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Chapter 9

Renewable Energy in the Context of Sustainable Development

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Author(s):	CLAs:	Jayant Sathaye and Atiq Rahman			
	LAs:	John Christensen, Junichi Fujino, Oswaldo Lucon, Monirul Mirza, Hugh Rudnick, August Schlaepfer, Andrey B Shmakin			
	CAs:	Tom Wilbanks			
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Chapter 9: Renewable Energy in the Context of Sustainable Development

CONTENTS

EXECUTIVE SUMMARY

Development is a concept frequently associated with economic growth, still in many cases disregarding income distribution, physical limits from the environment and the external costs of impacts caused by some and borne by others. Climate change is one of these most relevant impacts, with externalities present at global level.

Sustainable Development (SD) is a relatively recent concept, aiming to consider such impacts. There are several definitions of SD, but probably the most important came up in 1987, with an influential report published by the United Nations, entitled ‘‘Our Common Future’’ (or “The Brundtland Report’’). In this publication, sustainable development is a principle to be pursued, in order to meet the needs of the present without compromising the ability of future generations to meet their own needs. The report recognized that poverty is one of the main causes of environmental degradation and that equitable economic development is a key to addressing environmental problems.

Energy for sustainable development has three major pillars: (1) more efficient use of energy, especially at the point of end-use, (2) increased utilization of renewable energy, and (3) accelerated development and deployment of new and more efficient energy technologies. The questions of renewable and sustainable energy have their roots in two distinct issues: while renewability is a response to concerns about the depletion of primary energy sources (such as fossil fuels), sustainability is a response to environmental degradation of the planet and leaving a legacy to future generations of a reduced quality of life. Both issues now figure prominently on the political agendas of all levels of government and international relations.

Much of the discourses on SD have historically focused on economic and environmental dimensions of renewable energy technologies and their implementation. Social and institutional dimensions have not received the same degree of attention. With growing interest in the two-way relationship between SD and renewable energy, the latter two dimensions need to be given the same level of importance. The use of renewable energy technologies can significantly reduce GHG emissions and some technologies have ancillary or co-benefits that will reduce local pollution and improve health benefits.

The reverse relationship whereby development that is sustainable can create conditions in which renewables mitigation can be effectively pursued is equally important and needs to be highlighted in future development pathways. Most development pathways already focus on SD goals such as poverty alleviation, water and food security, access to energy, reliable infrastructure, etc. How to make these pathways more sustainable such that GHG emissions are reduced is critically important for permitting an increased role for renewable energy technologies. For most nations, increasing sustainability will be about navigating through an unexplored and evolving landscape.

Access to modern forms of energy, especially electricity for all purposes and clean fuels for cooking, heating and lighting to the billions of people without them today and in the future is a major challenge in itself. Wide disparities within and among developing countries contribute to social instability and affect basic human development. Making the joint achievement of promoting access while simultaneously making a transition to a cleaner and secure energy future is a challenging task.

Energy services can play a variety of direct and indirect roles in helping to achieve the millennium development goals (MDGs). They can halve extreme poverty, reduce hunger, increase access to safe drinking water, allow lighting that permits home study, increase security, etc. Moreover, efficient use of energy sources and good management can help to achieve sustainable use of natural resources and reduce deforestation.

Renewable energy technologies are ones that consume primary energy resources that are not subject to depletion. Renewable energy resources have also some problematic but often solvable technical and economic challenges, like being generally diffuse, not fully accessible, sometimes intermittent and regionally variable. To weigh the positive effects against the negative ones can be a lengthy and complex task, e.g., small vs. large hydro power. An expedient way out of the controversy was to define small hydropower as being renewable, and eligible for government support, and excluding large hydropower from subsidies or other incentive measures. In addition to the direct SD implications of renewable energy, it is important to assess their life-cycle impacts. The latter can significantly influence the selection choice among competing renewable technologies.

From the policy perspective, the main attractions of renewable energy are their security of supply, and the fact that they are environmentally relatively benign compared to fossil fuels. Most forms of renewable energy, such as hydro, wind, solar and biomass, are available within the borders of one country and are not subject to disruption by international political events.

9.1 Introduction

The concept of sustainable development (SD) has its roots in the idea of a sustainable society (Brown, 1981) and in the management of renewable and non-renewable resources. The World Commission on Environment and Development adopted the concept and launched sustainability into political, public and academic discourses. The concept was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987; Bojo et al., 1992).

While there are many definitions of sustainable development, the international sustainability discourse is helping to establish some commonly held principles of sustainable development. These include, for instance, the welfare of future generations, the maintenance of essential biophysical life support systems, ecosystem wellbeing, more universal participation in development processes and decision-making, and the achievement of an acceptable standard of human well-being (WCED, 1987; Meadowcroft, 1997; Swart et al., 2003; MA: Millennium Ecosystems Assessment, 2005).

Renewable energy applications are essential to deliver genuine results on Millennium Development Goals and all five World Summit on Sustainable Development 2002 (WSSD) development components:

- water: sustaining communities and industry without waste or pollution;
- energy: generated from clean, renewable sources;
- health: ensuring clean water, air and sanitation;
- agriculture: renewable base with sustainable forms of irrigation;
- biodiversity: elimination of habitat destruction, such as energy poverty induced deforestation practices, or water depletion and contamination in fossil and nuclear power generation.

The discussion of sustainable development in the IPCC process has evolved since the First Assessment Report which focused on the technology and cost-effectiveness of mitigation activities, to the Second Assessment Report (SAR) that included issues related to equity and to environmental (Hourcade et al, 2001) and social considerations (IPCC (Intergovernmental Panel on Climate Change), 1996). The Third Assessment Report (TAR) further broadened the treatment of SD by addressing issues related to global sustainability and the Fourth Assessment (AR4) included chapters on SD in both WG II and III reports with a focus on a review of both climate-first and development-first literature.

In light of this background, every chapter of this WGIII SRREN focuses to some extent on its links to sustainable development practices. Chapter 1 introduces the concept, Chapters 2 to 7 cover the environmental and other implications of bioenergy, direct solar energy, geothermal, hydropower, ocean and wind energy, and Chapters 8, 10, and 11 focus on integration, costs and benefits, and policy respectively[1].

The goal of this chapter is thus to summarize and consolidate the material reported in the other chapters. It begins by highlighting the two-way relationship between SD and renewable energy in Section 9.2. The discussion focuses on the impacts of renewables on the environment in Section 9.3 and on socio-economic aspects in Section 9.4. Section 9.5 describes the implications of sustainable development pathways for renewables and finally Section 9.6 synthesizes the above material particularly the policy implications including socio-economic and environmental considerations on the renewable potential.

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[1] This material will be clarified and expanded after the zero order drafts are received

9.1.1 The Two-way Relationship between Sustainable Development and Renewables

Making development more sustainable recognizes that there are many ways in which societies balance the economic, social, environmental, and institutional aspects, including climate change, dimensions of sustainable development. It also admits the possibility of conflict and trade-offs between measures that advance one aspect of sustainable development while harming another (Munasinghe, 2000). For a development path to be sustainable over a long period, however, wealth, resources, and opportunity must be shared so that all citizens have access to minimum standards of security, human rights, and social benefits, such as food, health, education, shelter, and opportunity for self-development (Reed, 1996).

The earlier chapters (mainly Chapters 2-7) provide an overview of the impacts of the implementation of many renewable technologies and practices that are being or may be deployed at various scales in the world. In this chapter, the information from the sectoral chapters is summarised and supplemented with findings from the sustainable development literature.

Synergies with local sustainable development goals, conditions for their successful implementation, and tradeoffs where the climate mitigation and local sustainable development may be at odds with each other are discussed. In addition, the implications of policy instruments on sustainable development goals are described in Section 9.5 and 9.6. As documented in the sectoral chapters, renewables options often have positive effects on aspects of sustainability, but may not always be sustainable with respect to all three dimensions of SD -- economic, environmental and social. In some cases the positive effects on sustainability are more indirect, because they are the results of side-effects of reducing GHG-emissions such as through the use of biofuels. Therefore, it is not always possible to assess the net outcome of the various effects.

The sustainable development benefits of renewable energy options will vary across sectors and regions. Table 1 describes the positive and negative impacts of renewables, fossil fuels ands nuclear energy technologies on a variety of selected SD indicators. Generally, options that improve productivity of resource use, whether it is energy, water, or land, yield positive benefits across all three dimensions of sustainable development. The use of bioenergy and efficient cook stoves can enhance productivity, and promote social harmony and gender equality. Other categories of options have a more uncertain impact and depend on the wider socioeconomic context within which the option is being implemented. A finite amount of land area is available for bioenergy crops, for instance, which limits the amount of fuel that can be produced and the carbon emissions that can be offset.

In the sectoral discussion below we focus on the three aspects of sustainable development – environmental (Section 9.3), and economic and social (Section 9.4). Environmental impacts include those occurring in local areas on air, water, and land, including the loss of biodiversity, human health and the built environment. Virtually all forms of renewable energy supply demand land and/or water resources, and cause some level of environmental damage. The emission of greenhouse gases (GHG) is often directly related to the emissions of other pollutants, either airborne, e.g. particulates from burning biomass which causes local or indoor air pollution, or waterborne, e.g., from leaching of nitrates from fertilizer application in intensive bioenergy cropping.

Economic implications include costs and overall welfare. Sectoral costs of various mitigation policies have been widely studied and a range of cost estimates are reported for each sector at both the global and country-specific levels in the sectoral chapters and in Chapter 10. Yet mitigation costs are just one part of the broader economic impacts of SD. Other impacts include growth and distribution of income, employment and availability of jobs, government fiscal budgets, and competitiveness of the economy or sector within a globalizing market. The social dimension includes issues such as gender equality, governance, equitable income distribution, housing and education opportunity, health impacts, and corruption. Most renewable energy options will impact one or more of these issues, and both benefits and tradeoffs are likely.

In addition to the above renewable energy impacts on sustainable development, the reverse implications of SD paths on renewable energy are equally important. The pursuit of rural development in all countries for example has been accelerated through the process of electrification. In the modern era, renewable energy sources such as the use of solar lanterns as a substitute for kerosene-fuelled lamps offers a low-pollution technology with significant health benefits. Similarly the increased demand for water can be facilitated through the use of biogas-driven electric pumps. The two-way relationship between SD and renewables thus is a key feature which is described in Section 9.4.1 and Table 2.

Climate change is the most important global environmental challenge facing humanity with implications for food production, natural ecosystems, fresh water supply, and health. It is projected to lead to temperature increases as high as 6 degrees C by 2100 (IPCC SRES, 2000) and cause changes in regional and severity of precipitation patterns, sea level rise and flooding, regional temperature increases, wind storms, and sea level rise. Since all the renewable energy sources are directly connected to one or more of the above natural parameters, their energy output will be affected either through an impact on the infrastructure and energy source, or through a change in operating parameters. The impact on sea level rise, hydro power sources and biomass is probably the most studied among the renewable sources because of the impact on land and water is easier to estimate than the change in wind patterns and regimes.

While renewable energy sources may be affected by climate change impacts they can also be used as adaption strategies. Micro grids using PV technologies for instance can serve as a means of electricity in cyclone shelters.

9.1.2 Energy Indicators of Sustainable Development

To make development more sustainable, indicators can help to monitor progress towards sustainable development, and identify where improvements need to be made. There are many different ways to classify indicators of sustainable development (Sathaye, Najam, et al. 2007). In 1995 United Nations Department of Economic and Social Affairs (UNDESA) began working to produce an overall set of indicators for sustainable development and concluded with a package of 58 indicators, of which only 3 energy related: annual energy consumption per capita, intensity of energy use and share of consumption of renewable energy resources. At the 2002 WSSD, the International Atomic Energy Agency (IAEA) presented a partnership initiative, in cooperation with UNDESA, the International Energy Agency (IEA),the Statistical Office of the European Communities (Eurostat) and the European Environment Agency (EEA), defining a set of 30 energy indicators and corresponding guidelines and methodologies to be used worldwide by countries in tracking their progress toward nationally defined sustainable energy development goals. These are based on seven themes that include equity, health, use and production patterns, security, air, water and land themes. Most of the social and environmental trends can be clearly identified as being desirable or undesirable, but it is not possible to provide a black-and-white evaluation of the economic ones. The development of sustainability criteria requires the analysis of local conditions and, for the formulation of what is to be considered sustainable, the involvement of local stakeholders. According to the field of activities, different organizations have developed sustainability criteria and tools, e.g. ILO for acceptable labor conditions, the WWF for ecological aspects, the Worldbank for financial results; the OECD and the UN for development policymaking and information (Lewandowski and Faaij, 2006).

Measurement and reporting of indicators is thus a critical aspect of the implementation of sound renewable energy technologies. Measurement not only gauges but also spurs the implementation of sustainable development and can have a pervasive effect on decision-making (Meadows, 1998; Bossel, 1999). In the subsequent sections, we make use of some of the relevant indicators provided by the IAEA in reporting the relative sustainable development synergies and tradeoffs of various renewable energy options.

9.1.3 Barriers and Opportunities

There are several key barriers that prevent the more rapid introduction of renewable energy technologies into the energy market. These include (1) high first cost of renewable technologies, (2) lack of accounting of externalities of conventional generation, (3) lack of data and information about resources, (4) challenge of integrating renewable energy technologies into the electricity grid, (5) susbsidies for conventional generation, (6) lack of storage facilities, (7) inadequate capacity to build and monitor performance of renewables, and (8) impact on agricultural land use.

Higher first cost of renewable energy technologies compared to conventional generation options hinders their large scale adoption particularly in developing countries, where cost is a prime concern. Since environmental and social costs of conventional generation options are not monetized, renewable energy does not have a level playing field given that it has advantages over conventional generation on these fronts. Subsidies to fossil fuel technologies are common across many countries which makes it difficult to justify the cost-effectiveness of renewable technologies in remote areas for instance.

Wind energy can be very seasonal which can lead to a low capacity factor. In addition, data on off-shore wind resources is often limited. Solar thermal (and photovoltaic) generation, some of which does not have significant storage potential, will not match the evening peaking system in most countries thus reducing the value of its generation. Such characteristics of renewable resources hinder their large scale adoption.

Other renewable energy options such as biomass/biogas and small hydro face many constraints related to scale, cost, institutional capacity, and integration policies. Access of renewable generation to the grid is an issue. A rational tariff setting framework, appropriate and simple interconnection for small RE, and solutions for the inter-state transfer of RE are ways that grid integration can be enhanced.

International opportunities for transfer of funds and technologies are being pursued on several fronts. These include the use of the Clean Development Mechanism, Clean Technology Fund established recently by the IBRD, and many bilateral activities. In addition, in many countries, renewable portfolio standards have been promulgated, and are being implemented in the US and India for example. Innovative financing mechanisms are being pursued in Bangladesh by the Grameen Bank to support the introduction of solar technologies at the village level.

Ultimately capacity building is a key barrier to the rapid transfer of technologies across and within countries. Lack of capacity to set policies and design and implement programs delays and sometimes negates implementation of renewable technologies. Within countries, lack of maintenance in rural areas prevents adoption or limits the scale up of commercially available technologies.

9.2 Interactions between sustainable development and renewable energy

9.2.1 Past and present roles of renewable energy for development

Economic and social development has always depended on energy services for comfort (e.g., space heating and cooling), convenience (e.g., food storage and cooking), mobility (e.g., motive power), and productivity (e.g., power for operating tools). Throughout most of human history, these services have been provided by renewable energy sources such as biomass, hydropower, and passive solar energy because they were the only alternatives at hand; but over the past several centuries industrial economies and societies have transformed landscapes and the quality of life by exploiting non-renewable fossil energy sources or other non-traditional sources such as nuclear energy.

In most respects, consumers of energy services are focused on whether those essential services are abundant, reliable, and affordable – not on where the energy comes from. In many industrial societies, in fact, energy is viewed not as a commodity but as an entitlement (Aronson et al., 1984), and governments are considered responsible for meeting this fundamental human need, along with food, shelter, and safety. When more energy services are considered essential for sustainable development, getting more energy can be a higher priority than carbon emissions or other indirect effects associated with choices among energy sources. In other words, whether the energy source is renewable or not is not always the most important issue for sustainable development in the near to mid-term.

Central issues for renewable energy in the modern context include all three of the dimensions of energy services for development:

- Abundance. Based on currently available renewable energy technologies other than large-scale hydropower, it is difficult to conceive of significant urban/industrial development based on renewable energy sources. Where current renewable energy niches in either electricity production or transportation fuels are now on the order of four to eight percent, increasing them to twenty or thirty percent is a profound challenge to scalability because of the magnitude of the needs. Clearly, Brazil stands out as a sizeable economy built to a considerable degree on hydropower, plus significant attention to biofuels but realistic trajectories toward that kind of energy mix for other large countries remain elusive. Meanwhile, some smaller countries and regions are becoming laboratories for pursuing more ambitious goals, such as Denmark's use of wind power as an electricity source.

- Reliability. Many renewable energy sources are based on continuous energy sources, such as water flow or plant growth, but some are based on intermittent energy sources, such as solar radiation or wind. Where the sources are intermittent, the only ways that they can meet continuing needs for energy services are either by energy storage or by using other energy sources as supplements, either of which tends to increase costs and reduce net benefits.

- Affordability. Energy costs are a complex issue for renewable energy. At a local scale, in many cases renewable energy options offer a prospect of reduced energy costs. But for larger-scale energy needs for development, fossil energy sources – or intermediate sources dependent on them -- are considerably less expensive at present (except for hydropower), and efforts to promote clean energy by increasing the cost of fossil energy can be a threat to development. For example, where kerosene is important for cooking and lighting in lower-income rural areas in developing countries, or where electricity is becoming important for job creation, interventions in energy markets in order to make renewable energy sources more competitive with fossil sources could have severe development impacts in some areas.

9.2.2 Human settlement and energy access

Historically, access to energy sources has had a significant effect on human settlement patterns. For instance, the world's population map reflects the importance of the seas for ocean transport in the colonial period, along with the importance of rivers for both transport and local hydropower for milling and industrial production. In the fossil fuel era, areas accessible to coal and oil sources (and to the wealth that they enabled) had comparative advantages for regional and urban growth, and in some cases this feeds opposition to major changes in energy sources.

A different dimension of this issue, however, is access to energy services in places where people already live, rather than where they may choose to locate. In this regard, the current issues tend to divide between concerns about energy access in rural settlements and in urban settlements:

- Rural settlements. Rural electrification to promote development (and reduce pressures for rural to urban migration) has been a development priority for many decades. In most cases, the preferred approach has been to combine local renewable resource endowments (such as solar radiation or biomass) with institutional innovations. For instance, a notable early success was the successful deployment of solar cells in rural villages in the Dominican Republic in the 1980s, led by Richard Hanson and Enersol Associates (Hanson, 1988; Waddle and Perlack, 1992). One focus for this effort became the World Summit on Sustainable Development in 2002, which confirmed that energy is a basic human need and supported such initiatives as the UNEP Global Clean Energy Network and the Global Village Energy Partnership, along with adding support for sustained attention to rural energy needs by the World Bank (World Bank, 1996). Often, however, rural electrification efforts have been so subsidized that they are not themselves sustainable, which can be worse for overall sustainability than not introducing those changes at all.

- Urban settlements. In many urban areas in developing countries, the major energy access issues are (a) the lack of reliability of electricity supply and (b) air pollution associated with local industrial, transportation, and energy production, which affect rich and poor alike. But even where it is generally available, the poor often lack ready, affordable access to electricity, as urban electricity supply institutions emphasize supplies to relatively large customers who can pay. In many cases, traditional renewable energy sources such as wood or charcoal for cooking and heating and passive solar energy for food preservation are used as the only affordable options, but urban wood and charcoal consumption often poses threats to the sustainability of regional biomass energy supply capacities.

9.2.3 The scale of action and prospects for closing the development gap

Where renewable energy can be developed and implemented at a relatively small scale and accessible technological level, it may offer potentials for relatively rapid improvement in social and economic well-being. Compared with large-scale electricity generation or liquid fuel production, for example, renewable energy sources can open up opportunities for local innovation (e.g., Kamkwamba and Mealer, 2009) and enable local technology production and business development/job creation (e.g., Lovins, 2002; + refs to China's growth in solar energy). Moreover, renewable energy technology deployment can deliver improvements quickly when it is coupled with effective local institutions. For instance, the 2009 Zayed Future Energy Prize was awarded to Dipal Chandra Barua, Director of Grameen Shakti, for that institution's successes in bringing solar PV electricity and biogas to rural populations in Bangladesh, linked with local micro-credit programs (www.gshakti.org).

A cautionary note, however, is that local energy resource-technology actions can in some cases have cumulative effects at larger scales that some stakeholders consider undesirable, such as effects of local bioenergy developments on biosphere protection

9.2.4 Energy security as an aspect of sustainable development

Where reliability of energy services is important to sustainable development, which is nearly always the case, threats to that reliability – including threats of sudden spikes in energy prices – are an important concern. Many developing regions, for example, still recall the effects of the oil crisis of the 1970s on their development, their well-being, and even their landscapes as biomass cover disappeared for tens of kilometres around cities, and more recent reports suggest that developing countries have become more vulnerable to external shocks than at that time (World Banks, 2008). One of the most attractive features of increasing the use of local renewable energy sources, especially if local populations either control or share in the control of the use of those sources, is that it decreases risks that external factors may introduce disruptive supply shortages or price increases, often very suddenly.

9.3 Environmental Impacts: global and regional assessment

9.3.1 Introduction

Development and exploitation of renewable energy have increasingly been important in the past three decades. In recent years, greenhouse gas abatement policies and the need for climate change mitigation and meeting increasing energy requirements have led to a rise in the development of renewable energy sources. They are relatively cleaner in terms of GHG emissions, environmental pollution than the fossil energy sources Apart from hydropower, windpower (White, 2007) and bioenergy (Blanco-Canqui and Lal, 2009; Liska et al., 2009; Luo et al., 2009), literature on the impacts of other renewables-direct solar, geothermal and ocean energy sources on environment is rather limited. In this section, environmental impacts of renewable energy sources on land, water, air, ecosystems and biodiversity, human health and built environment are discussed for bioenergy, direct solar and hydropower sources.

9.3.2 Bioenergy

9.3.2.1 Land

Bioenergy from crops is an important source of renewable energy and large-scale land use changes due to bioenergy production are occurring in many areas of the world. Although bioenergy production from perennial biomass crops has many potential benefits, land conversion to grow these crops may reduce, displace, and certainly change other important products and services of the existing land such as food production and biodiversity services (Lovett et al., 2009; Van Der Velde et al., 2009; Searchinger et al., 2008).

To help alleviate potential conflicts over land use, perennial biomass crops could be planted on more marginal and idle lands. Although most of the trials have so far been conducted on experimental sites, the economics simply dictate that, if bioenergy crops are in demand, they will expand to as much land as needed, and also try to obtain the highest yields possible. However, there should be a balance between food and biofuel production. One response to the potential competition between energy and food crops is to target degraded as well as grazing lands rather than prime, cropland for bioenergy production, while prime, higher quality croplands are left for food production. A possible benefit of this could be that cultivating energy crops on degraded lands would restore soil organic matter and nutrient content, stabilize erosion, balance moisture conditions, and thus contribute to overall improvement of the land.

Not only will the land use competition between bioenergy crops and food crops affect the prices and expand croplands, but it will likely result in an overall decrease in the average yield of crops as well (Gillingham et al., 2007). Both types of crops will be grown first in the most profitable and higher quality lands to obtain the highest yield. With growing demand of food and energy, the expansion will take place to lower quality lands. This may have implications in terms of increasing land and crop prices as well as reduction of yields due to utilization of lower quality lands (Gillingham et al., 2007).

9.3.2.2 Water

The expansion of land for growing bioenergy crops can impact the quantity and quality of surface water and groundwater through nitrate pollution from the applied fertilizers (Lovett et al., 2009).

9.3.2.3 Air

The chemical structures of bioenergy resources make them a potentially renewable and greenhouse-gas-free source of energy that could contribute to a more environmentally-friendly and sustainable energy system. Biomass fuels can be used in high efficiency combustion systems as a substitute for fossil fuels and can result in improving air quality and decreasing greenhouse gas emissions into the atmosphere (Fan et al., 2007). However, in practice some biofuel chains cause relatively high nitrous oxide emissions from soil and need a lot of auxiliary energy for refining which can weaken the GHG balance considerably. Further, some bioenergy chains cause in initial phase large GHG emissions through land clearing for bioenergy crops (Searchinger et al., 2008; Achten et al., 2007). This concern can be addressed by cultivating perennial crops in marginal, degraded or abandoned lands with reduced tillage and leaving behind crop residues (Jessup, 2009; Lal, 2009; Tilman et al., 2009).

Besides CO_2, using bioenergy leads to smaller emissions of SO_2 compared with the use of coal. Biomass such as municipal organic waste contains small quantity of sulphur and SO_2 can be released into the atmosphere through the combustion process for biogas manufacturing. Note that emissions of SO_2, CO, and NO_x from biogas are considered trivial (Fan et al., 2007) thus resulting in cleaner air and health benefits such as reduced respiratory complaints (Sims, 2004). In the future, biomass can provide a source of hydrogen for fuel cells, heat for environmentally sound, small scale, distributed generation systems, and gaseous biofuels for micro-turbines.

9.3.2.4 Ecosystems and Biodiversity

Cultivation of bioenergy and biofuel crops can directly affect biodiversity, both positively and negatively. These effects include small scale changes to species abundance at field level, as well as larger scale issues such as changes in landscape diversity, and potential impacts on primary and secondary habitats (Firbank, 2007). Bioenergy cropping has the potential to benefit biodiversity by mitigating climate change, which can have significant impacts on ecosystems and biodiversity.

Cultivation of bioenergy crops is likely to eliminate niches for some species living on that land through conversion processes, but can create niches for a new suite of species (Firbank, 2007). One of the major negative impacts of bioenergy production on biodiversity is the loss of a high quality habitat; either by replacing it with bioenergy crops, or by introducing major changes in land use and management (e.g. increased extraction of wood fuel from woodland). Another major negative impact occurs through introduction of invasive crop species, e.g., switchgrass, giant reed, and miscanthus (Barney and DiTomaso, 2008). Another negative impact arises when linear habitat features such as lines of trees, hedgerows, water edge and ponds are either added or removed. This can consequently cause losses of habitat and species dispersion (Firbank, 2007). On the positive side, bioenergy crops provide a stabilized vegetation cover that can offer habitat for some elements of native biodiversity (Fan, 2007).

9.3.2.5 Human Health

As was previously mentioned, using biomass fuels instead of fossil fuel produces lower emissions of human health-harming substances and thus helps to improve quality of life (Sims, 2004). However, use of biomass in traditional cooking stoves is a source of indoor air pollution through high particulate emissions and thus constitutes a health hazard.

9.3.2.6 Built Environment

Growing energy crops can affect the built environment, specifically the visual aspect and settlement routine. Depending on the original land use (prior to growing the energy crops), these tall crops such as Miscanthus and short rotation coppice willow (3 to 5 m high) may impact the character and visual appearance and perception of the landscape (Lovett et al., 2009). Poor people are usually settled in marginal and degraded lands. Any expansion for bioenergy plantation to these lands could result in displacement of these rural poor (Johansson and Azar, 2007).

9.3.3 Direct Solar Energy

Most sources of renewable energy are related to the Sun and are dependent on it in one way or another. The heat from solar energy sets up the differences in temperature and pressure that cause wind and waves, provides rainfall and melts snow. These will in turn generate the mechanical energy that is required to drive water mills and turbines to produce hydroelectical energy. Therefore, solar energy can be converted into two main forms of energy: as a source of heat, and by converting the radiation into electricity (Springer Netherlands, 2008).

Solar energy can be used for thermal applications such as water and space heating. Currently, these applications mainly use electricity, fossil fuels and traditional or modern biomass as their energy source. Solar hot water systems are a widely available technology in today's world and can be used to satisfy the hot water requirements of typical homes (Torrie et al., 2002). Installing solar water heaters can reduce the electricity or fossil fuels commonly used for water heating by 40% to 50%, hence reducing the energy bills of residents by the same amount (Etcheverry et al., 2004). Due to the popular concept of energy conservation measures, the demand for hot water through fossil energy in a typical home will likely be reduced. This reduction may result in solar hot water heaters providing an even larger share of a typical home's hot water needs. In addition, mass production of solar hot water systems e.g., in apartment houses and multi-storied office buildings could cause a significant reduction in the price (Torrie et al., 2002). Aside from thermal applications to heat water, solar energy can be used to heat spaces. In addition to heating purposes, solar energy can be used to generate electricity using solar photovoltaic (PV) systems.

9.3.3.1 Land

Solar energy can be used as a non-chemical alternative to soil disinfection. During intensive agriculture, agricultural lands can deteriorate and become infected with pathogens, insects, and weeds, which negatively affect the quality of crops (Camilo et al., 2007). Currently, methyl bromide is the common pesticide that is used to disinfect agricultural lands but its gaseous toxins deplete the stratospheric ozone layer. Steam soil disinfection is a highly efficient method and a safe alternative that uses steam generated directly from solar energy by means of parabolic trough collectors (PTC) to disinfect contaminated soil. It has a short processing time and it does not leave toxic residues behind (Camilo et al., 2007).

Typically, large land areas are not required to produce solar energy. This is especially of concern in urban environments where there is likely shortage of available land. Solar energy systems, with the exception of very large solar thermal electric plants, whether it is a hot water system or photovoltaic system, do not occupy any dedicated urban land as they are either placed on roofs or they incorporate/replace existing building cladding systems (Guen and Steemers, 2008).

9.3.3.2 Water

Desalination technology has been used in many large cities all across the world to satisfy growing water needs and this industry continues to grow especially in arid regions with limited water availability. Solar energy can be combined with desalination technology to generate a sustainable source of freshwater as well as a source of energy (Ettouney and Rizzuti, 2007).

Solar energy has been proven effective for water treatment methods such as chlorination and bacterial disinfection. Small amount of electricity is generated from solar cells for drinking water chlorination. This method uses readily available chemicals and materials salvaged from waste streams, and eliminate the use of specialized laboratory equipment (Appleyard, 2008). Moreover, solar energy can effectively be used in to disinfect biologically contaminated water. Using the thermal power of solar energy and heating water to a disinfecting temperature level as well as exposing the water to ultraviolet radiation result in inactivation of micro-organisms and elimination of coliform-group bacteria (Saitoh and El-Ghetany, 2001).

9.3.3.3 Air

Solar energy can contribute to avoid considerable amount of GHG emissions. Unlike conventional fossil fuels which produce large amounts of GHG gases, solar energy produces almost zero emissions (Kalogirou, 2008).

Minimal quantities of air pollution could possibly occur from the manufacture, normal maintenance operations, and demolition of solar energy systems. The great majority of the components of solar energy systems are recyclable, thus posing minor burden on the environment (Kalogirou, 2008). The pollution produced in the manufacturing stage of the solar collectors is estimated by calculating the energy invested in the manufacture and assembly of the collectors and estimating the pollution produced by this energy (Kalogirou, 2008).

9.3.3.4 Human Health

Solar energy is considered a clean energy source with essentially zero emissions in terms of air pollution and greenhouse gas production. As a result, it is not harmful and can contribute to cleaner air and improved public health.

9.3.3.5 Built Environment/Visual Aspects

As was mentioned before, solar energy technologies such as PV systems and space and water heating systems are typically installed on existing buildings and do not occupy large land areas. Thus, they are not likely to disturb the visual aspects of environments to a great extent. However, “solar chimneys” that are used to produce electricity using solar radiation could be as high as 1 km with turbines near the base, which can affect visual aspects of the built environment (Springer Netherlands, 2008).

9.3.4 Geothermal Energy

Geothermal fuels have considerably higher potential (up to 75%) for reducing GHG emissions compared to fossil fuels used for power generation (Etcheverry et al., 2004). In addition to existing natural wastes, they produce limited additional local pollution with some exceptions (e.g., waste heat stream), but depending on the technology used, they may have some adverse environmental impacts. Technologically, three types of geothermal power plants- dry steam; flash steam and binary-cycle are now operating.

9.3.4.1 Water

Any release of polluted water from the geothermal plant into rivers or lakes can damage aquatic life and make the water unsafe for human and agricultural uses due to presence of poisonous chemicals, minerals and gases in the geothermal fluid used for energy. The most serious environmental effect of the geothermal industry is pollution of fresh water from arsenic. For example, due to discharge of geothermal waste water contaminated with arsenic from the Wairākei geothermal power station in New Zealand, the levels of arsenic in the Waikato River almost always exceed the World Health Organization standard for drinking water (Stewart, 2007). It also contaminates the Waikato River with hydrogen sulphide, carbon dioxide, mercury at concentrations that have adverse, if not calamitous effects (Abbasi and Abbasi, 2000).

9.3.4.2 Air

Generally, emissions from the geothermal power plants are none (binary cycle plants) to negligible as compared to fossil fuel powered plants. However, some geothermal plants can discharge pollutants (arsenic, hydrogen sulphide, methane, ammonia, radon, etc.) to the atmosphere that need special attention. Mostly, the pollutant gases are denser than air and can collect in pits, depressions or confined spaces. They pose potential hazards for working at geothermal stations or bore fields and human settlements. In the USA, official requirements for the removal of hydrogen sulphide from geothermal emissions are already established (U.S. Department of Energy, 2009).

9.3.4.3 Ecosystems and biodiversity

Some “open loop” heat pump systems may affect aquatic ecosystems if they draw water from a water body and discharge warmer or cooler water back into the water body, and/or pollute it.

9.3.4.4 Human health

Hydrogen sulphide emissions (0.1 ppmv as against permissible 0.03 ppmv) from the Geysers, California power plant have resulted in complaints of odor annoyance and health impairment (Anspaugh and Hahn, 1979). Concerns raised by the local residents of respiratory diseases, asthma, eye problems, cold and flu from a geothermal energy project in Kenya (Mariita, 2002). With established monitoring systems in potential areas of water and air pollution, the geothermal plants become practically safe for people.

9.3.4.5 Built environment (visual aspects, infrastructural aspects, transmission lines, settlement etc.)

Geothermal power plants occupy relatively small area and do not require storage, transportation, or combustion of fuels. These qualities reduce the overall visual impact of power plants in scenic regions. Transmission lines and other power-related infrastructure usually are the same as for other types of power plants or less visible.

Extraction of geothermal fluids can reduce the pressure in underground reservoirs and can cause land subsidence. In the Wairākei (New Zealand), the centre of the subsidence bowl is sinking at a rate of almost half a metre every year which is the largest subsidence on record (Stewart, 2007). As the ground sinks it also moves sideways and tilts towards the centre. This puts a strain on bores and pipelines, may damage buildings and roads, and can alter surface drainage patterns.

9.3.5 Hydropower

Hydropower generation is currently contributing slightly over 16% to global energy supply (IHA, 2005) and is the highest contributor among all the renewable energy technologies. Because hydropower requires storage of vast amount of water, in many ways it interacts with environment, ecology and livelihoods.

9.3.5.1 Land Submergence

Dams have been built for thousands of years throughout history for irrigation, flood control, management of water supply and for mechanical power and electricity generation for more than a hundred years. Despite the benefits however, dams are also associated with loss of forests, agricultural land, and grasslands in upstream watershed areas due to inundation of the reservoir area (Tefera and Sterk, 2008). In addition, dams play a role in alteration of traditional resource management practices and often cause displacement of population and impoverishment of people due to livelihood losses (Tefera and Sterk, 2008). The displaced people usually move to available areas within the watershed and take up agricultural activities on steep slopes and flood-prone areas. The process of migration and agricultural activities on new lands, in combination with normal population growth, can cause significant and harmful land use changes and exacerbate the rate of environmental degradation within the watershed area (Tefera and Sterk, 2008).

9.3.5.2 Water-quantity/quality

Constructing hydropower dams and reservoirs can dramatically affect the quality of water. Reservoirs generally act as traps for nutrients and sediments, since these matters tend to settle down when water is discharged into the reservoir area. As a result, reservoirs are reliable and provide higher quality water supply sources for irrigation and domestic and industrial use. Additionally, reservoirs provide for fisheries because of the storage of high amount of nutrients in the water (Kaygusuz, 2009).

Hydropower dam construction and operation can negatively impact the quality of water downstream river channel below the dam. The water discharged through the turbine is almost free of sediments and nutrients but it can scour and erode the streambed and banks. This scouring effect can have significant negative impacts on the flora, fauna, and structure of biological community in the downstream river channel. In addition to this, dams and reservoirs also change aquatic habitats. Riverine habitat is replaced with reservoirs, and downstream habitat may be altered as a result of modifications in flood regime and trapping of sediments in the reservoir (UNEP).

Headwater streams provide unique habitats for aquatic biota and are extremely important sources of sediment, nutrients, and organic matter for downstream areas. Hydropower dams act as physical barriers and their presence hinder the longitudinal movement of organisms and downstream export of matter and nutrients. In addition, as a result of flow reductions in the de-watered reach of river between dams and turbines, discontinuities between upstream and downstream areas, aka river fragmentations, occur (Anderson et al., 2008). De-watered reaches downstream from dams typically have slower water velocities, warmer water temperatures, and shallower habitats compared with adjacent upstream and downstream areas. This change in water quantity leads to habitat alterations, and can eventually impact distribution of aquatic organisms and affect their long-term survival in the river (Anderson et al., 2008).

9.3.5.3 Emissions and Air Quality

Hydropower is considered a green technology, as it has very few greenhouse gas emissions compared with other large-scale fossil energy options. It produces 60 times less greenhouse gas emissions than those from coal-fired power plants, and 18-30 times less than natural gas power plants (Canadian Hydropower Association, 2009). Generation of hydropower allows for the power demand to be met without producing heated water, air emissions, ash, or radioactive waste (Kaygusuz, 2009). Hydropower does not produce air pollutants that cause acid rain and smog and polluting or toxic waste by-products (Government of Canada).

According to US Environmental Protection Agency, hydropower's air emissions are negligible because no fuels are burned. However, if a large amount of vegetation exists alongside the riverbed when a dam is built, this vegetation can decay in the created reservoir, causing the buildup and release of methane gas, a potent greenhouse gas (US EPA). Despite this however, hydropower is still considered a green and clean technology and can be a significant contributor to address air pollution and climate change as it offsets greenhouse gas emissions and air pollutants from fossil fuel power plants (Government of Canada).

9.3.5.4 Ecosystems and biodiversity

Construction and operation of water reservoirs/dams for hydropower generation can cause harm to ecosystems and loss of biodiversity (Rosenberg et al., 1997; IUCN, 2001; Fearnside, 2001; Craig, 2001). Loss of biodiversity compromises the structure and function of ecosystems, which can in turn compromise the economic well-being of human populations. Hydropower development may cause losses of biodiversity well in excess of natural, background losses (Coleman, 1996). For example, the reduction or extirpation of native species through alteration of physical habitat or introduction of exotic species is a form of biodiversity loss connected with large-scale hydroelectric development (Power et al. 1996). These losses could occur over extensive spatial and temporal scales. Rancourt and Parent (1994) documented loss of biodiversity for the La Grande development project in Canada which operates a chain of reservoirs. Fearnside (2001) listed loss of forests which led to loss of natural ecosystems in the Tucuruı´ Dam in Brazil.

9.3.5.5 Human health

Health impacts of hydropower reservoirs are well researched. Major health impacts are spread of vector borne diseases associated with the reservoirs itself and irrigation projects. Lerer and Scudder (1999) documented health concerns beyond vector-borne diseases which include impacts through changes in water and food security, increases in communicable diseases and the social disruption caused by construction and involuntary resettlement (Table 1) .

Table 1: Potential health impacts of large dam projects

Impact Area	Health impact
Upstream catchment and river	Changes in flood security, water related diseases, difficulties with transportation and access to health facilities
Reservoir area	Involuntary resettlement, social disruption, vector borne diseases, water related diseases, reservoir induced seismicity Food security affected on flood plains and estuaries (farming and fishing), water related diseases, dam failure and flooding
Downstream river	Changes in food security, vector borne and water related diseases

Irrigation areas	Water related diseases, sexually transmitted diseases, HIV/AIDS, accidents and occupational injuries
Construction activities	Communicable diseases, violence and injury, water related diseases, loss of food security
Resettlement areas	Macro-economic impacts on health, inequitable allocation of revenue, health impacts of climate change
Country/regional/global	

Source: Oud and Muir, 1997.

9.3.5.6 Built environment (visual aspects, infrastructural aspects, settlement etc.)

Hydropower projects usually create adverse as well as positive impacts on the built environment. Inundation of infrastructure that includes houses, rural roads, business centers, archeological and historical sites usually occur. During construction of Kaptai hydropower project in Bangladesh in the 1960s, damage to human settlements and infrastructure occurred. Similar damages also reported from the Three Gorges Dam in China. A 50-km stretch of highway was inundated during construction of the Samuel Dam in Brazil (Fearnside, 2005). Hydropower projects also facilitate construction of new infrastructures like roads, highways and urban centers. The reservoirs are usually used for recreational purposes.

9.3.6 Ocean energy

The ocean energy technologies can have very different environmental effect, depending on the type of technology employed and its location (Pelc and Fujita, 2002). Following are the currently available technologies: Tidal and current power stations (in turn, there are two types of them: barrage systems and stream systems); wave energy stations (several types of devices); ocean thermal energy conversion (OTEC); and salinity gradient energy (SGE). However, our current understanding of the effects of intervention through the ocean energy technology on the marine environment is limited because for now, ocean energy production is mostly at experimental stage, and, except for few tidal installations, there are no industrial power stations based on ocean energy.

9.3.6.1 Land

The ocean power stations do not largely influence land ecosystems. Some adverse effects can occur for the coastal landscapes, mostly due to occupation of the territory during construction. Wave stations can partially block the coast from wave impacted erosion, but they also can re-distribute natural sedimentation in the coastal zone. The tidal barrages can flood the coastal areas depending on the elevations, at least for certain time periods. The OTEC technology requires small surface area; if located in a platform, only land is required for the cable and connecting to the station. For the offshore stations, the high voltage transmission cables have the potential to influence the aquatic animals that are sensitive to electromagnetic fields, thus disrupting their ability to navigate (Gill, 2005). The power generation and transmission structures may affect local water movements, which are fundamental to some aquatic species (Montgomery et al., 2000) and also determine the transportation and deposition of sediments (Gill, 2005).

9.3.6.2 Water

The barrage tidal stations can increase some water pollution above of them. Brackish water waste and polluted polyethylene membranes from the SGE sites can adversely impact the local marine and river environment. For OTEC technology, catastrophic failure such as thermal fluid escape has only some minor local effects. Up-welling effect of bringing nutrient-rich deep water to the surface can occur. This mixing may be beneficial for aquatic lives but further study is required. If water is discharged at proper depth, effect is essentially eliminated (Vega, 1999). For the wave energy systems, uncertainties exist on the specifics of toxic compounds to be used in the power installations and possibility of their release into the sea water.

9.3.6.3 Air

The ocean energy production is mostly safe for the air quality; in fact, it eventually makes the air cleaner due to possibility to decrease the fossil fuel energy production. For OTEC technology, no solid wastes and no emissions of conventional air pollutants (Cohen et al., 1982).

9.3.6.4 Ecosystems and biodiversity

Technology wise, differential impacts of ocean power infrastructure on ecosystems and biodiversity can occur. The tidal barrages are potentially the most harmful to the marine and coastal ecosystems unless the effects are addressed seriously. The change in water level and possible flooding would affect the vegetation around the coast. The quality of the water in the basin or estuary would also be affected; the sediment levels would change the turbidity of the water and can affect fish and birds. Fish would undoubtedly be affected unless safe fish passes are installed. Decline in fish population would affect population of birds and they will migrate to other areas with more favourable conditions. However, emergence of new environment may allow different species of plant and creature to flourish and their overall impacts need to be independently assessed (Tidal power, 2009). Colwell (1997) argued that problems would arise during quantification of environmental capital of the recreated environment compared to the original one, which possesses a wide array of values.

Sea streams (including tidal ones) are not as severe as those for a tidal barrage. They are positioned in the sea bed and this might have an effect on the aquatic life in that particular area. This site-specific can be avoided or minimized through proper environmental impact assessments (Tidal power, 2009).

The SGE technology can influence the local salt and fresh water mixing regime. Each species of aquatic plant and animal is adapted to survive in either marine, brackish, or freshwater environments. The main waste product of this technology is brackish water and its large quantity discharge into the surrounding waters may significantly alter aquatic environment. Fluctuations in salinity will result in changes in the plant and animal community. Variation in salinity occurs where fresh water empties into an ocean or sea, these variations become more extreme on for both bodies of water with the addition of brackish waste waters. Extreme salinity changes in an aquatic environment may be detrimental to both animals and plants due to sudden severe salinity drops or spikes (Montague, Lay, 1993).

Organisms impinged by an OTEC plant are caught on the screens protecting the intakes, fatal to them. Entrained organisms may be exposed to biocides, and temperature and pressure shock. Entrained organisms may also be exposed to working fluid and trace constituents (trace metals and oil or grease). Intakes should be designed to limit the inlet flow velocity to minimize entrainment and impingement (Vega, 1999).

OTEC plant construction and operation may affect fishing. Fish will be attracted to the plant in part due to redistribution of nutrients, potentially increasing fishing in the area. However, the losses of inshore fish eggs and larvae, as well as juvenile fish, due to impingement and entrainment and to the discharge of biocides may reduce fish populations. Through adequate planning and coordination with the local community, recreational assets near an OTEC site may be enhanced (Vega, 1999).

9.3.6.5 Human health

Mostly, the ocean power generation is remote from the settled regions, even from the coastal areas. Except for rare situations like possible water pollution behind the tidal barrages, these technologies do not influence the human health directly. Accidents at OTEC plants can lead to limited emission of gases like ammonia and chlorine. However, the risks are not larger than those for other industrial applications involving these chemicals.

9.3.6.6 Built environment

Visual impacts are particularly important in areas of designated coastline and those used for recreational purposes. Ocean energy infrastructure could cause visual impacts if they are constructed around such areas. Wave energy devices may be potential navigational hazards to shipping as they could be difficult to detect visually or by radar. Several of the areas proposed for wave energy devices around European coasts are in major shipping channels and hence there is always an element of risk that a collision may occur. The result, for example, of an oil tanker colliding with an array may have consequences for colonies of seabirds in the locality (Thorpe, 1999).

9.3.7 Wind Energy

Wind is the fastest growing source of renewable energy in the world (Etcheverry et al., 2004). Beyond the process of production of power-generating and storage devices, it does not result in any emissions. Nevertheless, wind power plants can affect the environment in other ways.

9.3.7.1 Land

Compared to other types of power production, the wind power plants occupy less space (Canadian Wind Energy Association, 2009). In many cases, wind power plants can be located in un-used spaces (mountain passes, elevated plateaus, etc.). The leasing of land for wind turbines can benefit landowners in the form of increased income and land values. But in some cases, wind power development may create conflicts among the land owners and other people living in the neighbourhood.

9.3.7.2 Water

Except for making the wind farm equipment and cleaning the rotor blades, water is not used during the wind energy production. Wind energy is one of the technologies least influencing the water sources (U.S. DOE, 2009).

9.3.7.3 Air

Once again, except for making the wind farm equipment, the wind energy production is one of the most environment-friendly technologies. The wind energy plant itself does not produce any emissions to the air.

9.3.7.4 Ecosystems and biodiversity

Fatalities of birds by flying into wind turbine rotors have been reported in many regions of the world. In Denmark, overall, less than 1% of the ducks and geese fly close enough to the turbines to be at any risk of collision (Desholm and Kahlert, 2005). In the early 1980s, a large number of raptor fatalities were reported at Altamont Pass, California (Orloff and Flannery, 1992). However, most turbines in North America, have low impacts on birds. Studies by the U.S.-based National Wind Coordinating Committee indicate an average bird kill of two to three birds per turbine each year. Direct mortality and injury of birds have also been reported from the U.K. However, the majority of studies of collisions caused by wind turbines have recorded relatively low levels of mortality (Painter et al., 1996).

There are many ways to minimize risks to local and migratory birds. Current wind turbine technology offers solid tubular towers to prevent birds from perching on them. Turbine blades also rotate more slowly than earlier designs, reducing potential collisions with birds. They consider the location of common migratory bird routes and, wherever possible, avoid those areas for wind farms.

9.3.7.5 Human health

Wind turbines, particularly older designs, emit noise that can be heard near wind farms. According to the U.S. Renewable Energy Policy Project, the noise from a typical wind farm at 350 meters distance can vary between 35 and 45 decibels. Sound levels can grow with increases in wind speeds, and are objectionable to some people. To minimize noise levels, operators are using improved rotor technology, constructing plants away from densely populated areas and including sound-absorbing materials in the generator. The frequency and volume of this noise can be controlled, but not eliminated by wind turbine design. At the same time, wind turbines do not produce infrasound at a level detectable by humans or that has been shown to have any impacts on health (Leventhall, 2006; Rogers et al., 2006).

9.3.7.6 Built environment

Because wind farms are composed of large numbers of turbines and tend to be located on or just below ridgelines or within sight of shores, they can often be seen for a long distance. As a result, some people object to the visual impacts of wind turbines. To reduce these impacts, operators sometimes paint wind turbines to blend in with their natural surroundings. During planning for new projects, they also consider the spacing, design and uniformity of the turbines and locate wind farms away from populated centres. Actually, acceptance of wind farms by people increases once the wind power plant has been built, and for some people they seem attractive. Experience in Europe and U.S. has shown that wind turbines can easily and safely coexist with all types of radar and radio installations (Canadian Wind Energy Association, 2009).

9.3.8 Assessment and comparison of environmental impacts

The environmental impacts associated with RE clearly vary by technology, location, availability of resources (e.g., water), the potential for human exposure, and local ecological susceptibilities. Proper assessments and comparisons of such issues typically require a life-cycle assessment (LCA) approach. Ideally, an LCA will characterize the flows of energy, resources, and pollutants across the life-cycle of an RE technology, which includes activities related raw materials acquisition, manufacturing, transportation, installation and maintenance, operation, and decommissioning. The ecological and human impacts associated with such flows are further characterized across a range of impact metrics (e.g., global warming potential, human health damages, ecotoxicity, and land use). As such, LCA provides a framework for assessing and comparing RE technologies in an analytically-thorough and environmentally-holistic manner.

Formal LCA methodologies have evolved over the past 20 years (SAIC 2006), and have been steadily refined and improved over time through various international working groups (e.g., UNEP 2009), professional associations (e.g., ACLCA 2009), and methodological standards initiatives (e.g., ISO 2006). As discussed in previous chapters, LCA is now being applied with increasing frequency to environmental analyses of RE technologies, most notably biofuel systems, wind energy, and solar energy. This report also shows that LCA considerations are increasingly being adopted by governments to guide far-reaching policies that accelerate RE technology adoption, such as California's Low Carbon Fuel Standard (CEC 2009) and the U.S. EPA's Renewable Fuel Standard (U.S. EPA 2009).

Despite the increasingly widespread application of LCA to RE technologies, key analytical limitations and challenges exist. Notably, most LCAs of RE technologies focus predominantly on life-cycle energy and GHG emissions characterization, with less attention to other key resource inputs (e.g., water) and environmental impact categories (e.g., ecological and human health impacts). The narrow focus on energy and GHG emissions can probably be attributed to several key factors: (1) the relative ease of data access for life-cycle fuels and GHG emissions compared to more obscure data required for emissions related to other environmental impacts; (2) the obvious policy relevance of understanding GHG emissions abatement potentials of RE technologies; and (3) a lack of scientific methods and consensus on characterizing localized impacts such as land use, biodiversity loss, and ecological and human health impacts. It will be important to address these challenges moving forward so that RE technologies can be assessed across a fuller spectrum of environmental impacts, such as those discussed previously in Section 9.2. More complete LCAs would allow for better understanding of the potential tradeoffs across this diverse range of impacts—and possible unintended consequences associated with large-scale RE technology deployment—such that they can be managed and mitigated through the appropriate policy measures.

As discussed in Chapter 2, a number of fundamental methodological challenges exist as well. Major issues include lack of credible data to conduct full LCAs for most RE technologies, defining sound functional units such that RE technologies can be properly compared to each other and to existing fossil fuel sources, and consensus on analytical system boundaries. Furthermore, for increased policy relevance LCA needs to move beyond characterization of straightforward RE technology "footprints" (i.e., an attributional LCA approach) towards analyses that assess the impacts of RE technologies in more dynamic and macro-economic contexts (i.e., a consequential LCA approach). A move toward the latter approach would allow the full effects RE technologies on environmental, social, and economic systems to be assessed simultaneously for more informed policy making.

Still, as this report shows, the application of LCA to RE technologies has provided many important insights to date. Previous LCAs have shed light on the net energy and GHG emissions balances of RE technologies compared to fossil fuels, vastly increased our knowledge of the complex life-cycle systems and environmental interactions associated with RE technologies, increased our understanding of potential environmental tradeoffs, and uncovered key methodological and data challenges. As such, this work has laid a critical foundation for continuously improving LCA as a policy-relevant decision-making tool for RE policies.

9.4 Socio-economic Impacts: global and regional assessment *(energy supply security)*

9.4.1 Sustainable Development Links to Renewable Energy Options

Sustainable Development (SD) can be translated in a set of socioeconomic goals applicable to different energy sources and technologies. Some of the most relevant are described in Table 2: poverty reduction; water security; sanitation; food security; energy security; energy access; energy affordability; infrastructure; governance; land use and rural development. Compared to conventional fossil fuels, nuclear energy and large hydros – which have overall highly concentrated and capital intensive production, transformation and distribution chains - renewables have an important role in rural development. Relatively simple systems such as solar panels, improved cookstoves or micro hydro plants can provide the necessary lighting, heat or electricity to pump water, prepare food, refrigerate vaccines and medicines, allow education during the night period. Local pollution and health benefits are improved.

In some cases, there are also impacts associated with these technologies – as shown in Table 2 – also may have limited number of years of use if grid electricity arrives at a cheaper price in the future. These multiple benefits of the increased use of renewable energy technologies, which in general are coupled with efficient end use devices, are environmental protection; reduction of indoor pollution; promotion of energy security through decentralization and source diversification; job creation and income generating activities through the use of local resources; improving the quality of waste management systems (like landfills for gas); reduction on the dependence of oil imports; relieving pressure on the balance of payments.

The 2002 WSSD´s Johannesburg Plan of Implementation reflects a growing interest in renewables and addresses as well the problems of social exclusion and poverty eradication. A large number of people in the rural areas in developing countries have no access to commercial energy due to the lack of purchasing power or for other reasons. In order to survive, these people depend on non-commercial sources of energy, mainly fuelwood, manure and agricultural waste that can be obtained at a negligible monetary cost. In many of these countries, non-commercial energy corresponds to a significant share of the total primary energy consumption.

Developing countries have in their energy matrices a very significant share of biomass, of which a fair part may be notoriously neither renewable nor “sustainable” since it comes from deforestation. About 2 billion people in the world rely on fuelwood and other primitive solid fuels for their basic needs. If each person were to use kerosene, 50 kg a year would be necessary, which would represent 100 Mtoe of oil or about 3 per cent of the world’s consumption of this fuel (Goldemberg, 2002). Clearly, this does not represent a resource limitation.

An intrinsic characteristic of a dual society in developing countries is the fact that the elite and the poor differ fundamentally in their energy uses. The elite try to mimic the lifestyle prevailing in industrialized countries and have similar luxury-oriented energy standards. In contrast, the poor are more concerned on obtaining enough energy for cooking and for other essential activities. For the poor, development means satisfying basic human needs, including access to employment, food, health services, education, housing, running water, sewage treatment, etc. The lack of access to these services by most people is a fertile ground for political unrest and hopelessness that leads to emigration to industrialized countries in search of a better future.

A large part of the energy for agriculture, transportation and domestic activities in poorer developing countries comes from the muscular effort of human beings and from draught animals. Other sources include biomass in the form of fuelwood, animal and agricultural waste. Fuelwood is actually the dominant source of energy in rural areas, especially for cooking. In rural areas, women and children usually pick up wood sticks as fuel to cook instead of buying wood. A basic level is the fulfilment of basic human needs, which may vary with climate, culture, region, period of time, age and gender. There is not a single level of basic needs, but a hierarchy of them. There are needs that have to be supplied for survival, such as a minimum of food, of dwelling and protection against fatal illnesses. The satisfaction of a greater level of needs such as basic education makes ‘productive survival’ possible. Even higher levels of needs such as trips and leisure emerge when people try to improve their quality of life beyond ‘productive survival’. Obviously, the needs perceived as basic vary according to the conditions of life in any society.

Negative aspects include environmental impacts, such as resources depletion, inputs usage (e.g. water), contaminating emissions (to air, water, soils), toxic wastes and risks of accidents. Another topic is the competition with food for land, a controversial issue due to its relation to biodiversity protection, to the distribution of goods and different aspects of international trade. Also to mention are geopolitical disputes and international security (case of weapon proliferation). Impact assessment implies consideration to life cycle approaches that are described in Section 9.3, where different boundaries and functional units may consider indirect impacts. Cost analyses also differ, according to the considered parameters (such as discount rate or indirect costs).

Table 2: RE and conventional technologies and impact on selected SD indicators (Draft quantitative data)

Each cell entry assumes that:
1. Renewable resource is available, and energy and/or electricity is produced on site.
2. Local emissions may vary by regional grid and site; a range is provided where data are available.

Selected SD Indicators	**RE Technologies**						**Conventional Fossil Fuel Technologies**			***Nuclear***
	Bio-Energy	***Direct Solar***	***Geothermal Energy***	***Hydro Power***	***Ocean Energy***	***Wind***	***Oil***	***Gas***	***Coal***	
Environmental										
Emissions and Air Quality Unit: gCO$_2$e/kWh	Sustainable GHG emissions, but there is a risk of unsustainable harvesting. Emissions contribution to air quality. Indoor PM, CO from fuelwood. PM, CO, NOx from harvest burning and land clearing (including deforestation). Net GHG emissions in most cases of land use change. Local emissions vary according to fuel and technology, including end of pipe controls. (Ranges available from the US EPA AP-42 database) Wood 120 [1]	Minor emissions during operations. Lifecycle emissions are more important. 90 [2] PV (9.4 – 300) [3] 60 [1] Solar Thermal (36.2 – 202) [3]	Site specific emissions, including sulfur compounds. Lifecycle emissions. 170 [2]	Methane emissions from reservoirs, very high range, site specific. Lifecycle emissions, mainly in construction phase. 41 [2] Small Hydro (18 - 74.9) [3]	No emissions during operations. Lifecycle emissions. Neutral [4]	No emissions during operations. Lifecycle emissions. (20 - 25) [2] [3]	Significant emissions of pollutants (PM, SOx, NOx, VOCs, heavy metals) and GHGs, some of which can be mitigated Oli 870 [1] Diesel 730 [1]	Significant emissions of pollutants (less than oil and coal, except NOx in some cases) and GHGs, some of which can be mitigated 543 [2] Natural Gas 650 [1] Natural Gas CC 440 [1] Gas 590	Significant emissions of pollutants (PM, SOx, NOx, VOCs, heavy metals) and GHGs, requiring controls for reduction. 1,004 [2] Lignite 1,240 [1] Hard Coal 1,060 [1]	No emissions during operations. Emissions during the life cycle may be significant, in mining, uranium enrichment, decommission etc. Potential of radioactive emissions in case of accidents and leakages. 30 [1] (in the complete nuclear power chain)

Water Quantity and Quality Unit: m^3/MWh indicates water consumption, unless indicated	Agrochemicals may affect water quality . Irrigation required in non-rain fed areas. Possibility of competition with other water uses. Water for cooling thermal plants. Thermal pollution. Leakages can affect ground water quality and recharge. Biodiesel-vegetables 3500000 m^3/MWh [5] Biodiesel-perennials 1200000 m^3/MWh [5] Biomass (1134 - 1814) Lt/MWh [6] Wates (residuums) (756 - 1814) Lt/MWh [6] Fossil/Biomass steam turbine Open Loop (200 – 300) Gal/MWhe [7] Closed Loop (300 – 480)	Limited water usage and pollution during manufacturing and utilization Can be utilized to disinfect biologically contaminated water 10 [2] Concentrating Solar 740 Gal/MWhe [7] PV 0.0 Gal/MWhe [7] Solar Thermal 311 Gal/MWha [8] Large Solar Thermal (800 - 1000) Gal/MWha [8] PV < 1 Gal/MWha [8] Water Footprint Solar Thermal 0.3 m^3/Gj [9]	Minor water usage in the binary-cycle plants Sulfur emission could be transformed into acid and acid rain (12 – 300) [2] Geothermal 1350 Gal/MWhe [7] < 5 Gal/MWha [8]	Possibility for water storage; limited water pollution in the reservoirs from biomass rotting Release of sediment free water can cause downstream erosion. 36 [2] 715 - 3145 Lt/MWh [6] Water footprint 22 m^3/Gj [9]	N/A	Limited water usage and pollution during manufacturing and utilization 1 [2] Water Footprint 0.0 m^3/Gj [9]	Risk of spills (1216 - 1814) Lt/MWh [6] Water Footprint 1.1 m^3/Gj [9]	N/A 78 [2] Natural gas (0.94 - 39.6) m^3/MWh [5] Gas (684 - 1814) Lt/MWh [6] Cycle Combined Open Loop 100 Gal/MWhe [7] Close Loop 180 Gal/MWhe [7] Natural Gas Open Loop 492 Gal/MWha [8] CC 350 Gal/MWha [8] Water Footprint 0.1 m^3/Gj [9]	Water usage for washing; pollution due to this 78 [2] (756 -1815) Lt/MWh [6] 548 Gal/MWha [8] Water Footprint o.0 m^3/Gj [9]	Water usage for cooling; risk of high pollution 4.1 m^3/MWh [5] (1512 - 2722) Lt/MWh [6] Nuclear Steam Turbine Open Loop 400 Gal/MWhe [7] Closed Loop (400 - 720) Gal?MWhe [7] 785 Gal/MWha [8] Water Footprint 0.1 m^3/Gj [9]

	Gal/Mwhe [7] Biomass 351 Gal/MWha [8] Water Footprint (24 – 143) m^3/Gj [9]									
Land and soil Unit: km^2/TWh unless noted otherwise	Agricultural land occupation for growing, possible soil pollution Biodiesel-wastes 0.04 Biodiesel-vegetables 25,069 m2/kW [5] Biodiesel-perennials 4,200 m2/kW [5] (101 - 193) m^2/Gj [10]	Land occupation for large solar thermal power but usually unused for other purposes (28 -64) [2] 50 m^2/kW [5] Solar Thermal 3561 m^2/GWh [11] PV 3237 m2^/GHW [11] PV (164 - 549) m^2/GWH [10] Solar Thermal Tower 552 m^2/GWh [10] Solar Thermal Parabolic Trough 366 m^2/GWh [10]	Limited land occupation; some risk of soil pollution (18 - 74) [2] 404 m^2/GWh [11]	Land occupation for reservoirs, including most productive soils (73 – 750) [2] Reservoirs (2,350 - 25,000) m^2/GWh [10] Run of River 3 m^2/GWh [10] (130 - 1050) hectares/MW [12]	Minor land occupation on coasts Sealand Tidal 7.5 km^2/kW [13] Wave 34.3 km^2/kW [13]	Limited land occupation 72 [2] 1335 m^2/GWh [11] (1030 – 3230) m^2/GW [10]	Land occupation for mining and processing; possibility of soil contamination (2.2 -17.2) km^2/kW [14]	Land occupation for developing gas fields and processing and supply installations Natural Gas 0.222 m^2/kW [5]	Significant land occupation for mining, processing and wastes 5.5 Km^2/kW [15] 3642 m^2/GWh [11]	Land occupation for mining, processing and wastes 1.74 m^2/kW [5]

Hazardous Waste Risk Unit: tons	Possibility for waste from by-products	N/A	Risk of pollution by toxic water and air	Large scale supply of sediments and nutrients during failure of a dam or sudden release of flood water	N/A	N/A	Risk of spills Fossil Fuel Plants 8.5 billion metric tons of carbon directly into the atmosphere [1]	Gas leak from the pipeline and fire hazard from the gas field could be dangerous	Risk of fires in waste fields	High risk 12,000 metric tons a year from the world's nuclear power plants [1]
Ecosystems and biodiversity	Monoculture growing; Adverse impacts on biodiversity for land clearance; Positive impacts on local biodiversity from stabilized vegetation cover	Some limitation of solar irradiation on the soil surface	Hot water spills, introduction of thermally tolerable species	Biodiversity loss from inundation of forests Alteration of downstream habitat for modification of flood regime and lack of nutrients in the released water	Limitation of biodiversity near dams and some turbines. Introduction of mollusks and water plants on constructions	Risk of collision for birds and bats; infrasound effects.	Change of vegetation and wildlife in the mining and processing areas	Some change of vegetation and wildlife in the gas field areas Fire hazard could be dangerous to ecosystem and biodiversity	Significant change of vegetation and wildlife in the mining areas and waste fields	Risk of radiation-influencing changes in biodiversity
Natural and built environment/Visual Aspect	Sometimes positive (blossoming cultures, young forest, etc.). Displacement of poor from the marginal and degraded land	Large areas occupied by installations. Change of albedo; large solar chimneys can affect visual aspect of built environment.	Not so large installations	Can cause Damage to existing built environment like settlements; New structures can add positive impacts Dams and reservoirs can be used for recreation purpose	Sometimes large structures (dams, barriers, etc.)	Complaints from some people; good for other people	Very large mining and processing structures; chimneys with fire	Large mining and processing structures	Large waste fields, sometimes large structures	Large constructions and chimneys

Economic										
Employment Opportunities Unit: Employment/ Power or Energy Include: construction, installation, operation and maintenance.	Increased job opportunities, particularly in rural areas 6 [16] 0.32 Employment/kToe [17] Biodiesel-wastes 30 jobs/MWh [5] Biodiesel-vegetables 98.6 Jobs/MWh [5] Biodiesel-perennials 9.76 Jobs/MWh [5]	Jobs in rural and urban areas PV (6.4 – 10.6) [16] Employment ratio/MWa Solar Thermal (5.9 – 6.8) [16] Solar Thermoelectric 46.4 [16] PV 7.69 Employment/kToe [17]	High compared to natural gas (5.7 – 19.2) [16]	Medium 20 [16]	Not developed	High (2.8 – 22) [16] (0.3-1.0) Employment ratio/MWp [16] 0.36 Employment/kToe [17] (20 - 45) Jobs/MWh [5]	High	High	High	Small
Income and Livelihood	Increase in income in agricultural and forestry sector	Increase income in rural areas of developing countries	Improve livelihood and income in developing countries	Medium – loss of productive assets v. increase in energy	Not developed	Revitalize the economy of rural communities	Increases Income – but has negative impact on livelihood in places	Improve livelihood and income	Income generation- High risk occupation	High income generation in a small sector – Living with risk
Energy Generation/Supply Costs Unit: US cent/ kWhe	Opportunities for co-generation – reducing cost (•) (62 - 85) current US/MWh (49 – 123) year 2050 US/MWh	Still relatively high- but becoming more competitive PV (19 - 20) [3] (•) CSP (125 - 225) US/MWh	Capital-intensive, with low variable costs and no fuel costs (•) Hydrothermal (33 - 97) current (30 - 87) year 2030.	High-capacity, low-cost means of energy storage (•) Large Hydro (30 –120) year 2005. (30 – 115) year 2030.	Not developed (•) Tidal Barrage (60 – 100) year 2005 (50 – 80) year 2030. (45 - 70) year	Competitive with other sources (5-74) [3] (•) Onshore Low average wind speed (8.9 - 13..5) US cents/kWh Low average wind	Fluctuating Price; competitive but subsidized for some uses	Competitive – but subsidized for some uses	Competitive – but subsidized for some uses	Competitive – but subsidized (•) (62 - 88) US/MWh

		Year 2020 CSP (43- - 62) US.MWh Tower (35 - 55) Us/MWh	(29 - 84) year 2050. Hot dry rock (150 – 300) year 2005. (80 – 200) year 2030. (60 – 150) year 2050	(30 - 110) year 2050. Small Hydro (56 – 140) year 2005. (52 – 130) year 2030. (49 -120) year 2050.	2050. Tidal Current (150 -200) year 2005 (45 -90) year 2030. (40 – 80) year 2050. Wave (200 -300) year 2005 (45 -90) year 2030. (40 - 80) year 2050.	speed (6.5 – 9.4) US cents/kWh Year 2015 (43 -5.3 Low 6.3 Hihg Ofshore 20 US cents/kWh Year 2015 16 US cents/kWh Year 2030 15 US cents/KWh				
Price of energy generated/supplied Unit: USD/kWh Average price of electricity	Potential for cheap, locally produced power	On grid costs high, off-grid more competitive 0.24 [2]	Competitive with some fossil fuel facilities 0.07 [2]	Cost competitive 0.05 [2]	Not developed	Competitive with other sources 0.07 [2]	Fluctuating Price; competitive but subsidized for some uses	Competitive – but subsidized for some uses 0.048 [2]	Competitive – but subsidized for some uses 0.042 [2]	Competitive – but subsidized
Investment Unit: US $/kW Ref. IEA, 2008 (•)	Potential for large and small scale investment (•) Biomass Integrated Gasifier / Combined Cicle 2,500 (Current)	Large potential for investors - solar growth 30% every year from 2000 to 2005 (•) PV 5,500 (current) 1,900 (year 2035)	Asian countries urging large investment in geothermal (•) Hydrothermal (1,700 – 5,700) (1,500-5,000) year 2030.	Large and small projects still expanding (•) Large Hydro (1,000 – 5,500) year 2005.	Developing market (•) Tidal Barrage (2,000 – 4,000) year 2005 (1,700 –	Capital investment is high – but world's fastest growing energy source (•) Onshore 1,200 (current) 900 (year 2025)	Demand increase – Mainly in upstream – risk because of uncertainty over remaining reserves	Demand increase Acts as driver Uncertainty of remaining reserves is risk (•) Gas - IGCC 1,800 (current)	Large potential because of expansion in the coal sector – China, India, US	Heavily promoted to combat climate change – re-emerging investment opportunities (•) III+ 2,600 (current) 2,100 (year

		CSP 4,500 (Current)	(1,400 – 4,900) year 2050. Hot dry rock (5,000 – 15,000) year 2005. (4,000 – 10,000) year 2030. (3,000 – 7,500) year 2050	(1,000 – 5,400) year 2030. (1,000 - 5,100) year 2050. Small Hydro (2,500 – 7,000) year 2005. (2,200 – 6,500) year 2030. (2,000 -6,100) year 2050.	3,500) year 2030. (1,500 - 3,000) year 2050. Tidal Current (7,000 - 10,000) year 2005 (5,000 - 8,000) year 2030. (3,500 – 6,000) year 2050. Wavw (6,000 - 15,,000) year 2005 (2,500 - 5,000) year 2030. (2,000 – 4,000) year 2050.	Offshore 2,600 (current) 1,600 (year 2030)		1,400 (year 2035)		2025) IV 2,500 (year 2030) 2,000 (year post 2050)
Social										
Displacement of people Unit: persons/MW	Case specific. Large scale biomass farming requires adequate land ownership, which may cause displacement of people in some cases and on others may provide jobs in the rural area and	Very unlikely to cause displacements. Providing decentralized energy enhances access and thus better dwellings in isolated areas, relieving populational pressure in urban	Case specific, but people displacement may be very rare and in small scale. Improves decentralized energy and settlements close to the	Case, site, technology specific. Risks of significant displacements, requiring adequate assessments and compensation.	Very unlikely to cause displacements. Providing decentralized energy enhances access and thus better dwellings in isolated areas, relieving	Unlikely to cause displacements, but some onshore projects can cause nuisances such as noise with effects in local communities.	Pipelines and other infrastructure projects may displace people. Local pollution from refineries may also have such effects.	Pipelines and other infrastructure projects may displace people.	Mining and quarrying, as well as local pollution (e.g. water contamination) may cause displacements.	Relatively few local displacements close to the power plant. Large accidents can cause very large scale displacements.

	therefore additional settlements.	areas.	energy source.	(61 – 120) persons/MW [12]	population pressure in urban areas.					
Gender equity	Improved biomass systems (e.g. efficient cookstoves) enhance lifestyles and lighten domestic workload. Large scale biomass provides jobs on a gender friendly basis.	Improved systems enhance lifestyles. Decentralized energy have potential to provide more and gender friendly jobs.	Gender neutral.	Gender neutral.	Gender neutral.	Gender neutral.	Conventional energy, usually gender neutral. However, some fuels (e.g. kerosene and LPG) may be the first substitutes to fuelwood for climbing the energy ladder thus promoting gender neutrality,	Gender neutral.	Usually gender neutral, but primitive use of this solid fuel causes domestic health impacts, affecting mainly women, children and the elderly.	Gender neutral.

9.4.2 Impacts of Renewable Energy on Use of Resources

The deployment of renewable energy is very often pointed out as one of the most important steps on the way to a more sustainable future. Wind power, solar and geothermal power and heat, biofuels and other forms of renewable energy are often called “green”, for they are believed to have no adverse impacts to the environment. Even though this is only partially true, generation of power and heat from renewable sources per se has indeed very little impact on the environment in terms of emissions of polluting substances, unlike the conventional fossil fuel-based technologies.

It is important to understand, however, that in order to produce the conversion technologies, install them, operate, maintain and dismantle them, a broad spectrum of activities and industries needs to be involved, which certainly impact the use of natural resources like water and land. This does not mean to say that renewable energy utilisation is not an ‘environmentally friendly’ option in comparison to conventional fossil fuel technologies. On the contrary, emissions and other negative impacts to the environment are certainly lower for renewable energy technologies. (Pfaffenberger et al., 2006)

However, it should be noted that future development of renewable sources could be constrained by air, land, water and other requirements. This issue is specific to each project, because compatibility with requirements differs widely. The constraints depend on many factors, among others population density and compatibility of a project with other requirements.

Two approaches are often used to evaluate resource utilization caused by different generation technologies. Elementary approaches quantify the use of air, land and water (among others) directly utilized in the energy conversion process. More sophisticated approaches identify direct and indirect use of the resources involved. This kind of analysis is used to quantify all the resources involved in the complete life-cycle of the electricity generation process.

A life-cycle assessment (LCA) is an environmental assessment of all of the steps involved in creating a product. Its goal is to give an all inclusive picture of the environmental impacts of products, by taking into account all significant ‘‘upstream’’ and ‘‘downstream’’ impacts. In the power sector, the assessment includes extraction, processing and transportation of fuels, building of power plants, production of electricity and waste disposal. (Gagnon et al., 2002)

Comparative analysis of resources used by power generation systems should take into account the intermittency of the generation technology, thus, resource per energy or average power are preferred instead of resource per installed capacity. For example, it would not be fair to compare bioenergy to windpower in terms of m^2/MW (Gagnon et al., 2002).

It is possible to evaluate the water requirements along the life-cycle for a generation technology, a concept defined as Water Footprint (WF). The WF of a product (commodity, good or service) is defined as the volume of fresh water used for the production of that product at the place where it was actually produced. Most of the water used is not contained in the product itself. In general, the actual water content of products is negligible compared to their WF (Gerbens-Leenes et al., 2009).

9.4.2.1 Overview on resources and technologies

Most of the literature makes a qualitatively assessment of the impact and the use of resources by renewable technologies. The following Table 3 summarizes both the qualitative and quantitative information available on the use of resources and the impact of different renewable technologies on sustainable development. For comparison purposes, conventional fossil fuel and nuclear technologies are also included.

Table 3: Sustainable Development ←→ Renewable Energy

Selected SD Goals	***Renewable Energy Technologies***						***Conventional Fossil Energy Fuels***			***Nuclear***
	Bio-Energy	*Direct Solar*	*Geothermal Energy*	*Hydro Power*	*Ocean Energy*	*Wind*	*Oil*	*Gas*	*Coal*	
Poverty Reduction	Cooking, jobs	Reduces poverty	Low	Medium - high	Low	Medium - high	High	High	High	Low
Water Security	Water usage, wastewaters	Medium	Low	High	Too early to know	Medium	Spills	NA	Coal washing, water contamination	Potential high contamination
Sanitation	Improved landfills	NA	NA	NA	NA	NA	(-)medium	NA	(-)high	NA
Food Security	Competition for land, cooking, source of fertilizers.	Drying grains					Fertilizers, cooking.	Cooking	NA	NA
Energy Security	Secure source more subject to climate conditions	Secure	Secure source	Secure source more subject to climate conditions	Early technology	Intermittent available	Geopolitical issues, finite	Geopolitical issues, finite.	Largely available	Diversifies sources but poses risks
Energy Access	Wide, easy access particularly for the poor	Easy access particularly for poor.	Limited	Somewhat limited		Somewhat limited				
Energy Affordability	High affordability	Upfront costs	Upfront costs	Long project life, cheap energy after investment is amortized	High initial costs	Competitive technology, providing energy at nearly same cost as conventional				
Infra-structure	Roads for biomass transport	Required, for large scale CSP	Required	Long transmission lines, large dams	Required	Transmission lines		Very intensive in infra-structure.		Security related infrastructure, final waste disposal sites

9.4.3 Requirements for increased RE deployment

9.4.3.1 Public awareness on RE potential and opportunities

Most renewable energy applications have traditionally been perceived very favorable by the general public maybe with exceptions around some large hydro dams and parts of the bioenergy agenda. Many solar, wind and bioenergy initiatives have originally been rooted in local community initiatives contributing directly to the positive perception. With up-scaling and having the development of new installations being driven by other stakeholders, typically utilities or private power companies it is not evident that the positive public perception is immediately maintained. Increased public resistance to new large installations have been experienced in many countries also beyond the more narrow "not in my backyard" type concerns. Public awareness and acceptance is therefore a very important part of the climate mitigation driven need to rapidly and significantly scaling up the adoption and deployment of RE technologies. Such large scale implementation can only successfully be undertaken with the understanding and support from the public and this will require dedicated awareness raising on the achievements of existing RE options and the opportunities, prospects, and potentials associated with wider scale applications (Barry et al., 2008).

Awareness raising is evidently only one necessary component in gaining public acceptance for increased RE deployment; it will require more direct engagement at the local level for specific policies and installations and often need to be seen as part of a broader sustainable development process. Increased awareness of opportunities for direct use of RE installations e.g. solar water heaters or PV systems in households is a distinct part of the overall expansion of RE utilization.

Providing relevant and carefully targeted information to the different stakeholders including the general public in order to respond to concerns over climate change related issues, and to the private sector to leverage commercial interest and investments in RE, is found to be key and is already happening in many countries (Wolsink, 2007). Various types of information on RE technologies are relevant and the dissemination channels may vary. Examples of these include:

- TV is already in use quite widely for information campaigns, corporate promotion, direct marketing
- Internet is similarly widely used for providing access to information and awareness material and an increasing number of innovative applications are available for esp. the youth engagement (games, YouTube videos, forums, etc.)
- Social networks either web based (like Facebook or MySpace) or more traditionally organized can be effective in facilitating communication and impacting opinions
- Different types of publications from newspaper articles to leaflets to simple slogan statements and many more
- Public meetings, talks and quiz games
- Inclusion in education curriculum from kindergarten level and upwards
- Direct demonstration plants with public access

It should also be noted that there are many strong economic and political interests vested in the energy sector and opponents to increase RE utilization have significant financial resources to provide counter information and lobby policy makers. A recent report from the US based Centre for Public Integrity concluded that both developed and developing countries are under heavy pressure from fossil fuel industries and other carbon-intensive businesses to slow progress on negotiations and weaken government commitments. The clash cannot simply be framed as one between richer and poorer nations

As an element of RE technology support programmes many national or cross–national governmental institutions have initiated RE promotion campaigns aiming to increase public awareness and thus influencing choices of end consumers (see e.g. European Commission, 2006). Interest groups, NGO's, trade associations, and industry organizations, among others, may also play a central role in this regard.

Experience shows that such efforts as well as related demand side management initiatives may have a large impact on the choices made by consumers and RE deployment over time (Christiansen, 2002). Private sector actors generally show interest in accessing more specific technical and economic data; including availability of RE input resources, technology reliability and commercial maturity, sourcing opportunities, technology cost effectiveness, etc. All part of the information basis that companies require to judge the relevance of entering into new business opportunities either directly or as part of corporate image building. Lately the issue of "carbon footprint" and carbon neutrality have become important corporate concerns for many larger national and multinational companies leading to increased focus on options in clean energy supply, enhanced efficiency and carbon trading.

Besides national initiatives, international platforms for RE information, clearing houses, networks and knowledge sharing forums on RE technology options like REN 21 may play important roles, on a broader international scale, for augmenting deployment of RE technologies. Examples include the Energy and Environmental Technologies Information Centres (EETIC) and the Global Renewable Energy Policies and Measures Database and others. The recently established International Renewable Energy Agency (IRENA) is expected to play an important international role in the future in this area. However, information needs to be targeted at and be accessible for very different types of stakeholders and consequently the total spectrum is very broad ranging from small scale rural household RE technology options to large scale off–shore windfarms. This can in most cases not be covered by the same institutions and targeting information at the many different stakeholders is a key challenge both in terms of format and timing.

9.4.3.2 Institutional capacity – policy, encouragement and enforcement

At the national level there are a variety of policy instruments, measures, and activities relevant for policy makers and governmental institutions to increase the deployment of RE technologies (Beck and Martinot, 2004). The adoption of such policies may be directed towards supporting various stages in the RE promotion process from basic R&D at universities, private companies, or non–profit institutions, to demonstration, commercialization, and full deployment stage.

Experiences from countries that have effectively promoted private investments in renewable energy show that national strategies, policies and targets are key elements [REN21, 2006]. Most existing successful national renewable energy strategies have wider goals, such as security of energy supplies, environmental protection, climate change mitigation, renewable energy industry development, and ultimately sustainable development (enhancing energy access, alleviating poverty, addressing gender and equity issues, etc). See Box from Agenda 21.

Agenda 21, Chapter 37:

Creating Capacity for Sustainable Development

A country's ability to develop more sustainably depends on the capacity of its people and institutions to understand complex environment and development issues so that they can make the right development choices.

People need to have the expertise to understand the potential and the limits of the environment. They will face difficult policy choices when dealing with such complex problems as global climate change and protecting biodiversity. This will require scientific, technological, organizational, institutional and other skills.

Information, data and capacity constraints is often a barrier both for the setting of broad policy priorities and for drafting actual sector-specific legislation. The same constraints may also prevent the private industries, including finance companies, from estimating more accurately the risks of cleaner energy technology investments, and stifles more widespread adoption of cleaner energy technologies by industry esp. in many developing countries. Limited institutional and human capacities are a particularly important concern amongst governmental agencies, which face growing demands in the area of climate change, but lack of capacity also hampers the private sector's ability to organize itself in a more effective manner.

Strategies for promoting certain RE technologies may therefore aim at accelerating the innovation process in specific stages of the technology push – and market pull continuum (EIA, 2000). However, the institutional capacity to make strategic choices and support schemes for RE implementation often is limited and need to be built in the relevant agencies and organizations.

This need for capacity development for making appropriate planning efforts on RE is most urgent in developing countries, however, the capacity of many industrialized countries to develop and implement RE policies and technologies is still limited (Assmann, et al., 2006). This often constitutes a significant and real barrier to increased utilization and deployment of RE technologies (Painuly, 2001).

Furthermore, the process of implementing RE policies spans from goals and targets setting to implementing concrete activities and finally to monitor and verify the results and this requires different types of institutional capacity to secure effective outcomes. Many developing countries have typically received support to develop national policies and plans but lack support for ensuring the successful implementation and follow-up.

Decision making and policy implementation has also in many countries changed from solely being the responsibility of certain government levels to increasingly involving various private sector stakeholders, NGO's, and civil society. This shift is incorporated in the inclusive concept of governance, which reflects the need to involve and give influential mandate to relevant parties in order to reach desired and successful outcomes (REN 21, 2006).

Participatory approaches to encourage stakeholder involvement as well as local democracy considerations are therefore key issues to achieve wider support of deployment of RE initiatives in a broader sustainable development context. Planning efforts and governmental intervention in the area of various RE technologies may also be understood as one element, i.e. the institutional infrastructure, of the technology system of innovation in question (Jacobsen and Johnson, 2000). Therefore, increasing RE technology deployment depends on a comprehensive understanding of other involved actors and the interactions between them in this innovation system.

In very broad terms, policies can be grouped into seven main categories i) research, development and demonstration incentives; ii) investment incentives; iii) tax measures; iv) incentive tariffs; v) voluntary programs; vi) mandatory programs or obligations; and vii) tradable certificates. [REN21, 2006] The evolution of these policies since the 1970s reflects among other things, an increased market orientation or policies moving from regulation towards economic policy tools. Presently, feed-in tariffs, obligations and tradable green certificates are emerging as the main policy instruments in many developed and increasingly some developing countries. Investment incentives and various tax measures do, however, remain important mechanisms to stimulate renewable energy investment, and it remains to be seen if the current financial crisis will affect policy tools in a potential move back towards more direct government regulation.

The gradual shift from regulatory approaches towards more economic and market oriented policy tools also has implications for the expertise required to develop and implement policies reflecting back on the need for new approaches on the capacity building side. This links in many developing countries with broader shift of the whole perception of RE implementation from niche applications and demonstration projects to having targets and policies at national level. The elements in the new paradigm are illustrated in Table 4 from Martinot et al. (2002)

Table 4: Renewable Energy Markets in Developing Countries

Old Paradigm		New paradigm
Technology assessment	⇨	Market assessment
Equipment supply focus	⇨	Application, value-added, and user focus
Economic viability	⇨	Policy, financing, institutional, and social needs and solutions
Technical demonstrations	⇨	Demonstrations of business, financing, institutional and social models
Donor gifts of equipment	⇨	Donors sharing the risks and costs of building sustainable markets
Programs and intentions	⇨	Experience, results, and lessons

Source: Eric Martinot. et al (2002)

9.4.3.3 Technical capacity – development and deployment

In most cases, the proprietary ownership of RE technologies is in the hands of private sector companies and not in the public domain and the diffusion of technologies also typically occurs through markets in which companies are key actors (Wilkins, 2002).

This necessitates a need to focus on the capacity of these actors to develop, implement and deploy RE technologies in various countries. Therefore, besides considering capacity development at the institutional level, the importance of increasing technological capability at the micro or firm–level needs to be addressed (Figueiredo & Vedovello, 2002, Lall, 2002). The concept of firm–level technological capabilities has in this regard been put forward to characterise the ability of companies, as a whole, to utilise technological knowledge efficiently to assimilate, use, replicate, adapt, and generate changes in existent technologies and the ability to develop new technologies, products, and processes (Lall, 1992, Bell and Pavitt, 1993, Dutrénit, 2004,). Companies, as organisations, may incrementally accumulate such capabilities over time enabling the company to undertake progressively more demanding, dynamic and innovative activities. This is by no means an automatic process and the literature identifies both failures and successful outcomes of companies' aspirations to increase their technologies capabilities (Metcalfe, 1995, Figueiredo, 2003).

An important strand of literature especially addresses the factors important for capability accumulation in firms in late–industrialising or emerging economies (Sharif, 1994, Hobday, 1995, Perkins and Neumayer, 2005, Mathews, 2007). In many developing countries, the initial focus will be on attainment of basic level capabilities to conduct operational functions and maintenance of RE technologies and/or to manufacture minor sub–components (Chandra and Zulkieflimansyah, 2003, Bell, 2007). In others, companies may be aspiring to achieve higher levels of innovative capability to adapt and develop RE technologies to changing circumstances. The types of capabilities needed are many–sided and country specific; and concerns various company related functions, including prefeasibility phase activities, project engineering, investment decisions, product and process organisation, and more (Jacot, 1997, Lorentzen, 1998).

A variety of factors may have an effect on fostering the accumulation of technological capabilities for RE technology deployment at the firm–level. Organisational intra–firm aspects are important but macro level structures such as industry specific regulations, political and economic factors, legal issues, cultural and social factors, etc., plays an equally important role. The supporting structure of technology–specific, national, or regional system of innovation for increased RE deployment may therefore be influential (Jacobsen and Johnson, 2000). National and cross–national company partnerships as well as technical assistance and joint cooperation programs for RE technologies may also influence capability accumulation positively.

Capacity building and technical support by or for the public sector can usefully address issues that facilitate more rapid development and implementation of RE by private companies and can for example cover issues like:

- Resource and technology data

This is an area for capacity development especially for developing countries, but also in many industrialised countries is the lack of appropriate data on resources and technology performance an important barrier to increased RETs implementation.

- Testing and licensing

An important contribution to the successful development of the wind industry was the enforcement of strict testing and licensing procedures – still applicable – which helped ensure that quality of the developed turbines was high and in this way increased the credibility of a new technology. This approach is increasingly replicated in other technology areas and will facilitate credibility both with the end user and with the financing institutions involved in providing capital for the up from investment

- Research and development

Governments individually or in the context of regional or bilateral collaboration will need to step up the investments in general technological advances and demonstrations both on individual technologies, integrated energy systems or implementation measures. Compared to other areas like nuclear fusion and fission the funds devoted to RE research and development have been on a much lower scale. For example the OECD country governments in 2005 are estimated to have spent 9.6 billion USD on energy related research with approx. 1.1 billion for renewable broadly and 3.9 billion on nuclear [OECD, 2008]. This is not arguing for lowering funding for nuclear research but significantly increasing the R & D for RE as is being demonstrated by several countries that have substantially increased funding during 2008-09.

In the context of the UNFCCC technology transfer has been a permanent issue as part of the negotiations and there is a strong focus in current talks before COP 15 to have new dedicated efforts as part of a possible new agreement [needs to be revised after COP 15!!] and this is expected to among other issues to focus on:

- Development of effective policy frameworks to accelerate the transfer, deployment and dissemination of existing and new technological solutions;
- Strengthen investment, research, innovation, information and skills sharing, dissemination and uptake of clean technologies, through bilateral and multilateral partnerships;
- Promote sustained and joint efforts between government and the private sector, including the financial sector, to promote the market for new technologies;
- Provide technical support to developing countries in conducting and improving their technology needs and in transforming such assessments into bankable technology transfer projects that meet the standards of potential financiers;
- Develop international energy management standards to increase the efficient use of existing and future technologies in industry and other sectors.

9.5 Implications of (sustainable) development pathways for renewable energy

Environmental consequences of energy consumption have been neglected for too long, because the idea of continuing economic growth is still central to policy makers across the globe. Clearly, it would be preferable to concentrate on providing energy services that will satisfy the needs of the people rather than working towards increasing the capacity of supply, based mainly on non-renewable resources.

It is widely accepted that energy is linked with more or less all aspects of sustainable development. It is an engine for growth and poverty reduction, and therefore it has to be accorded high priority and this has to be reflected in policies, programs and partnerships at national and international levels (WEHAB, 2002). The provision of energy in a sustainable way is therefore pivotal to the aim of achieving sustainable development.

To make global energy systems compatible with sustainable development requires a sustained effort that includes awareness raising, capacity building, policy changes, technology innovation and investment. The shift towards a sustainable energy economy also requires sound analysis of the options by policymakers, good decisions and the sharing of experience and knowledge of individuals and organizations involved in the many practical challenges that such a transition presents. These activities, and the resulting changes, are needed in industrial as well as developing countries (WEHAB, 2002).

These interactions involve science, technology, learning, production, policy and demand, so that entrepreneurs innovate largely in response to incentives coming from the wider innovation system (Foxon, 2008). The technology has to be appropriate for a specific context, so that the target community has the capacity to afford it and to maintain it.

Renewable resources can also become non-renewable if the rate of utilization exceeds the capacity of the planet to recycle them. In other words, excessive consumption can lead to limits in the availability of renewable resources, and consumption itself can become unsustainable (Gutierrez, 2009). Thus, pathways to sustainable use of renewable energy generation and use have to take these limits into consideration.

The feasibility of stabilizing GHG concentrations is dependent on general socio-economic development paths. Climate policy responses should therefore be fully placed in the larger context of technological and socio-economic policy development rather than be viewed as an add-on to those broader policies (Swart et al, 2003).

We need to measure progress by how quickly we can build a renewable energy platform, meet basic human needs, discourage wasteful consumption, and invest in rather than deplete natural and cultural capital (State of the World, 2008 – The World watch Institute).

In the context of development pathways for renewables and possible implications long-term sustainability aspects of intergenerational, as well as intragenerational equity issues will need to be discussed, to satisfy the basic principle of sustainable development.

Criteria for sustainable energy:

Availability of resources
Security of supply
Environmental compatibility
Economic compatibility
Social compatibility
Production associated with low risks

9.5.1 Future scenarios of renewables

The previous sub chapters were discussing the impacts of renewables on the environment (9.2), as well as impacts of renewables on socio-economic aspects (9.3). The aim of this subchapter is to consider future scenarios for renewable energy development and define different pathways.

In 2005 renewables produced 16% of world primary energy. Globally, electricity made up 19%, mostly from large hydropower and the rest from other renewables such as wind, biomass, solar, geothermal and small hydropower. Biomass and solar energy contribute to hot water and heating, and biofuels provide transportation fuels. Most renewable technologies, except large hydropower, have been growing at rates of 15-60% annually since the late 1990s. It is this group of technologies that are projected to grow the fastest in the coming decades (Martinot et al, 2007).

Future scenarios of renewables for different regions, different end-user sections and different energy sources need to consider a broad spectrum of possible RETs, as well as the associated risks, the affordability and limitations of the proposed technologies. Furthermore, to achieve low stabilisation targets, not only all technology options have to be evaluated, but also all sources of CO_2 and non-CO_2 emissions have to be considered (PIK, 2009).

When considering different future scenarios for renewable energy in the context of sustainable development, questions like how are we going to deal with a conventional baseline in terms of equity, trade, security, environment, as well as the impact of subsidies, need to be addressed. What will be possible outcomes in the medium to long-term? And how will this impact on how development pathways are determined.

To determine different pathways it is essential to first have a desired future vision or target and then work out a way on how to achieve that vision or target. In this case the target is an increase in renewable energy deployment which in turn will lead to a more sustainable development pathway. A method used to incorporate sustainable development into the strategic planning process is "backcasting" [Robinson,1982]. The idea behind backcasting is to define the goal or destination and then work backwards from the destination to the current situation. In this case the overarching vision is to keep the level of CO_2 at or below 450 ppm in terms of CO_2 equivalent concentration and keep the global temperature increase at or below 2°C. A part of this vision is the increased use of renewable energy.

Once the pathway has been determined, the potential barriers to development pathways for renewable energy technology innovation/implementation have to be identified. Many barriers are well known, however, overcoming these barriers remains difficult. Other barriers may be less obvious and consequently more difficult to remove. (See subsection 9.1.3 Barriers and Opportunities for more details).

9.5.1.1 Development pathways for renewable energy in different regions

The development of renewable energy technologies has to take place within the wider context of sustainable development, including economic and social development, protection of the environment and enhancement of equity. A sustainable energy system is a system consisting of (renewable energy) technologies, laws, institutions, education, industries and prices governing energy demand and supply for the sustainable development process (Diesendorf, 2007).

Given their large cumulative emissions and higher income levels, the immediate burden of development and financing renewable technologies (RETs) should fall on the shoulders of industrialized countries. This does not mean, however, that many developing countries do not have technology bases that enable them to make significant R&D contributions to RETs. For developed nations, the reduction of the cost/power ratio must drive their research agenda (Wagner, 2004).

To facilitate a global transition to renewable energy will require large investment in national, regional and local energy infrastructures in developing as well as developed countries and economies in transition. These investments will need to come from the public and the private sectors and will have to take many forms, including financial incentives from government; loans and capital investment from banks, private investors, venture capital funds and communities; as well as new innovative markets that contribute to the benefits of renewable energy and energy efficiency (CanREA, 2006).

There are a number of national and international funds that provide grants or interest-free loans to developers of energy efficiency and renewable energy projects. These include among other the Global Environmental Facility (GEF), the Global Village Energy Partnership (GEVP) and the Renewable Energy and Energy Efficiency Partnership (REEEP) (CanREA, 2006). There are a number of innovative funding models available, including:

- Clean Development Mechanism (CDM)
- Dealer-Credit Model (Grameen Shakti)
- Consumer Credit Model
- Supplier Credit Model
- Energy Service Company Model
- Revolving Fund
- Global Environment Facility (GEF)

9.5.1.1.1 Developing Countries

Developing countries face two main energy challenges; firstly, to meet the energy needs that are essential for economic growth and poverty reduction; secondly, to reduce the threat of regional and global environmental disruptions, particularly addressing the vulnerability of societies to the negative impacts of climate change (Usher, 2007).

To meet the rapidly growing energy needs of present and future populations in developing countries, and to reduce poverty, will require large capital investments (WEHAB, 2002). Many renewable energy companies in developing countries are frustrated by the lack of interest in their businesses from finance institutions, either to finance their operations or to lend to their customers (Usher, 2007).

Development pathways for renewable energy in developing countries have to ensure that the chosen energy options will be able to improve productivity of resource use, increase economic prosperity and provide positive benefits across all three dimensions of sustainable development (WEHAB, 2002). The development pathway for renewable energy in developing countries has to be compatible with climbing the energy ladder and economic development. Therefore, programs like the UNEP's Rural Enterprise Development programs are a first step towards a pathway for renewable energy in the developing world (Usher, 2007).

A recent initiative dealing with these issues is the African Rural Energy Enterprise Development (AREED) programme which was launched in 2001 under the joint auspices of the United Nations Environment Programme (UNEP), the United Nations Foundation (UNF), E+Co, and UNEP Risoe Centre and with funding from the UNF, SIDA, BMZ and the Dutch government (Akuffo and Obeng, 2008). This initiative has succeeded in developing an ingenious plan of loan provision, building capacity in bankable business plan development, analysing market conditions and identifying efficient energy systems for Small and Medium Enterprises (SMEs). However, according to Akuffo and Obeng (2008), energy SMEs in Africa are facing several constraints and challenges including: lack of relevant policies and institutional framework to provide sufficient leverage for SMEs to tap into new energy business; lack of capacity building in energy system development and commercialization; limited rural energy market; inherently high initial cost of renewables and energy efficient products; and poor access to clean energy financing. This suggests that without an enabling policy framework, SME energy providers in Africa will not be in a position to participate in the emerging energy market. What is needed is a multidimensional approach that has the effect to transform energy systems, social systems, economic systems, and institutions at an unprecedented rate and scale (O'Brien 2008).

The provision of renewable energy has not been defined as a Millennium Development goal in its own right; nevertheless, access to clean energy services is an important pre-condition not only for environmental sustainability but also for the achievement of most of the other millennium development goals. The development pathways for renewable energy in developing countries have to therefore closely align themselves with the MDGs. Developing countries have to build knowledge and manufacturing capacity in the renewable energy sector within their own countries. It is imperative that researchers and innovators from developing countries remain there and contribute to increasing capacity within their countries instead of leaving the countries to follow a more lucrative career path in a developed country.

Some developing countries have the opportunity to leapfrog the more polluting fossil fuel based technologies and industries and move directly to more advanced renewable energy technologies (see subchapter 9.2.1.3 for more detail on leapfrogging and microenergy) [TSU: No section has currently been dedicated to cover leapfrogging and microenergy]. Developing countries cannot afford to be dependent on technology transfer and foreign supply to sustain their technological progress. Instead, technology transfer needs to be coupled with capacity building. This requires finance mechanisms that are appropriate for the specific conditions within which they are applied. In the case of providing finances to the rural poor, Grameen Shakti in Bangladesh has come up with a micro-credit scheme to finance renewable energy technologies to reduce down payment and offer free after sales service solutions that empower women, the disadvantaged, create jobs, facilitate rural development and protect the environment (Barua, 2008).

9.5.1.1.2 Developed Countries

Electricity grids across Europe are 40 years old and fast approaching the end of their operating lives. This presents an opportunity for fresh thinking and innovation, exploring possibilities of alternative energy options, based to a large extent on renewable energy resources. The Global Energy Network Institute (GENI) proposed a strategy for developing remote renewable energy sources and linking them to population centers via long distance electrical transmission lines (GENI, 2007).

Most large scale renewable energy sites are located far from population centers. Today, interconnection of renewable energy sources is a viable and feasible energy alternative, from a technological viewpoint (GENI, 2007). With the development of high-voltage valves, it is now possible to transmit DC power at higher voltages and over longer distances.

In 2008 the Trans Mediterranean Renewable Energy Co-operation (TREC) proposed an interconnected grid between Europe, North Africa and the Near East. This is an ambitious plan to turn Europe, North Africa, and the Near East into a super-grid based on renewable resources, ranging from solar (solar CSP and Solar PV), wind, hydro, biomass and geothermal.

To enable the development of renewable energy requires national programs and policies to support renewable energy markets.

- Establish renewable friendly laws and regulation
- Promote renewable friendly building codes and standards
- Stimulate long term financing
- Provide sustained financial support for projects

According to PEER (2009) the following should happen to stimulate increased energy market by renewable energy:

- Climate-based subsidies and budget allocations could be increased or new ones introduced;
- Subsidies and taxes with harmful climate impacts could be removed or redesigned;
- Budget allocations and taxes with favourable side effects from a climate point of view could be increased;
- Rules and texts stipulating the way in which present budget allocations may be used could be more climate-based by stipulating climate-based limits or goals for the administrative bodies that govern these means (PEER Report No 2, 2009).

Similarly, the White Book from the DESERTEC Foundation posits that a scenario that meets all criteria of sustainability will require determined political support and action. It lists five focal points for national and international policy for all countries in Europe, the Middle East and North Africa (EUMENA):

1. Increase support for research, for development and for the market introduction of measures for efficient supply, distribution and use of energy (efficiency focus).
2. Provide a reliable framework for the market introduction of existing renewable energy technologies, based on best practice experience and increase support for research and development for promising enhancements (renewable energy focus).
3. Initiate a EUMENA-wide partnership for sustainable energy. Provide European support to accelerate renewable energy use in MENA (interregional cooperation focus).

4. Initiate planning and evaluation of a EUMENA High Voltage Direct Current super-grid to combine the best renewable energy sources in this region and to increase diversity and redundancy of supply (interconnection focus).
5. Support research and development for shifting the use of fossil fuels from bulk electricity to balancing power production (balancing power focus) (TREC, no date)

9.5.1.2 Development pathways for renewable energy in different end-use sectors

Unlike centralized energy generation based on fossil fuel or uranium, distributed energy generation based on local renewable energy sources provides diversity which in turn means greater strength in guarding against unforeseen events. It offers a risk management strategy that reduces the potential of adverse impacts resulting from interruptions in supply, or excessive price rises in any single supply sector.

9.5.1.2.1 Built-environment

Buildings consume a lot of energy. Direct emissions from buildings grew by 26% between 1970 and 1990 (IPCC, 2007). Furthermore, the buildings sector has a high level of electricity use and hence the total of direct and indirect emissions in this sector amounts to 75%. In recent years, there has been a lot of emphasis placed on energy efficiency. To meet this energy demand, renewable energy can be used. The built environment offers many opportunities for this. Roofs can be used to produce renewable heat with solar collectors, or renewable electricity with solar panels. In addition, renewable heat can be extracted from the ground, using heat pumps. In some cases small wind turbines can be mounted on the roofs to produce electricity. Through the combination of efficient use of energy and the use of local, energy sources, a situation can be achieved where renewable energy meets the biggest part of the energy demand in buildings (ECN, no date).

9.5.1.2.2 Transport

Today's transport sector is predominantly based on combustion of fossil fuels, making it one of the largest sources of urban and regional air pollution and greenhouse gases. The growth in direct emissions from transport between 1970 and 1990 was 120% (IPCC, 2007). However, the movement of goods and people is crucial for social and economic development. Consequently, there is a need to move towards sustainable mobility. Solutions need to be found that address mid-term, as well as long term concerns about transportation, energy and emissions.

According to UNEP (no date) this requires:

- Urban planning, changing lifestyles and production patterns to reduce the need for transport at the source;
- Rethinking transport systems, promoting inter-modality and encouraging the use of the most energy efficient mode of transport, i.e., wherever possible switch from air to rail, from the personal vehicle to public transport or non-motorized transportation;
- Improving fuel efficiency of each mode of transport, and promoting the use of alternative fuels.

UNEP has identified three key areas of work to assist countries:

- The improvement of urban planning to promote inter-modality;
- The diffusion of cleaner technologies and the deployment of relevant policies that drive them to reduce environmental impacts,
- The introduction of price signals that capture the full costs of different modes of transport.

Options to develop pathways for renewable energy in the transport sector include increasing the energy from biomass from local resources; i.e. ethanol and bio-diesel. Explore the potential of the electric car using electric motors, based on electricity generated from renewable energy sources. Hybrid cars and to lesser extent battery cars[2] are a proven technology. Additionally, hydrogen and fuel cells based on renewable energy generation have the potential to play a part in transportation. Several countries are involved in hydrogen bus projects, including Brazil, the US, the UK and a number of other European countries. An LCA of emissions of these proposed options needs to be considered.

9.5.1.2.3 Land-use

Renewable energy and land use is not without its controversy. Some environmentalists argue that the increased use of renewable energy would have severe environmental consequences. Key renewable energy sources, including solar, wind, and biomass, would all require vast amounts of land if developed up to large scale production (Pearce, 2006). Between 1970 and 1990 direct emissions from agriculture grew by 27%, and the total land use, land use change, and forestry grew by 40% (IPCC, 2007).

The EU Parliament (2009) places importance on monitoring the impact of biomass cultivation, such as through land use changes, including displacement, the introduction of invasive alien species and other effects on biodiversity. It further posits that biofuels should be promoted in a manner that encourages greater agricultural productivity and the use of degraded land.

Educating policy makers as well as the general public of the true impacts of renewable energy through land use changes has to be part of the strategy towards the development of renewable energy on a larger scale.

9.5.1.3 Development pathways for renewable energy in different energy sources

The challenges associated with renewable energy technologies, like intermittency of wind generated grid power and storage of electricity from solar power are well documented. To facilitate development pathways for renewable energy technologies it is therefore essential to finance research to find solutions to these challenges.

Besides the more conventional storage technologies including hydro-pumped and compressed air storage for electricity generation there are examples of alternative, existing storage technologies, like the Vanadium Redox Flow Battery (VRB), which was developed and commercialized by the University of New South Wales (UNSW) Australia. According to the UNSW website, it has shown to have high energy efficiencies between 80 and 90% in large installations and is low cost for large storage capacities. (Skyllas-Kazacos, no date).

Biomass has the potential to supply large amounts of CO_2 neutral energy. It is already competitive in some markets. Currently about 13% of the world's primary energy supply is covered by biomass. Industrialized countries source around 3% of their energy needs from biomass, while Africa's share ranges from 70-90% (WBCSD, 2006). Current use of agricultural biomass for non-food purposes, including energy, amounts to around 9% of agricultural biomass being harvested and grazed for food (Wirsenius, no date). Thus, agricultural products and residues, as well as dedicated energy crops, are a key part of the overall supply of biomass. In 2005 roughly 46 EJ out of the total supply of 490 EJ were derived from biomass making it the most important renewable primary energy source (Sims et al, 2007).

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[2] Zebra high-energy battery made from common salt, ceramics and nickel is able to store four times more energy than a lead acid battery holding the same weight and allows a range of up to 400 km (http://www.solartaxi.com/technology/zebra-battery/)

Possible negative impacts associated with large scale biomass farming need to be considered. A framework is required to address issues of land ownership, de-forestation and land-clearing, displacement of people, competition with food production and in some cases emissions from fuel-wood negatively impacting on indoor air quality (See 9.3.1 for more detail on bio-energy).

In addition to residues and purpose grown energy crops, waste products like animal wastes, human wastes (e.g. anaerobic digestion of sewerage sludge to produce bio-gas or inter-esterification of tallow to give bio-diesel) have large potential for carbon neutral energy production. Similarly, municipal solid waste, either combusted in waste-to-energy plants or placed in landfills with the methane gas collected for electricity and heat production play some part (Sims, 2004). Human and animal waste has been in use in countries like China and India for some time to produce biogas (methane) in anaerobic digesters, and the technology is being introduced in some African countries. Its potential as a source of energy for lighting and cooking and waste treatment, particularly in densely populated areas, has to be looked at more seriously.

Box 9.1: Biogas from human Waste – the case of Rwanda
(Copied from Ashden Award Pdf)
Kigali Institute of Science, Technology and Management (KIST), Rwanda, 2005 (on line) Available:
http://www.ashdenawards.org/files/reports/KIST%20Rwanda2005%20Technical%20report.pdf

The Kigali Institute of Science, Technology and Management (KIST*), Rwanda, has developed and installed large-scale biogas plants in prisons in Rwanda to treat toilet wastes and generate biogas for cooking. After the treatment, the bio-effluent is used as fertiliser for production of crops and fuelwood.

Large prisons, each housing typically 5,000 prisoners, are a legacy of the troubled past of Rwanda. Sewage disposal from such concentrated groups of people is a major health hazard for both the prison and the surrounding area. The prisons also use fuelwood for cooking, putting great pressure on local wood supplies.

Using biogas digesters to manage animal or human sewage is not a new idea, but in Rwanda has been applied on an enormous scale, and with great success. Each prison is supplied with a linked system of underground digesters, so the sight and smell of the sewage are removed. KIST staff manage the construction of the system, and provide on-the-job training to both civilian technicians and prisoners. The biogas is piped to the prison kitchens, and halves the use of fuelwood. The fertiliser benefits both crop production and fuelwood plantations.

The first prison biogas plant started operation in 2001, and has run with no problems since then. Biogas plants are now running in six prisons with a total population of 30,000 people, and KIST is expecting to install three more each year.

Technology and use

Biogas systems take organic material such as manure into an air-tight tank, where bacteria break down the material and release biogas - a mixture of mainly methane with some carbon dioxide. The biogas can be burned as a fuel, for cooking or other purposes, and the remaining material can be used as organic compost. The systems installed in Rwanda have an impressive international heritage: the original design came from China, was modified by GTZ, and finally scaled up and refined by a Tanzanian engineer working in Rwanda.

The biogas system uses a number of individual digesters, each 50 or 100m3 in volume and built in an excavated underground pit. Toilet waste is flushed into the digesters through closed channels, which minimize smell and contamination. The digester is shaped like a beehive, and built up on a circular, concrete base using bricks made from clay or sand-cement. The sides taper gradually and eventually curve inward towards a half-meter diameter man-hole at the top. It is crucial to get the bricks laid in exactly the right shape, and to make the structure water-tight so that there is no leakage of material or water out of the digester. Biogas is stored on the upper part of the digester.

The gas storage chamber is plastered inside with waterproof cement to make it gas-tight. On the outside, the entire surface is well plastered and backfilled with soil, then landscaped. The biogas system is finally inspected and, when approved, it is certified for operation.

From the manhole cover, the gas is piped underground towards the kitchen where it is used for cooking porridge, beans and maize in enormous (500 liter) pots, and in stoves that are insulated with a brick lining. A 100m3 plant can store 20m3 of gas, but may generate up to 50m3 per day, so it is important that the gas is consumed regularly.

A particular feature of the plant design is a compensating chamber that acts as a reservoir of methane bacteria for enhanced gas generation. At first, gas pressure displaces the liquid to the compensating chamber. Consumption of gas leads to backflow of the waste from the compensating chamber into the bio-digester; this agitates the waste, circulates the bacteria, and releases trapped gas.

The continuous input of waste, and the gas pressure, push digested effluent out of the bio-digester to a stabilizing tank, and from there, to a solid/liquid separation unit. The stabilizing tank allows additional gas production. The solids are composted for three months and then used as fertilizer in the prison gardens and woodlots. Great care is taken to ensure that the effluent is safe to use in this way, with regular laboratory checks on samples for viruses, bacteria and worms. As an additional precaution, the fertilizer is used only for crops that stand above ground, such as papaya, maize, bananas, tree tomato and similar tree crops.

The scale of these biogas systems is enormous: a prison with a population of 5,000 people produces between 25 and 50 cubic metres of toilet wastewater each day. Using a 500m3 system (five linked digesters), this produces a daily supply of about 250m3 of biogas for cooking.

How users pay

The biogas plants are purchased for the prisons by the Ministry of Internal Security. The cost of a 500m3 plant is about 50 million Rwandan francs (£50,000). A system of phased payments is used, with the final 5% paid only after 6 months of satisfactory operation.

Training and support

There is great emphasis on quality and reliability in the design and construction of the biogas plants, and they are expected to last for at least 30 years. Prisoners are trained to operate the systems, with support from the KIST team, and are very diligent in this task. Their work includes regular checks on the digester seals, emptying condensate bottles, guiding the flow of the bioeffluent, and application of the compost on the farm. It is also advisable to completely de-sludge the digesters every seven years.

Benefits of the project

The initial reason for using biogas systems was to improve the sanitation in prisons, reducing health risks and smell for both prisoners and the neighbouring residents. The Ashden judge who visited this project noted the overflowing septic tanks and dreadful odour at a prison where the biogas plant was still being installed, and the remarkable lack of odour (even from the output effluent) at a prison with an operating plant. Some prisons have used the effluent to make gardens over their underground biogas system.

Large institutions put enormous demands on fuelwood for cooking, and can cause local deforestation even in a generally well-wooded country like Rwanda. A prison of 5,000 people consumes about 25 m3 (approximately 10 tonnes) of fuelwood per day. Using all the biogas from their sewage system can save about half of this fuelwood. The overall prison population served by biogas plants is now about 30,000 people, so the annual fuelwood saving is about 27,000 m3.

The project saves greenhouse gas emissions by reducing the unsustainable use of fuelwood, and also by preventing the uncontrolled emission of methane from overloaded septic tanks and sewage pits. Both these savings are site-specific and difficult to quantify. As an indication of savings, if 50% of the fuelwood saved is unsustainable, then the greenhouse gas saving from the current systems is about 10,000 tonnes of CO_2 equivalent per year. Similarly if 20% of the biogas production would have occurred with unmanaged sewage disposal, then an additional 1,000 tonnes of CO_2e per year would be saved.

A significant benefit from the project is the technical and business training that is provided to the civilian technicians, prisoners, and even KIST graduates on-the-job at each installation: the technicians often come from the neighbouring population. To date, over 30 civilians and 250 prisoners have received training, and three private biogas businesses have been started. CITT has employed one of the released prisoners as a trainee.

Through their training programmes, CITT have started the development of private biogas companies in Rwanda. These will install plants with CITT acting as the certification body, and thus keeping quality standards high. Failures (as have occurred in other countries) would damage the biogas sector as a whole.

There is clear potential for widespread replication of these biogas plants, in Rwanda and many other countries. Many other large institutions which are remote from mains sewage services also have problems with sewage disposal, and housing developments could also benefit. CITT has already undertaken smaller installations in three residential schools: here the percentage of fuelwood replaced is less (around 20% rather than 50%, because more cooked food is provided) but still a significant benefit

Management, finance and partnerships

When a biogas system is requested, a team from CITT make a site inspection along with a representative of the Ministry for Internal Security and the Director of the Prison. Technical and financial staff at CITT produce a detailed specification and contract. All site work is managed by a manager and site engineer from CITT, with materials supplied through a tender system, often from local sources. The Ministry also has a project controller on site, to supervise installation.

The International Committee of the Red Cross (ICRC) has been a key partner throughout the biogas programme, because they see the benefits which it brings to health and welfare in prisons. Both the ICRC and the government of the Netherlands have assisted the government of Rwanda in financing the programme.

The project won an Ashden Award for Sustainable Energy

*KIST is a public Institute of Higher Learning, which was established in 1997 to replace professional manpower that had been lost from Rwanda. The main focus is on technology and management.

Note: this is more or less an ad verbatim copy from the Ashden Award document

Direct solar produces minor emissions during operation, and the overall life cycle environmental performances are improving. For example, all PV technologies generate far less life-cycle air emissions per GWh than conventional fossil-fuel based electricity generation technologies (Fthenakis et al, 2009). Furthermore, because it generates mainly decentralized energy, direct solar potentially increases job opportunities and income in rural areas, particularly in developing countries. Possible negative impacts to consider are issues around land occupation for large solar thermal installations, resulting in change of albedo. The up front costs are relatively high but there are no fuel costs (see 9.3.3 for more detail on direct solar).

Electrical production from geothermal results in an order of magnitude less CO_2 per kilowatt-hour of electricity produced compared to burning fossil fuels (Bloomfield et al (2003). However, there are some site specific emissions associated with energy production form geothermal. Similar to other renewable technologies it has potential to improve employment opportunities in developing countries. The capital costs are still high; however, variable costs are low. (See 9.3.4. for more detail on geothermal energy).

Hydro power has the capacity to store energy, as well as water for irrigation. However, large hydro dams release methane emissions, have high lifecycle emissions, mainly during construction, and potential to displace people and damage existing settlements. Energy price is very cost competitive. (See 9.3.5. for more detail on hydropower).

Ocean power, particularly wave and tidal power has potential to provide base load energy with no emissions during operations. However, some emissions may arise during manufacturing and installation of the devices. Tidal power may require large structures that have environmental impacts (See 9.3.6. for more detail on ocean energy).

Wind power is the most-cost-effective renewable energy technology producing electricity (except for large hydropower) with some lifecycle emissions but no emissions during operation. It has a positive impact on rural economies. There are some issues about visual and noise pollution, as well as risk of collision for birds and bats (see 9.3.7 for more detail on wind energy).

Development pathways for different energy sources vary; some like wind, hydropower and bio-energy are already competitive and well established; others like direct solar, geothermal and ocean power in particular require assistance to advance their development and scale up production.

9.5.2 Policy framework for renewable energy in the context of sustainable development

On the global level there is a recognized need for the international community to strengthen its commitment to the scaling up of renewable energy development and use, especially in developing countries (BIREC, 2005).

International organizations like the UN Framework Convention on Climate Change (UNFCCC) (i.e. Clean Development Mechanism), the International Energy Agency, the UN Development Program (UNDP), Energy and Environment, the UN Division of Sustainable Development, the World Bank Energy Program, the UNDP/World Bank ESMAP (Energy Sector Management Assistance Program) and others play an important role in building capacity and improving financing and transfer of technology know-how for renewable energies. For example, UNEP has made support for renewable energy a top priority in its call for a “Global Green New Deal” at the recently held COP14 in Poland (Sawyer, 2009).

Similarly, organizations like the Renewable Energy and Energy Efficiency Partnership (REEEP), , the Global Network on Energy for Sustainable Development (GNESD), the Global Village Energy Partnership (GVEP), the International Network for Sustainable Energy (INFORSE), the UNEP Sustainable Energy Finance Initiative, the World Council on Renewable Energy (WCRE), the World Alliance for Decentralized Energy (WADE), the World Business Council for Sustainable Development (WBCSD) and the World Renewable Energy Congress/Network (WREC/WREN) all aim to accelerate the global market for sustainable energy by acting as international and regional enablers, multipliers and catalysts to change and develop sustainable energy systems.

The International Renewable Energy Agency (IRENA) is a relative newcomer to assist in the promotion of future oriented development pathways for renewable energy. IRENA is the first international organization exclusively focused on the issues of renewable energies. It is a first, but important step on the global level to have a body that aims to close the gap between the large potential of renewables and their relatively low market in energy consumption.

The World Summit for Sustainable Development (WSSD), the Bonn International Conference for Renewable Energies, the G-8 Gleneagles Summit, and other international and regional initiatives all play an important role to promote renewable energy.

On the regional level there is a need to build stronger partnerships between governments, regional authorities and municipalities, energy producers and consumers, market intermediaries, non governmental organizations (NGOs) and financial institutions in order to facilitate a common understanding of the issues, challenges and constraints related to renewable energy development, and to pave the way for greater cooperation among all groups in society (Slavov, 2000).

There is a growing body of regional organisations involved in the advancement of renewable energy technologies. For example, the European Union energy policy aims to create a single, liberalised energy market (electricity and gas) at the EU level that is both transparent and efficient; to diversify sources for greater security of supply; to reduce energy consumption and promote development of new forms of renewable energy (European Parliament,2007).

On a national level, organizations like NREL in the US have a role to play in the area of R&D, as well as the dissemination about renewable energy to consumers, homeowners and businesses. Similarly, organizations the American Wind Energy Association (AWEA), the Basel Agency for Sustainable Energy (BASE), the Brazilian National Reference Center on Biomass etc assist the development of renewable fuels and electricity that advance national energy goals in their respective countries.

The role of national governments is to provide an enabling policy framework, through government institutions to stimulate technical progress and speed up the technological learning processes so that RETs will be able to compete with conventional technologies, once the environmental costs have been internalised (see Chapter 11 for more detail).

1. Renewable energy solutions on the local level should be resource and need driven. Local participation in selecting appropriate solutions is important. Studies like the ones conducted by Gregory et al. (1997), Nieuwenhout et al. (2000), Taylor (1998) and Lloyd, Lowe and Wilson (2000) stress the importance of technical reliability. To ensure the reliability of a system it is important that local installers and maintenance personnel are adequately trained. The need for improved education programs and improved accreditation of installers for remote areas was recognised in a recent market survey by the Australian Cooperate Research Centre (CRC) for Renewable Energy (ACRE) (Lloyd, Lowe and Wilson, 2000).

2. The renewable energy solution has to be appropriate and fit in with the specific local context. Innovations based on Western style consumerist ideology should not always be presumed to offer the best or only solution to a problem. That does not mean that traditional technology is necessarily preferable. What it does suggest however, is to allocate equal importance to both Western technology and traditional technology, when considering available options and solutions.

The developers of sustainable energy technology based on renewable energy on the local level face the difficulty of designing a system or product that remains flexible enough to be able to adapt to a number of different social, cultural, political, economic and environmental situations and peculiarities and take local knowledge into account, and at the same time can be mass-produced, in order to remain competitive.

9.5.2.1 Required instruments for sustainable development pathways for renewable energy

Appropriate policy instruments for sustainable development pathways for renewable energy are required on the global, regional, national as well as local level. The available instruments are similar to those used in environmental policies, with similar discussion involved in their choice.

At the international level, multilateral as well as bilateral agreements like the current Kyoto Protocol are imperative to provide a global framework for the promotion of sustainable development pathways for renewable energy. The three instruments or mechanisms that help industrialized countries achieve their Kyoto emission reduction targets agreed to by allowing them to reduce the cost of reduction are emission trading (ET), joint implementation(JI) and clean development mechanism (CDM). These three instruments provide the conditions for the development of pathways for renewable energy development in developing as well as industrialized nations.

The use of subsidies to promote the development of renewable energies worldwide includes the gradual phase out of subsidies to the fossil fuel and nuclear energy production and consumption and instead increasing the provision of subsidies to renewable energy production and use.

At the regional level, the EU proposes a mandatory target of 20% of renewable energy sources in gross inland consumption by 2020, as well as a minimum target for biofuels of 10% of overall consumption of petrol and diesel in transport for 2020.

In the Asia-Pacific region there is a recognized need to strengthen the policy framework to accelerate the implementation of policies towards achieving sustainable development pathways for renewable energy. Feed-in tariffs and mandatory targets [TSU: here is text missing]

At the national level a mix of command and control or regulatory instruments, as well as market based incentives is required. The two main instruments are feed in tariffs and certificate markets. These two policy instruments in combination are necessary to achieve the desired transformation towards sustainable development in the context of the global climate challenge. The countries with successful renewable energy programs are those that have legislated a feed-in tariff, which ensures fixed prices for every kWh that is being produced by renewable energy sources and is fed into the grid. For example, Germany brought in the Renewable Energy Sources Act, (EEG) in 2000, introducing feed-in tariffs, with fixed payment per kWh for a period of 20 years with steady reductions of the payment amounts at a rate of 1.5% per annum (BMU, 2008).

In addition, defining national targets and setting bidding systems, establishing markets for tradable permits for CO_2 emissions, green certificate markets and renewable energy certificates are important instruments to promote the development of RETs. Other financial incentives for renewables and energy efficiency are in the form of corporate and personal tax credits, subsidies, as well as loan and grant programs.

9.6 Synthesis *(consequences of including environmental and socio-economic considerations on the potential for renewable energy, sustainability criteria)*

9.6.1 RE policies and sustainability - background

Development is a concept frequently associated with economic growth, still in many cases disregarding income distribution, physical limits from the environment and the external costs of impacts caused by some and borne by others. Climate change is one of these most relevant impacts, with externalities present at global level.

Sustainable Development (SD) is a relatively recent concept, aiming to consider such impacts. There are several definitions of SD, but probably the most important came up in 1987, with an influential report published by the United Nations, entitled “Our Common Future” (or “The Brundtland Report”). In this publication, sustainable development is a principle to be pursued, in order to meet the needs of the present without compromising the ability of future generations to meet their own needs. The report recognized that poverty is one of the main causes of environmental degradation and that equitable economic development is a key to addressing environmental problems. The report also emphasized the issue of the legacy that the present generation is leaving for future generations.

Since the early 1960´s, the SD concept that has grown out of concerns about a declining quality of the environment coupled with increasing needs for resources as populations expand and living standards rise. Early initiatives focused more on individual attributes of the environment, including water quality, air quality, management of hazardous substances and cultural resources. Some of the outcomes from the initiatives included a complex array of regulations intended to manage and improve development, a movement toward recycling of consumable resources and an emphasis on renewable energy as a substitute for energy production that consumed resources (Frey and Linke, 2002). While the initiatives taken regionally had many positive effects, it soon became evident that there were global environmental issues that needed to be addressed as well.

A significant event to the SD movement was the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in 1992, when the United Nations Framework Convention on Climate Change (UNFCCC) was proposed, seeking to stabilize atmospheric concentrations of greenhouse gases at considered safe levels. In 1997, the 3rd Conference of the Parties (COP) to the UNFCCC resulted in the Kyoto Protocol, a multilateral environmental agreement (MEA) aiming to curb worldwide emissions.

Energy policy came to the fore with the oil crisis of the 1970s, bringing about considerable concerns over security of energy supply, environmental issues, competitiveness of economies and regional development. Before then, governments had largely paid attention to electrification and created large integrated monopolies that generated, transmitted and distributed electricity. In most countries in Western Europe governments were engaged in nuclear power development. In some countries governments also involved themselves in the supply of oil, coal and/or natural gas. Renewable energy sources, with the exception of hydropower in countries having significant hydropower potential, attracted very little interest (Johansson et al., 2004). With the crisis, research, development and deployment of renewable energy had flourishing years, until the relative political stability in the Middle East reduced international oil prices, making it difficult for renewable energies to compete in the market. There were exceptions, such as hydropower, an already mature technology. Other renewables, such as biomass, solar and wind, evolved considerably during the crisis, with reducing costs and significant environmental advantages over non-renewable technologies that provided the basis for a new growth after the late 1990´s (Frey and Linke, 2002). Practical experience has shown that support for renewable energy technology development is a way to build a competitive industry that will have a global market, as alternatives to conventional energy sources are increasingly sought.

Energy for sustainable development has three major pillars: (1) more efficient use of energy, especially at the point of end-use, (2) increased utilization of renewable energy, and (3) accelerated development and deployment of new and more efficient energy technologies (Johansson et al., 2004). The 9th Session of the CSD, held 16–27 April 2001 in New York, was the first time energy was addressed in an integrated way within the United Nations system. The conclusions of CSD9 are particularly important because they formed much of the basis for the UN World Summit on Sustainable Development (WSSD, also known as “Rio+10) negotiations in Johannesburg, 2002 (Johansson et al., 2004). Energy was probably the most intensely debated subject at the WSSD. Proposals were made at WSSD to adopt a global target for renewable energy, increasing the share to 10% by 2010. Although no agreement was reached, the final text recognized the importance of targets and timetables for renewables (Johannesburg Plan of Implementation, paragraph 19) a text that significantly advanced the attention given to energy in the context of sustainable development. Setting a target for renewable energy was one of the most controversial issues during the WSSD. The fundamental issue was whether to set any global target at all. Energy continues to be a 'cross-cutting issue', with no dedicated institutional structure for energy within the UN system. Several voluntary energy initiatives (called "Type 2", contrasting with "Type 1" multilateral agreements) were launched at WSSD, but without the character of an international negotiating forum. Political leadership still does not exist on both energy access and cleaner energy. (Spalding-Fecher et al, 2005).

9.6.2 The importance of access to energy

Access to modern forms of energy, especially electricity for all purposes and clean fuels for cooking, heating and lighting to the 2 billion people without them -- and the additional 3 billion people projected to increase world population by 2020 -- is a major challenge in itself. Wide disparities within and among developing countries contribute to social instability and affects basic human development. Making the joint achievement of promoting access while simultaneously making a transition to a cleaner and secure energy future is a challenging task. Key policy areas to be addressed include the impact of energy reform programmes (including private sector investment) on the poor, the excessive focus on upstream investment and large-scale fossil energy supply projects, the lack of appropriate institutional structures to support international energy and development programmes, research and development not being sufficiently relevant to policy, and the lack of funding to support major infrastructure investments. Energy sector reform, particularly in the electricity sector, has become a priority of the multilateral institutions involved in energy and development, and is having a profound impact on access (Johansson et al., 2004 and Spalding-Fecher et al, 2005).

Energy services can play a variety of direct and indirect roles in helping to achieve the millennium development goals (MDGs), in order to halve extreme poverty; to reduce hunger and improve access to safe drinking water; to reduce child and maternal mortality and to reduce diseases; to achieve universal primary education and to promote gender equality and empowerment of women and to ensure environmental sustainability. Access to energy services facilitates economic development -- micro-enterprise, livelihood activities beyond daylight hours, locally-owned businesses, which will create employment – and assists in bridging the ''digital divide''. Energy services can improve access to pumped drinking water -- clean water and cooked food reduce hunger (95 % of food needs cooking). Energy is a key component of a functioning health system, for example, operating theatres, refrigeration of vaccines and other medicines, lighting, sterile equipment and transport to health clinics. Energy services reduce the time spent by women and children (especially girls) on basic survival activities (gathering firewood, fetching water, cooking, etc.). Lighting permits home study, increases security and enables the use of educational media and communications in schools (including information and communication technologies, or ICTs). Improved energy services help to reduce emissions, protecting the local and global environment. Moreover, efficient use of energy sources and good management can help to achieve sustainable use of natural resources and reduce deforestation (Goldemberg, 2002).

9.6.3 Sustainable renewables

From the policy perspective, the main attractions of renewable energy are their security of supply, and the fact that they are environmentally relatively benign compared to fossil fuels. Most forms of renewable energy, such as hydro, wind, solar and biomass, are available within the borders of one country and or not subject to disruption by international political events. Central and State

Governments in many countries have enacted laws and regulations to promote renewable energy and to encourage sustainable technologies. In doing so, they had to define what they meant by ‘‘renewable’’ and ‘‘sustainable’’, and they had to decide which particular technologies or organizations would be eligible for subsidies and tax concessions, and which others would be excluded. Not infrequently, a considerable amount of lobbying would precede the passage of such laws and regulations, and the resulting definitions of ‘‘renewable’’ and ‘‘sustainable’’ are often different than their original meaning (Frey and Linke, 2002). According to Spalding-Fecher et al (2005), at CSD9 in 2001 a strong fault-line arose around the national recommendations, either favoring the term ‘‘sustainable energy’’ (more prescriptive) or ‘‘energy for sustainable development’’, addressing particularly the need to bring access to energy to more people and to use locally available energy resources). The questions of renewable and sustainable energy have their roots in two distinct issues: while renewability is a response to concerns about the depletion of primary energy sources (such as fossil fuels), sustainability is a response to environmental degradation of the planet and leaving a legacy to future generations of a reduced quality of life. Both issues now figure prominently on the political agendas of all levels of government and international relations (Frey and Linke, 2002).

Renewable energy technologies are ones that consume primary energy resources that are not subject to depletion. Non-consumptive renewable technologies include solar power and wind power. Included in the family of renewable energy technologies are hydropower (considering water supplies replenished in the hydrologic cycle), geothermal (an abundant resource) and biomass (when capable of replenishing itself rapidly). Able to provide cost-effective and environmentally beneficial alternatives, the attributes of renewable energy technologies (e.g. straightforward implementation, modularity, flexibility, low operating costs, local availability, security of long-term supply) differ considerably from those for traditional, fossil fuel-based energy technologies (e.g., large capital investments, long implementation lead times, operating cost uncertainties regarding future fuel costs). Renewable energy resources have also some problematic but often solvable technical and economic challenges, like being generally diffuse, not fully accessible, sometimes intermittent and regionally variable. The overall benefits of renewable energy technologies are often fully assessed, leading to such technologies often being assessed as less cost-effective than the traditional ones. Renewables may cause local impacts which give rise to concerns and opposition to the development. The risk of public opposition increases if the benefits of the proposed development are not clear to the local people. That is further fuelled by uncertainties, lack of information and media amplification. The provisions of capital grants and regulatory reforms alone are not sufficient to make such energy development successful (Upreti and van der Horst, 2004).

To weigh the positive effects against the negative ones can be a lengthy and complex task. For example, there are many laws or regulations which define ‘‘small hydro’’ as renewable and sustainable, whereas ‘‘large hydro’’ is labeled by some of the legislators as being either not renewable or not sustainable. To further complicate matters, the definition of ‘‘small hydro’’ varies widely from jurisdiction to jurisdiction, from as little as 1MW capacity to as much as 100MW capacity. It has become apparent to policy makers that large hydro projects can attract opposition and become controversial, whereas smaller ones usually do not. An expedient way out of the controversy was to define small hydropower as being renewable, and eligible for government support, and excluding large hydropower from subsidies or other incentive measures. Some organizations opposed to hydropower call for a moratorium on the construction of new dams, or the decommissioning of some dams which interfere with salmon migration, or even the decommissioning of many more dams for a variety of environmental reasons. Eliminating these facilities will not reduce power demand, since most of the world electric energy comes from thermal, nonrenewable and in the majority unsustainable resources. The question for policy makers and decision-makers of this generation is whether the impacts created by this hydropower facility are a reasonable tradeoff for the benefits generated according to the current value system and importance attached to both the positive and negative effects. (Frey and Linke, 2002).

The demand for bioenergy is growing due to the climate policies of various countries that search for cost-effective strategies for the reduction of greenhouse gas emissions. Trade of biomass-related products changed the traditional view that such fuels should be used in the region where it was produced due to high transport costs and limited availability. This happened in northern Europe in the 1990s with the introduction of biomass in district heating. There are different reasons for international biomass trade, but the most important drivers are the lower prices (nowadays also true when sea transport is included) and enhanced supply security. Energy balances and subsequent greenhouse gas balances show that international bioenergy trade is possible against a modest energy loss. Bioenergy exporting countries benefit from trade, in terms of market access and enhanced socio-economic development. However, concerns arise on the potential negative impacts of the rising bioenergy related activities, e.g. competition with food production; deforestation or high input of agrochemicals; increased water use and many other indirect effects. Criteria and tools are searched for that help to avoid that biomass, unsustainably produced, is sold as a sustainable resource. Previous experiences in the forestry (since 1993) and agricultural (since 1991) sectors are useful tools containing sustainability criteria, indicators for sustainable development and indicators to assess the sustainability of projects (Lewandowski and Faaij, 2006).

9.6.4 Assessment tools and policy implications

Tools for environmental impact and sustainability include: (i) life cycle assessment (LCA), to assess the environmental burden of products (goods and services) at the various stages in a product's life cycle (''from cradle-to-grave'); (ii) environmental impact assessment (EIA), assessing the potential environmental impact of a proposed activity, assisting a decision making process; (iii) ecological footprints analysis, an estimation of resource consumption and waste assimilation requirements of a defined human population or economy in terms of corresponding productive land use; (iv) sustainable process index (SPI), measuring a process producing goods in terms of total land area required to provide raw materials, process energy (solar derived), infrastructure and production facility and disposal of wastes; (v) material flux analysis (MFA), an accounting tool to track the movement of elements of concern through a specified system boundary; (vi) risk assessment, to estimate potential impacts and the degree of uncertainty in both the impact and the likelihood it will occur; (vii) exergy, analysis of the quality of a flow of energy or matter, estimating its useful part. Energy potential surveys and studies have a useful role in promoting renewables. Existing energy utilities are important to determining the adoption and contribution of renewable energy technologies and their integration to the system. The importance of effective information exchange, education and training programs lie in the fact that the use of renewable energy often involves awareness of perceived needs and sometimes a change of lifestyle and design. Energy research, technology transfer and development, together with demonstration projects, improve information and raise public awareness, stimulating a renewable energy market. Financial incentives reduce up-front investment commitments and encourage design innovation (Dincer and Rosen, 2005).

9.6.5 Sustainability criteria for the Clean Development Mechanism

Under the Kyoto Protocol, host countries for the Clean Development Mechanism decide whether a project meets its sustainable development needs. Criteria and indicators can be based on previously agreed principles or obligations, such as the Millennium Development Goals or the nationally-prepared Poverty Reduction Strategy Papers. Limitations of comprehensive approaches are the complexity, site and project specificities difficult to the international policy community establishing cross-country frameworks comparability. The CDM Executive Board agreed to consider a recommendation on documentation regarding the written approval of voluntary participation from the designated national authority of each Party involved, including confirmation by the host Party that the project activity assists it in achieving sustainable development (Decision EB 12). This confirmation would have the form of a statement issued by the designated national authority (DNA) of a Host Party involved in a proposed CDM project activity (Decision EB 16). Revision to the crediting period must not alter the project's contribution to sustainable development (Decision EB 24). The statement has a form of a letter of approval (Decision EB 25). Developing countries, especially those in sub-Saharan Africa, should to improve their level of participation in the CDM, further promoting sustainable development, mitigation of climate change and poverty alleviation (Decision EB 35). Renewable energy policies may establish mandatory targets, which can conflict with the additionality criteria of CDM projects; nevertheless Decision EB 16 states that national and/or sectoral policies or regulations that give positive comparative advantages to less emissions-intensive technologies over more emissions-intensive technologies (e.g. public subsidies to promote the diffusion of renewable energy or to finance energy efficiency programs) that have been implemented since 11 November 2001 may not be taken into account in developing a baseline scenario (i.e. the baseline scenario should refer to a hypothetical situation without the national and/or sectoral policies or regulations being in place). This is clarified by Decision EB 22, by which a baseline scenario shall be established taking into account relevant national and/or sectoral policies and circumstances, such as sectoral reform initiatives, local fuel availability, power sector expansion plans, and the economic situation in the project sector. As a general principle, national and/or sectoral policies and circumstances are to be taken into account on the establishment of a baseline scenario, without creating perverse incentives that may impact host Parties' contributions to the ultimate objective of the Convention..

9.6.6 Sustainable energy policies in the developing and in the developed world

The world's primary energy system was in 2004 at least a 1.5 trillion dollars per year market dominated by fossil fuels, subsidized with over $US 240 billion per year. Subsidies comprise all measures that keep prices for consumers below market level or keep prices for producers above market level or that reduce costs for consumers and producers by giving direct or indirect support, in a wide variety of public interventions not directly visible but is hidden in public and economic structures. Policies that aim to promote the instigation of renewables, but fail to deliver a reliable and economically beneficial supply in the long-term, fail to contribute to the concept of sustainability. To change this situation, solutions encompass extending the life of fossil fuel reserves and expanding the share of renewable in the world energy system through top down and bottom up policies. The best example of a top down approach is the Kyoto Protocol, which established mandatory targets for countries for the reduction of greenhouse gas emissions. Renewable Portfolio Standards (RPS) represent bottom-up approaches at regional or country level, policies that States may use to remove market barriers to renewable energy. In their simplest form, RPS specify shares from certain renewable energy sources (Goldemberg, 2006).

National renewable energy policies in South Africa, Egypt, Nigeria and Mali were analyzed by Bugaie (2006). Main constraints to access of other forms than fuelwood of energy in the rural areas are the high capital costs for electrical grid connection, installation and maintenance of appliances and limited distribution of petroleum fuels due to the poor or lack of private or public transport, as well as limited support services. Renewable energy resources, abundant in all the African countries, would provide a major breakthrough in finding a solution to this energy crisis. While South Africa and Egypt present very encouraging models of renewable energy harnessing and utilization, Mali provides a case study of urgency in addressing sustainable energy policy especially in view of the environmental degradation associated with the traditional energy use patterns. Nigeria is a case of abundance of resources - both conventional and renewable - but lack of infrastructural support to harness the renewable resources. South Africa seeks to increase significantly the share of renewable energy. Egypt has policies to develop and diffuse the application of solar (thermal and photovoltaic), wind and biomass energy technology in the local economy.

For large emerging economies energy choices and the related strategic policies are required at the earliest opportunity, to fulfill four key objectives: (1) to deliver the power needed for economic growth and sustainable development; (2) to ensure security of energy supply; (3) to ensure that energy supply and use are conducted in ways that safeguard public health and the environment; (4) to achieve an equitable distribution of energy services (Weidou and Johansson, 2004). In developed countries, there are examples of how sustainable development strategies constituted by a combination of savings, efficiency improvements and renewables can be implemented. Two major challenges are how to integrate a high share of intermittent resources into the energy system (especially the electricity supply) and how to include the transportation sector in the strategies. Reaching this stage of making sustainable energy strategies the issue is not only a matter of savings, efficiency improvements and renewables. It also becomes a matter of introducing and adding flexible energy technologies and designing integrated energy system solutions (Lund, 2007). Even if technology developments will reduce the specific consumption, the world energy demand is likely to increase in line with its population. Energy and material efficiency and the integration of the renewable resources will therefore have to play a major role for sustainable development. The challenge concerns not only the technologies at the conversion and useful energy level, but also the energy management and infrastructures. The Board of the Swiss Institutes of Technology suggests pathways to the 2000W per capita society (Marechal et al, 2005).

9.6.7 Existing RE-SD policies

The Organization for Economic Cooperation and Development, together with the International Energy Agency (OECD and IEA, 2008) have organized a dataset of existing renewable energy policies by country, describing issues related to sustainable development. Policies were classified by type (Regulatory Instruments; Financing; Incentives, subsidies; Education and Outreach; Policy Processes; Voluntary Agreement; RD & D; Tradable Permits; Public Investment), by target source (Bioenergy, Geothermal, Hydropower, Ocean, Solar, Multiple RE Sources) and sector (Electricity, Framework Policy, Heating & Cooling, Transport and Multi-sectoral Policy). Examples of such RE-SD policies in force in developing countries include: (i) biofuels promotion laws with Environmental Impact Assessment procedures (Argentina); (ii) promotion of best practices (through UK in several countries); (iii) mandatory solar stills for schools (Barbados); (iv) mini-grid projects (Brazil); (v) mandatory biofuels blending requirements (Brazil, Phillipines); (vi) solar in buildings (China, Fiji, Ghana, South Africa, Uganda); (v) subsidies to renewables in rural areas (China); (vi) efficiency improvements (Turkey) also with closure of inefficient facilities (China); (vii) feed-in tariffs (India); (ix) RE targets (Israel); (x) women empowerment (Mali); (xi) R&D (Russia, Singapore).

9.7 Gaps in Knowledge and Future Research Needs

As noted in the introductory section, there is a two-way relationship between sustainable development and renewables. Renewable sources can reduce emissions that will help to better manage the process of climatic change but this reduction may not be adequate to lower temperature increases to tolerable levels. Sustainable development pathways can help achieve these reductions by lowering the overall need for energy particularly fossil fuel supply. Pathways that improve energy access and infrastructure in rural areas for example can lead to less-carbon-intensive energy demand thus reducing the need for overall energy supply. Identifying, documenting and quantifying such pathways and their impact on renewables is a critical need.

A related important step is to identify non-climate policies that affect GHG emissions and sinks, and ways these could be modified to increase the role of renewable energy sources. Often such policies have to be context specific requiring research and analysis that is local or regional.

The current set of global models has rarely looked at development paths with non-climate policies. Development of such models requires a broader set of researchers with strong quantitative SD background who can help define and understand various development paths such as those described in Table 3. This applies to both industrialized and developing countries.

Renewables mitigation and adaptation capacity will be critical in the future as implementation of projects and programs begins to play an increasingly important and time-sensitive role. Limiting temperature increases to 2 degrees C for instance requires that global emissions peak within the next decade. Even if agreements are reached soon to limit global emissions, capacity building to implement renewable energy policies, programs and projects will be essential. Turning capacity into rapid action will require cooperation among all stakeholders.

Future research will need to examine the role of renewable energy and its implications on the pursuit of sustainable development goals. Several chapters in this report provide information on the implications of renewable energy sources on various SD attributes. These are noted in Table 1, which includes both quantitative and descriptive information about the impacts. Missing in the table is a complete understanding of the life-cycle analysis (LCA) of the implications of the use of renewable energy. The biofuels chapter contains the most information on this topic, but it correctly notes that methods, tools, and data sources aren’t of sufficient quality and comparability yet. Future work will need to focus on this important aspect of renewable energy, which has few and in some case virtual no direct GHG emissions but may have significant indirect emissions.

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