can come available as (primary) energy supply without affecting the supply for food crops (Hoogwijk et al., 2003)

^d Based on scenario 4 in the source, where a type of agricultural management applied is similar to the best available technology in the industrialized regions (Smeets et al., 2006)

^e Includes traditional and modern uses

Figure 7. World primary energy demand for years 1980, 2000, 2006 and forecasts for years 2015, 2030 and 2050 and estimates for total global bioenergy production potentials in 2050

The future potential for energy from biomass depends to a great extent on land availability. Currently, the amount of land devoted to growing biofuels is only 0.025 billion hectares or 0.19% of the world's total land area of 13.2 billion hectares and 0.5-1.7% of global agricultural land (Figure 8).



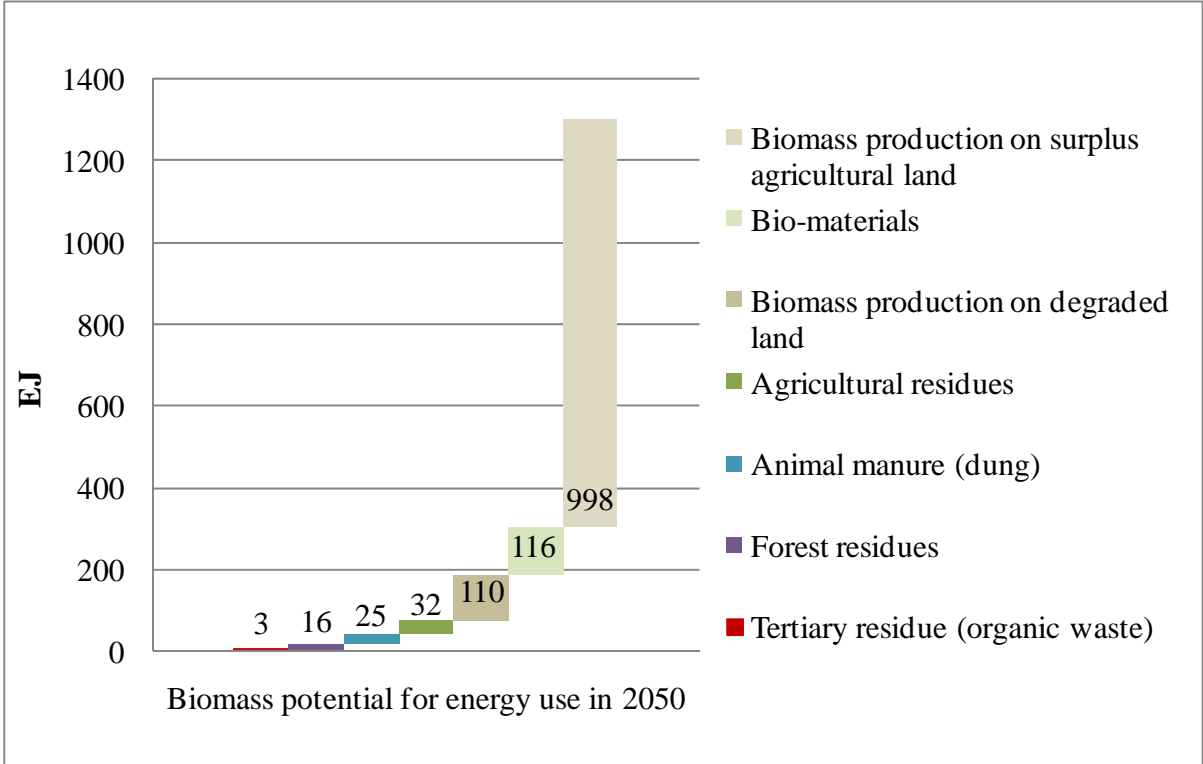
- Notes:
- ^a Other land: Land not included in the FAO land use categories
 - ^b Permanent pastures: Land used permanently for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land)
 - ^c ITTO, 2006ab
 - ^d Smeets et al., 2004

Figure 8. Distribution of land use types in world's total land area (Source: Faaij, 2008).

There are many scenarios that predict a future potential in biomass. There are also many studies performed during the past decades which attempt to estimate the future demand and supply of bioenergy (Lashof & Tirpak 1990; Hall et al., 1993; WEC, 1994; Fujino et al. 1999; IPCC, 2000; Rogner, 2000; Fischer & Schrattenholzer, 2001; Hoogwijk, 2004). For a detailed analysis and comparison of studies on global biomass production potentials see Berndes et al. (2003). However, published estimates of the total global bioenergy production potential in 2050 ranged from 33 to 1,135 EJ annually (Hoogwijk et al., 2003), from which 0 to 358 EJ annually came from woody biomass (Sørensen, 1999; Hoogwijk et al., 2003). Energy crops from surplus agricultural land have the largest potential contribution of 0-988 EJ/year (Hoogwijk et al, 2003).

This large range of estimates was the result of: differences in the type of biomass included; differences in the theoretical, technical, economic, or ecologic limitations related to the supply of woody biomass for energy use; differences in data on key parameters, such as the consumption of wood fuel, the annual growth of forests, and the efficiency of conversion; differences in scope whereby most of the existing bioenergy potential assessments focused on either the demand (e.g. WEC, 1994) or the supply (e.g. Yamamoto et al., 1999) of bioenergy and consequently ignored demand-supply interactions (Smeets & Faaij, 2007). Moreover, as Smeets & Faaij (2007) pointed out, most of the studies they reviewed ignored existing studies on the demand and supply of wood (e.g., Lazarus et al., 1993; Sørensen, 2001), despite the extensive literature and data on the subject (e.g., Solberg et al., 1996; FAO, 1998; Sedjo & Lyon, 1998). Overall, differences between the various scenarios are due to large differences in demand and energy mix, as a result of variations in population dynamics, and economic and technological development.

Taking data from a variety of international sources (e.g., FAO⁴, WB⁵, IFPRI⁶, IIASA⁷, RIVM⁸, UNPD⁹, EFI¹⁰, WEC¹¹), rough estimates of the energy production potential of woody biomass from forestry show that, forests can, in theory, become a major source of bioenergy, and that the use of this bioenergy can, in theory, be realized without endangering the supply of industrial roundwood and woodfuel and without further deforestation (e.g., Smeets & Faaij, 2007). For example, according to one global energy scenario (Smeets et al., 2006), the total global bioenergy production potential in 2050 is 1,548 EJ based on scenario 4, where the agricultural management practices applied are similar to the best available technologies in the world's industrialized regions (Figure 7). These results are in line with other estimates of bioenergy production potential. For example, according to recent studies, range of the global potential of biomass in 2050 is 1,135-1,300 EJ (Hoogwijk et al., 2003; 2005) (Figures 7 and 9). Energy crops from surplus agricultural land account for the largest potential contributions (Figure 9).



Note: The biomass resource categories are distinguished to assess the theoretically available potential of biomass for energy use.

Figure 9. Contribution of each biomass resource category to the global potential of biomass for energy use in 2050 (Source: Hoogwijk et al, 2003).

⁴ Food and Agriculture Organization of the United Nations
⁵ The World Bank
⁶ International Food Policy Research Institute
⁷ International Institute for Applied Systems Analysis
⁸ The Netherlands National Institute for Public Health and the Environment
⁹ United Nations Procurement Division
¹⁰ European Forest Institute
¹¹ World Energy Council

The global primary energy demand was 302 EJ in 1980, 420 EJ in 2000 and 491 EJ in 2006 (IEA, 2008), but was expected to increase to 591 and 712 EJ by 2015 and 2030 respectively (IEA, 2008), Figure 7, and to 826 EJ (as averaged for different scenarios) by 2050 (Smeets et al., 2004). However, even in the case featuring the highest consumption scenarios of 1,041 EJ in 2050 (Smeets et al., 2004), the 1,342 EJ which is the average of the cited bioenergy production potentials in 2050 is enough to meet this demand. The current theoretical potential of biomass energy is 2,900 EJ (WEA, 2000). The current stock of standing forest, with a total energy content corresponding to 2,011 EJ, is a large reservoir of bioenergy (Figure 8). Although the large potential of algae as a resource of biomass for energy is not taken into consideration in this report, there are results that demonstrate that algae can, in principle, be used as a renewable source of energy production (e.g., Velasques-Orta et al., 2009; Beer et al., 2009). Overall, the world's bioenergy potential seems to be large enough to meet global energy demand in 2050 (Figure 7).

6. Sustainability criteria

Commercial biomass can be used to provide heat and electricity as well as liquid biofuels and biogas for transport. However, without structural changes to the energy system, the production of biomass energy crops and removal of biomass residues from forest and agricultural systems for energy production can result in negative environmental, economic, or social impact. Moreover, unsustainable biomass production would erode the climate-related environmental advantage of bioenergy. In addition, there are risks related to such factors as supply, fuel quality, and price increases, as well as issues such as competition for land area and the degree of renewability of given resources. Sustainability reduces such risks, and can be supported by certification of substrates' origin (Skambracks, 2007). Taken as a whole, it's more important than ever to reliably demonstrate that the advantages of biofuels made from biomass exceed the cost of potential environmental damage caused by their production. Therefore, sustainable production of biomass for use as fuels is the major issue in order to increase bioenergy production.

Generally, the sustainable development debate is based on the assumption that societies need to manage three types of capital (economic, social, and natural), which may be non-substitutable and the consumption of which might be irreversible (Figure 10). There are international efforts underway to find ways to regulate the production and trade of bioenergy by establishing sustainability criteria (e.g., Palmujoki, 2009). Thus, with an increasingly controversial public debate and more scientific evidence about the downsides of biofuels, the European Union's biofuel targets have recently been bound to the condition that they be produced in a sustainable manner. As a result, the European Commission is currently developing sustainability criteria for biofuels (Schlegel & Kaphengst, 2007).

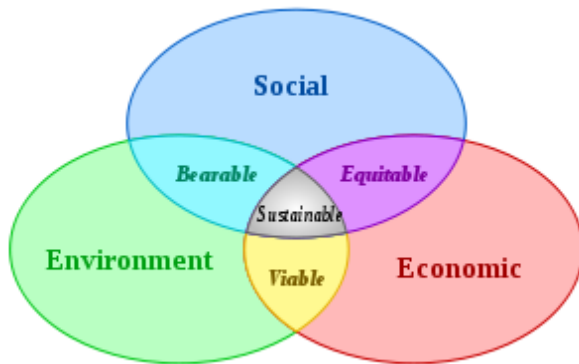


Figure 10. Scheme of sustainable development: at the confluence of three constituent parts (Based on UCN, 2006).

Publications on sustainable use of forest biomass for energy, roles and problems in relation to policy, legislation, certification standards, as well as recommendations and guidelines and science is discussed by Stupak et al. (2007). Criteria to ensure the sustainable production of biomass are needed urgently (van Dam et al., 2008). The sustainable use of biomass as an energy source requires the comprehensive management of natural resources such as land and water. Establishing certification schemes is a possible strategy to ensure that bioenergy is produced in a sustainable manner.

Overall, certification is judged to be the most suitable instrument for the development of sustainable bioenergy systems and further development and implementation of certification systems is an important tool. Therefore, the World Bioenergy Association (WBA)¹² has initiated research to create certification systems for the sustainable production of biomass worldwide. These initiatives are currently underway and will be presented in a subsequent WBA Report on certification criteria for sustainable biomass for energy.

¹² <http://www.worldbioenergy.org>

IV. CONCLUSIONS

This report takes a global perspective and synthesizes the amount of information on bioenergy and its relative distribution in different fields. The report contains two main sections, organized around bioenergy issues including an information survey and a literature review of bioenergy potential. The information survey reveals that the overwhelming research activity is focused on bioenergy compared to all other renewable energy types. Given that publications are the concrete result of scientific research and that scientific research is among the most important of human activities and considered central to a knowledge-based society, this result illustrates that bioenergy may be the most important renewable energy source in the near- and medium-term future (Figure 1). It will therefore play a crucial role in integrated systems of future energy supply and will be a valuable element of a new energy mix.

We found that publications on each of the four main sources of biomass (agriculture, forest, waste and other) represent about one quarter of the 4,911 bioenergy records retrieved. However, refining the bioenergy records using different criteria reveals that sustainability and certification are not issues which figure prominently in existing literature on bioenergy, despite the public attention both topics receive from various stakeholders and policymakers. Of all 4,911 bioenergy records retrieved, only relatively few discuss certification criteria (51 records) and certification and sustainability criteria (23 records), (Figure 3).

Through a review of existing data and literature, the literature review seeks to identify some key trends and shifts in bioenergy topics related to global potential of sustainable biomass for energy. The references cited in this report demonstrate that the world's bioenergy potential is large enough to meet global energy demand in 2050. Taken as a whole, the literature review of bioenergy potential concludes that it is more important than ever to reliably demonstrate that the advantages of biomass fuels exceed the cost of potential environmental damage caused by their production. Therefore, sustainable production of biomass for energy is the major issue in order to increase bioenergy production.

Rough estimates of the energy production potential of woody biomass from forestry show that, forests can, in theory, become a major source of bioenergy supply, and that the use of woody biomass can, in theory, be realized without endangering the supply of industrial roundwood and woodfuel and without further deforestation.

Liquid fuels made from biomass are attracting growing interest worldwide. Three principal factors drive the growing interest in liquid biofuels: 1) concerns about energy security; 2) environmental considerations that focus on GHG emissions; 3) to maintain and create jobs and economic development in rural areas.

Bioenergy is based on resources that can be utilized on a sustainable basis all around the globe and can provide an effective option for the provision of energy services from a technical perspective. In addition, the benefits accrued go beyond energy provision, creating unique opportunities for regional development.

In the past decade, the number of countries exploiting biomass opportunities for the provision of energy has increased rapidly. The global use of biomass for energy increases continuously and has doubled in the last 40 years

The future potential for energy from biomass depends to a great extent on land availability. Currently, the amount of land devoted to growing crops for bioenergy is only 25 million hectares or 0.19% of the world's total land area.

Certification is judged to be the most suitable instrument for the development of sustainable bioenergy systems. We therefore need more research on sustainability and certification as

well as on topics that could form the basis for a credible and comprehensive system of sustainability standards for bioenergy. These initiatives are underway and will be presented in the coming WBA Report on Certification Criteria for Sustainable Biomass for Energy.

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