MAPPING OUT GLOBAL BIOMASS PROJECTIONS, TECHNOLOGICAL DEVELOPMENTS AND POLICY INNOVATIONS

Prepared for International Institute for Environment and Development (IIED) by

Mairi Black[1] and Goetz M. Richter[2]

[1] Porter Institute, Centre for Environmental Policy, Imperial College London SW7 2AZ

[2] Centre of Bioenergy and Climate Change; Dept. of Sustainable Soil & Grassland Systems, Rothamsted Research, Harpenden AL5 2JQ

Citation

Black, M. and Richter, G.M. (2010) Mapping out global biomass projections, technological developments and policy innovations. A background paper prepared for the International Institute for Environment and Development (IIED) for an international ESPA workshop on biomass energy, 19-21 October 2010, Parliament House Hotel, Edinburgh.

Acknowledgements

This report was funded by the Ecosystem Services and Poverty Alleviation Programme of the UK Government Department for International Development (DFID), the UK Natural Environment Research Council (NERC) and the UK Economic and Social Research Council (ESRC). Additional IIED frame funds were used from the Danish International Development Agency (DANIDA), the UK Government's Department for International Development (DFID), the Directorate General for International Cooperation, the Netherlands (DGIS), Irish Aid, the Norwegian Agency for Development Cooperation (NORAD), Swiss Agency for Development and Cooperation (SDC), and the Swedish International Development Agency (SIDA). The views expressed in this report do not necessarily represent those of the supporting institutions involved. Rothamsted Research is an institute of the UK Biotechnology and Biological Sciences Research Council.

This report was prepared as one of five background reports for an international workshop on 19-21 October 2010 on biomass energy at the Parliament House Hotel, Edinburgh. The workshop was part of a UK ESPA programme Partnership and Project Development (PPD) Grant to build a consortium around a project on 'Biomass energy – Optimising its contribution to poverty reduction and ecosystem services'. The authors are grateful for the active discussion of the draft ideas by participants of that meeting.

Table of contents

List of figures

List of tables

Executive summary

Biomass as a renewable energy source is one of the options to secure energy supply and to reduce greenhouse gas (GHG) emissions from fossil fuels in response to the climate change threat. Biomass is the Number 1 energy resource for developing countries, supplying energy to households for cooking representing about 70-80% of the global bioenergy contribution. This report reviews the state of the art of resource assessment and was commissioned by the IIED in preparation for the submission of a full proposal to the ESPA programme of the Natural Environment Research Council (NERC).

In this report, theoretical and implementable potentials, conversion routes and pathways for energy from biomass feedstocks are considered. The global perspective is presented in a whole system approach balancing all major demands on land use. The availability of land and land classification categories (marginal agricultural land; abandoned crop and pasture) are briefly discussed.

Country-specific summaries for policy initiatives and biomass opportunities have been supplied by partners in the potential South-South-North (India-Malawi-Kenya-UK) collaboration. Actual and implementable potentials of biomass energy are highlighted in a study on energy grass and wood feedstocks in the UK, as a regional example whereby various physical, socio-economic and cultural constraints are applied to the allocation of energy crops. From the total land area in England about 36% is dedicated to arable production and constrained only by the competition between food and fuel. Under the assumption that farmers would only use lowest grade, marginal land (reduced accessibility) 2.6% of the land area (337 000 ha) were available for biomass from dedicated energy crops. This would supply little over 2% of the total UK electricity demand of the intended 12.5% renewable energy. Any further consideration of the next highest land quality (2 800 000 ha, ~21% of total land area) would compete more strongly with other agricultural food products.

Depending on the land use scenario and technological progress, the potential contribution of biomass to satisfying the global energy demand of approximately 500 EJ/yr varies greatly. Considering only abandoned agricultural land for bioenergy and current natural productivity, biomass would contribute a minimum of 5% of the global energy demand. Including a wide range of resources, like wastes and residues (100 EJ/yr), surplus forestry (60 EJ/yr), and dedicated energy crops on unrestricted land (120 EJ/yr), potentials are much higher. Including biomass production on marginal and degraded land (70 EJ/yr) and gains from improved agricultural management (120 EJ/Yr) could satisfy today's global energy demand from renewable resources. It is essential to consider these global estimates in the context of the countries in question, but it appears that there are substantial underused resources which could provide beneficial renewable energy in sustainably managed scenarios.

Some recommendations and points of caution are made with regard to the potential climate and ecosystem benefits and also negative impacts arising from biomass energy. The approaches for carbon balance and greenhouse gas (GHG) benefits applied to the UK case study are generic and need adaptation to the Indian and African (Kenya, Malawi) situation.

We conclude with some key points for a research framework to promote biomass energy while enhancing the positive impact of the Ecosystem Service and Poverty Alleviation (ESPA) programme.

- Developing inventories of land use and land resources, bio-diversity and conservation areas

- Developing agro-ecological zoning (AEZ) in terms of potential crop productivity at regional and sub-regional scale
- Bioresource inventory – food, feed and fibre supply and demands, and calculation of the bioenergy potential differentiated according to form and usage
- Integration and analysis of multi-crop/multi-purpose production systems and supply chain analysis according to feedstock diversification, demand and infrastructure
- Efficiency assessment and an economic analysis and business plan for regional case studies

1. Introduction

Activities to reduce greenhouse gas (GHG) emissions and the dependence on fossil fuels, to develop the economy and energy availability for rural and developing populations, have led to the promotion of biomass materials as sources of feedstock for energy supply chains. Alongside these laudable goals, there has also been great concern about food security due to competition for agricultural land providing feedstocks for bioenergy, expansion of agricultural land and unsustainable harvest of biomass causing reduction and depletion of natural habitats and resources. In many countries, the development of agriculture is essential to improving living conditions by developing local economies. In the North, developing principles to assess the sustainability of feedstocks has been a priority to provide assurances for new biofuel supply chains, however, the level of detail being paid to issues such as Indirect Land Use Change (iLUC) is also seen as barrier to development in countries such as Africa (Sapp, 2010). A key component of this project is to provide and encourage different means of supporting sustainable biomass production through active participation in the development of frameworks with countries where poverty alleviation is of the highest priority. This paper is intended to provide background to facilitate the development of an interdisciplinary South-South-North research partnership (India-Africa-Europe) and strategy to address current expectations for bioenergy and to help re-shape the impact of biomass expansion in India, Kenya and Malawi.

The objectives of this report are

- to give an overview of dedicated biomass energy crop potentials (initially from as global a perspective as possible),
- to develop and postulate some principles of best practice in the use of biomass (including dedicated crops, residues and agricultural waste),
- to review the impact assessment of the use of bioenergy crops on climate change and vice versa,
- to draw some conclusions on the components of a research framework to promote a transition towards biomass energy that reduces poverty and detrimental impacts on ecosystem service.

2. Biomass potential for bioenergy production

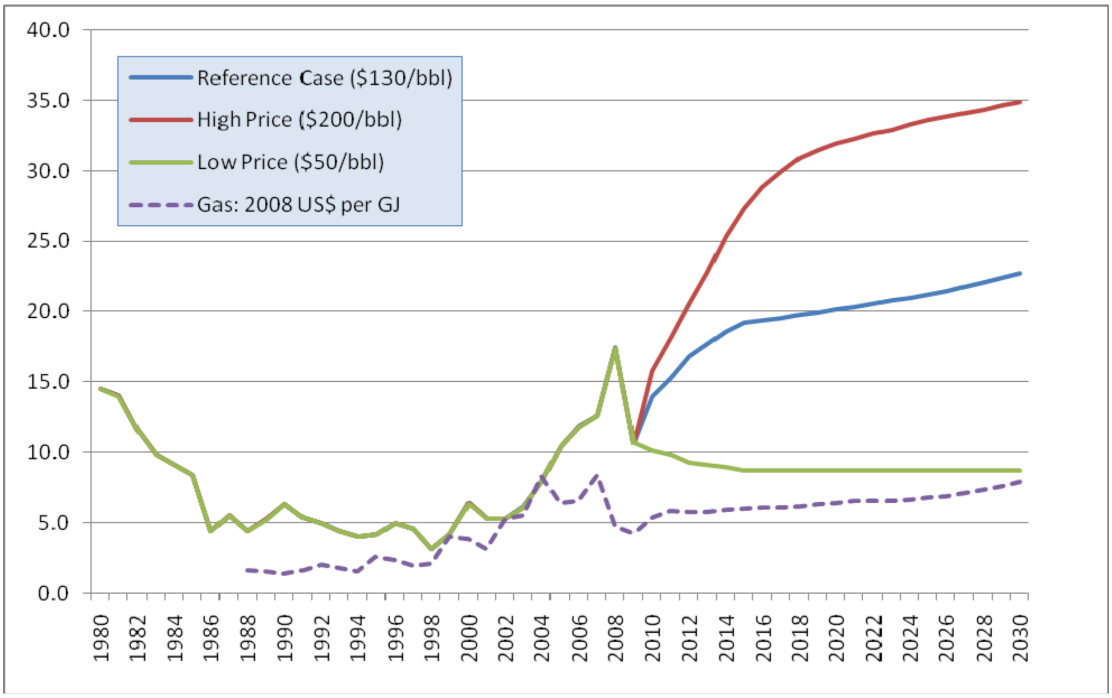
Climate change is one of the most considerable challenges faced globally in the 21st Century. It is inextricably linked to the growing global population and our demands on natural resources for food, fuels and materials. The effect of anthropogenic activities to supply our needs and in particular, the use of fossil derived materials such as coal, oil and gas are considered to have rapidly increased GHG emissions since the industrial age, resulting in a build-up of atmospheric GHGs which impacts on global climate patterns[1]. The potential economic consequences of climate change have been reported in the Stern Review (Stern, 2007) and perhaps more importantly, increasing occurrences of extreme weather events which are occurring globally, provide alarming views of the outcomes of climate change which the earth's inhabitants may face in the future.

In the face of these climate change scenarios, fossil resources continue to be utilised and for many countries in the world, the development of energy and transport infrastructures has

[1] GHG emissions resulting from burning of fossil fuels account for 75% of anthropogenic GHG emissions (Le Quere, 2009).

resulted in almost total dependence on fossil resources. The depletion of these resources is also seen as a major challenge for the future, with the likely outcomes manifesting themselves in the cost of fossil fuels.

Figure 1: Projected oil and gas price ranges to 2030; US$/GJ (US EIA 2009)



Efforts to address climate change and ensure the security of energy supply have led to the development of a number of policy mechanisms. In the European Union, the Climate and Energy Package (2008) commits the 27 member states to reduce CO_2 emissions by 20%, and to target a 20% share of energy supply from renewable energy, by 2020. Policy instruments within the package are the European Union Fuels Quality Directive (EU FQD 2009) and the Renewable Energy Directive (EU RED 2009). The FQD aims to reduce harmful atmospheric emissions, including greenhouse gases, and includes mandatory monitoring of life cycle GHG emissions. The RED aims to promote renewable energies including bioenergy and biofuels and has a component which addresses sustainability of biofuels and the land used to grow feedstocks.

The opportunities for the development of renewable energy from biomass has important implications for land use, both on changing cropping patterns on agricultural land and on impacts on natural habitats. Setting targets for biomass used for bioenergy must consider the availability of biomass resources (and other current demands), the potential for developing dedicated biomass crops and the requirements of land for food crop provision and ecosystems services. The timescales applied in assessing biomass potential for bioenergy production will also affect the outcome of studies for bioenergy utilisation. Estimates of the potential of renewable energy from biomass can be based on theoretical, technical or economic concepts (Fischer and Scharttenholzer, 2001) and on implementation potential (Thrän et al., 2010). Analysis of the theoretical potential of bioenergy is based on the physical possibilities of biomass production (resulting from land or aquatic productivity potential). It can be based on net primary production (NPP) of biomass[2] (Smeets et al., 2007) or using the AEZ[3]-approach proposed to estimate crop production potential (Sivakumar and Valentin, 1997). Technical potential depends on the availability, accessibility and efficiency of conversion processes which transform biomass into an energy carrier and will change as technologies progress. Economic consideration is the most variable as it is influenced by economic feasibility of conversion processes and also by many external market factors such as fossil fuel prices and fiscal incentives. Implementation potential is linked to both technical and economic potential and is also affected by policy interventions. It considers practical outcomes of likely bioenergy scenarios based on the available understanding of technical and economic aspects and the likelihood of development of a particular supply chain scenario in a given geographic location, after applying relevant constraints.

Before reviewing current expectations of biomass for bioenergy uses, it is relevant to consider the technologies utilised to convert feedstocks into energy carriers and the end uses/markets to be addressed (all of which are generally referred to as bioenergy in this report). From a technology perspective, biomass can be divided according to conversion via thermochemical pathways (combustion, gasification and pyrolysis) or by biochemical pathways (digestion, fermentation, methylesterification and hydrogenation). The outcomes of these technology options provide heat, electricity, liquid fuels, solid fuels and feedstocks for other chemical uses (Joelsson and Gustavsson, 2010). The current technologies which dominate these options are those which have been developed over many centuries of humankind's use of biomass. Combustion of biomass to provide heat and energy, fermentation of sugar or starch crops to provide bioethanol (more traditionally to provide potable alcohol) as well as the methyl-esterification to convert vegetable oil to biodiesel are at the commercial scale of production today. Those more technically challenging routes for biomass to liquid biofuels (e.g. lignocellulosic ethanol) and biochemicals are still in the developmental stages with few available at the commercial scale in 2010[4]. For all conversion technologies, even those well known and current technologies such as basic combustion, the advancement of ***conversion efficiency*** is the goal of many technology development initiatives, including those of the partners in this project.

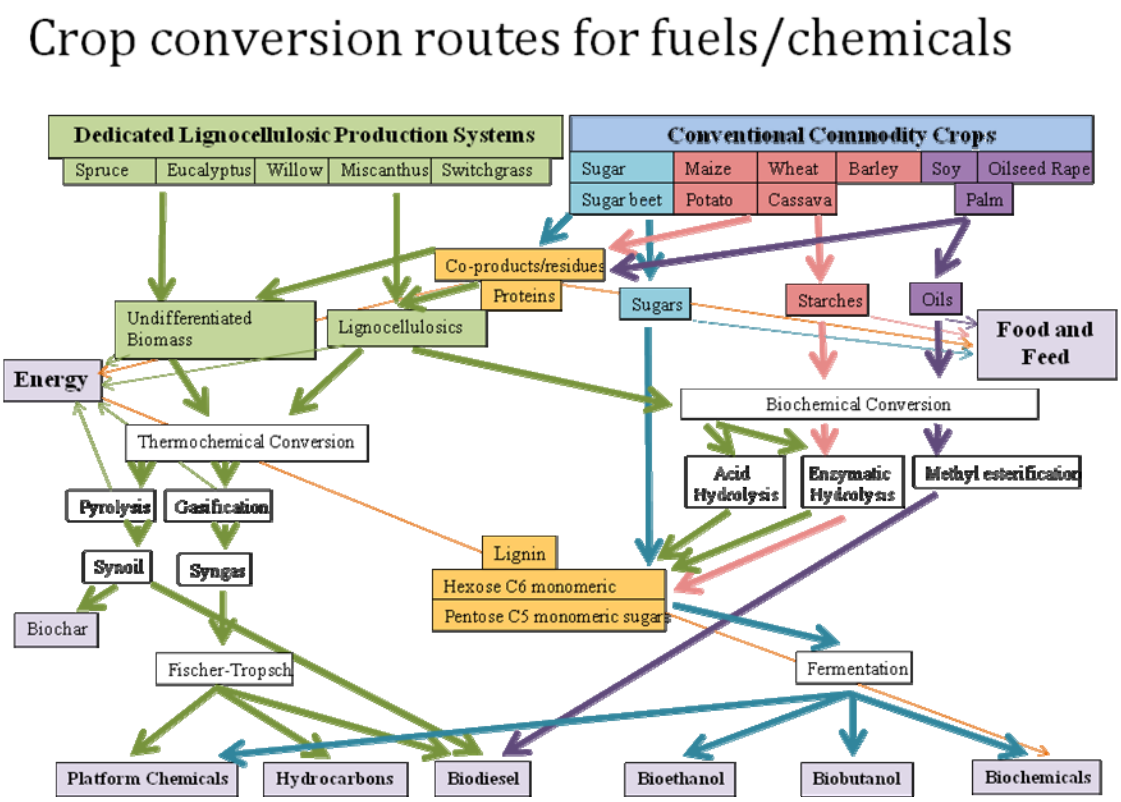
In considering biomass feedstocks for bioenergy it is useful to consider biomass as material derived from natural habitats (which can also include biomass from aquatic habitats), from dedicated biomass crops, as co-product material or residue from commodity crops grown for other food, feed or industrial markets, agricultural waste or municipal solid waste (MSW). The technological definitions given in the previous paragraph also provide a means of defining crops by their chemical components. Crops may be grown to provide lignocelluloses, which can be utilised across the spectrum of technologies (dedicated polygeneration biomass feedstocks) or to provide sugars and starches for fermentation technologies or vegetable oils for methylestericaton or hydrogenation. Where crops are currently grown for commodity markets but can also be used in the production of bioenergy, co-products or residues from the production pathway may also provide materials as secondary products for other markets (animal feed, lignocellulosic feedstock). Figure 2 provides an outline of commodity crops and dedicated lignocellulosic crops, potential conversion pathways and end use outcomes. Details given in Figure 2 are by no means exhaustive and there is potential for the development of crops suited to local growing

---

2 Net Primary Production (NPP) = Gross Primary Production (the amount of CO_2 converted into carbohydrates during photosynthesis) – autotrophic respiration and decomposition.
3 Agro-ecological zonation (AEZ) = concept introduced by the FAO to assess crop production potential based on length of growing periods, rainfall and temperature suitable for food, feed/fodder and fuel.
4 Liquid biofuel technologies are often described as 1st, 2nd, 3rd Generation reflecting the stage of development, 1st Generation being those commercially available today.

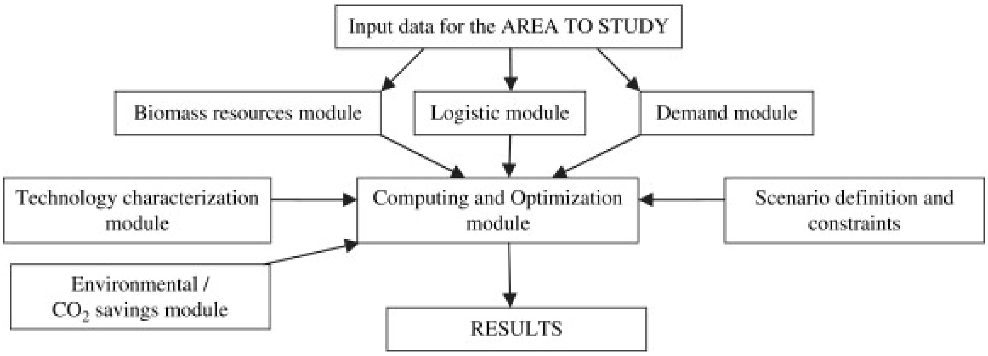
conditions (e.g. there is great interest in developing Jatropha and Moringa crops for the production of vegetable oils; sweet sorghum for sugar production for conversion to ethanol and energy cane as a dedicated biomass feedstock).

Figure 2: Crops and conversion options for the provision of energy carriers and platform chemical (Woods et al., 2009)



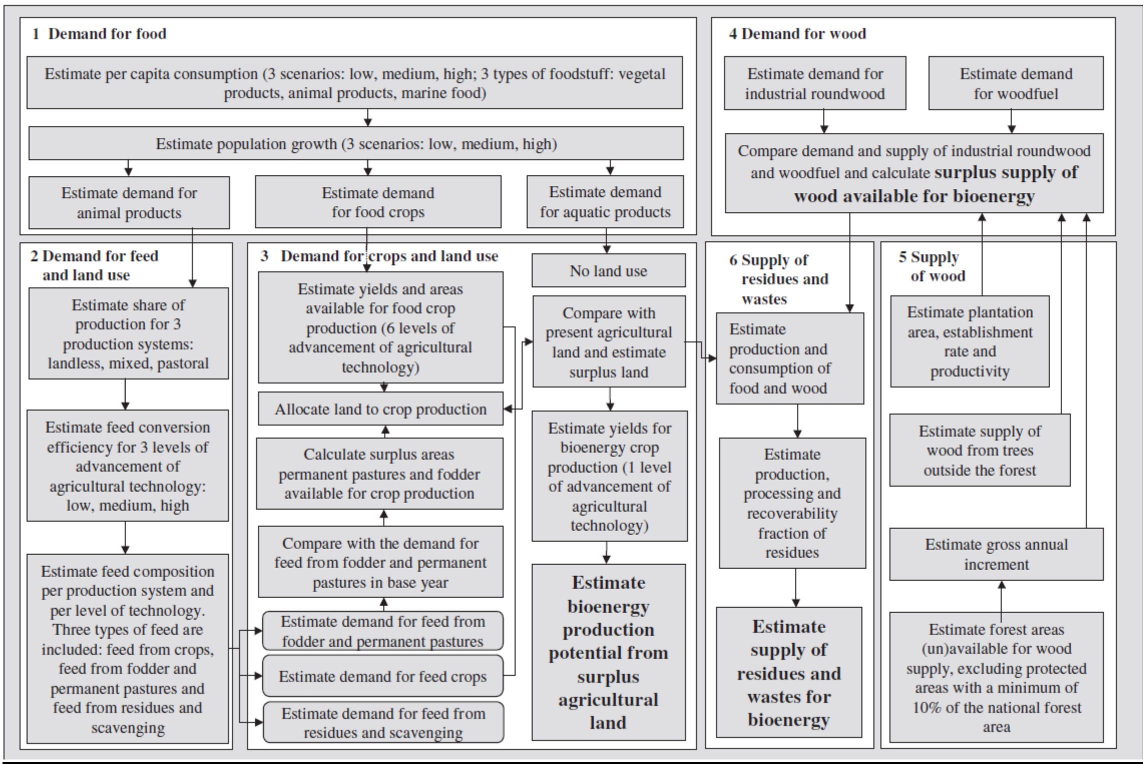
Each technological option comes with its own set of specificities, not least the accessibility and cost of conversion technology to provide energy in a given geographic location but also the availability and type of feedstock (quantity, quality, seasonality, composition and uniformity), efficiency of feedstock production (land/soil productivity; varietal choices and agronomic practises and options for co-product utilisation) and overall supply chain GHG balances and sustainability. For any geographic location, choices in the use of biomass will vary to fulfil local market and policy expectations but also to provide cost-effective options for energy provision.

Figure 3: Scheme of methodology to assess the optimum energy valorisation of biomass resources (Alfonso et al., 2009)



Developing local and global biomass scenarios are quite distinct activities and involve a number of considerations and assumptions. Figure 3 describes a model for reviewing local production for bioenergy scenarios (Alfonso et al., 2009) with a view to assessing best available options for bioenergy production/use. The development of GIS land-mapping work (top-down) and agro-ecological zoning of land areas (bottom-up analysis) provides a starting point for land areas under study. Figure 4 reviews the wider considerations for dedicated biomass crop production, including the interaction with agricultural crops grown for food and the availability of land, with a view to predicting global bioenergy potential to 2050 (Smeets et al, 2007).

Figure 4: Overview of the key elements in methodology to assess bioenergy potential of dedicated biomass crops (to 2050) (Smeets et al., 2007)



Thrän et al. (2010) summarise the following as the main influencing factors which are universally valid for predicting bioenergy potentials at any scale:

1. Development of the global [and regional/national] population
2. Per capita consumption of food
3. Increase in yield of biomass as the result of improved plant varieties
4. Increase in yield as the result of improved agricultural practices
5. Influence of climate change on the availability of acreage and the development of yield
6. Loss of acreage as the result of soil degradation and increased utilisation of land for non-agricultural purposes
7. Competing needs for nature conservation
8. Acreage for flood protection
9. Extensification towards environmental protection
10. Use of resources as raw materials in competing industries
11. Use of resources for non-subsidised exports

There is a large body of literature which looks at global bioenergy predictions (Table 1). Likewise, for localised biomass/bioenergy production systems many (country-specific) reports have been published. This emphasises the importance of considering case by case or country by country analysis, specifically with regard to biomass import, which contributed about 8% or 400 kilo tonnes oil equivalent to the use of Primary Renewable Energy in the UK in recent years (DUKES, 2010). Such imports may actually impact on the markets of developing countries.

Table 3: Selected comparative studies for biomass supply scenarios and potentials (exajoules) (Fischer and Schrattenholtzer, 2001)

Bioenergy			
Scenario	Potential	Year	Authors
	93	1990	Dessus [12]
91		2030	Greenpeace [16]
	93	—	Woods, J. and Hall, D.O. *Bioenergy for development — Technical and environmental dimensions*, FAO Environment and Energy Paper 13, Food and Agricultural Organization of the United Nations, Rome, Italy (1994)
	126	2020	Dessus [12]
140–235		2100	Kusumikawa and Mori [17]
145		2025	Johansson et al. [18]
153		2050	IIASA–WEC [2]
181		2100	Greenpeace [16]
181		2050	Leemans et al. [19]
193		2100	Lashof, D.A. and Tirpak, D.A. *Policy Options for Stabilizing Global Climate: Draft Report to Congress*, US Environmental Protection Agency, Washington, D.C. (1990)
200		2050	Johansson et al. [18]
207–221		2060	Shell. *The Evolution of the World's Energy System*, Shell International Limited, Group External Affairs, SIL Shell Centre, London (1996)
292–317		2060	Yamamoto H., Yamaji, K., and Fujino, J. *Bioenergy in Global Energy Systems in the Future — Considering Land Use Competitions and Energy Resource Constraints*, paper presented at the IAEE 21st Annual International Conference, May 13–16, 1998, Quebec City, Canada
315		2100	IIASA–WEC [2]
331		2100	Leemans et al. [19]
	350–450	2050	This study
	338–675	—	Lashof, D.A. and Tirpak, D.A. (1990) (*as above*)

A recent study by Dornburg et al. (2010) also highlights the range of biomass supply potentials anticipated up to 2050, depending on scenarios considered and methodologies used. The highest global biomass projection for 2050 is estimated at 1500 EJ. This considers production based on highly developed systems of intensive agricultural production which also meet food demands and allows for natural habitat protection. Conversely, the worst case scenario predicts zero potential for biomass supply, where high population growth and high food demand are supplied by low-yielding, low-input agricultural production systems.

Dornburg et al. (2010) included a wide range of resources, like wastes and residues from agriculture and forestry (30-180 EJ/yr) with 100 EJ/yr being certain. Resources from surplus forestry could range from 60 to 100 EJ/yr, and dedicated energy crops on unrestricted, better land could contribute 120 EJ/yr while biomass production on marginal and degraded land is estimated to add another 70 EJ/yr. Biggest gains could come from improved agricultural management (140 EJ/Yr), a point that is also made by Dale et al (2010) with regard to integrating production systems providing fuel and feed. It is not clear how much of this renewable resource potential would be implemented to satisfy the growing future global energy demand. It is essential, to down-scale these global estimates to the scale of the countries in question. After all, there are substantial underused [land] resources, and the activation of an additional 130 EJ/Yr needed a clear policy steer (Dornburg et al., 2010).

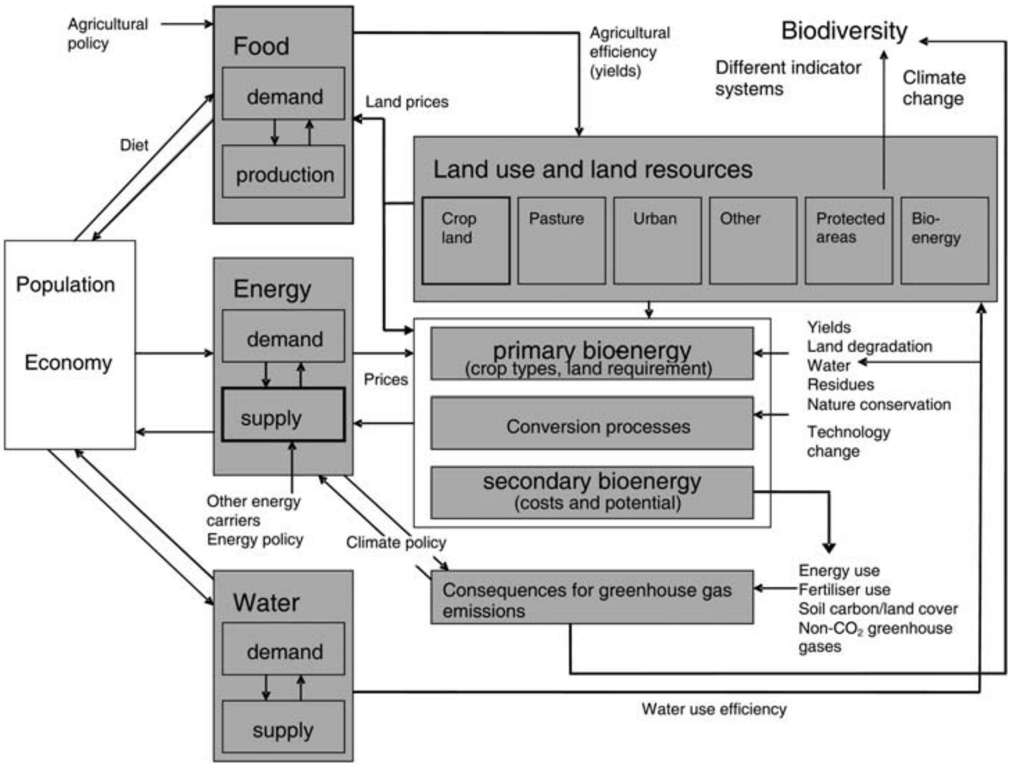
3. Current expectations for bioenergy from biomass

3.1 Global estimates of potential and actual biomass usage

The world depends on the production of biomass for food, feed and as a raw material for industrial processes. In recent years there has been an increase in interest in bioenergy from biomass as an energy carrier in industrialised countries where it is seen as an opportunity to develop non-fossil energy sources and reduce GHG emissions. Policies to promote the use of bioenergy and the reduction of GHG emissions have been developing over time and in the EU are now encompassed in the EU Energy and Climate Change Package, which commits the 27 Member States to reduce CO_2 emissions by 20% by 2020 and to target a 20% share of renewable energies in energy consumption. It is anticipated that these targets will be met by a variety of renewable energies, including solar, wind and hydro, but specific targets have not been defined, other than to address a 10% target for transport (no further definition regarding liquid biofuel). For many developing countries, biomass has been used over centuries as the main energy carrier to provide for domestic energy requirements. In many cases, biomass fulfils the most basic needs for heating and cooking but there is a need to develop energy for the provision of light, transport and industrial uses. According to Dornburg et al. (2010) energy from fossil fuels provides approximately 500 EJ/yr, whilst biomass accounts for approximately 50 EJ/yr. The proportions of energy used from fossil or bioenergy sources vary significantly between industrialised countries and developing countries and it is reported that 70-80% of biomass used globally is used in traditional, non-commercial applications.

The study of Dornburg et al. (2010) also provides a more comprehensive catalogue of criteria applied to the assessment of global bioenergy potential. They included and integrated the eventually conflicting demands for food, water and energy in the context of wider ecosystem functions, e.g. the need to maintain biodiversity and avoid negative GHG balances (Figure 5). They also include the impacts of economic variables and services, like agricultural commodity markets.

Figure 5: Key factors affecting bioenergy supply (from Dornburg et al., 2010)



Their conclusion was that biomass energy potentials would range between 200 and 500 EJ/yr in 2050. Improvements of agricultural efficiency and crop choice (especially perennial cropping systems offer the best perspectives) were essential preconditions to reach the higher end of the range.

The distribution of biomass availability is also important to developing understanding of trade flows for biomass as these will also influence development opportunities at the geographical level. Skytte et al. (2006) have reviewed types of biomass and biomass distribution (Table 2). It needs pointing out that the world regions considered as southern partners in this consortium already use large parts of their biomass potential for their daily consumption, while European states use only one fifth. Therefore, concepts of a sustainable production system are extremely important to establish under the consideration of local patterns of land use and competing demands. The premises for the evaluation of bioenergy potential have been discussed in the previous section and highlight the need for developing frameworks which anticipate local bioenergy potential but which do not limit development by becoming restrictive in considering 'best case scenarios' or idealistic and impractical models for a given geographic landscapes.

Table 4: Biomass potential and use distribution between regions (10^3 PJ/year) (Skytte et al., 2006)

Biomass potential	North America	Latin America	Asia	Africa	Europe	Middle East	Former USSR	World
Woody biomass	12.8	5.9	7.7	5.4	4.0	0.4	5.4	41.6
Energy crops	4.1	12.1	1.1	13.9	2.6	0.0	3.6	37.4
Straw	2.2	1.7	9.9	0.9	1.6	0.2	0.7	17.2
Other	0.8	1.8	2.9	1.2	0.7	0.1	0.3	7.6
Total potential	19.9	21.5	21.6	21.4	8.9	0.7	10.0	103.8
Use	3.1	2.6	23.2	8.3	2.0	0.0	0.5	39.7
Use/potential (%)	16	12	107	39	22	7	5	38

3.2 Availability of land that does not conflict with Best Practice Principles

Best Practice Principles for renewable energy production must be concerned with impact on the environment per se and all services of the ecosystem produced by such environment. Ecosystem Services will be infringed if the environment is damaged in any way, e.g. erosion will reduce the productivity of the soil and also reduce the quality of open waters and may create problems for the production of hydro-power. The ideal land use system, which integrates renewable energy, would be based on land quality, the distance to human settlements and frequency of consumption, value of the product and costs for manufacturing and transport, and any other beneficial side effects.

Most important for the land use discussion is the conflict with food production and literature considers two classes of available land without major impact on the current food production, marginal agricultural land (Cai et al., 2010; unpublished) and abandoned crop and pasture land (Field et al., 2008). Cai et al. (2010) considered four different scenarios: 330 to 700 MHa on degraded and abandoned cropland. Together with pastures, up to 1100 MHa could be made available for bioenergy crops without impacting on food production. Large areas of this marginal land would be available in the southern hemisphere (Africa, S. America). They estimate that between 26 and 62% of the current fuel demand could be fulfilled in this way.

The estimates of Field et al (2008) are more conservative and based on abandoned crop and pasture land only, estimating the contribution to fuel demand to a maximum of 5%. Certainly, the pressure on land and different agricultural commodities needs to consider all impacts (e.g. Dornburg et al., 2010). The reviewed global energy demand could range between 600 and 1040 EJ/yr (whereas the energy production from biomass could range from 100 EJ/yr (residues only) to 1500 EJ/yr (considering the ultimate technological potential). Considering all ecosystem constraints 200 to 500 EJ/yr would be available and possibly only 50 to 250EJ/yr if economic constraints were applied. These contributions would equate to between 25 and 33% of the global energy demand supplied from biomass, depending on which rates of future consumption and production are assumed.

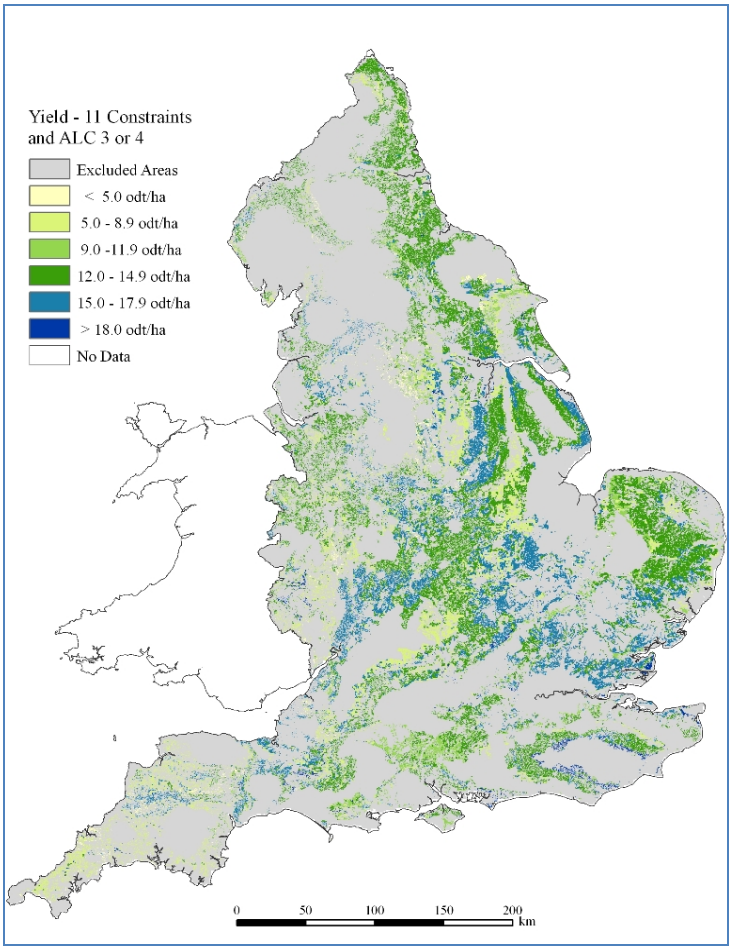
In reviewing these figures, it should also be highlighted that definitions of land, in terms of availability for biomass crop production, have led to concerns about the knowledge of local uses of land (Cotula et al., 2008). Land areas which have been described as ‘marginal’ and ‘abandoned’, from the agricultural point of view, may provide critical services to local populations and may also imply a value from the ecosystem and ecosystems services point of view, which may be overlooked.

4. Regional studies

4.1 The Northern perspective – United Kingdom

Of course, regional studies are available for a number of countries and they show the large diversity of ways to implementation. For the UK, maps of potential (attainable) yields were developed for energy trees (willow, poplar) (Aylott et al., 2008) and grasses (Miscanthus) (Richter et al., 2008) on arable land. Both of these studies applied a series of biophysical and some basic ecological constraints to where such crops could be grown. Lovett et al. (2009) gave an interesting example for the application of successive primary and secondary socio-economic constraints for planting a perennial energy grass in the UK, which narrowed down the area from a potential 8 million hectares (Mha) in England to less than 5 Mha and finally to about 3 million ha, when the accessibility and value of the land for food production were considered (Figure 6).

Figure 6: Biomass yield potentials on 3 Mha of arable land in England after applying constraint criteria (including landscape sensitivity) and economic priority given to food production on Agricultural Land Classification grade 1 and 2



Large regional differences emerged with regard to yield potential and availability. Bauen et al. (2010) combined the potential resource maps for Miscanthus, willow and poplar with an energy crop supply–cost curve based on the resource distribution and associated production costs in England and Wales. The spatial resource model was then used to inform the supply of biomass to geographically distributed demand centres, with co-firing plants used as an illustration to show the relative regional advantages of the alternative feedstocks when used in co-firing for combined heat and power production.

Lovett et al. (2009) showed that, in England alone, about 3 Mha would be available if only lower quality land was considered and if grassland was completely excluded from the conversion to 2nd generation bioenergy crops due to a potentially negative GHG emission balance. The Renewable Obligations of 350 000 ha would not impact much on the food production. Newer developments show that dedicating 400 000 ha to transport fuels (wheat to ethanol) could have a much bigger impact since it directly competes with food production to a much larger extent. However, multiple uses of the feedstocks, like the use of residue after fermentation in cattle feed show that these calculations to be a lot more complicated and demand a serious Life Cycle Analysis.

4.2 The Southern perspective – India

India has been implementing one of the largest renewable energy programmes in the world (Ravindranath and Balachandra, 2009), and renewable energy is considered as one of the most promising alternatives. Bioenergy has a large diverse portfolio including efficient biomass stoves, biogas, biomass combustion and gasification and process heat and liquid fuels. India has formulated and implemented innovative policies and programmes to promote bioenergy technologies; however, the success rate is marginal compared to the potential. This indicates the need for a serious reassessment of the bioenergy programme. In their paper they consider the potential of bioenergy to meet the rural energy needs: (1) biomass combustion and gasification for electricity; (2) biomethanation for cooking energy (gas) and electricity; and (3) efficient wood-burning devices for cooking. Bioenergy technology (BET) alternatives compare favourably with the conventional; however, the unit costs of BET vary widely (15–187% of conventional energy).

Rao et al. (2010) report on the potential of biogas generation from anaerobic digestion of different waste biomass in India. Renewable energy from biomass is one of the most efficient and effective options among the various other alternative sources of energy currently available. The anaerobic digestion of biomass requires less capital investment and per unit production costs as compared to other renewable energy sources such as hydro, solar and wind. Further, renewable energy from biomass is available as a domestic resource in the rural areas, which is not subject to world price fluctuations or the supply uncertainties as of imported and conventional fuels. The total installed capacity of bioenergy generation up to 2007 from solid biomass and waste to energy is about 1227 MW against a potential of 25,700 MW. The bioenergy potential from municipal solid waste, crop residue and agricultural waste, wastewater sludge, animal manure, industrial waste which includes distilleries, dairy plants, pulp and paper, poultry, slaughter houses, sugar industries could provide a total potential of biogas from all the above sources excluding wastewater of 40,734 M m^3/year.

Hiremath et al (2010) presented Decentralized Energy Planning (DEP) as one of the options to meet the rural and small-scale energy needs in a reliable, affordable and environmentally sustainable way. The main aspect of the energy planning at decentralized level would be to prepare an area-based DEP to meet energy needs and development of alternate energy sources at least-cost to the economy and environment. The approach adopted for analysing the DEP was bottom-up (village to district) to allow a detailed description of energy services and the resulting demand for energy forms and supply technologies. Decentralized bioenergy system for producing biogas and electricity, using local biomass resources, are shown to promote multiple goals such as self-reliance, local employment, and land reclamation apart from CO_2 emissions reduction. Their main conclusions for their example of the 3 million people district of Timkur were:

- Biogas is viable only at **village scale** due to inability to liquefy it and the lack of infrastructure.
- Biomass demand can be met by raising wood fuel on degraded agricultural or waste land.
- Gasification plant location at **Panchayats scale** depends on supply of land & biomass, transport and distribution costs.
- At **block level**, 27-45% of the waste land is needed for energy production under *business as usual scenario.*
- The different energy needs in the **district** (10 blocks) have can be met by allocating 12% of the wasteland (assuming yield of 8 t/ha/year) under a *sustainable development scenario.*

4.3 The Southern perspective - Africa – Kenya and Malawi

Kenya and Malawi differ largely in their resource demand, availability and management as shown in the individual reports associated with this report. Kenya largely depends on biomass (68%, includes crop residues) according to a national study of 2000; while 22% comes from petroleum fuels and 9% is electricity. Fuel wood provides almost 90% of the energy in rural areas, in approximately equal shares traded as wood and charcoal (15.1 and 16.5 MT, respectively). Sustainable wood yields meet only 43% of the total demand. The balance of 57% is drawn from standing stock – leading to further deforestation in closed forests, woodlands and wooded grasslands. National annual requirement for area dedicated to fuel production is about 0.54 Mha, of which 0.3 is providing woodfuel. Charcoal making is legalized and there are some examples of successful projects for biomass energy supply and use in Kenya, like Kakuzi Charcoal Production Enterprise and the RAFDIP – Charcoal Production Model (220 ha), which provides either roundwood (100 T/ha) or charcoal (30t/ha) within 6 years from efficient kilns. Also electricity is generated from biomass (Mumias Electricity Generation using bagasse) and the GTZ supported the Ministry of Energy Biogas Project. Future energy demand will go up as urban and rural population is increasing. Both components, growing sustainable resources and increasing the efficiency of charcoal making, are crucial to satisfy the increased demand of bioenergy.

In Malawi, the situation is more drastic with regard to the energy demand from biomass because alternative fuels are missing and a legal system for charcoal making does not exist. Biomass accounts for 97% of total primary energy supply, of which 59% is used in its primary form as firewood (52%) or residues (7%), and 41% are converted into charcoal. More than 80% of the wood consumption goes into private households and 98% of all households depend on it.

5. Review impact assessment of bioenergy crops on climate change and vice versa

Bioenergy is one of the renewable sources of energy, which can be carbon neutral or even sequester extra carbon. There is a large body of literature to back this up, which exceeds the remit of this report and the associated presentation. However, the impacts of land-based renewable energy forms are complex to assess and can be negative when the wrong type of land-use change is implemented (St Clair et a., 2008; Hillier et al., 2009). Naturally, replacement of forest by any kind of crop even perennial will have a negative carbon balance. For perennial energy crops in the UK the carbon balance is certainly positive, whether it is replacing arable crops or grassland, while replacing forest causes a negative GHG balance. Reviewing a large body of literature it must be said that the evidence base for GHG balance and carbon sequestration is very thin and needs more work.

In India, the climate change benefits in terms of carbon emission reductions are to the tune of 110 T C per year provided the available potential of BETs are utilized (Ravindranath & Balachandra, 2009). However, the question is how this can be done in a sustainable manner in managed plantations. In summary, it would be very useful to quantify the effects and impacts of energy crops in tropical and sub-tropical, semi-arid and arid environments under the following viewpoints:

- positive effects of carbon sequestration under perennial crops,
- land reclamation for degraded, eroded soils,

- define circumstances leading to negative GHG balances (e.g. false allocation of energy crops),
- water budget and quality benefits and hazards from energy crops,
- change of the energy balance due to land cover changes.

The effects of climate and environmental change on energy crops could be the following:
- increase/decrease in yield and yield uncertainty,
- promotion/prevention of pests and diseases.

The focus of the Biomass for bioenergy should be the stabilization of the system, providing long-term opportunities for people living of the land, preventing desertification and supplying essential resources to an increasingly urbanised society.

6. Conclusions for a research framework to promote biomass energy within ESPA

As noted from our UK case study, before biomass energy systems can be promoted, a thorough understanding of local/regional needs is critical to ensure that increasing biomass production does not impact adversely both on ecosystems services and socio-economic requirements. Key components which should be considered at the local and regional levels include the energy requirements from biomass production systems (for cooking, heating, electricity, and transport fuel); biomass availability or crop suitability for biomass provision; land use for other provisions, e.g. food crops, livestock production; and available conversion technologies. Evaluating land use is arguably one of the most difficult challenges to assess, as the value of land and the services it provides are considered differently by different stakeholders. Furthermore, methodologies for defining and classifying land use are developing at different 'rates' and with different 'meaning' in different geographical regions and it is considered here that collaborative effort should be made to understand the following key points:

- inventory of land use and land resources
- bio-diversity inventory and conservation areas
- agro-ecological zoning in terms of productivity at regional and sub-regional scale
- water and energy balance modelling
- bio-resource inventory – food, feed and fibre supply and demands
- calculation of the bioenergy potential differentiated according to form and usage
- integration and analysis of multi-crop/multi-purpose production systems
- supply chain analysis according to feedstock diversification, demand and infrastructure
- efficiency assessment and an economic analysis and business plan for regional case studies

These practical land use management and crops production strategies should be part of an integrated approach, which aims to synergize with top-down strategies (national and international action plans) with the requirements and needs of communities at the local level, and those services which are seen as means of alleviating poverty from the bottom-up.

References

Alfonso, D.; Perpiñá, C.; Pérez-Navarro, A.; Peñalvo, C.; Vargas, C. And Cárdenas, R., 2009. Methodology for optimization of distributed biomass resource evaluation, management and final energy use. Biomass and Bioenergy, 33, 1070-1079.

Bauen, A.W., Dunnett, A.J., Richter, G.M., Dailey, A.G., Aylott, M.J., Casella, E, Taylor, G., 2010. Modelling demand and supply of bioenergy from short rotation coppice and Miscanthus in the UK. *Bioresource Technology* 101: 8132-8143.

Cai, X.M., Zhang, X., Wang, D.B., 2010. Combining marginal cropland and grassland may meet the world's biofuel demand . UIUC (unpublished) http://www.emlub.com/wp-content/uploads/2010/09/cai,zhang,wang.pdf

Cotula, L., Dyer, N., and Vermeulen, S., 2008 Fuelling exclusion? The biofuels boom and poor people's access to land, IIED, London. ISBN: 978-1-84369-702-2

Dornburg et al., 2010. Bioenergy revisited: Key factors in global potentials of bioenergy. Energy Environ. Sci. 3, 258–267. Online DOI: 10.1039/b922422j

DUKES, 2010. Digest of United Kingdom energy statistics. Dept of Energy and Climate Change, DECC. http://www.decc.gov.uk/assets/decc/Statistics/publications/dukes/313-dukes-2010-ch7.pdf

EU Climate and Energy Package. 2008. COM (2008) 30 final.

EU FQD. 2009. Directive 2009/30/EC. Official Journal of the European Union, L 140/88.

EU RED. 2009. Directive 2009/28/EC. Official Journal of the European Union, L 140/16.

Field, C.B., Campbell, J.E., Lobell, D.B., 2008. Biomass energy: the scale of the potential resource. Trends in Ecology & Evolution 23, 65-72.

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

Hiremath, R.B., Kumar, B., Balachandra, P., Ravindranath, N.H., 2010. Bottom-up approach for decentralised energy planning: Case study of Tumkur district in India. Energy Policy 38, 862-874.

Hillier J, Whittaker C, Dailey AG, Aylott M, Casella E, Richter GM, Riche A, Murphy R, Taylor G, Smith P. 2009. Greenhouse gas emissions from four bio-energy crops in England and Wales: Integrating spatial estimates of yield and soil C balance in life cycle analyses. *Global change Biology-Bioenergy* 1: 267-281.

Joelsson, J. M. and Gustavsson, L., 2010. Reduction of CO_2 emissions and oil dependency with biomass-based polygeneration. Biomass and Bioenergy 34, 967-984.

Le Quéré, C. 2009. Recent trends in the sources and sinks of carbon dioxide. The Global Carbon Project. University of East Anglia. www.globalcarbonproject.org

Lovett AA; Sünnenberg GM; Richter GM; Dailey AG; Riche AB and Karp A., 2009. Land use implications of increased biomass production identified by GIS-based suitability and yield mapping for Miscanthus in England. Bioenergy Research 2: 17-28.

Rao, P.V., Baral, S.S., Dey, R., Mutnuri, S., 2010. Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renewable & Sustainable Energy Reviews 14, 2086-2094.

Ravindranath, N.H., Balachandra, R., 2009. Sustainable bioenergy for India: Technical, economic and policy analysis. Energy 34, 1003-1013.

Richter GM, Riche AB, Dailey AG, Gezan SA, Powlson DS, 2008. Is UK biofuel supply from Miscanthus water-limited? Soil Use and Management 24: 235-245.

Sapp, M., 2010. ILUC and the International Development Agenda – The Case of Africa' F.O. Lichts 8(24), 495-498.

Sivakumar MVK and Valentin C, 1997. Agroecological zones and the assessment of crop production potential. Philos Trans R Soc Lond B Biol Sci.; 352(1356): 907–916.

Skytte, K., Meibom, P., Henriksen, T.C., 2006. Electricity from biomass in the European Union - With or without biomass import. Biomass and Bioenergy 30, 385-392.

Smeets, E. M. W.; Faaij, A. P. C.; Lewandowski, I. M. And Turkenburg, W.C., 2007. A bottom-up assessment and review of global bioenergy potentials to 2050. Progress in Energy and Combustion Science 33, 56-106.

St Clair S, Hillier J, Smith P, 2008. Estimating the pre-harvest greenhouse gas costs of energy crop production. Biomass and Bioenergy, 32, 442–452.

Thrän, D.; Seindenberger, T.; Zeddies, J. and Offerman, R., 2010. Global biomass potentials – Resources, drivers and scenario results. Energy for Sustainable Development 14, 200-205.

Woods, J.; Black, M. and Murphy, R., 2009. Future Feedstocks for Biofuel Production Systems Chapter 13 in Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach, Germany. R.W. Howarth and S. Bringezu, editors.