Trees as a Global Source of Energy: from fuelwood and charcoal to pyrolysis-driven electricity generation and biofuels

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Abstract

Future increased demand for energy worldwide must be based on renewable sources of energy to avoid catastrophic increases in atmospheric CO_2 and to replace non-renewable sources of energy that have already passed their peak production. Trees can provide renewable biomass in the form of fuelwood, charcoal, pyrolysis-driven electricity production and biofuels. People's access to energy is often referred to as "the missing Millennium Development Goal", but energy is important for development and it is certain that energy access will be included in the post-2015 development agenda within a new set of Sustainable Development Goals. Unfortunately, current global policy initiatives to ensure universal access to sustainable energy essentially ignore the potential of tree-based bioenergy despite the fact that trees are important components of climate change. This is because of partially correct perceptions that wood fuels are associated with poverty and are polluting and dangerous, and to generally false assumptions about links between woodfuel use and environmental degradation. Problems associated with the use of tree biomass could be overcome relatively easily. There have been valid concerns that growing crops for bioenergy might compete for resources for food production. However, bioenergy provides farmers and land-users with new and important sources of income and fit well into integrated food-energy systems. Trees provide multiple benefits to agriculture, including soil fertility, water management, fruit production, fodder production, fuelwood and timber. Tree growing is eminently scaleable, suitable for large-scale production in woodlots and small-scale production on farms under agroforestry systems. Even where large scale processing of products is needed, such as the processing of biofuels or biomass production for community electricity generation, small-scale landowners can provide products for collection and bulking up, as currently happens in a number of agricultural value chains. An unprecedented global partnership is needed to ensure that renewable tree-based bioenergy plays its proper role in future global energy mixes.

Key words: woodfuel, scaleable, biomass, global-energy, bio-energy, livelihoods

Executive summary

People need access to energy in order to escape from poverty. Although the Millennium Development Goals did not include specific targets on energy, the debates that are currently leading to the design of a post-2015 development agenda all include discussions of specific targets on energy access. The United Nations Secretary General's Sustainable Energy for All initiative has the ambitious target of providing energy services to 500 million people by 2030. The role of trees in providing access to sustainable energy is currently essentially ignored in energy policy debates. This is partly because of partially-correct perceptions that wood fuels are associated with poverty and are polluting and dangerous, and to generally false assumptions about links between woodfuel use and environmental degradation. The potential for trees to be a basis for abundant, renewable and modern energy is usually disregarded. The lack of inclusion of tree-based energy is unfortunate, as trees have the potential to meet urgent current needs for energy for poor people, and to be a basis for truly renewable and modern energy services in the future.

Poor people around the world, predominantly in sub-Saharan Africa and South Asia, depend upon woody biomass for their primary energy needs. This will continue to be the case for the poorest sections of societies, even as more "modern" energy sources become available for the better off. There is scant evidence that use of fuelwood has led to large-scale deforestation, as is commonly assumed, although local shortages of fuelwood place unacceptable burdens of drudgery on women and girls who are obliged to spend many hours collecting wood to cook with. A logical response is to help poor people to produce wood near to where they need it. Charcoal production undoubtedly does put natural forest under severe pressure, as the fuel is valued in urban centres and is light, easily transported and widely marketed. A crisis in charcoal supply and in environmental degradation requires concerted action to manage charcoal production better, through improved forest management and agroforestry, improved production technology and improved cooking technology. The health hazards of cooking with firewood and charcoal are very real, and must not be ignored in the hope and assumption that their use will rapidly diminish. Much more effort is needed to help poor people to protect themselves from the effects of indoor air pollution through the improved ventilation of cooking areas and the use of improved cooking stoves that reduce pollution and improve the efficiency of fuel use.

Currently, energy from biological sources makes up only 10% of global use, although it has been estimated that bioenergy has the potential to provide 50% of global energy by 2050. Trees currently provide only the most basic energy services for poor people, namely cooking, warmth and some rudimentary lighting. However, trees have the potential to provide all of the forms of energy needed to drive development. Woody biomass can easily be used in gasification systems that provide fuel to drive machinery and generate electricity. These systems are cost-effective and already widely used in both developed and developing countries. They can be effective at large scales, such as the major electricity woody biomass generating plants used in developed countries and in smaller, community scale installations that are already in use in developing countries. Trees have a major potential to provide liquid biofuels, both biodiesel and ethanol, and will become more important as techniques for converting the lignin and cellulose of trees directly into ethanol improve.

Valid concerns have been expressed that growing crops for bioenergy might compete for resources for food production. However, bioenergy provides farmers and land-users with new and important sources of income and improved livelihoods and contributes to the battle

against poverty. All efforts should be applied to integrate bioenergy production into integrated food-energy systems. Trees fit extremely well into such systems, as they provide multiple benefits to agriculture, including soil fertility, water management, fruit production, fodder production, fuelwood and timber. Tree growing is eminently scaleable, suitable for large-scale production in woodlots and small-scale production on farms under agroforestry systems. Even where large scale processing of products is needed, such as the processing of biofuels or biomass production for community electricity generation, small-scale landowners can provide products for collection and bulking up, as currently happens in a number of agricultural value chains, such as milk production.

Current energy trajectories are not sustainable. Unless major changes are brought about, global CO^2 emissions will rise to 37 Gt by 2035, leading to a long-term increase in atmospheric temperature of 3.6°C. Available fossil fuels have passed their peak production capacity. New sources of renewable energy must and are being developed. Trees should play their full role within them. All of the planet's energy originally derives from solar radiation. Trees are one of the most effective ways of harnessing the sun and turning it into usable energy, and trees can do this in a truly renewable way. It is important that poor people participate fully in the energy transformation that is needed. Cynical past policies that encouraged poor people to use inefficient renewable energy sources while the developed world continue to enrich itself using fossil fuels are coming to an end, and efforts are being made to give poor people access to complex mixes of energy sources. Trees have major benefits for poverty reduction and improving livelihoods, especially because their use and production can be under the control of the people who need them, and trees can provide immediate and urgently needed energy while providing a basis for many forms of modern energy for development.

There is a need for a coordinated global effort to (i) review, quantify and publicize the potential of tree-based bioenergy, (ii) put tree-based bioenergy into its proper place in international and national energy policies, (iii) develop urgently-needed energy resources for poor people, (iv) develop tree-based bioenergy for power supply and electricity production for development, and (v) promote and develop biofuel production from trees. The development of tree-based bioenergy should be encouraged through the application of principles of integrated food-energy systems, with an emphasis on sustainability and the provision of renewable energy. The global effort might be promoted through existing policy platforms such as the Global Bioenergy Partnership or a new platform. Such a platform would be made up of members who bring together the skills and knowledge of agroforestry forest and agricultural scientists, technologists, energy policy specialists, multilateral funding institutions, donors, government officials, the private sector and non-governmental institutions. This review document outlines the justification for a global effort and provides more detailed proposals on how a global platform might function.

Review

1. Background and justification

Currently, energy from biological sources makes up only about 10% of global use, but almost 90% of all bioenergy worldwide comes from woody biomass. (IEA Bioenergy, 2009). Bioenergy has the potential to provide 50% of global energy by 2050. (Dornburg *et al*, 2008).

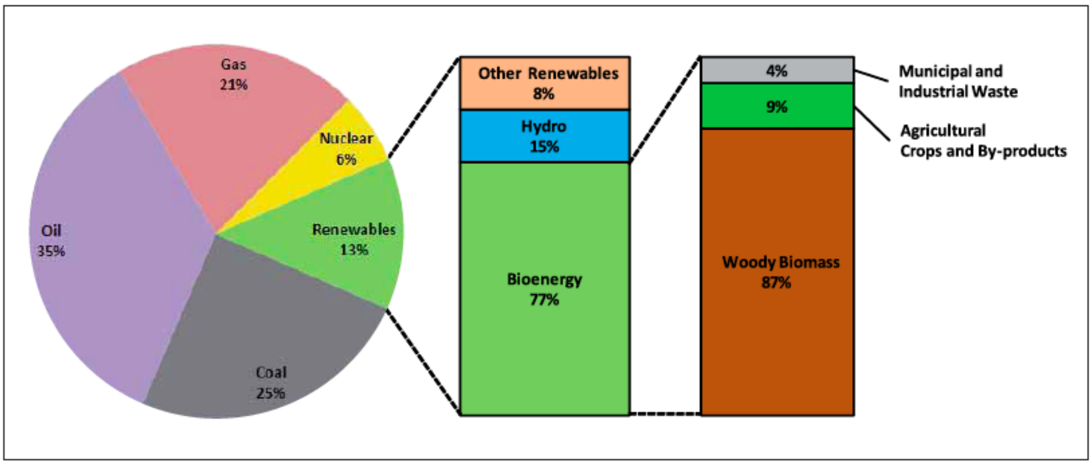

Figure 1. Share of bioenergy in the world primary energy mix. Source: based on IEA, 2006; and IPCC, 2007.

[1] 1 EJ = 10^{18} Joules (J) = 10^{15} kilojoules (kJ) = 24 million tonnes of oil equivalent (Mtoe).

This projection is based on the potential to increase biomass production through improving agricultural production, energy crops, surplus forest production and agricultural and forest waste. Tree-based energy will have to compete with other forms of energy. Coal is in abundant supply, but is likely to be used less in the future because of its contribution to atmospheric warming unless costly means of carbon capture are employed. (MIT, 2007). Oil is the world's most abundant fuel, but it is non-renewable, and "peak oil" has been passed in most oil producing countries, and even including new sources including tar sands and polar sources, most authorities conclude that global peak oil has either already happened or will do so soon. This will affect the availability of liquefied petroleum gas, which currently has a good potential to reach poorer people. Natural gas is becoming more abundant than previously, especially with new discoveries and advances in technology for extracting it such as hydraulic fracturing ("fracking"). Currently, natural gas production is concentrated in a few major producing countries: Russia, the United States, Canada and Iran. The biggest users are rich countries including the United States, Russia, Iran, China and the European Union. However, very large reserves of natural gas are being explored for exploitation in East Africa and other parts of Africa, and although the true potential is not yet known, there is a good chance that natural gas will become a greater part of the energy mix in some developing countries.

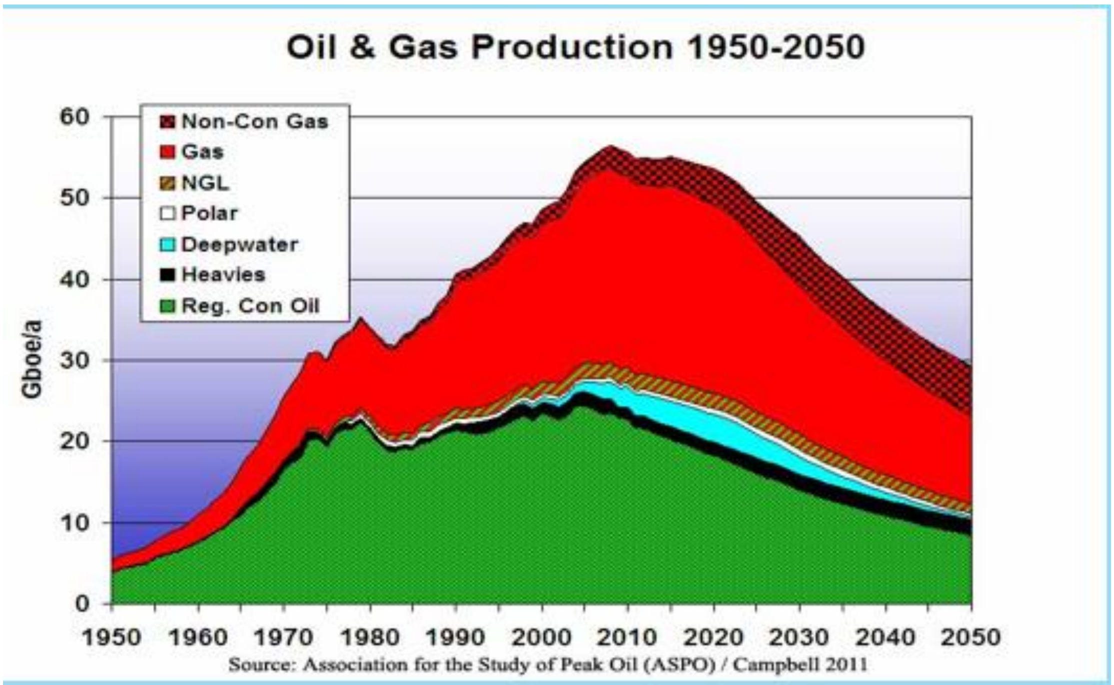

Figure 2. Historical and projected production of oil and gas from conventional and new sources (GigaBarrels of Oil Equivalent per year)

The Association for the Study of Peak Oil predicts that total oil and gas supplies have peaked even taking unconventional gas production into account. (Figure 2). In practice, unconventional gas is likely to be of most value where is can be produced and consumed without excessive transport costs, and its role in future energy mixes in developing countries will depend upon the success of investment in extraction, transport and use. India and Egypt are examples of countries that have adopted compressed natural gas for motor vehicles at a significant scale. In India all city buses and auto rickshaws have been obliged to run on CNG since 2004, and many taxis and private cars have been similarly modified. Urbanization and the growth of the transport sector are likely to be drivers of the adoption of natural gas in developing countries, assuming that production and transport challenges can be met.

Nuclear energy has the potential to grow, although at present it is not doing so to any great extent because of safety fears. Its adoption in developing countries is constrained by technical and geo-political issues. The World Energy Agency predicted in 2012 that global nuclear power generation would increase by 60% by 2035, but that was a 10% reduction on the same estimate made in 2011. (WEA, 2012).

In summary, confirmed conventional energy resources are decreasing, and even with innovative and unconventional means of expanding their availability, their long-term availability will be restricted, even though they remain the main part of OECD country and emerging economy energy plans. Demand for energy will grow by 70% by 2035, including increased absolute demand for coal, oil and gas (although their proportional level of total energy will reduce). This pathway is unsustainable: global CO^2 emissions will rise to 37 Gt in 2035, leading to an estimated long-term atmospheric energy increase of 3.6°C. Fortunately, renewables will provide almost as much energy as coal by 2035, but most of that prediction is based on increased production from hydro-schemes, wind and tide installations and other "new technology" solutions, as well as biofuels. (IEA, 2012). Woody biomass is already by far the most productive source of renewable energy, and there is a good *a priori* justification to invest in greatly expanding renewable energy production from trees.

2. Poverty and livelihoods

Woody biomass currently produces only 8-10% of the world's energy, but its importance to poor people is much greater. In sub-Saharan Africa, about 80% of all energy is bioenergy (WEA Statistics, 2009 data), almost all wood and charcoal for cooking. The poorest people on the continent, usually women and children, spend huge amounts of time collecting fuel. (Thorlakson and Neufeldt, 2012). When people are unable to collect enough wood to burn they often turn to more extreme ways of cooking their food, including the burning of otherwise valuable materials, such as dung, or toxic materials, such as plastics. (Köhlin *et al*, 2012; Gathui and Ngugi W., 2010). In the most extreme circumstances women are unable to cook food properly. (Mugo and Ong, 2006).

Providing woody biomass for cooking represents only the very basics of people's energy needs. The fight against poverty requires energy for social needs and to help people escape from the drudgery of collecting fuelwood and gain access to energy for productive use so that they can invest in income-earning enterprises. Total Energy Access (TEA) has been defined as access to key energy services that all people need, want and have a right to. (Practical Action, 2012). Minimum household TEA standards have been defined as in Table 1.

Energy service		**Minimum standard**
Lighting	1.1	300 lumens for a minimum of 4 hours per night at household level
Cooking and water heating	2.1	1kg woodfuel or 0.3kg charcoal or 0.04kg LPG or 0.2 litres of kerosene per day
	2.2	Minimum efficiency of improved solid fuel stoves to be 40% greater than a three stone fire in terms of fuel use
	2.3	Annual mean concentrations of particulate matter (PM2.5)$<10 \mu g/m^3$
Space heating	3.1	Minimum daytime indoor temperature 18˚C
Cooling	4.1	Households can extend the life of perishable products by a minimum of 50% over that allowed by ambient storage
	4.2	Maximum apparent indoor temperature 30˚C
Information and communications	5.1	People can communicate electronic information from their households
	5.3	People can access electronic media relevant to their lives and livelihoods in their household

Table 1. Minimum Total Energy Access standards. Source, Practical Action, 2012

Bioenergy is currently providing only the most basic elements of Total Energy Access, namely cooking, water heating and some rudimentary lighting. Fuel for cooking is a basic human need. All starch staple foods require cooking before they can be digested and tree-based bioenergy is predominantly used to satisfy this basic need. However, with development, bioenergy could contribute to all of the elements of Total Energy Access through the use of biofuels and the conversion of biomass into electricity.

Energy is needed for people to earn a living. Agriculture without external energy inputs is an exhausting, tedious, inefficient and low-yielding exercise. Many people in the developing countries have made the first important step by using animals for land preparation, tillage and

moving things around, including taking products to market. Mechanization can greatly improve productivity when energy is available for land preparation, irrigation, harvesting, threshing, drying, milling and transport. Agriculture is becoming increasingly “knowledge intense” and electricity is needed to maintain connectivity for computers and mobile telephones.

Few income-earning enterprises can be successful without access to energy. Rural enterprises based on agriculture need energy for food processing, packaging and transport. All other productive enterprises in the manufacturing and service sectors depend upon access to energy. Bioenergy currently meets very little of the energy demand for earning a living. This could change through the development of biofuels and the greater use of biomass for electricity generation.

3. The potential of bioenergy to fight poverty and improve livelihoods

3.1 Fuelwood production

This paper uses the following definitions. *Woodfuel* refers to all woody biomass used in some way to provide energy. *Fuelwood* (the topic of this section) consists of unprocessed biomass used to fuel fires, usually for cooking and warmth. (Boucher *et al*, 2011).

In general, only the poorest people in the world use wood for energy. Women and children usually have the task of collecting wood, which is burned in inefficient fires, often laid inside a small circle of three stones that hold the cooking pots. These are generally referred to as “three stone fires”. These fires are inefficient, and need to be constantly tended especially where the only firewood available is in the form of small sticks and twigs. They are known to contribute to around 2 million premature deaths per year caused by the toxic fumes they produce. In addition to emitting CO^2 into the atmosphere, they also emit particulate matter that also contributes to global warming.

Patterns of fuelwood use vary across developing regions (Table 2)

Region	Sub-region	Woodfuel production (1,000 m^3)
Africa	Central Africa	110,621
	East Africa	200,699
	North Africa	47,792
	Southern Africa	58,469
	West Africa	171,091
	Total Africa	**588,673**
Latin America and Caribbean	Caribbean	5,120
	Central America	40,195
	South America	195,856
	Total Latin America and Caribbean	**241,171**
	East Asia	216,621
	South Asia	382,745
	South East Asia	185,903
	Oceania	12,838
	Total Asia and Pacific	**794,104**

Table2. Woodfuel production by region, 2006. (Source FAO, 2009)

Fuelwood production is often assumed to cause major deforestation. This is often true locally, but in most places demand for domestic fuelwood has been met from scrub, bush fallow, the pruning of farmland or agroforestry (Mead, 2005; FAO, 2010). Most forest clearance has been driven by agricultural expansion (which opens opportunities for households to collect firewood) and most firewood is collected from outside of forests and usually consists of dead wood and not felled timber (Boucher *et al*, 2011). Small-scale local enterprises such as brick-making put greater pressure on local forests (FAO, 2010). However, there is no doubt that there are widespread problems in local supply of fuelwood for domestic purposes around the world, although this is not particularly well documented and there is much anecdotal evidence referred to. Arnold *et al* reviewed the situation on 2003, and concluded that reductions in access to woodfuels can negatively affect poor subsistence users. This confirms reports on the burden of firewood collection in developing countries, which is reported much more by social scientists than scientists studying fuelwood availability. For example, it has been reported that in some villages in India in the early 1990s, women used to spend one to two hours per trip collecting firewood, which increased to three to five hours after forest protection policies were put in place (Agarwal, 2001 quoted in UN, 2010). Some rather old data[1] from Ghana and Zambia revealed patterns of burden on women of collecting firewood. Households in Ghana made 0.6 trips per day to collect firewood, and in Zambia 0.81 trips per day. The time taken was 43 minutes and 92 minutes respectively to collect 20kg of fuelwood. The effort per household to collect firewood was 20 tonne-km in Ghana per year and 36.2 tonne-km per year in Zambia. However, effort put into collecting fuelwood varied considerably from place to place depending upon its availability, with typical rural women dedicating from 63 to 696 hours per annum. (Word Bank, 1994).

[1] Much of the data on fuelwood use was collected during the 1990s, and the emphasis on the "fuelwood crisis" appears to have diminished through the 2000s.

Fuelwood consumption is projected to increase in Africa and South Asia while reducing in other developing regions (Figure 3).

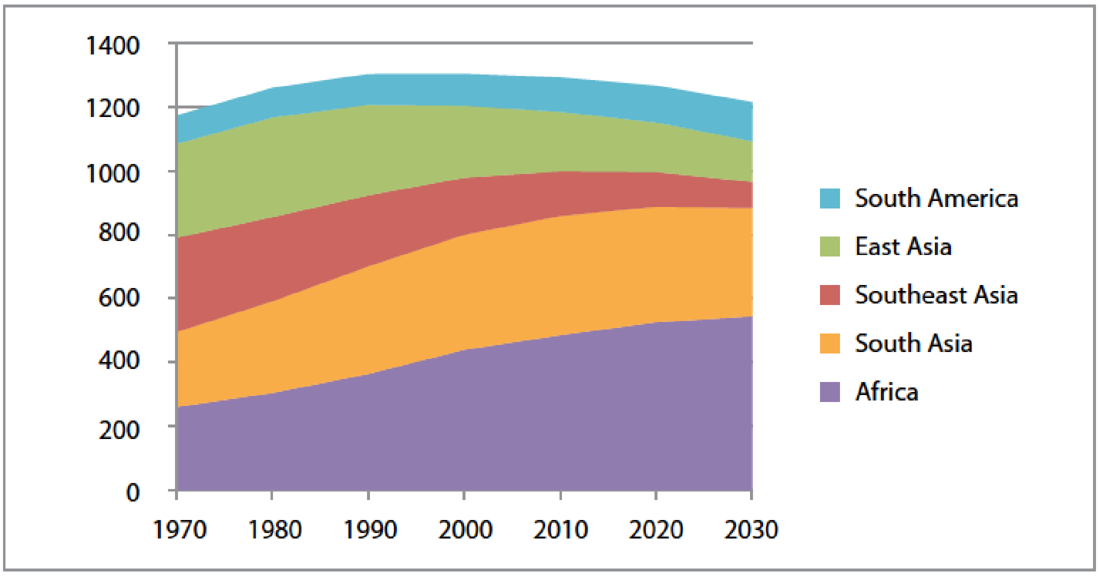

Figure 3. Projection of fuelwood consumption in developing regions (million m3). Hofstad *et al*, date?. Source Broadhead *et al*, 2001.

In summary, demand for domestic fuelwood can be expected to remain strong in all developing parts of the world, especially in sub-Saharan Africa. There is scant evidence that current fuelwood demand has led to massive loss of woody biomass or to a general crisis in the availability of fuelwood. It should be noted that much of the data on the current availability of fuelwood is dated, and more research is needed. Local shortages are often acute, and women and girls are obliged to spend long periods in the drudgery of collecting enough wood to cook with. A common response to local shortages is to plant trees closer to the homestead [references?] and there would appear to be a strong demand for increased production of fuelwood on farms and in local landscapes. It is probable that this will normally be satisfied through the planting of trees for multiple purposes (trees are seldom planted only for fuelwood). There is good potential to increase fuelwood production through improved short rotation tree planting and efficient harvesting techniques. It is important to grow the right the right species for efficient heat production and to avoid the use of excessively toxic varieties.

It will be morally defensible to promote woodfuel production only if the severe risk of indoor air pollution can be tackled. Numbers of people cited as killed by indoor air pollution associated with cooking vary greatly. The World Health Organization has published relatively conservative figures. They estimated from 2005 data that indoor air pollution in houses contributed 1.6 million addition deaths per year worldwide, which was equivalent to 3% of the world's disease burden (WHO, 2010). WHO figures in 2011 referred to "nearly 2 million" people dying prematurely and indoor particulate pollution from biomass being responsible for nearly 50% of infant deaths (WHO, 2011). Emissions from burning biomass are high in comparison with other sources of fuel (Figure 4).

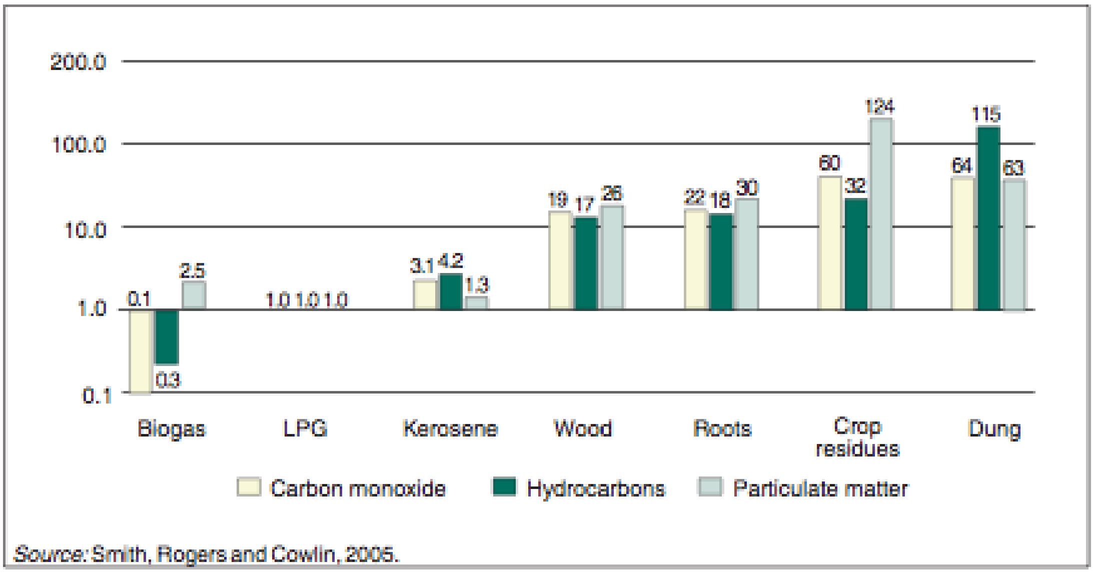

Figure 4. Pollution emissions in India by meal by cooking fuel relative to LPG (=1). The scale of the dependent variable is logarithmic. (Smith, 2006)

In principle, the technical challenges of ventilating cooking areas are not great, but in practice the uptake of improved stoves and cooking hoods has been poor. Many assumptions have been made about the likely rate of uptake of improved cookstoves, especially where they have been subsidized. In fact, rates of uptake vary tremendously. In some cases, assumed benefits in terms of ease of use and efficiency were not realized (Jeuland *et al*, 2012). Even where reasonable satisfaction with improved stoves have been reported, there has not been complete transfer to them, at least in part because people are familiar with their traditional technology (Quaiyum *et al*, 2006). In a comprehensive review of people's exposure to biomass-generated pollution Ezzati and Kammen (2012) comment that solid fuel combustion and other determinants of exposure to indoor smoke are complex phenomena and recommend a number of important research areas. They state that adoption of interventions is likely to vary from place to place and it is not evident what factors motivate households to adopt interventions.

3.2 Charcoal and Pyrolysis

Pyrolysis (in the context of this paper) refers to the thermal treatment of organic matter in the absence of oxygen. The organic matter is separated into gaseous, liquid and solid components. The solid component – the char – is rich in carbon. The liquid and gaseous components might be lost during production or captured for further processing.

3.2.1 Charcoal

The commonest form of pyrolysed fuel is charcoal. This is manufactured throughout the developing word, yielding an energy rich, light, easily transported fuel. Charcoal is produced from the slow pyrolysis of wood, often under simple rural manufacturing conditions, typically with the wood buried in earth to exclude oxygen. In contrast to fuelwood, charcoal is easily transported from rural producing areas to centres of population and its use is likely to increase in developing countries in future decades (Arnold *et al*, 2005). See Figure 5.

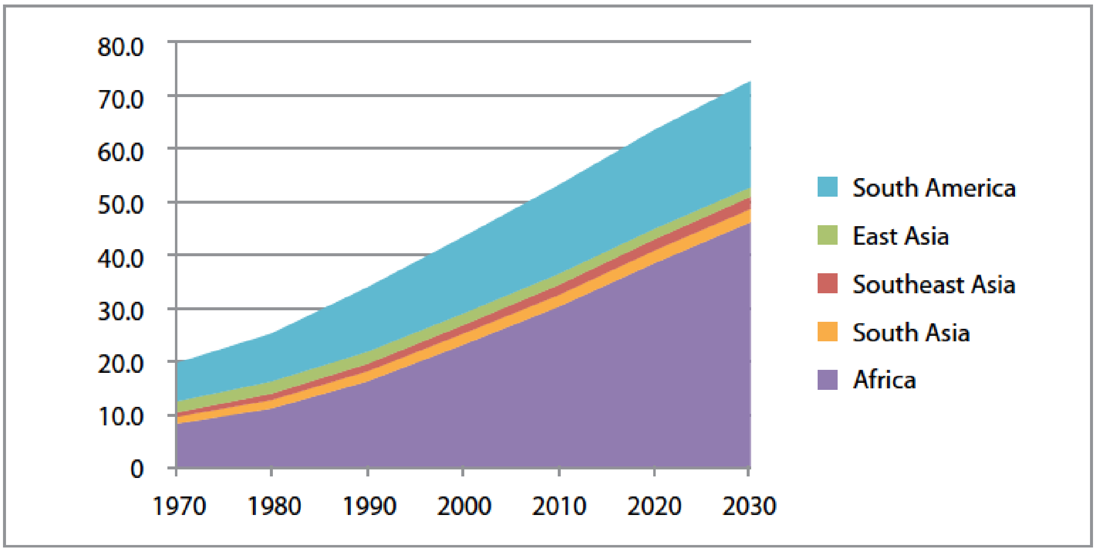

Figure 5. Projection of charcoal consumption in developing regions (million tonnes). Hofstad *et al*, date?. Source Broadhead *et al*, 2001.

In contrast to locally-sourced fuelwood, there is considerable evidence that charcoal production leads to considerable deforestation (FAO, 2007), especially where it is harvested from communal (or poorly managed) land that is treated as a free resource. The scale of charcoal production and marketing is indicated by the fact that over 3 million tonnes of charcoal per year are transported to Kampala in Uganda. (UNDP, undated). In common with much of the currently available data on woodfuels, much of the information on charcoal extraction is dated, and updating the information is an urgent research priority. Much of the available data are scattered in national assessments and have not been collated. For example, annual national consumption of charcoal in Kenya was estimated to be 2.4 million tonnes over a decade ago, in 2000 (ESDA, 2005). In Tanzania, charcoal production has been stated to be responsible for degradation of 24.6% of closed woodland and deforestation of 19.5% of closed woodland and 50.8% of open woodland in the catchment area to the West and North of Dar es Salaam (Mwalimbwi and Zahabu, 2009). Achieving sustainability in the charcoal industry will present considerable challenges. Demand for charcoal is likely to remain strong, and the charcoal trade contributes to incomes and livelihoods. The charcoal industry in sub-Saharan Africa was estimated to be worth US$ 8 billion in 2007 (World Bank, 2011). With poor regulatory frameworks in place, weak implementation of regulations and strong demand, pressures on forested areas for charcoal production are likely to increase. Reducing demand for charcoal will be difficult: it is not a fuel associated with poverty but a fuel exported to urban areas where it is regarded as clean and efficient. Efforts could be made to improve charcoal yield by improving its production technology. Traditional production techniques have energy conversion efficiencies of 10-22% in converting wood into charcoal, requiring 8-12 kg of wood for 1 kg of charcoal. Improved kilns can increase efficiency up to 30-40%, requiring only 3-4 kg wood to produce each kg of charcoal (Adam, 2009). Improved kilns that can be easily constructed locally have been available for many years. For example, the Casamance Kiln outperforms traditional technologies, although results for all charcoal production might depend upon the quality of the feedstock – especially the moisture content of the wood, which is often dried to an unrealistic 0% for comparability of testing (Kammen and Lew, 2005). The Adam Kiln is a more advanced high efficiency (35-40%) fixed kiln that recycles gases to a burning chamber during pyrolysis (Gouvello *et al*, 2008). Further reduction in demand might be available through the use of high-efficiency stoves. Burning charcoal is much cleaner than fuelwood, but high levels of carbon monoxide are

emitted and protection against indoor air pollution is important. Different types of stove produce very different levels of carbon monoxide emissions (Zhang *et al*, 1999).

There is a major need for attention to the supply side of charcoal production. Needs range from improving natural forest use through improved management and institutional reform to increasing wood production for charcoal on farms and in productive landscapes.

It should be noted that while the main reason for focusing on charcoal is its importance in cooking in developing countries, it also has potential as an industrial crop. Brazil used an estimated 8.3 million tonnes of charcoal for iron and steel production in 2006 (World Bank, 2009).

3.2.2 Gasification and power generation

Woody biomass can be put through a process of hydrolysis in a suitable combustion chamber, where the volatile gases are removed and subsequently burned for energy. The gases can be used for improved cookstoves or driving engines, including generators to produce electricity. In this way woody biomass can contribute to the achievement of Total Energy Access. Relatively simple gasifier stoves are available for domestic use and can reduce fuel use by one-third, CO emissions by three-quarters and particulate matter by a half when compared with simple three stone fireplaces (MacCarty *et al*, quoted in World Bank, 2011 b).

Gasification can provide the energy for electricity production at various scales.
Countries with large and developed forest industries often generate considerable amounts of electricity from woody biomass, much of which is forest waste. The European Union, as part of ambitious policies to achieve targets for renewable energy, already generates significant amounts of electricity from biomass, much of which is produced nationally and some is imported. See Figure 6.

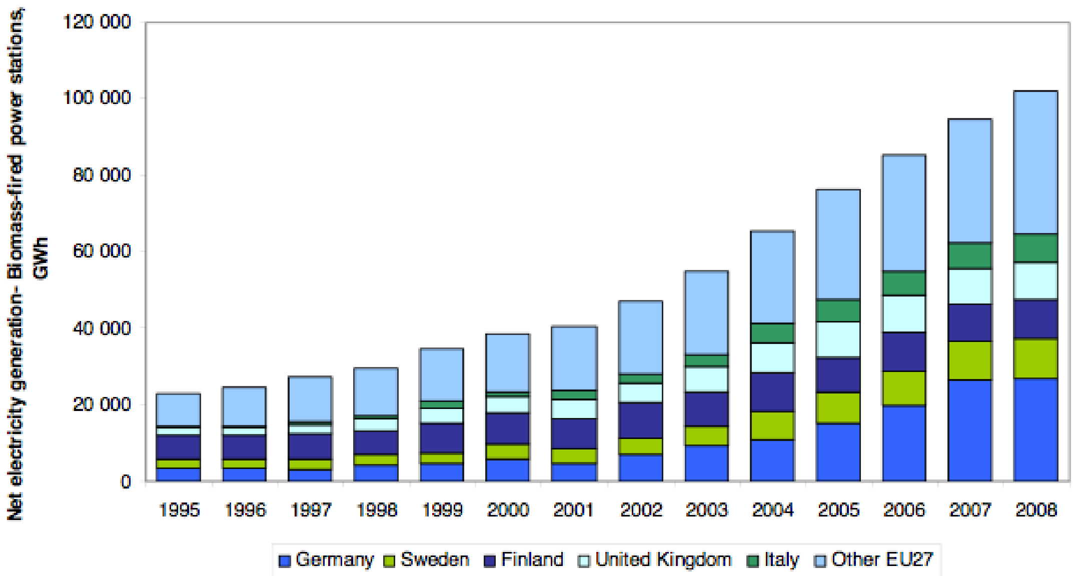

Figure 6. Electricity generation from biomass-fired power stations in the European Union. Source Maija and Kiviluoma (2011).

Biomass electricity generators are available for community-level application, where the fuel can be obtained from woody sources and from agricultural waste. For example, The Energy

and Resources Institute (TERI) in India has developed downdraft biomass gasifier generation systems in the range of 3.5 kWe - 100 kWe (kilowatt of electricity) (TERI website). A number of practical community-level applications of biomass power generation have been installed around the world, for example in India, Sri Lanka, Cambodia, Mali and developed countries, and while the technologies are at an early stage of development and not yet widely adopted (Dimple, 2011), their potential is judged to be promising. As woody biomass has the potential to be renewable, increased efforts are needed to develop it for Total Energy Access at community levels.

3.3 Liquid Biofuels

A number of valuable biofuels can be obtained from tree species. They have a great advantage over many sources of energy in that they are potentially renewable and can be used with relatively little processing. Oils extracted from the seeds or fruits of plants provide biodiesel to drive engines. Biodiesel fuels lend themselves to either large-scale or small-sale processing. Processing begins with mechanical cold pressing to extract the oil followed by filtration or sedimentation of suspended solids. Sometimes pre-preparation, such as roasting the seeds, is necessary. Where small-scale pressing is practiced, the extracted oil can sometimes be used directly to drive diesel engines, or used as a fuel for cooking or lighting (Brittaine and Lutaladio, 2010). Alternatively, biodiesel can be processed at larger scale (with fruits or seeds sourced either from small-scale or large-scale producers) where oils are put through an industrial process of transesterification that produces a refined fuel and removes a number of undesirable contaminants (Rutz and Janssen, 2007). A solid cake typically representing 10% of the original fruit or seed is left after processing, which depending on the toxicity and palatability of the original crop, can be used for animal feed or returned to the soil (Paul and Kemnitz, 2006). At present, much of the lipid feedstock used for biofuel is obtained from field crops, including soybean, rapeseed and sunflower. Among the trees, oil palm fruit, coconut fruit and *Jatropha curcas* are sources of biodiesel. Oil palm has proven potential for transformation into a number of products and fuels, including biodiesel (Chew and Bhatia 2008). *Jatropha curcas* has been heavily promoted as a biofuels crop for small-sale producers which could be grown on dry and otherwise marginal land (Brittaine and Lutaladio, 2010). In practice, the expected potential of jatropha has not been realized, mainly because although it grows on marginal land, it yields poorly and gives poor economic returns under smallholder management (IIyama *et al*, 2013; Alexon *et al*, 2012). However, industrial interest in jatropha as a biofuel crop remains high, but based on improved cultivars and good management rather than the essentially wild varieties promoted as development opportunities for small-scale farmers (SGB website). The development of jatropha as a small-holder crop will require more research and trials. *Pongamia pinnata* has been identified as a tree with potential for biodiesel production (Bobade and Khyade, 2012) but while commercial trials are under way, the crop is at an early stage of development.

Tree crops might also be used to provide feedstock for the distillation of ethanol as a fuel. One potential tree is *Nypa fructans*, the Nipa Palm, which is widely distributed among mangrove forests of Southeast Asia and produces an abundant sap from which ethanol can be produced at a rate of 6,480-10,224 L/hectare/year. This is less than sugarcane, but more than many other ethanol feedstocks (Hamilton and Murphy, 1988 quoted in Koji *et al*, 2011).

There are many other trees around the world with oilseed or other production potential for either biodiesel of ethanol. In India, an estimated 300 species of oil bearing trees are

available. Some of these species have been shown to be valuable feedstock for biofuel such as Pongamia (*Pongamia pinnata)*, neem (*Azadirachta indica)*, mahua (*Madhuca indica / Madhuka logifolia) and Simarouba (Simarouba glauca).* Indeed, if these trees are grown in Agroforestry model along with food crops, these trees can augment the food production by increasing the soil fertility and can also offer year round supply of feed stock. Agroforestry systems can be used by small holder farmers to produce non edible or multiple use oils from these tree species. Agroforestry systems used for biofuels production have been shown to increase the productivity of food crops and also improved soil fertility (Shivakumar, 2011). The oil bearing tree species should be selected in such a way that at least one species is in fruiting stage at any given period of time.

As techniques become available for the efficient processing of the lignin and cellulose fractions of trees (Somerville *et al*, 2010) then the potential importance of trees for biofuel production will become even greater. Given the immense capacity of trees to produce biomass, it is now timely to take a long-tern approach to developing a number of species for biofuels.

4. Trees in food and energy systems: technical and policy challenges

Since the emergence of biofuels as potential renewable sources of energy, considerable attention has been paid to perceived dangers that biofuel production might expand at the expense of food production. Integrated Food Energy Systems have been described as farming systems that integrate, intensify and thus increase the simultaneous production of food and energy (Sachs and Silk, 1991). This might be achieved through combining the production of food and biomass on the same land through multiple-cropping systems including agroforestry. Also, agro-industrial technology can be adopted (as described previously in this document) to allow the maximum use of all inputs and residues. Different areas of land might be used to produce different outputs, but the focus should be on overall integrated systems. (Bogdanski *et al*, 2010). Trees, in many ways, have characteristics that make them highly suited to integrated food and energy systems:

- Trees integrate well with crops in gardens, in short-rotation woodlots or in the landscape.

- Trees can be multi-functional, providing shade, fruit, forage, fuel and land and landscape management services (van Noordwijk *et al*, 2011).

- Trees can enhance food production, especially where they contribute to soil fertility (Ajayi *et al*, 2011).

Considerable flexibility will be needed in establishing integrated food-energy systems. Different farmers and communities will determine the balance of effort put into energy and into food. Depending on the locality, there will be different balances between energy feedstocks obtained from the landscape (eg Nipa Palm), from cultivated trees (jatropha, moringa and many others) and from field crops (eg sweet sorghum and cassava). Different communities will make their own decisions about how much of their food security they wish to ensure by growing their own crops, and to what extent they wish to sell commodities outside of the system to bring in money to buy food. It is probable that within any community degrees of complementary specialization will evolve, with different households specializing

in field crops, fuelwood production, charcoal processing, biofuel production, service provision and more. It is probable that some energy will be brought in from outside the Integrated Food and Energy System, particularly grid electricity and kerosene or LPG for cooking.

There must be an emphasis on sustainability. In environmental terms, this will mainly relate to the maintenance of the productive capacity of farms, especially taking into consideration the high levels of extraction of tree products, crop residues and crops from the system. Agroforestry systems will be a basis for maintaining land health. Financial feasibility and stability will be a key factor. Capacity building and institutional development will help to support the social stability of these complex systems.

Considerable policy support will be needed to develop integrated food-energy systems. Tree planting for fuelwood and the sustainable production of charcoal will require legislative and institutional reform, and financial incentives. There will need to be considerable attention paid to the development of markets and value chains from charcoal production to the most sophisticated systems of electricity and biofuel production.

Action

Tree-based energy has been neglected for many years, and urgent action is needed to ensure that wood is properly developed as a renewable source of energy to complement other sources in energy mixes available to developing countries.

There are significant knowledge gaps. There was a great deal of scientific research into wood as an energy source following oil shortages in the 1970s, but since oil re-appeared as a plentiful commodity, work on wood energy has decreased. Some very basic knowledge is out-of-date, including whether and where fuelwood shortages exist, what the demand for trees for energy will be if the sector is fully developed and what the potential for tree wood production is to meet demand. There has been much scattered effort to improve cookstoves and reduce emissions, but much more is needed if health hazards are to be eliminated. The development of biofuels is at an early stage, and much research and development is needed to maximize production, put in place processing capacity and value chains. The challenge of making wood-based biomass use truly renewable requires investigation; in theory tree-based energy should be renewable, but much current biomass use is not renewable, and systems must be developed to ensure sustainability. This will require life cycle studies. Concurrent impacts on climate will need to be understood. If wood use is made renewable, then there should be a positive impact on climate change, but the effects of emissions, including particulates will need better understanding.

There are many policy challenges to be faced. At the global level, the potential of wood-based energy must be taken into account in policy debates such as those under the UN Sustainable Energy for All initiative, and discussions leading to the definition of the post-2015 development agenda and its Sustainable Development Goals. At national level, wood-based fuels must be considered positively in national energy policy debates so wood a a renewable form of energy can play its proper role among other sources of energy in available energy mixes. Many policies around the word are perverse in terms of encouraging the use of wood. Forests policies often prevent farmers from growing, cutting down and selling trees. Charcoal is usually only barely legal in developing countries, preventing the establishment of a properly regulated industry. Instead, it becomes a rent-seeking enterprise, with much of its value accruing to corrupt officials and even terrorist groups.

An unprecedented partnership is needed to take this agenda forward. Serious consideration should be given to the development of such a partnership, leading to a global tree-based energy platform for action

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