Report

Global Potential of Sustainable Biomass for Energy

Svetlana Ladanai
Johan Vinterbäck

SLU, Institutionen för energi och teknik
Swedish University of Agricultural Sciences
Department of Energy and Technology

Report 013
ISSN 1654-9406
Uppsala 2009

SLU, Swedish University of Agricultural Sciences
Department of Energy and Technology

Global Potential of Sustainable Biomass for Energy

Svetlana Ladanai
Johan Vinterbäck

Rapport (Institutionen energi och teknik, SLU)
ISSN 1654-9406
2009:013

Uppsala 2009

Keywords: renewable energy, bioenergy, biomass potential, biomass sources, biomass use, sustainability

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 EJ[1] 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 = 10^{18} 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 payback 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, SMARTimbers 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.

The authors would last but not least also like to gratefully acknowledge financing for the project from the Swedish Board of Agriculture.

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

Contents

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.

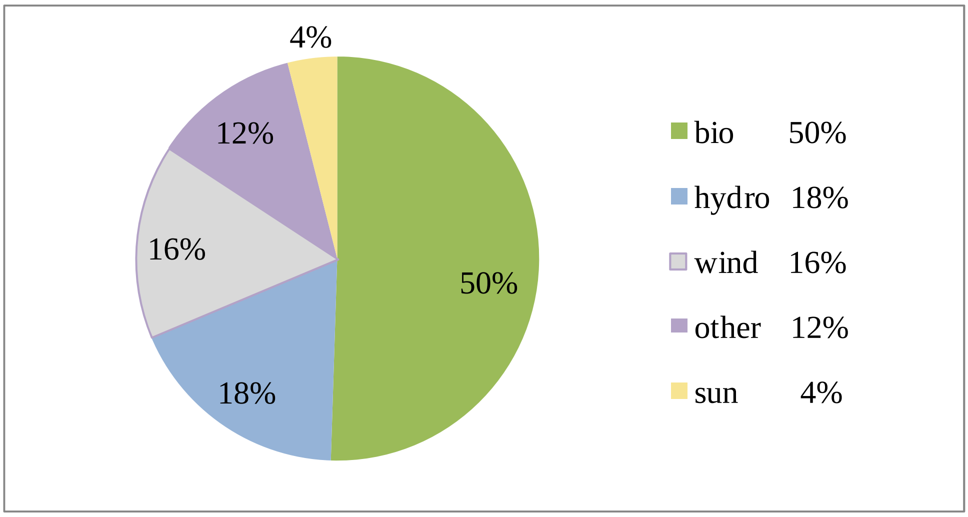
II. INFORMATION SURVEY

"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.

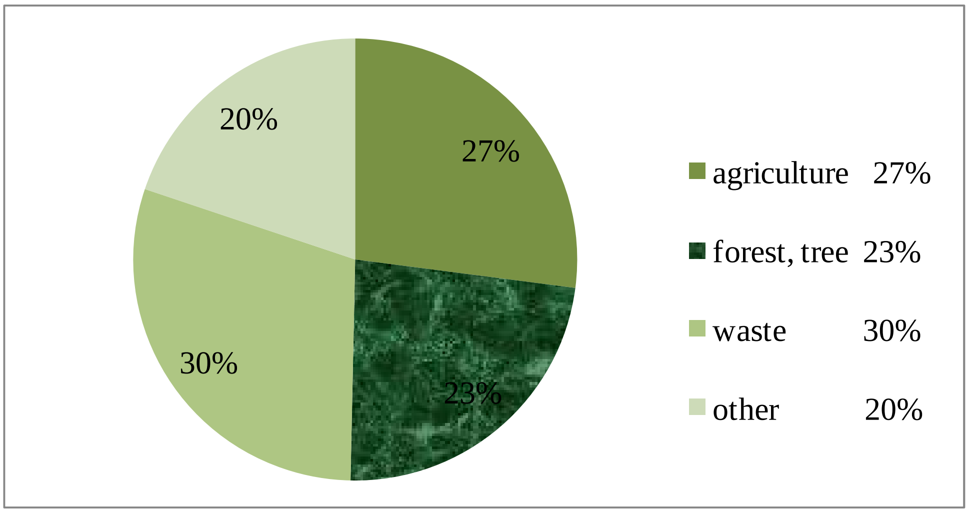
The growing interest in bioenergy is reflected in the large number of energy articles published. We found that more than 50% (4,911 records) of 9724 renewable energy records available within ISIWIKAD have bioenergy as their subject (Figure 1).



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).

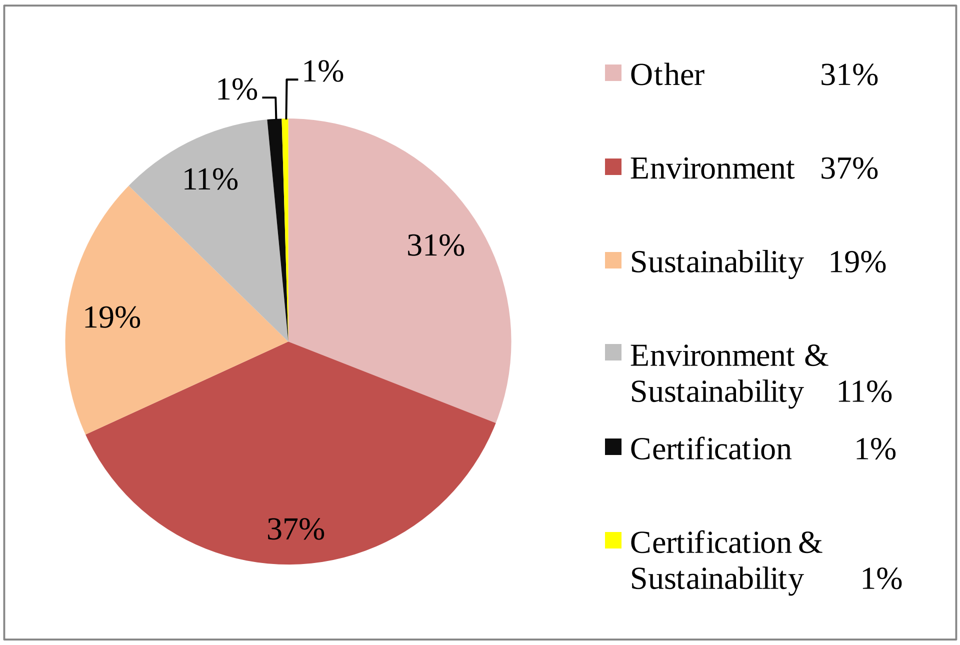
Scientific research is among the most important of human activities and considered central to a knowledge-based society. Publications are the concrete result of scientific research. As research problems are adjusted to changing global trends, the overwhelming research activity focused on bioenergy compared 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 4,911renewable 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 MTtoe[3]) 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).

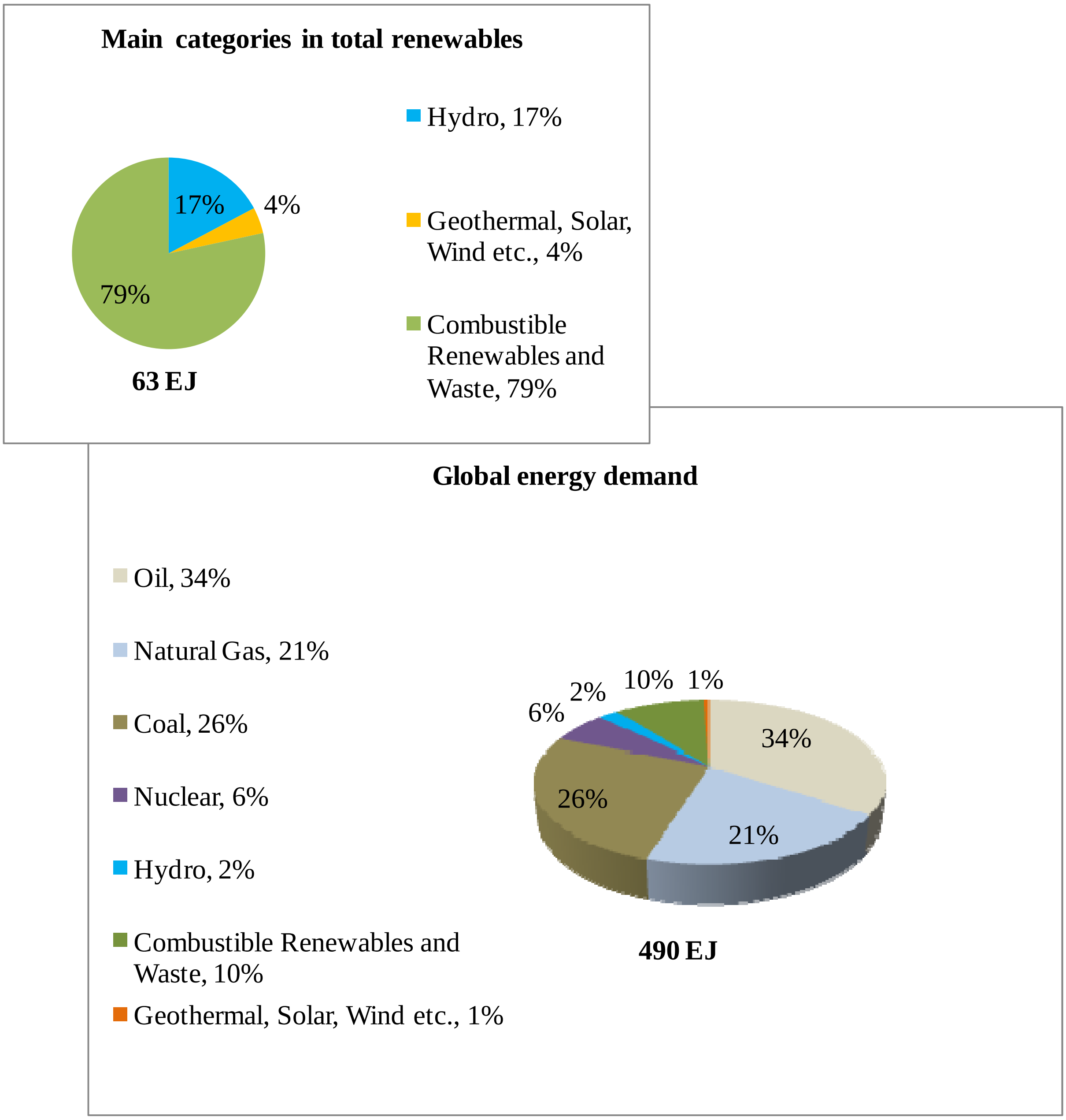


Figure 4. Constitutes of the global energy demand and share of the main categories in total global renewables in 2006. (Source: IEA, 2008).

[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

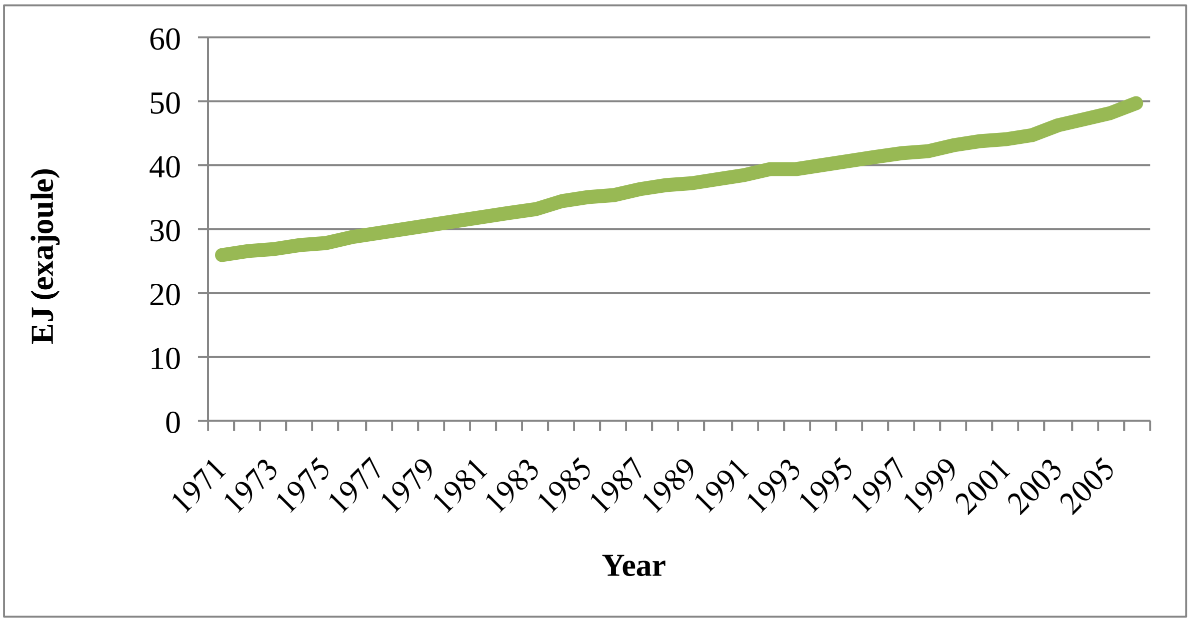
Bioenergy is attractive at all stages of development due to its potential integration with all possible development strategies worldwide. The potential of bioenergy is widely recognized and bioenergy offers opportunities to address questions other than energy. Thus, bioenergy can be a solution for matters 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).

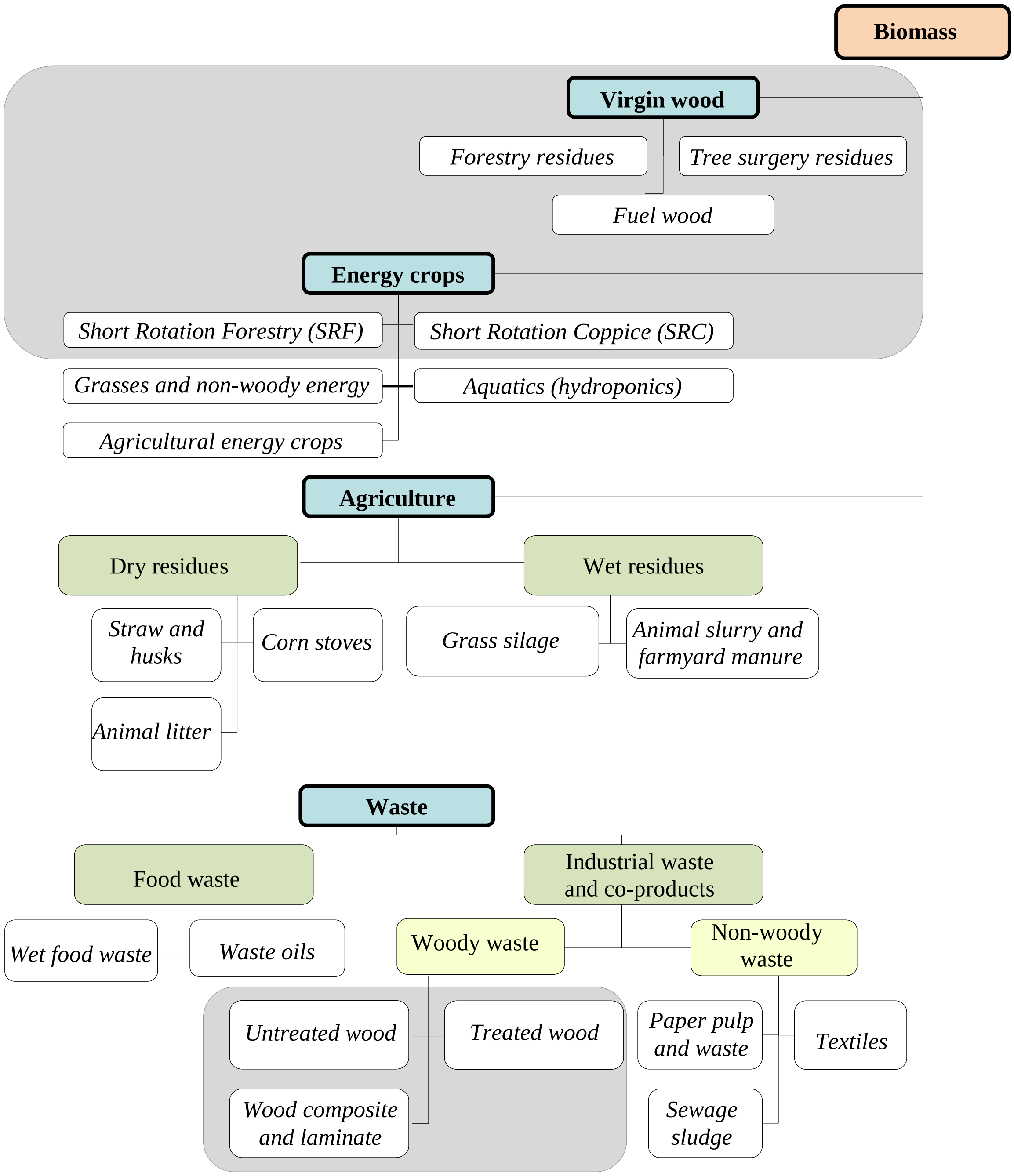
4. Biomass as a renewable energy source

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.

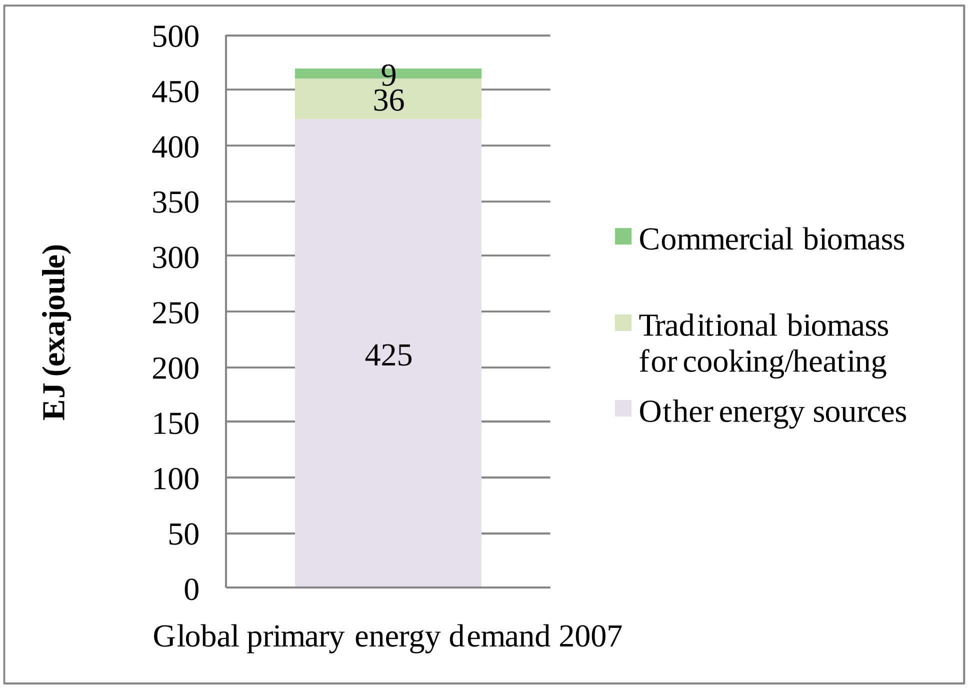


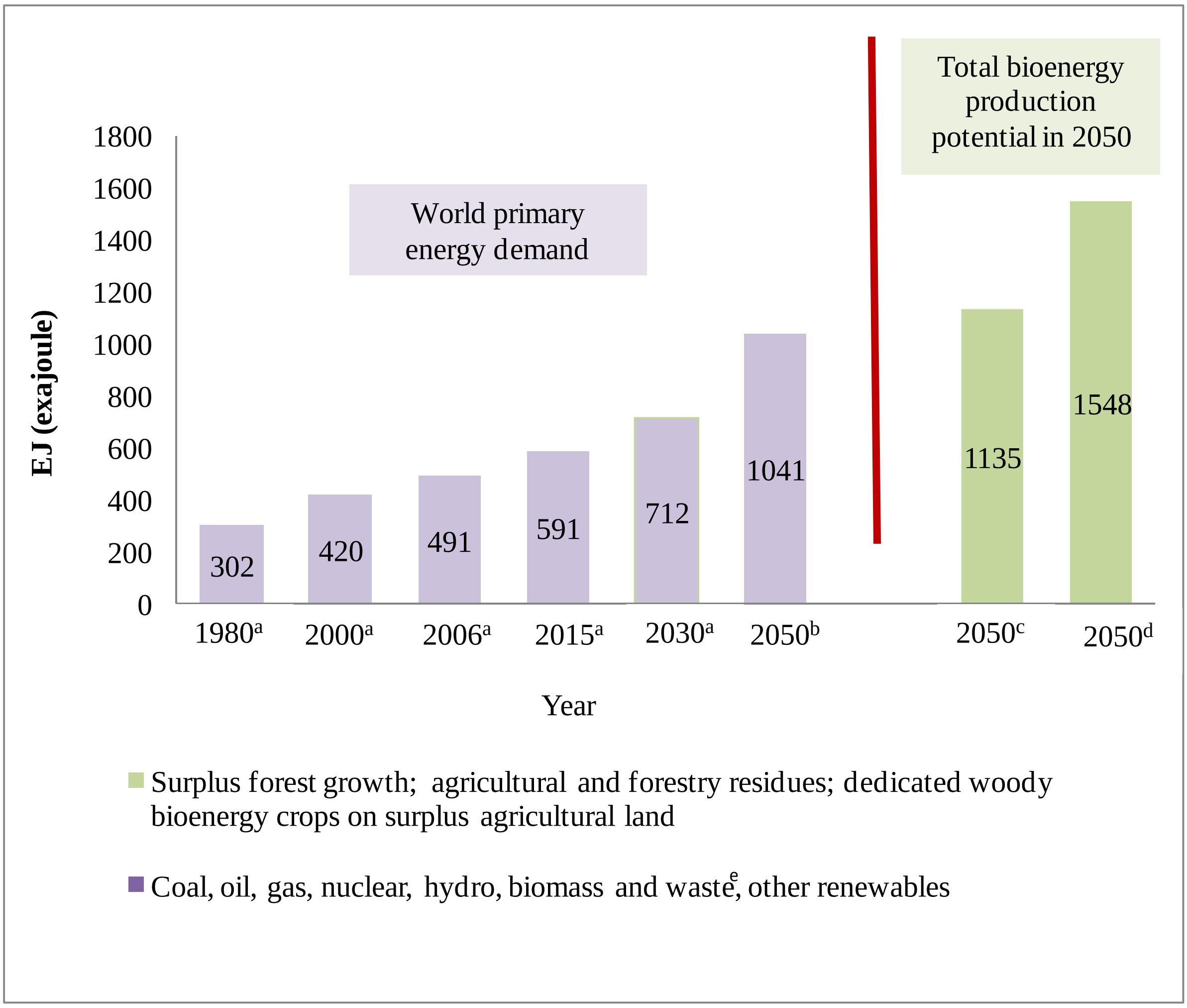
Figure 6. Contribution of biomass to global primary energy demand of 470 EJ in 2007. (Source: Faaij, 2008).

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)

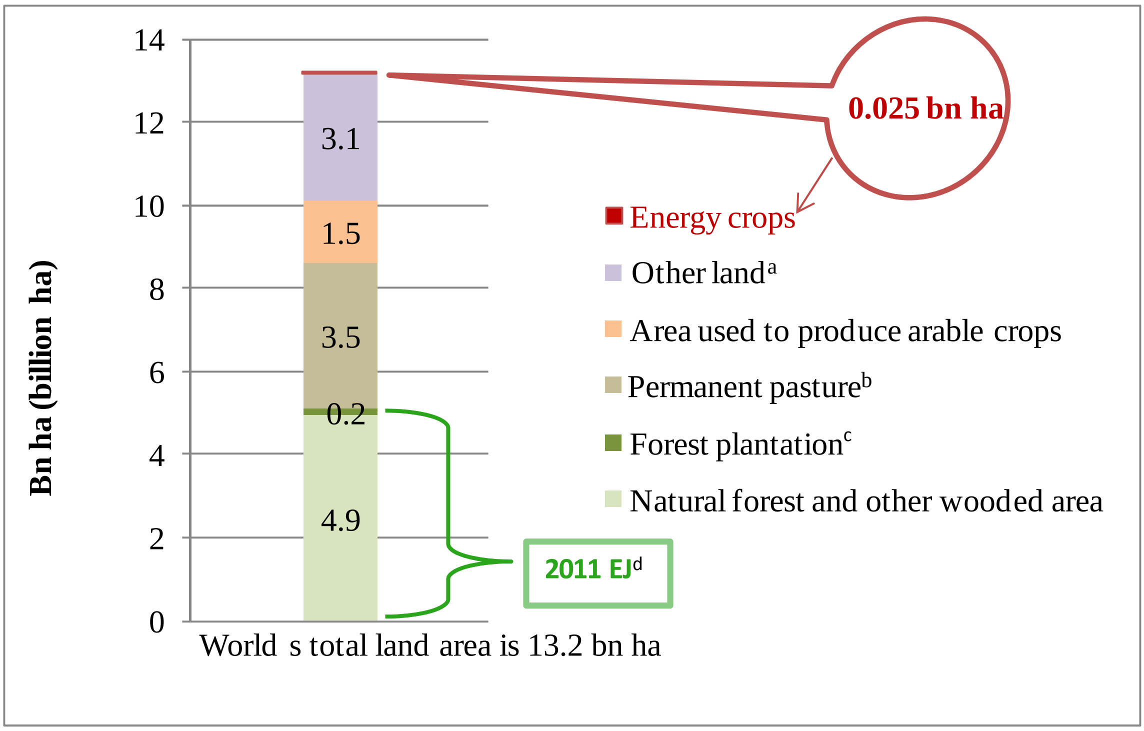
[c] Based on an upper limit of the amount of biomass that can come available as (primary) energy supply without affecting the supply for food crops (Hoogwijk et al., 2003)

[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).



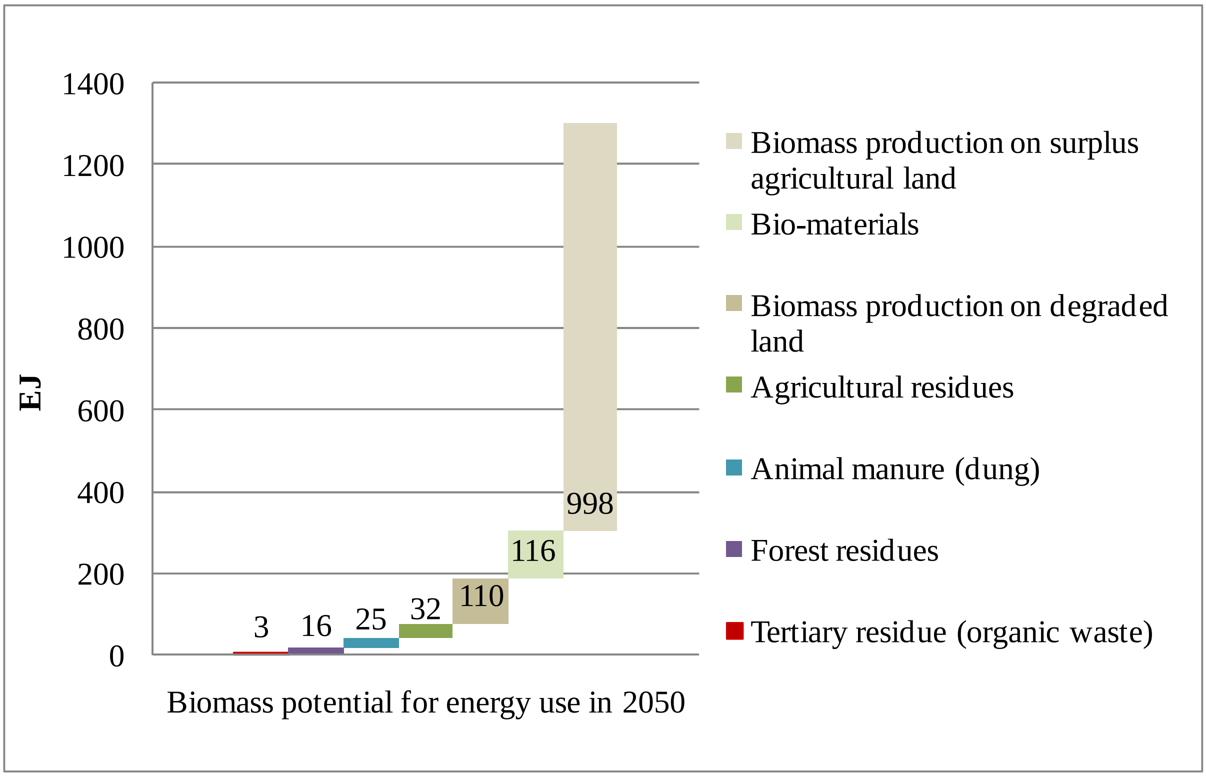
Notes: [a] Other land: Land not included in the FAO land use categories
[b] Permanent pastures: Land used permanently for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land)
[c] ITTO, 2006ab
[d] Smeets et al., 2004

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 annualy (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., FAO[4], WB[5], IFPRI[6], IIASA[7], RIVM[8], UNPD[9], EFI[10], WEC[11]), 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 asses 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).

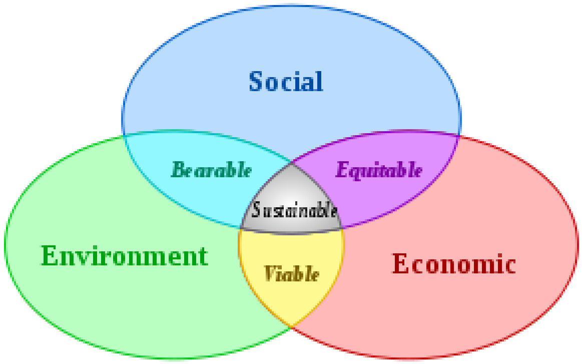


Figure 10. Scheme of sustainable development: at the confluence of three constituent parts (Based on UCN, 2006).

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.

REFERENCES

A. Literature cited in this report

Barbir F. & Ulgiaty S. 2008. *Sustainable Energy Production and Consumption: Benefits, Strategies and Environmental Costing.* Springer Science & Business Media B.V., Dordrecht, Netherlands.

Beer L.L., Boyd E.S., Peters J.W. & Posewitz M.C. 2009. Engineering algae for biohydrogen and biofuel production. *Current Opinion in Biotechnology* 20(3), 264-271.

Berndes G., Hoogwijk M. & van den Broek R. 2003. The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass and Bioenergy* 25**(**1), 1-28.

Börjesson P., Ericsson K., Di Lucia L., Nilsson L.J. & Ahman M. 2009. Sustainable vehicle fuels – Do they exist*?* Report No. 67, Department of Technology and Society, Lund University, Sweden

Cleveland C.J., Kaufmann R. & Stern S.I. 2000. Aggregation and the Role of Energy in the Economy. *Ecological Economics* 32, 301-317

van Dam J., Junginger M. & Faaij A. 2008. Overview of the recent development in sustainable biomass certification. *Biomass and Bioenergy 32(8),* 749-780

Dias R.A., Mattos C.R. & Balestieri J.A.P. 2004. Energy education: breaking up the rational energy use barriers. *Energy Policy* 32(11), 1339-1347

EC 2002a. *Decision 2002/358/EC of the Council concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder.* The Council of the European Union, Official Journal L 130.

EC 2002b. *Final report on the Green Paper 'Towards a European strategy for the security of energy supply'.* COM(2002) 321 final. Commission of the European Communities, Brussels.

EC 2005. *Report on the green paper on energy. Four years of European initiatives*. Directorate-General for Energy and Transport, European Commission. Office for Official Publications of the European Communities, Luxembourg. Available at: www. jet.efda.org/documents/ad-hoc/2005-green-paperreport-en.pdf [Accessed 23 March 2009].

Faaij A.P.C. 2008. “Sustainable Biofuels”. *Presentation at Roclfeller Bellagio Conference on North-South Biopact*, 25 March, Bellagio, Italy.

FAO. 1998. *Global forest products consumption, production, trade and prices: global forest products model projections to 2010.* United Nations Food Agricultural Organisation, Rome, Italy, p 345.

Fischer G. & Schrattenholzer L. 2001. Global bioenergy potentials through 2050. *Biomass and Bioenergy* 20, 151–159.

Fujino J., Yamaji K. & Yamamoto H. 1999. Biomass-balance table for evaluating bioenergy resources. *Applied Energy* 63(2), 75–89.

Giampietro M. 2008. Studying the “addition to oil” of developed societies using the multy-scale integrated analysis of societal metabolism (MSIASM). In: *Sustainable Energy Production and Consumption. Benefits, Strategies and Environmental Costing*. Barbiar & Ulgiaty (eds). Springer Science & Businnes Media B.V., Dordrecht, Netherlands.

Hall D.O. & Rosillo-Calle F. 1998. *Biomass - other than wood.* World Energy Council 1998, Survey of Energy Resources, 18th Edition, London, pp.227-241.
Hall D.O., Rosillo-Calle F., Williams R.J. & Woods J. 1993. *Biomass for energy: supply prospects.* Renewable energy: sources for fuels and electricity. Earthscan, London, pp.593-651.
Hashiramoto O. 2007. *Wood-product trade and policy issue.* Cross-sectoral policy developments in forestry, pp.24-35.
Hoogwijk M. 2004. *On the global and regional potential of renewable energy sources.* PhD thesis, Utrecht University, Utrecht, The Netherlands, p 256.
Hoogwijk M., Faaij A., Van den Broek R., Berndes G., Gielen D. & Turkenburg W. 2003. Exploration of the ranges of the global potential of biomass for energy. *Biomass and Bioenergy* 25(2), 119–133.
Hoogwijk M., Faaij A., Eickhout B., de Vries B. & Turkenburg W. 2005. Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios.
IEA 2008. World Energy Outlook. OECD/IEA. IEA, Head of Communication and Information Office, Paris, France.
IPCC 2000. *Special report on emissions scenarios*. Intergovernmental panel on climate change. Cambridge Univ. Press, Cambridge, UK.
ITTO 2006a. *Global Study on Forest Plantations. Private Sector Investments in Industrial Plantation in the Tropics.* International Tropical Timber Organization (ITTO), Yokohama, Japan.
ITTO 2006b. *Global Study on Forest Plantations: Market Study on Tropical Plantation Timber.* International Tropical Timber Organization (ITTO), Yokohama, Japan.
Karekezi S. & Kithyoma W. 2006. Bioenergy and Agriculture: Promises and Challenges. Bioenergy and the Poor. In: *2020 Vision for Food, Agriculture, and the Environment.* International Food Policy Research Institute, Washington DC, USA.
Kojima M., Mitchell D. & Ward W. 2007. *Considering Trade Polocies for Liquid Biofuels. Renewable Energy.* Special Report 004/07. ESMAP, Energy Sector Management Assistance Program. The International Bank for Reconstruction and Development/The World Bank, Washington, USA.
Krstulovic A. & Barbiar F. 2008. Bio-diesel and/or hydrogen in Croatia – challenge and necessity. In Barbiar F., Ulgiaty S. (eds). 2008. *Sustainable Energy Production and Consumption. Benefits, Strategies and Environmental Costing.* Springer Science & Business Media B.V., Dordrecht, Netherlands.
Lashof D.A. & Tirpak D.A. 1990. *Policy options for stabilizing global climate*. United States Environmental Protection Agency, Hemisphere, New York, USA.
Lazarus M.L., Greber L., Hall J., Bartels C., Bernow S., Hansen E., Raskin P. & Von Hippel D. 1993. *Towards a fossil free energy future: the next energy transition*. A technical analysis for Greenpeace international. Boston Center, Boston, USA.
Marchal D., Van Stappen F. & Schenkel Y. 2009. Sustainable production criteria and indicators for solid biofuels. Biotechnologie Agronomie Societe et Environnement 13 (1), 165-176.
Palmujoki E. 2009. Global principles for sustainable biofuel production and trade. *International Environmental Agreements – Politics Law and Economics* 9(2), 135-15.
Roberts D. 2007. *Globalization and Its Implications for the Indian Forest Sector.* TIFAC/IIASA Joint Workshop "Economic, Societal and Environmental Benefits Provided by the Indian Forests", New Delhi, India, April.
Rogner H.H. 2000. *Energy Resources. World Energy Assessment.* J. Goldemberg, UNPD, Washington, District of Columbia, USA, pp135–171.

Rosch C. & Skarka J. 2008. European Biofuel Policy in a Clobal Context: Trade-Offs and Strategies. *GAIA-ecological perspectives for science and society* 17(4), 378-386.
Schlegel S. & Kaphengst T. 2007. European Union policy on bioenergy and the role of sustainability criteria and certification systems. Editor(s) Gardner B., Tyner W. *Journal of Agricultural & Food Industrial Organization* 5 (2), Article 7.
Sedjo R.A. & Lyon K.S. 1998. *Timber supply model 96: a global timber supply model with a pulpwood component.* Resources for the Future, Washington, District of Columbia, USA, p 43.
Silveira S. 2005. Bioenergy – Realizing the potential. Swedish Energy Agency, Eskilstuna, Sweden.
Sims R.H. 2003. Bioenergy to mitigate for climate change and meet the needs of society, the economy and the environment. *Mitigation and Adaptation Strategies for Global Change* 8(4), 349-370.
Sims R.H. 2004. *Bioenergy Options for a Cleaner Environment: In Developed and Developing Countries.* Elsevier Ltd., Oxford, UK, 184 pp.
Sims R.H., Hastings A., Schlamadinger B., Taylor G. & Smith P. 2006. Energy crops: current status and future prospects. Review. *Global Change Biology* 12, 2054–2076.
Skambracks D. 2007. Financing of bioenergy: sustainability in credit allocation? Conference Information: Naturschutz und Landwirtschaft im Dialog: "Biomasseproduktion - ein Segen fur die Land(wirt)schaft?" Tagung am Bundesamt fur Naturschutz - Internationale Naturschutzakademie Insel Vilm 12. bis 15. Marz 2007. *BfN - Skripten (Bundesamt fur Naturschutz)* 211, 76-88.
Smeets E., Faaij A. & Lewandowski I. 2004. *Aquickscan of global bioenergy potentials to 2050. An analysis of the regional availability of biomass resources for export in relation to the underlying factors.* Report NWS-E-2004-109, Utrecht University, Netherlands.
Smeets E.M.W., Faaij A.P.C., Lewandowski I.M. & Turkenburg W.C. 2006. A bottom-up assessment and review of global bioenergy potentials to 2050. Progress in Energy and Combustion Science 33, 56-106.
Smeets E. & Faaij A. 2007. Bioenergy potentials from forestry in 2050 - An assessment of the drivers that determine the potentials. Climatic Change 8, 353-390.
Solberg B., Brooks D., Pajuoja H., Peck T.J. & Wardle P.A. 1996. *Long-term trends and prospects in world supply and demand for wood and implications for sustainable forest management*. Recearch Report no 6. European Forest Institute, Joensuu, Finland, pp 7–42.
Sørensen B 1999. Long-term scenarios for global energy demand and supply: four global greenhouse mitigation scenarios. Energy & Environment Group, Roskilde University, Roskilde, Denmark
Sørensen B. 2001. *Biomass for energy: how much is there?* Proceedings of ‘Hearing on biofuels and transportation’, Danish Parliament. Danish Board of Technology Assessment, Roskilde, Denmark, pp 149–162.
Stupak I., Asikainen A., Jonsell M., Karltun E., Lunnan A., Mizaraite D., Pasanen K., Parn H., Raulund-Rasmussen K., Roser D., Schroeder M., Varnagiryte I., Vilkriste L., Callesen I., Clarke N., Gaitnieks T., Ingerslev M., Mandre M., Ozolincius R., Saarsalmi A., Armolaiti K., Helmisaari H.S., Indriksons A., Kairiukstis L., Katzensteiner K., Kukkola A., Ots K., Ravn H.P. & Tamminen P. 2007. Sustainable utilisation of forest biomass for energy-possibilities and problems: Policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. *Biomass and Bioenergy* 31 (10), 666-684.

UCN. 2006. The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. Report of the IUCN Renowned Thinkers Meeting, 29–31 January 2006.
Ulgiaty S., Zucaro A. & Dumontet S. 2008. Integrated systems and zero emission production patterns in agriculture, industry and the energy sector – why “green” is not enough. In: *Sustainable Energy Production and Consumption. Benefits, Strategies and Environmental Costing*. In Barbiar F., Ulgiaty S. (eds). 2008. Springer Science + Businnes Media B.V., Dordrecht, Netherlands.
Velasquez-Orta S.B., Curtis T.P. & Logan B. E. 2009. Energy from algae using microbial fuel cells. Biotechnology and Bioengineering 103(6), 1068-1076.
WEA 2000. *World Energy Assessment of the United Nations, UNDP, UNDESA/WEC*. Published by: UNDP, New York.
WEC 1994. *New renewable energy sources. A guide to the future.* World Energy Council/Kogan Page Ltd, London, UK.
WEC 2004. *Survey of Energy Resources.* 20th ed. Elsevier Ltd. Netherlands
World Bank. 2009. World Development Indicators (WDI). WDI Online Databases. Available at http://web.worldbank.org/.
Yamamoto H., Yamaji K. & Fujino J. 1999. Evaluation of bioenergy resources with a global land use and energy model formulated with SD technique. *Applied Energy* 63(2), 101–113.

B. Comprehensive list of records from information survey that share factors of “Certification” and “Certification and Sustainability” within renewable bioenergy results cited in this report

Amaral W.A.N. do., Marinho J. P., Tarasantchi R., Beber A. & Giuliani E. 2008. Environmental sustainability of sugarcane ethanol in Brazil. In: *Sugarcane ethanol: contributions to climate change mitigation and the environment.* Zuurbier P., Vooren J. van de (Eds), pp. 113-138.
Anon 2007. Sustainable use of Forest Biomass for Energy, Proceedings of the Wood-en-Man session at the conference Nordic Bioenergy 2005 Trondheim, Norway, 27 October 2005. Clarke N.A. & Lunnan A. (Eds). *Biomass and Bioenergy* 31(10), pp.666-746.
Anon 1999. *Oil palm and the environment: a Malaysian perspective.* Editors: Singh G., Lim K.H., Leng T. & Kow D. L.
Anon 2007. Agro-energy, from biogas to fatty vegetable oils. *Informatore Agrario* 63(37), 33-48.
Anon 2008a. *Sugarcane-based bioethanol: energy for sustainable development*. Food and Agriculture Organization. Coordination BNDES and CGEE – Rio de Janeiro, 2008. 304 pp.
Anon 2008b. First Bioenergy-sustainability certificate probably later this year. *Zuckerindustrie*133(9), 596-597.
Anon 2008c. Palm oil only from sustainable sources. *Gemuse* 44 (1), 28-30.
Atkinson B. 2004. The CDM, Kyoto Protocol and the sugar, ethanol and bio-fuels industry. *International Sugar Journal* 106 (1263), 175-177.
van Belle J.F. 2006. A model to estimate fossil CO2 emissions during the harvesting of forest residues for energy-with an application on the case of chipping. Annual Workshop of IEA Bioenergy Task 31on Sustainable Production Systems for Bioenergy - Forest Energy in Practice SEP 2004 Garpenberg. SWEDEN. *Biomass and Bioenergy* 30(12), 1067-1075.

Berg S. 2003. Harvesting technology and market forces affecting the production of forest fuel from Swedish forests. *Biomass and Bioenergy* 24(4-5), 381-388.
Bertolini M. & Bevilacqua M. 2007. Recovering energy from biogas emission: the case of Mariana Mantovana landfill (Italy). *International Journal of Global Energy Issues*, 195-214.
Berton M. 2008. Green certificates and biomass. *Sherwood - Foreste ed Alberi Oggi* 147, 11-12.
Bhatnagar S.M. 2007. Carbon trading with clean development mechanism - a road to walk on. *Cooperative Sugar* 39(2), 21-32.
Bowyer J.L. 2008. The green movement and the forest products industry. *Forest Products Journal* 58(7-8), 6-13.
Bram S., De Ruyck J. & Lavric D. 2009. Using biomass: A system perturbation analysis. *Applied Energy* 86(2), 194-201
Brun F. & Mosso A. 2007. Profitability comparisons between some woody biomass crops and annual crops. *Georgofili* 4(Supplemento 3), 19-38.
Cabieses H. 2001. Alternative development in Peru: debates, types and reconsiderations. *Debate Agrario* (Lima) 32, 67-88.
Candolo G. & Meriggi P. 2006. Plant biomass, so much energy can be grown. *Informatore Agrario* 62(1), 30-34.
Cavieres Cancino A., Bachelet M., Bau C., Soler Mayor M., Dartnell Roy C., Meza Alvarez A., Barschak Brunman S., Medina Parra C.P., Contreras Rodriguez J.P., Fuentealba Rollat C., Toledo Sepulveda D., Perez Contreras M., Pozo Alvarado F., Sanhueza Silva A. & Carneiro C.M.R. 2008. Special issue: Promulgating of modern law for native forest in Chile. *Chile Forestal* 336, 1-58.
Ceron J.P. & Dubois G. 2008. Carbon compensation and tourism. *Espaces, Tourisme & Loisirs* 257, 13-35.
Cowie A.L. & Gardner W.D. 2007. Competition for the biomass resource: Greenhouse impacts and implications for renewable energy incentive schemes. *Biomass and Bioenergy* 31(9), 601-607.
Crooks A.M. 2005. Protecting forests and supporting renewable energy. *BioCycle* 46(4), 68-7.
van Dam J. Junginger M. & Faaij A. 2008. Overview of the recent development in sustainable biomass certification. *Biomass and Bioenergy* 32(8), 749-780.
Delzeit R. & Holm-Muller K. 2009. Steps to discern sustainability criteria for a certification scheme of bioethanol in Brazil: Approach and difficulties. 4th Dubrovnik Conference on Sustainable Development of Energy Water and Environment Systems. Jun 04-08. Dubrovnik, Croatia. *Energy* 34(5), 662-668.
Dixon R.K. 1997. The US initiative on joint implementation. *International Journal of Environment and Pollution* 8(1-2), 1-17.
Emer B. & Toldo S. Distribution of wood fuel boilers that were subsidised in Trento Province. *Sherwood - Foreste ed Alberi Oggi* 142, 31-36.
Faaij A. Developments in international bioenergy markets and trade. *Biomass and Bioenergy* 32(8), 657-659.
Fehrenbach H. 2007. Criteria for sustainable bioenergy use on a global scale. Naturschutz und Landwirtschaft im Dialog, "Biomasseproduktion - ein Segen fur die Land(wirt)schaft?" Tagung am Bundesamt fur Naturschutz - Internationale Naturschutzakademie Insel Vilm 12. BfN - Skripten (Bundesamt fur Naturschutz) 211, 76-88.
Finon D. & Perez Y. 2007. The social efficiency of instruments of promotion of renewable energies: A transaction-cost perspective. *Ecological Economics* 62(1), 77-92.

Flores R., Munoz-Ledo R., Flores B.B. & Cano K.I. 2008. Power generation from biomass estimation for projects of the clean development mechanism program. *Revista Mexiacana de Ingenieria Quimica* 7(1), 35-39.

Fossati F.R. 2007. What impacts do these technologies have on the agricultural companies? *Georgofili* 4 (Supplemento 1), 185-193.

Frombo F., Mindardi R., Robba M., Rosso F. & Sacile R. 2009. Planning woody biomass logistics for energy production: A strategic decision model. *Biomass and Bioenergy* 33(3), 372-383.

Garofalo R. 2006. Towards the revision of the EU biofuels directive what future for European biodiesel markets? *OCL - Oleagineux Corps Gras Lipides* 13(2/3), 121-129.

Gerin P.A., VIiegen F. & Jossart J.M 2008. Energy and CO2 balance of maize and grass as energy crops for anaerobic digestion. *Bioretechnology* 99(7), 2620-2627.

Glowacki R. & Cichy W. 2007. Energy use of wood in view of general legal regulations in Poland and Germany. *Drewno* 50(177), 5-55.

Groom M.J., Gray E.M. & Townsend P.A. 2008. Biofuel and biodiversity: Principles for creating better policies for biofuel production. *Conservation biology* 22(3), 602-609.

Hedman B., Naslund M. & Marklund S. 2006. Emission of PCDD/F PCB and HCB from combustion of firewood and pellets in residential stoves and boilers. *Environmental Science & Technology* 40(16), 4968-4975.

Heller W. 2008. Renewable energies in the EU. *ATW-International Journal for Nuclear Power* 53(5), 352.

Hoglund J., Vinterback J., Roos A. & Bohlin F. 2008. *The Swedish fuel pellets industry, production market and standardization.* In: Vinterback J. (Ed). Proceedings of the World Bioenergy Conference and Exhibition on Biomass for Energy, Jonkoping, Sweden, 27-29 May 2008, pp 35-39.

IEA Bioenergy 2007. Potential contribution of bioenergy ton the world’s future energy demand. Available at http://www.ieabioenergy.com/MediaItem.aspx?id=5586.

Jacobsson S. 2008. The emergence and troubled growth of a 'biopower' innovation system in Sweden. *Energy Policy* 36(4), 1491-1508.

Jager-Waldau A. 2007. Photovoltaics and renewable energies in Europe. *Renewable & Sustainable Energy Reviews* 11, 1414-1437.

Jager-Waldau A. & Ossenbrink H. 2004. Progress of electricity from biomass wind and photovoltaics in the European Union. *Renewable & Sustainable Energy Reviews* 8(2), 157-182.

Junginger M., Faaij A., Rosillo-Calle F. & Wood J. 2006. The growing rol of biofuels – opportunities, challenges and pitfalls. *International Sugar Journal* 108(1295), 618-+

Kimmins J.P. 1997. Predicting sustainability of forest bioenergy production in the face of changing paradigms. *Biomass and Bioenergy* 13(4-5), 201-212.

Kjoller C. 1998. The biorefinery, a quality investment opportunity. In: Kraxner F., Yang J. & Yamagata Y. (Eds). Attitudes towards forest biomass and certification - A case study approach to integrate public opinion in Japan. *Bioretechnology* 100(17), 4058-4061.

Kraxner Florian, Yang Jue & Yamagata Yoshiki. 2009. Attitudes towards forest biomass and certification - A case study approach to integrate public opinion in Japan. *Bioresource Technology* 100(17), 4058-406.

Kwant K.W. 2001. Renewable energy in The Netherlands: policy and instruments. *Biomass & Bioenergy* 24(4-5), 265-267.

Lasselsberger L. 2008. Combustion of solid biomass - type checking. In: Kaufmann R. & Hutl G. (Eds). Landtechnik im Alpenraum Feldkirch Osterreich 14-15 May 2008. *ART-Schriftenreihe* 7, 65-73.

Laurijssen J. & Faaij A.P.C. 2009. Trading biomass or GHG emission credits? *Climatic Change* 94(3-4), 287-317.
Leduc S., Schmid E., Obersteiner M. & Riahi K. 2009. Methanol production by gasification using a geographically explicit model. *Biomass and Bioenergy* 33(5), 745-751.
Lewandowski I. & Faaij A.P.C. 2006. Steps towards the development of a certification system for sustainable bioenergy trade. *Biomass and Bioenergy* 30(2), 83-104.
Lowe A.T. & Smith C.T. 1997. Special issue: Environmental guidelines for developing sustainable energy output from biomass: workshop proceedings of the International Energy Authority Bioenergy Agreement Task XII Activity 4.4 ”Environmental issues” 17-23 September 1995 Ontario Canada and Michigan U.S.A. *Biomass and Bioenergy* 13(4-5), ii +187-330.
Madlener R. & Stagl S. 2005. Sustainability-guided promotion of renewable electricity generation. 2nd International Energy Economics Conference FEB 21-23 2001 Vienna Univ. Technol. Austria. *Ecological Economics* 53(2), 147-167.
Magdzinski L. 2006. Tembec Temiscaming integrated biorefinery. *Pulp & Paper Canada* 107 (6), T147-T149.
Manganelli C. 2006. Prospects of energy production from biomass. *Industria Saccarifera Italiana* 99(5), 119-122, 123-126, 128, 130, 132.
Marbe A. & Harvey S. 2006. Opportunities for integration of biofuel gasifiers in natural-gas combined heat-and-power plants in district-heating systems. *Applied Energy* 83(7), 723-748.
Marchal D., Van Stappen F. & Schenkel Y. 2009. Sustainable production criteria and indicators for solid biofuels. *Biotechnologie Agronomie Societe et Environnement* 13(1), 165-176.
Martinez E., Sanz F., Pellegrini S., Jimenez E. & Blanco J. 2009. Life-cycle assessment of a 2-MW rated power wind turbine: CML method. *International Journal of Life Cycle Assessment* 14(1), 52-63.
Martinic I., Vondra V. & Sporcic M. 2007. Development of a new concept for improvement of forest techniques in Croatia - Areas of possible contributions. *Croatian Journal of Forest Engineering* 28(1), 47-54.
Mendis M. & Openshaw K. 2004. The clean development mechanism: Making it operational. *Environment Development and Sustainability* 6(1-2), 183-211.
Nelson HT. 2008. Planning implications from the interactions between renewable energy programs and carbon regulation. *Journal of Environmental Planning and Management* 51(4), 581-596.
Nishio K. & Asano H. 2006. Supply amount and marginal price of renewable electricity under the renewables portfolio standard in Japan. *Energy Policy* 34(15), 2373-2387.
Palmujoki E. Global principles for sustainable biofuel production and trade. 2009. *International Environmental Agreements – Politics Law and Economics* 9(2), 135-151.
Pireddu G. 2008. Subsidies and market mechanisms in energy policy. In: Clini C., Musu I. & Gullino M.L. (Eds). Sustainable Development and Environmental Management, pp. 301-315.
Poh P.E. & Chong M.F. 2009. Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. *Bioretechnology* 100(1), 1-9.
Reinhardt G.A., Rettenmaier N. & Muench J. 2008. Economic optimization potencial of the energetic utilization of palm oil. *Umweltwissenschaften und Schadstoff-Forschung* 20(3), 180-188.
Riva G., Pedretti E.F. & Toscano G. 2007. Biofuels, general and technical aspects of their production and utilization. *Georgofili* 4 (Supplemento 1), 163-183.

Rosch C. & Skarka J. 1008. European biofuel policy in a global context: Trade-offs and strategies. *GAIA – Ecological Perspectives for Science and Society* 17(4), 378-386.
Sakata K. & Konohira Y. 2004. Comparison of forest policies in Japan USA and EU (Sweden) for preventing global warming. *Journal of the Japanese Forestry Society* 86(1), 20-26.
Sale N.A.C. & Dewes H. 2009. Opportunities and challenges for the international trade of Jatropha curcas-derived biofuel from developing countries. *African Journal of Biotechnology* 8(4), 515-523.
Sampson P.H., Templeton C.W.G. & Colombo S. 199. An overview of Ontario's Stock Quality Assessment Program. *New Forests* 13(1-3), 469-487.
Schlegel S. & Kaphengst T. 2007. European Union policy on bioenergy and the role of sustainability criteria and certification systems. *Journal of Agricultural & Food Industrial Organization* 5(2), Article 7.
Secco L. 2006. Options for wood biomass certification. *Sherwood - Foreste ed Alberi Oggi* (128), 64-67.
Seppala R. 2006. Global trends and issues in the forest sector and challenges to forest research. *Allgemeine Forst und Jagdzeitung* 177(8-9), 138-141.
Shepard J.P. 2006. Water quality protection in bioenergy production, the US system of forestry Best Management Practices. *Biomass and Bioenergy* 30(4), 378-384.
Shewry P.R., Napier J.A. & Davis P.J. 1998. *Engineering crop plants for industrial end uses. Proceedings of the Symposium of the Industrial Biochemistry and Biotechnology Group held at IACR-Long Ashton Research Station, Long Ashton, Bristol, UK, September 1996.* Engineering crop plants for industrial end uses. Proceedings of the Symposium of the Industrial Biochemistry and Biotechnology Group held at IACR-Long Ashton Research Station, Long Ashton, Bristol, UK, September 1996. Pp. xvi + 221.
Skambracks D. 2007. Financing of bioenergy: sustainability in credit allocation? Conference Information: Naturschutz und Landwirtschaft im Dialog: "Biomasseproduktion - ein Segen fur die Land(wirt)schaft?" Tagung am Bundesamt fur Naturschutz - Internationale Naturschutzakademie Insel Vilm 12. bis 15. Marz 2007. *BfN - Skripten (Bundesamt fur Naturschutz)* 211, 76-88.
Solinski B. & Solinski I. 2008. Economical appraisal of the energetic application of hard coal in co-combustion process with biomass in system power plants. *Gospodarka Surowcami Mineralnymi – Mineral Resources Management* 24(4), 211-221.
Stupak I., Asikainen A., Jonsell M., Karltun E., Lunnan A., Mizaraite D., Pasanen K., Parn H., Raulund-Rasmussen K., Roser D., Schroeder M., Varnagiryte I., Vilkriste L., Callesen I., Clarke N., Gaitnieks T., Ingerslev M., Mandre M., Ozolincius R., Saarsalmi A., Armolaitis K., Helmisaari HS., Indriksons A., Kairiukstis L., Katzensteiner K., Kukkola A., Ots K., Ravn HP. & Tamminen P. 2007. Sustainable utilisation of forest biomass for energy-possibilities and problems: Policy legislation certification and recommendations and guidelines in the Nordic Baltic and other European countries. *Biomass and Bioenergy* 31(10), 666-684.
Tat M.E. & Van Gerpen J.H. 2003. Biodiesel blend detection with a fuel composition sensor. *Applied Engineering in Agriculture* 19(2), 125-132.
Unger T. & Ahgren E.O. 2005. Impacts of a common green certificate market on electricity and CO2-emission markets in the Nordic countries. *Energy Policy* 33(16), 2152-2163.
Verdonk M., Dieperink C. & Faaij A.P.C. 2007. Governance of the emerging bioenergy markets. *Energy Policy* 35(7), 3909-3924.
Vinterback J. 2008. Proceedings of the World Bioenergy Conference and Exhibition on Biomass for Energy, Jonkoping, Sweden, 27-29 May 2008. Pp. 620.

Wang Y. 2006. Renewable electricity in Sweden: an analysis of policy and regulations. *Energy Policy* 34(10), 1209-1220.
Weeks J. 2004. Renewable energy markets. *BioCycle* 45 (12), 38-40 42 44.
Wenzelides M. & Hageman H. 2007. Determination of sustainable mobilizable dendromass potential in North Rhine-Westphalia on the basis of the federal and state forest inventories. *Forstarchiv* 78(3), 73-81.
Willeboer W. 1998. The Amer demolition wood gasification project. *Biomass and Bioenergy* 15(3), 245-249.
Yassin L., Lettieri P., Simons S.J.R. & Germana A. 2009. Techno-economic performance of energy-from-waste fluidized bed combustion and gasification processes in the UK context. *Chemical Engineering Journal* 146(3), 315-327.

SLU
Institutionen för energi och teknik
Box 7032
750 07 UPPSALA
Tel. 018-67 10 00
pdf.fil: www.et.slu.se

SLU
Department of Energy and Technology
Box 7032
S-750 07 UPPSALA
SWEDEN
Phone +46 18 671000