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Yellow highlighted – original chapter text to which comments are referenced

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Chapter 1 has been allocated a maximum of 34 (with a mean of 27) pages in the SRREN. The actual chapter length (excluding references & cover page) is 43 pages: a total of 9 pages over the maximum (16 over the mean, respectively).

Expert reviewers are kindly asked to indicate where the Chapter could be shortened by 10-17 pages in terms of text and/or figures and tables to reach the mean length.

Pending final approval by the IPCC Plenary section 1.6 on methodology (foreseen by the original outline) has been moved to the back of the whole report as Appendix II.

All monetary values provided in this document are adjusted for inflation/deflation and converted to USD for the base year 2005 or will be if not yet done so.

Errors in formatting, spelling etc. will be corrected in the publication phase of the report

Chapter 1: Overview of climate change and renewable energy

CONTENTS

EXECUTIVE SUMMARY

The IPCC Fourth Assessment Report showed that climate change due to human activity (emissions of greenhouse gases especially carbon dioxide from the use of fossil fuels) is accelerating and that global warming in this century may be significantly greater and the consequences more severe than previously realized. Many governments now advocate that to avoid the most dangerous climate change it will be necessary to hold temperature rises to less than about 2°C above pre-industrial values. The Assessment Report indicates that to achieve this goal will require global greenhouse gas emissions to be 50% to 80% lower in 2050 than in 2000, and to begin declining by 2015. Renewable energy (RE) in combination with major changes in the end use of energy, including increasing efficiency and changing consumption patterns, is one of the solutions that enable reducing CO_2 output while maintaining energy services and economic growth. This Special Report on Renewable Energy (SRREN) explores the potential for renewable energy sources to meet goals for reduction of greenhouse gas emissions. It includes assessments of resources, technologies, integration requirements, future energy scenarios, costs and benefits, barriers and policy options.

The theoretical potential for renewable energy exceeds current and projected global energy demand by far, but the challenge is to capture and utilize it to provide the desired energy services in a cost effective manner. Various forms of RE are universally available, and can readily be introduced in both developed and developing countries. The technical potential exceeds the estimated 'business as usual' demand by a factor of 50 by 2050. Hence, there is no shortage of renewable energy supply to meet the demand, even when the only gains in end-use efficiency are endogenous ones rather than being policy driven. Substantial efficiency gains in the amount of heat, electricity and mechanical energy required to provide energy services benefit all forms of energy, but are especially important in matching the sometimes low and distributed energy density of renewable energy to end use energy services.

In 2008 the investment in new installations of RE systems by the electric power sector globally and in both the EU and the USA exceeded their investment in new coal and gas energy systems. RE is growing rapidly and in 2007 contributed about 18% of global energy use. Traditional use of biomass (firewood, dung and agricultural waste), much of which is both inefficient and ecologically unsustainable, accounts for 10% of global energy end-use and hydroelectricity (the most established RE technology) for 2.3%. (Note: these figures depend on the accounting conventions used for energy statistics, in ways discussed in this report.) Use of wind power and solar energy (PV) for electricity are both increasing rapidly from a low base.

The scenarios analyzed in this report indicates that with a combination of high market development for RE and a successfully implemented strategy for delivering energy services with higher efficiency, CO_2 could eventually be stabilized at 450 ppm by 2100. To be on this trajectory, RE would need to approximately double its current (2007) amount of primary energy, increasing from 64 EJ to about 133 EJ by 2030, and total primary energy would need to rise only slightly from 441 EJ in 2007 to 472 EJ (Chapter 10). The analysis also points to large uncertainties in such projections, including growth projections, development and deployment of higher efficiency technologies, the ability of RE technologies to overcome initial cost barriers, preferences, environmental considerations and other barriers. In this context it is important to consider the multi-step process whereby primary energy is converted into an energy carrier (heat, electricity or mechanical work), and then into an energy service. Doing so can help to identify the most cost effective, most energy efficient or least environmentally damaging strategy for meeting a particular energy service such as cooking, transportation, building heating, cooling or lighting or an industrial process.

To achieve the very large potential energy supply from RE requires a shift in development strategy in both developed and developing countries by systematically implementing policies on a wide scale that can overcome the economic, technical, institutional, and social barriers, which have limited the adoption of RE to date. Many of these policies are known and have already been attempted, but only on a limited economic or geographical scale.

Apart from climate change mitigation, renewable energy can play a significant role in meeting sustainable development goals in both developed and developing countries, not least by enhancing energy security and creating employment. In particular, use of modern energy services from renewable energy in developing counties can contribute to meeting Millennium Development Goals, e.g. by reducing smoke-related diseases especially for women and children, improving agriculture productivity, and developing micro-industries.

1.1 Background

1.1.1 Climate Change

The IPCC Fourth Assessment Report (AR4) expressed very high confidence (>90%) that the release of heat trapping greenhouse gases (GHGs) from human activities since 1750 has resulted in global warming. The global average temperature has been measured to increase by 0.76°C (± 0.2°C) between 1850-1899 and 2001-2005, and the warming trend has increased significantly over the last 50 years ((IPCC, 2007)). Although other GHGs contribute to this warming, CO_2 from fossil fuels accounts for some 60% of the radiative forcing from GHGs. By 2010 concentrations had increased from preindustrial levels of 280 ppm to 390 ppm and continue to increase ((NOAA, 2010)). Moreover, even if GHG concentrations were to be stabilised, warming due to human activity and the associated sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks **(**(IPCC, 2001)). Burning of fossil fuels is not the only source of GHGs. Notably, $CO_2$and some methane (another significant GHG) are released from coal mining, oil and gas production and natural gas transmission and distribution leaks. While this report focuses on the energy sector, forest clearing and burning and land use change as well as the release of non-CO_2 gases from industry, commerce and agriculture also contribute to global warming ((IPCC-WG1, 2007)).

IPCC (AR4, 2007) projected that global average temperature will rise over this century by between 1.1 and 6.4° C depending on socio-economic scenarios ((Nakicenovic & Swart, 2000)). The adverse impacts of such climate change (and the associated sea level rise) on water supply, ecosystems, food security, human health and coastal settlements were assessed by IPCC (AR4, 2007). The severity of the consequences of reaching irreversible tipping points in the climate system has led many governments to advocate limiting temperature rises to no more than 2°C, as is noted by the Copenhagen Accord of COP-15 in 2009.

It is the total concentration of GHGs in the atmosphere that directly affects the global temperature. Carbon dioxide concentrations are increasing in the atmosphere because emission rates from fossil fuels currently exceed the ability of natural sinks to absorb them (see Figure 1-1). Therefore the concentration of CO_2 in the atmosphere will continue to increase unless and until emissions decrease to less than the rate that they can be removed from the atmosphere by the natural sinks of the ocean and the terrestrial biosphere. Other GHGs such as nitrous oxide and industrial fluorinated gases are also rising. Methane concentrations are now more than double those of preindustrial levels, but their rise has slowed substantially in recent decades.

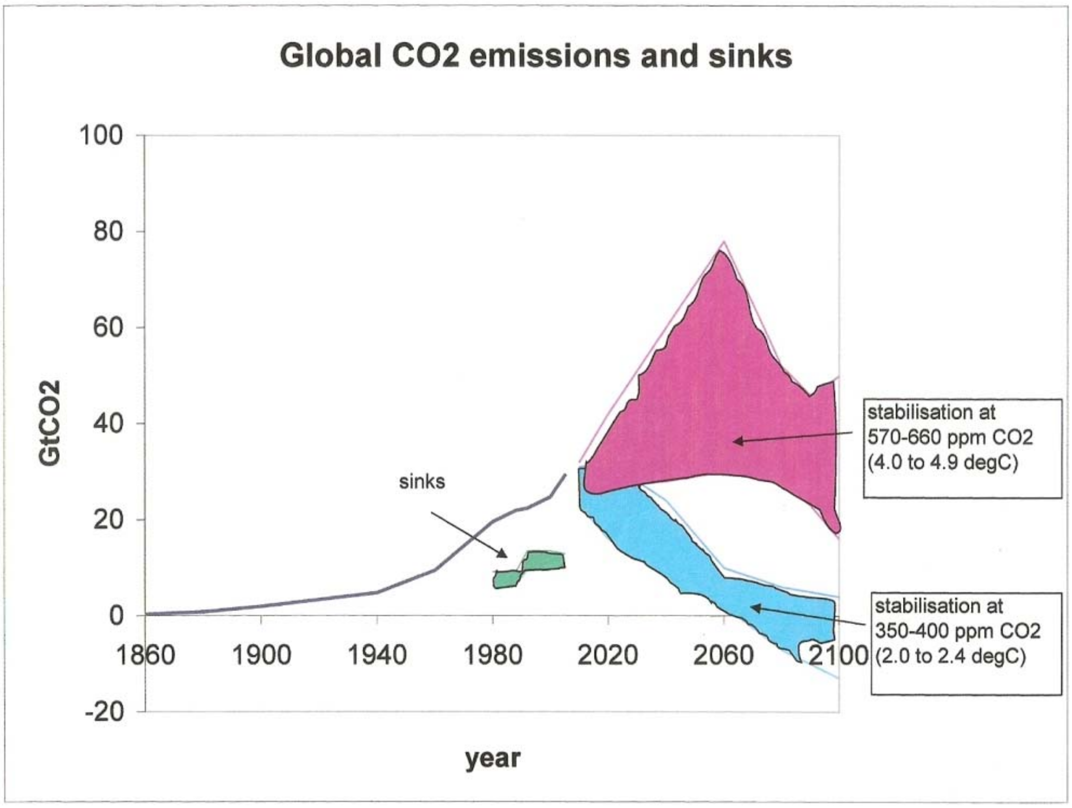

Figure 1.1. Global CO_2 emissions and sinks. Historical data is gross emissions from fossil fuels and cement from 1860 to 2000. ‘Sinks’ is measured difference between gross emissions and increase in tonnage of CO_2 in atmosphere; it includes both land and ocean components, is moderately uncertain (as indicated by the band) and may change over time, in response to the atmospheric CO_2 concentration and changes in climate. Projected emission bands to 2100 correspond to stabilisation of CO_2 *concentrations* at 570-660 ppm (upper band) and at 350-400 ppm (lower band). Width of bands reflects spread of modelled results in AR4. These bands correspond to 710-885 ppm CO_2-eq and 445-490 ppm CO_2-eq respectively, and to equilibrium global average temperature increases of 4.0-4.9^{o}C and 2.0-2.4^{o}C above preindustrial, assuming AR4 best estimate of ‘climate sensitivity’. Using the ‘likely’ range of climate sensitivity, the corresponding temperature ranges would be wider: 2.7-7.2^{o}C and 1.3-3.6^{o}C respectively. Note that approaching equilibrium can take several centuries, especially for scenarios with higher levels of concentrations. Diagram adapted from IPCC- Synthesis (2007) Figure SPM-11, using sinks data from IPCC AR4 WG1 Table TS-1 and historical emissions from the (GCP, 2009) and (Boden, Marland, & Andres, 2009).

If global emissions continue at their current or higher levels until 2100 (upper band of Figure 1.1), then global average temperature is projected to increase by 4 to 4.9°C. To limit the average temperature increase to less than 2.4°C above preindustrial levels requires emissions to decrease sufficiently to stabilise CO_2 concentration below 400 ppm (lower band of Figure 1). This in turn implies that global emissions will have to decrease by at least 50-80% below current levels by 2050 and begin to decrease (instead of their current increase) before year 2015. ((IPCC-Synthesis, 2007), Table SPM-6).

Analysis of the economic cost of damages from climate change and of the costs of mitigation to avoid those damages (notably by (Stern, 2006) and (IPCC-WG3, 2007)) has also influenced thinking concerning potential mitigation options. Chapter 10 of this report indicates some of the many issues in any analysis of mitigation costs. These include debates over appropriate discount rates and whether one utilizes a top down (usually more costly) or bottom up (usually less costly) analysis.

1.1.2 Factors increasing CO_2 emissions

Bioenergy (except for basic cooking, lighting and heating in developing countries) and other forms of early fortms of RE (except hydropower) were largely replaced by abundant coal, petroleum and natural gas during the 20th century. The rapid rise in fossil fuels has produced a corresponding rapid growth in CO_2. See Figures 1.1 and 1.2.

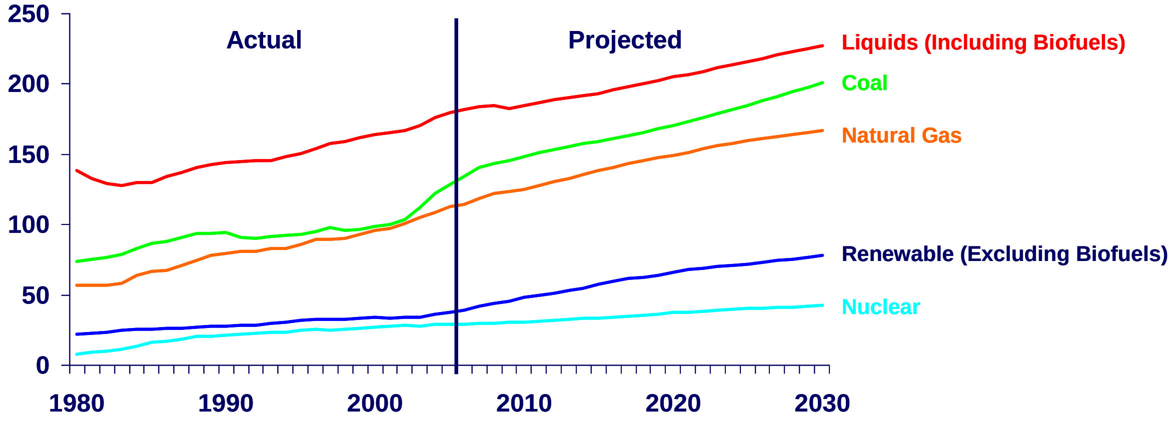

Figure 1.2 – Global Historical and Projected Marketed Energy Use by Fuel Type (EJ) 1980 to 2006. Projected marketed energy use by fuel from 2007-2030. ((IEA, 2009d)).

In developing strategies for reducing CO_2 emissions it is useful to use the Kaya identity that decomposes energy related CO_2 emissions into four factors: 1) Population, 2) GDP per capita, 3) energy intensity (i.e. total primary energy supply (TPES) per GDP) and 4) carbon intensity (i.e. CO_2 emissions per TPES) ((Ehrlich & Holdren, 1971); (Kaya, 1990)).

CO_2 = Population x (GDP/population) x (TPES/GDP) x (CO_2/TPES)

This is sometimes referred to as

CO_2 = Population x Affluence x Energy intensity x Carbon intensity

The absolute (a) and percentage (b) changes of global CO_2 emissions decomposed into the Kaya factors are shown in Figure 1.3, ((Edenhofer, Knopf, & al., 2010)).

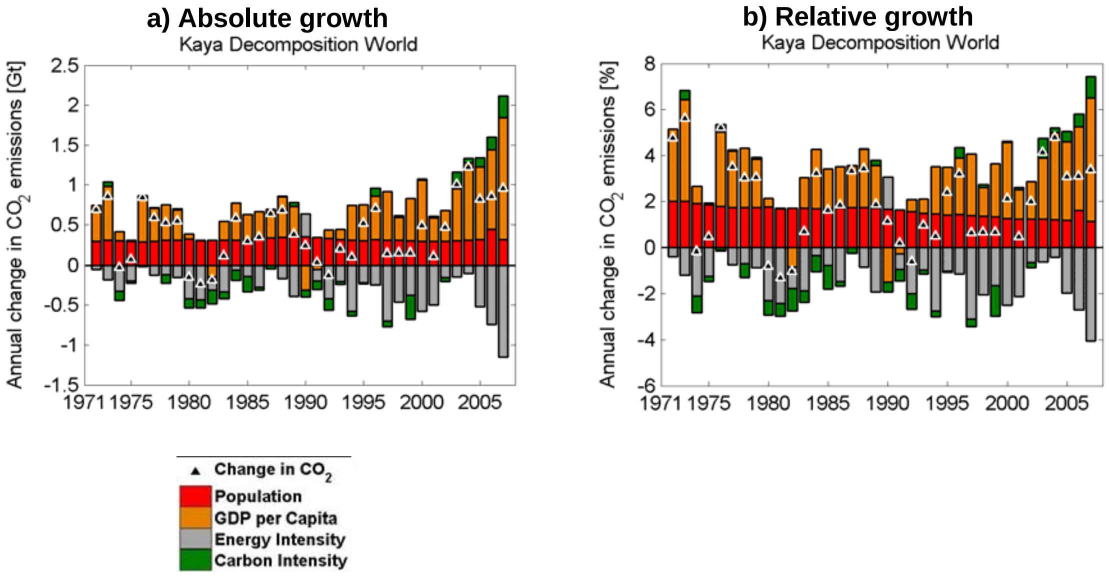

Figure 1.3: Kaya decomposition of global energy related CO2 emissions by population (red), GDP per capita (orange), energy intensity (grey) and carbon intensity (green) from 1971 to 2007. Total annual changes are indicated by a black triangle. Part (a) Absolute changes; Part (b) percentage changes. Data source: (IEA, 2009d)

While GDP per capita and population growth had the largest effect on emissions growth in earlier decades, decreasing energy intensity significantly slowed emissions growth in the period from 1971 to 2007. In the past, expansion of nuclear energy in the 1970s and 1980s, particularly driven by Annex I countries, caused carbon intensity to fall. In recent years (2000 – 2007), increases in carbon intensity have mainly been driven by the expansion of coal use by both developed and developing countries, although coal and petroleum use have fallen slightly since 2007. Since the early 2000s the energy supply has become more carbon intense, thereby amplifying the increase resulting from growth in GDP/capita.

In Figure 1.4 absolute emissions growth is examined on terms of different countries and country groups between 1971 and 2007. Historically developed countries have contributed the most to global emissions, but developing country annual emissions have risen to more than half of the total, and China surpassed the U.S. on annual emissions ((Edenhofer, et al., 2010)). Developed countries still have the highest total historical emissions and largest emissions per capita.

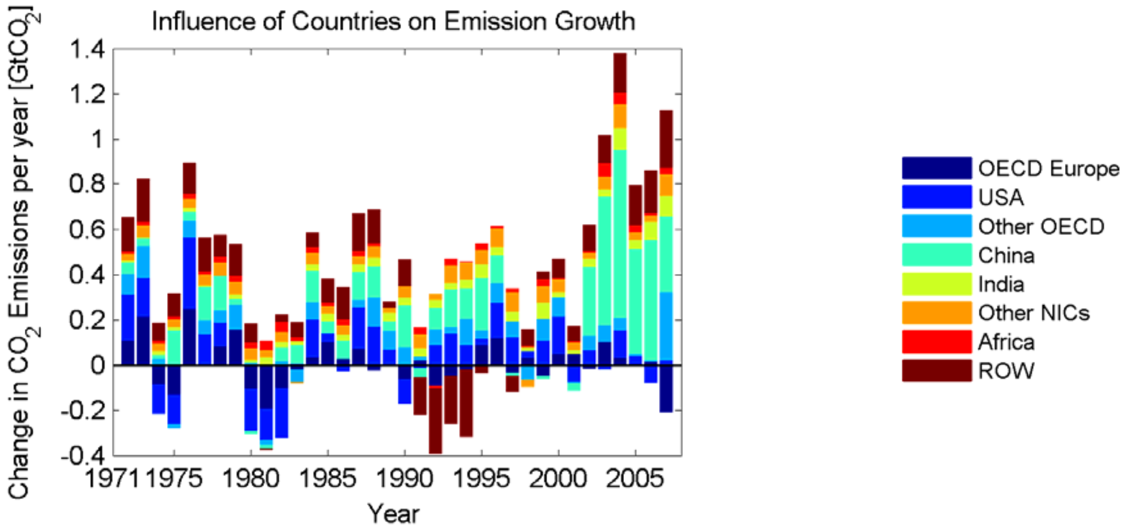

Figure 1.4: Emission growth decomposed by different countries/country groups. 'Other Newly Industrializing Countries' (NIC) includes Brazil, Indonesia, Mexico, South Africa and South Korea. Data source: (IEA, 2009c).

Shifting from carbon intensive fossil fuels to alternative low carbon sources can help to lower CO_2 emissions and avoid severe climate change. It will be essential for all countries, beginning with the most intensive energy users, to find ways to meet energy service needs with less energy and less carbon-intensive energy sources. This report explores the potential for low carbon RE sources in combination with increased energy efficiency to meet the GHG reduction goals set by policy makers to reduce the extent of future climate change.

1.1.3 What is Renewable Energy and what is its role in addressing climate change?

Renewable energy (RE) is any form of energy from geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. As long as the rate of extraction of this energy does not exceed the natural energy flow rate, then the resource can be utilized for the indefinite future, and may be considered as "inexhaustible." Not all energy classified as 'renewable' is necessarily inexhaustible; e.g. it is possible to utilize biomass at a greater rate than it can grow, or to draw heat from a geothermal field at a faster rate than heat flows can replenish it. By contrast, the rate of utilization of direct solar energy has no bearing on the rate at which it reaches the earth.

Most forms of RE produce little or no CO_2emissions, which makes them useful tools for addressing climate change. It is important to assess the entire life-cycle of each energy source to ensure that all of the dimensions of sustainability are met. For a RE resource to be *sustainable*, it must be inexhaustible and not damage the delivery of environmental goods and services including the climate system. For example, to be sustainable, biofuel production should not increase net CO_2emissions, should not adversely affect food security, or require excessive use of water and chemicals or threaten biodiversity To be sustainable, energy must also be economically affordable over the long term, it must meet societal needs and be compatible with social norms now and in the future. Indeed, as use of renewable energy technologies accelerates, a balance will have to be struck among the several dimensions of sustainable development.

Each RE technology has a specific set of associated environmental impacts, and the resource may be affected by climate change. These aspects are discussed in the 'technology' chapters of this report. The RE sources examined in this report are categorised as bioenergy (ch.2), direct solar energy (ch.3), geothermal (ch.4), hydropower (ch.5), ocean energy (ch.6) and wind energy (ch.7).

1.1.4 Why a special report on renewable energy

The IPCC Scoping Meeting on Renewable Energy Sources held in January 2008 in Lübeck, Germany, was convened to determine whether a special report was necessary, and what such a report might cover. The participants concluded that a Special Report would be appropriate for a number of reasons ((Hohmeyer, 2008)). First, RE technology is already being depolyed at a rapidly growing rate, and in combination with energy efficiency, is likely to contribute substantially to climate change mitigation by 2030 and has the potential to contribute a major portion of energy supply by 2100. Second, since the publication of the AR4, various stakeholders from governments, civil society and the private sector have asked for more information and more extensive coverage of renewable energy sources, particularly in regions where specific information was lacking. Consequently, this Special Report on Renewable Energy provides information for policy makers, the private sector and civil society on:

1. Identification of RE resource and available technologies by region and impacts of climate change on these resources;
2. Mitigation potential of RE sources;
3. Linkages between RE growth and co-benefits in achieving sustainable development by region;
4. Impacts on global, regional and national energy security;
5. Technology and market status, future developments and projected rates of deployment;
6. Options and constraints for integration into the energy supply system and other markets, including energy storage options;
7. Economic and environmental costs, benefits, risks and impacts of deployment;
8. Capacity building, technology transfer and financing in different regions;
9. Policy options, outcomes and conditions for effectiveness; and
10. Scenarios that demonstrate how accelerated deployment might be achieved in a sustainable manner.

1.1.5 Options for mitigation

Many studies suggest a strong correlation between economic growth and energy use, and since nearly 85% of global primary energy comes from fossil fuels, that economic growth is correlated with CO2 emissions as well. This has lead many to conclude that emissions are essential to development. There are however, a number of developed countries with very low emissions such as Norway that rely heavily on RE to supply energy services. Near term energy supply appears adequate to supply most energy services in most of the developed countries ((IEA, 2009d)).

In most developing countries, on the other hand, many people lack even basic energy services and especially those that are supplied by electricity. Since it is energy services and not energy that people need, it is possible to meet those needs in an efficient manner that requires less primary energy consumption with low carbon technologies that minimise CO2 emissions ((Haas, et al., 2008)).The long-term energy scenarios analysed in chapter 10 expect high growth rates of energy consumption in developing countries, so that energy supply with low energy and carbon intensities is indispensable to reducing CO2 emissions.

There are multiple means for lowering the heat trapping emissions from energy sources, while still providing energy services. RE and demand side energy efficiency work synergistically to lower the energy required to provide each end use energy service by lowering power density demands to match those of RE supply ((Pacala & Socolow, 2004); (IPCC, 2007)).

The following mitigation options related to energy supply are relevant:

- Shift to zero carbon primary RE sources such as solar, geothermal, hydropower, oceans and wind.
- Shift from coal, petroleum or natural gas to solid, liquid or gaseous biomass energy that is produced in a low-carbon emitting manner.
- Utilize combined heat and power technologies for thermal production of electric power from both fossil fuels and renewable energy sources.
- Switch from fossil fuels with high specific CO_2 emissions (especially coal) to fossil fuels with lower specific CO_2 emissions (especially natural gas) or to nuclear power.
- Utilize carbon capture and storage (CCS) technology to prevent fossil fuel combustion products from entering the atmosphere. CCS has the potential to remove carbon dioxide from the atmosphere when biofuels are burned.
- Reduce the release of black carbon particulates from diesel engines and other combustion sources and from the burning of biomass fuels.

The main mitigation options related to energy demand are as follows:

- Provide the same energy service with less energy. Energy savings of 50 to 80% have been identified for providing specific services in buildings, industrial processes and transportation throughout all economies (Weizsäcker, Club of Rome., & Natural Edge Project., 2009).
- Change consumer behaviours to use fewer carbon and energy-intensive products and services.

Alternative means of reducing GHGs include

- Utilize forests, soils and grassland sinks to absorb carbon dioxide from the atmosphere
- Reduce non-CO_2 heat trapping greenhouse gases (CH_4, N_2O, HFC, SF_6)

Geoengineer solutions

- Address other aspects of the heat balance of the earth such as increasing surface albedo, atmospheric light scattering or ocean fertilization to increase CO_2 absorption from the atmosphere.

The geo-engineering ‘solutions’ that are sometimes suggested to moderate climate change may address global warming, but leave untouched the unsustainable use of energy resources or the GHG emissions which are causing that problem. These efforts may also cause unanticipated biogeophysical and social problems. For example, deliberately releasing large quantities of sulphate aerosols into the atmosphere to reduce the amount of solar radiation reaching the Earth’s surface will not address the increasing acidification of the oceans by CO_2 or the growing air pollution and ozone in cities by the increasing number of motor cars on the road ((Robock, Marquardt, Kravitz, & Stenchikov, 2009); (RoyalSociety, 2009)).

This report focuses on substitution of low carbon, RE supply to reduce heat trapping carbon dioxide, and will examining the synergies between RE and energy end -use efficiency.

1.1.6 Role of renewable energy in addressing co-issues of climate change (energy security, employment, MDGs and sustainability goals)

Three major concerns about energy use motivate the consideration of RE: price, environmental impacts, development and energy security.

Despite the worldwide economic recession of 2008-2009, oil prices will likely continue to rise over the medium to long term with economic recovery in the absence of other market drivers ((IEA, 2009d)). Price volatility of petroleum and natural gas has created economic problems for most countries, and price spikes have been especially hard on poorer nations that must import their transportation fuels. Liquid biofuels and renewably generated electricity offer promise as potential alternatives for the transportation sector, and as a variety of RE sources are found throughout the world, countries can utilize locally available resources. A diversified and expanded supply of energy may act to lower the long-run price of all fuels and reduce price volatility benefitting all energy users ((Bartis, Camm, & Ortiz, 2008)). These benefits could accrue nationally even if one sector were to continue using fuels derived from conventional petroleum because of the displacement of other users of petroleum derived energy.

There are generally increased public and government expectations in all parts of the world for better environmental performance. The contribution to global GHG reductions as RE replaces non-sustainable energy sources is valued for this reason, but so too may be a reduction in local environmental impacts. Producing electricity with wind and PV solar require very little water compared to thermal conversion technologies. In addition, wind, PV, ocean and hydro technologies produce very little waste heat. Water demand for cooling thermal power generation is becoming a significant limitation for siting new thermal power stations including coal, biomass, gas, nuclear, solar concentrating power and geothermal, There have been necessary power reductions during drought conditions in the United States and France in recent years. Most renewable technologies produce lower conventional air and water pollutants than fossil fuels, but hydropower and biofuels require large amounts of land and water. See Figure 1.5. Chapter 9 of this report elaborates on many of the ways in which RE can contribute to sustainable development, in addition to mitigating climate change.

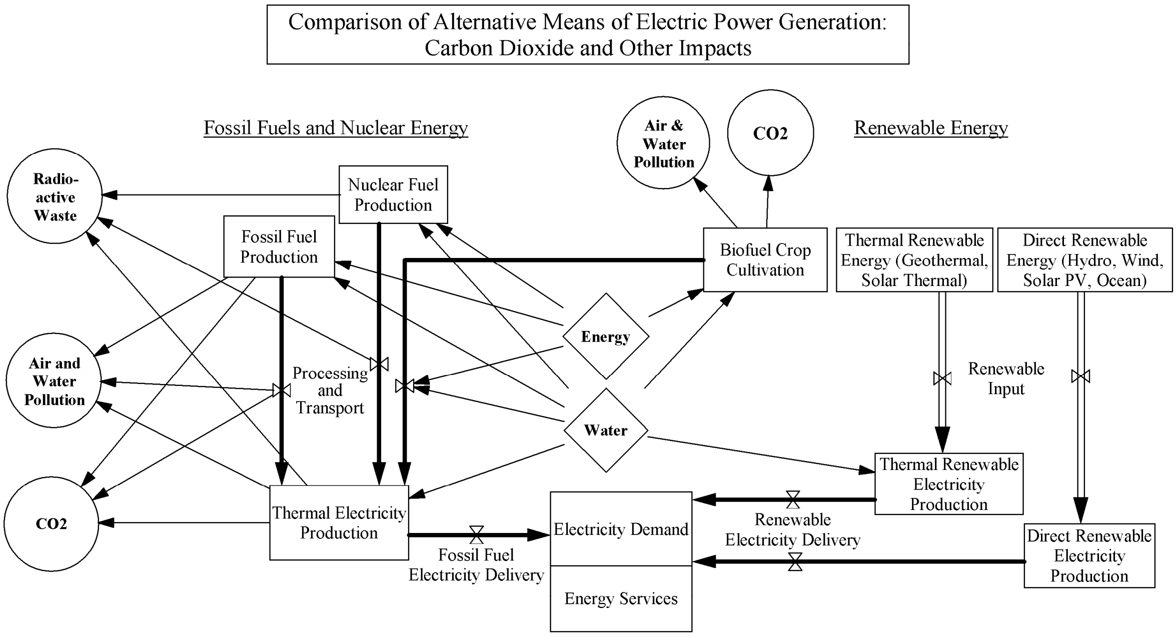

Figure 1.5. Comparison of co-benefits, water use and CO2 emissions associated with primary energy sources for electricity power generation. Not included are land impacts from surface mining of coal, land clearance for bioenergy and hydro reservoirs or methane leakage from coal natural gas and petroleum production and use, or damage from oil spills and coal ash storage. [TSU: Source? Legend?]

In developing countries, increasing the availability of energy services is central to sustainable development and poverty reduction efforts. It affects all aspects of development -- social, economic, and environmental -- including livelihoods, access to water, agricultural productivity, health, population levels, education, and gender-related issues. None of the *Millennium Development Goals* (MDGs) can be met without major improvement in the quality and quantity of energy services in developing countries. RE sources represent an important opportunity for developing countries, since access to energy is a key factor in combating poverty ((Cherian, 2007)). A large proportion of the population in these countries live in rural areas. The lack of transmission grids makes conventional energy supply challenging in such locations. The decentralised nature of some RE options offers the opportunity to provide a basic energy supplies through an off grid system ((BMU, 2008)). In this way, RE could provide access to modern energy services, particularly electricity, for a large number of people, which in turn improves living conditions and opportunities for economic development. For example, modern energy services can support MDG goal 1 of eradicating extreme poverty and hunger by freeing up household time from gathering firewood. This time can be reallocated to tending agricultural tasks, improving agriculture productivity and developing micro-industries to build assets, increase income, and financial well being of rural communities ((UNDP, 2006)). Production and utilisation of RE can also spur rural and economic development, providing opportunities for farmers and entrepreneurs to produce feedstocks for RE production and participate as owners of production facilities across all types of RE. Agriculture remains one of the most significant economic activities for large portions of the world. Hence renewable provides many rural economic development opportunities, ranging from improved energy access to industrial development, i.e., through wind power and biomass manufacturing and production facilities being located primarily in rural areas ((WIREC, 2008)). The opportunities culminate in improved income, job creation, and improved education, health care, distributive computing, telecommunications and public services. International energy assistance may provide a low-cost, effective opportunity to reduce future growth in greenhouse gas emissions and oil consumption before current development patterns become increasingly locked in throughout the developing world ((Hassell, et al., 2009)) Developing, installing and servicing RE resources and technologies is an effective creator of new employment in developed countries as well ((Wei, Patadia, & Kammen, 2010); (AIA, 2009); (BMU, 2009) **).**

National security concerns about the geopolitical availability of fuels has also been a major driver for many countries to consider RE. For example in the U.S, the military has led the effort to expand and diversify fuel supplies for aviation and cites improved energy supply security as the major driving force for sustainable alternative fuels ((Secretary of the Airforce, 2009 #71); (Hileman, et al., 2009); (USDoD, 2010)). Chapter 9 further expands upon the benefits of RE beyond climate impact mitigation and its role in sustainable development.

1.1.7 Trends in International Policy for RE

The international community's discussions of RE go back three decades to the fuel crises of the 1970s, when many countries began exploring alternative energy sources. Since then, various attempts have been made to ensure RE featured prominently in the United Nations agenda on environment and development through various initiatives and actions (WIREC, 2008), including:

1. 1981 UN Conference on New and Renewable Sources of Energy, which adopted the Nairobi Programme of Action; the 1992
2. UN Conference on Environment and Development (UNCED), Rio de Janeiro, Brazil, and Action Plan for implementing Sustainable development that addressed sustainable energy and protection of the atmosphere;
3. 2001 session of the UN commission on Sustainable Development through its decision "Energy for Sustainable Development", which highlighted the importance of RE;
4. 2002 World Summit on Sustainable Development (WSSD) in Johannesburg-South Africa, when several RE Partnerships were signed;
5. Bonn RE Conference 2004, which addressed best practices, research and policy development, energy services, and MDGs;
6. Beijing RE Conference (BIREC) 2005;
7. Washington RE Conference (WIREC) 2008.

These meetings all agreed on an evolving holistic view of energy for sustainable development which has three major pillars, as highlighted in Chapters 1, 9 and 11 of this report, namely the need for: (1) more efficient use of energy, in industrial applications, transportation, buildings and especially in the delivery of energy services at the point of end-use, (2) increased utilization of RE and low-carbon energy can reduce pollution and anthropogenic climate change in the short and long-term while having additional co-benefits of lower air and water pollution, and (3) accelerated research, development and deployment of new and more efficient energy technologies that offer

enhanced delivery of energy services can accelerate the introduction of energy efficient technologies and practices, RE and other low carbon emitting energy systems.
The International Energy Agency (IEA) has provided a forum for discussing energy issues among OECD industrialised countries. A new international organisation has also been established especially for RE in 2009 that currently has 143 member countries and the EU: the International RE Agency (IRENA).

1.2 Summary of RE resources

1.2.1 Resource advantages of RE

1.2.1.1 Wide distribution and low recurrent cost

Various forms of RE resources are far more uniformly distributed among all nations than are fossil fuels and uranium. Thus, from an energy security perspective, they are more available to more countries than other energy resources.

Primary energy for wind, solar, hydro, geothermal and ocean is free and it is delivered at no cost to the energy conversion technology. Furthermore, the capital costs for building the technology to extract and convert primary energy to a useful secondary form are known at the time of construction. Hence the price of delivered energy in the form of electricity, heat or mechanical energy is known with considerable certainty for the life of the project. Land based large-scale wind, hydro, geothermal and solar electric projects may require considerable investment in transmission infrastructure similar to that required for large central fossil and uranium fuelled power stations. Because population density is high along coastlines, offshore wind projects are relatively close to the demand, and require less extensive transmission systems. Distributed technologies such as rooftop solar PV deliver the electricity where it is made eliminating the need for transmission even when grid connected. For the world's poor who utilize wood, dung and crop residues for cooking and heating biofuels are available locally and can be gathered with their own labour with no market cost.

1.2.1.2 Scalability of RE technology

Some analyses conclude that only very large facilities such as nuclear power, large scale hydro or large coal plants with carbon capture and storage can be scaled up rapidly enough to meet CO_2 reduction goals ((MIT, 2003, 2007, 2009)). However, the rapid introduction of natural gas fired turbines during the past 20 years in North America and Europe demonstrates that modular scaling to produce sufficient modestly sized energy units can meet a large scale energy demand. This has important implications for RE.

Many renewable technologies such a solar PV, solar thermal, wind turbines and wave devices are modular in nature and can be readily and rapidly produced in conventional manufacturing facilities. This has the advantage of introducing additional production capacity in incremental amounts that more closely approximate the growth in demand rather than having to wait for the completion of very large, single power generation facilities. This lowers borrowing costs that have proven to be a major contribution to the costs of nuclear power plants. At current rates of production, it appears that wind, solar and biomass have all demonstrated that they can be manufactured at a rate that can meet growing demand. Wind and solar capacity production is currently doubling in three years or less, and the U.S. bioethanol program has achieved significant growth in three years to pass Brazil as the largest producer ((REN21, 2009a)).

1.2.2 Resource disadvantages of RE

Chapter 8 of this report discussses two issues in utilising RE for electric power:

- available for dispatch when needed. On the other hand, some RE resources are matched to Some renewable resources such as wind and solar are variable and may not always be demand such as solar electricity and air conditioning, and some energy services such as water pumping, purification or desalination can be provided whenever the energy source is available. Linked hybrid systems of multiple renewable sources significantly increase the capacity factor for the entire system, and this can be augmented with electric and thermal storage.
- The energy density of many renewable sources is relatively low, so that their power levels may be insufficient on their own for some purposes such as very large-scale industrial facilities. This is why providing end use energy services more efficiently is often a major factor in the utility of some renewable technologies. See chapter 8 for further discussion

1.2.3 Resource potential

The theoretical potential for RE is much greater than all of the energy that is used by all the economies on earth. The challenge is to capture it and utilize it to provide desired energy services in a cost effective manner. Estimated fluxes of RE and a comparison with fossil fuel reserves and 2007 annual comsuption of approximately 500 Exajoules/year are provided in Table 1.1.

Table 1.1: RE fluxes compared to annual energy use.

Renewable source	**Annual flux**	**Ratio** **Annual energy flux/ annual demand**	**Total reserve**
Solar	3,900,000 EJ/y*	8,700	- - -
Wind	6,000 EJ/y*	13	- - -
Hydro	149 EJ/y*	0.33	- - -
Bioenergy	2,900 EJ/y*	6.5	- - -
Ocean	7,400 EJ/y*	17	- - -
Geothermal	140,000,000 EJ/y*	31,000	- - -
Annual Primary energy source	**Annual Use**	**Lifetime of Proven Reserve**	**Total Reserve**
Total energy fossil fuel used/y	411 EJ/y**	111 years	46,700 EJ
Total Uranium used/y	10 EJ/y**	100 – 350 years	1,000- 3,500 EJ
Total RE used/y	61 EJ/y	- - -	- - -
Current Global Energy Use/y	482 EJ/y (2007)**	1	- - -

Sources: *IEA, World Energy Outlook 2000 and 2004, **IEA, 2009 converted to direct equivalent method (Appendix II), *** IEA, 2006.

The literature related to the technical potential supply of these RE types varies considerably (technology chapters contain details and references). Among other things, this variation exists in due to differences in calculation method, variant definitions of technical potential and variation due to differences between reviewers on how technologies and resource capture techniques may change over time. Table 1.2 provides an abbreviated list of the major resource types, associated technologies, the status of their development and the typical or primary distribution method (centralized network / grid required or decentralized, local standalone supply). Further details related to these technologies and types are provided in their respective chapters.

Table 1.2: Overview of Renewable Energy technologies and applications

Renewable Energy Source	**Select Renewable Energy Technologies**	**Energy Sector (Electricity, Thermal, Transport, Mechanical)**	**Technology Maturity***				**Primary Distribution Method****	
			R & D	**Demo & Pilot Proj**	**Early-Stage Com'l**	**Later-Stage Com'l**	**Centralized**	**Decentralized**
Bioenergy	Non-Commercial Use of Fuelwood/Charcoal	Thermal				X		X
	Cookstoves (Primitive and Advanced)	Thermal				X		X
	Domestic Heating Systems (pellet based)	Thermal				X		X
	Small- and Large-Scale Boilers	Thermal				X	X	X
	Digestion	Electricity/Thermal				X	X	X
	Combined Heat and Power (CHP)	Electricity/Thermal				X	X	X
	Co-firing in Fossil-Fuel Power Plant	Electricity				X	X	
	Combustion-based Power Plant	Electricity				X	X	X
	Gasification-based Power Plant	Electricity			X		X	X
	Sugar-Cane Ethanol Production	Transport				X	X	
	Corn Ethanol Production	Transport				X	X	
	Wheat Ethanol Production	Transport				X	X	
	Rapeseed Biodiesel Production	Transport				X	X	
	Palm Oil Biodiesel Production	Transport				X	X	
	Soy Biodiesel Production	Transport				X	X	
	Jathropha Biodiesel Production	Transport				X	X	
	Lignocellulose Ethanol Production	Transport			X		X	
	Lignocelluose Synfuel Production	Transport			X		X	
	Algae Fuel Production	Transport	X				X	
Direct Solar	Photovoltaic (PV)	Electricity				X	X	X
	Concentrating PV (CPV)	Electricity		X			X	
	Concentrating Solar Thermal (CSP)	Electricity			X		X	
	Low Temperature Solar Thermal	Thermal				X		X
	Solar Cooling	Thermal		X				X
	Passive Solar Architecture	Thermal				X		X
	Solar Cooking	Thermal			X			X
	Solar Fuels	Transport	X				X	X
Geothermal	Hydrothermal, Condensing Flash	Electricity				X	X	
	Hydrothermal, Binary Cycle	Electricity				X	X	
	Engineered Geothermal Systems (EGS)	Electricity		X			X	
	Submarine Geothermal	Electricity	X				X	
	Direct Use Applications	Thermal				X		X
	Geothermal Heat Pumps (GHP)	Thermal				X		X
Hydropower	Run-of-River	Electricity/Mechanical				X	X	X
	Reservoirs	Electricity				X	X	
	Pumped Storage	Electricity				X	X	
	Hydrokinetic Turbines	Electricity/Mechanical		X			X	X
Ocean Energy	Swell/Wave	Electricity		X			X	
	Tidal Rise and Fall	Electricity				X	X	
	Tidal Currents	Electricity		X			X	
	Ocean Currents	Electricity		X			X	
	Ocean Thermal Energy Conversion	Electricity/Thermal		X			X	
	Osmotic Power	Electricity		X			X	
	Marine Biomass Farming	Transport	X				X	
Wind Energy	On-shore, Large Turbines	Electricity				X	X	
	Off-shore, Large Turbines	Electricity			X		X	
	Distributed, Small Turbines	Electricity				X		X
	Turbines for Water Pumping / Other Mechanical	Mechanical				X		X
	Wind Kites and Sails	Transport		X				X
	Higher-Altitude Wind Generators	Electricity	X				X	

* The highest level of maturity within each technology category is identified in the table; less mature technologies exist within some technology categories.

** Centralized refers to energy supply that is distributed to end users through a network; decentralized refers to energy supply that is created onsite. Categorization is based on 'primary' distribution method, recognizing that virtually all technologies can, in some circumstances, be used in both a centralized and decentralised fashion.

[TSU: Source?]

We define technical potential as the *amount of RE output obtainable by full implementation of demonstrated and likely to develop technologies or practices.*[1] A recent publication, released by

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[1] The glossary provides a more comprehensive definition of this term.

the German Federal Ministry of the Environment (Krewitt, Nienhaus, Klessmann, Capone, & al., 2009) has surveyed many of the relevant articles and provided a consistent set of tables on the technical potential summarized in Table 1.3 below.[2] The range of technical potential, not defined in Table 1.3, is addressed both in (Krewitt, et al., 2009) and in each of the related chapters in this document. The table contains details on the sources for the higher and lower estimates.

Table 1.3: Technical potential for renewable energy (EJ/y).

	Energy	**Technical Resource Potential (EJ/y)**					***Sources for Range of Estimates[2]***
		Krewitt et al. (2009)[1]			**Range of Estimates**		
		2020	*2030*	*2050*	*Low*	*High*	
Electric Power (EJ/y)	Solar PV[3]	1,126	1,351	1,689	1,338	14,766	(Krewitt, et al., 2009); Chapter 3 reports total range of solar electric potential (PV and CSP) of 1440 to 50,400 EJ/y
	Solar CSP[3]	5,156	6,187	8,043	248	10,603	(Krewitt, et al., 2009); Chapter 3 reports total range of solar electric potential (PV and CSP) of 1440 to 50,400 EJ/y
	Geothermal	5	18	45	1	144	(Krewitt, et al., 2009)
	Hydropower	48	49	50	45	52	(Krewitt, et al., 2009)
	Ocean	66	166	331	330	331	(Krewitt, et al., 2009)
	Wind On-shore	362	369	379	70	1,000	Chapter 7: low estimate from (WEC, 1994), high estimate from (WBGU, 2004) and includes off-shore
	Wind Off-shore	26	36	57	15	130	Chapter 7: low estimate from (Fellows, 2000), high estimate from (Leutz, Ackermann, Suziki, Akisawa, & Kashiwagi, 2001)
Heat (EJ/y)	Solar	113	117	123	na	na	(Krewitt, et al., 2009)
	Geothermal	104	312	1,040	4	12,590	(Krewitt, et al., 2009)
Primary Energy (EJ/y)[4]	Biomass Energy Crops[5]	43	61	96	49	260	Chapter 2 (higher quality lands): large number of studies and several recent assessments, e.g., (Dornburg, van Vuuren, van de Ven, Leangeveld, & al., 2010)
					10	70	Chapter 2 (marginal/degraded lands): large number of studies and several recent assessments, e.g., (Dornburg, et al., 2010)
	Biomass Residues	59	68	88	100	200	Chapter 2: large number of studies and several recent assessments, e.g., (Dornburg, et al., 2010)
IEA Forecast (EJ/y)[6]	BAU Primary Energy	605	703	868[7]			
	450ppm Scenario	586	601				

1. Technical potential estimates for 2020, 2030, and 2050 are based on a review of studies in (Krewitt, et al., 2009); data presented in Chapters 2-7 may disagree with these figures due to differing methodologies.
2. Range of estimates comes from studies reviewed by (Krewitt, et al., 2009)as revised based on data presented in Chapters 2-7.
3. Estimates for PV and CSP from (Krewitt, et al., 2009) for 2020, 2030, and 2050 are based on different data and methodologies, which tend to significantly understate the technical potential for PV relative to CSP.

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[2] The definition of technical potential in Krewitt, *et al.* (2009), p. 75 is similar to the definition here in that it is bounded by local / geographical availability and technological limitations associated with conversion efficiencies and the capture and transfer of the energy.

4. Primary energy from biomass could be used to meet electricity, thermal, or transportation needs, all with a conversion loss from primary energy ranging from roughly 20% to 80%.
5. Even the high-end estimates presented here take into account key limitations with respect to food demand, water availability, biodiversity and land quality.
6. IEA (2009)
7. DLR (2008)

The table provides a perspective for the reader to understand the relative sizes of the RE resources in the context of demand for energy in the future. Both the technical potentials and future demand are highly uncertain; further refinement of the values adds little to the discussion. Issues related to technology evolution, sustainability, resource availability, land use and other factors that relate to this potential are explored in the various chapters. Analysis related to the technical potentials as defined in Table 1.3 and their impact on climate change are addressed in chapter 10.

Note also that one cannot necessarily add the various types of energy together to estimate a total. For example, one cannot assume that the total electric power available is the sum of those represented in the “Electric Power” section because each type was estimated independently of the others and, as such, there may be overlap or double counting (i.e., the assessment did not take into account land use allocation; one cannot have both PV and CSP occupying the same space even though a particular site was suitable for either of them).

While the resource is obviously large and could theoretically supply all energy needs long into the future, cost issues place further constraints on the exploitation of these resources. Table 1.4 provides data related to costs associated with the various technologies. Cost data were gathered from a variety of sources in the available literature; details can be found in respective chapters and a data table defining costs can be found in appendix III. All costs were assessed using standard discounting analysis at 3%, 7% and 10% as described in the appendix on methodology. The following default assumptions were made to define the Levelized Cost of Energy (LCOE) if data were unavailable:

- time of construction - one year, no production during that year
- O&M costs - constant over lifetime
- production - start after commissioning at (nameplate capacity x Capacity Factor)
- lifetime - excludes years of construction
- retrofit or other major costs during regular lifetime -assumed to be included as annuity in O&M costs, i.e., constant costs after construction
- decommissioning - costs not included in LCOE
- Lower bound = lower bound of capital and O&M cost, higher bound of capacity factor (CF) and lifetime
- Higher bound = higher bound of capital and O&M cost, lower bound of CF and lifetime

Table 1.4: Levelized Cost of Energy (2005 US$/kWh)

Source	**RE technology**	**LCOE at 3%**		**LCOE at 7%**		**LCOE at 10%**		**Learning Rate (%)**	
		lower bound	***higher bound***	***lower bound***	***higher bound***	***lower bound***	***higher bound***	***lower bound***	***higher bound***
Direct Solar Energy	**PV, res roof**	0.20	0.50	0.31	0.69	0.40	0.85	11	19
	PV, com roof	0.17	0.46	0.26	0.64	0.34	0.79	11	19
	PV, fixed tilt	0.11	0.25	0.17	0.34	0.22	0.42	11	19
	PV, 1-axis	0.10	0.28	0.15	0.38	0.19	0.47	11	19

	CSP	0.11	0.19	0.16	0.25	0.20	0.31	2	15
Geothermal Energy	**Condensing-flash**	0.03	0.08	0.04	0.11	0.04	0.13		
	Binary-cycle	0.03	0.11	0.04	0.14	0.05	0.17		
	Enhanced Geo Sys								
Hydro		0.01	0.06	0.02	0.08	0.02	0.11		
Ocean Energy	**Wave Energy**								
	Tidal Current								
	OTEC								
	Salinity Gradient								
Wind Energy	**On-shore, Large**	0.04	0.09	0.04	0.13	0.05	0.15	10	17
	Off-shore, Large	0.07	0.12	0.10	0.16	0.12	0.20		

Source: Various chapters provide cost details and a summary is provided in appendix III. Biomass is excluded due to high variation in costs; for details, see Chapter 2.

These costs are based on the most recent information available in the literature; some documentation exists for the rate at which the costs might come down in the future based on a doubling of the production of the technology. The final columns in Table 1.4 provide this Learning Rate for the technologies where such information was available.

Data on biomass sourced energy show great variation in costs based on local conditions, biomass supply and other factors. That said, there are significant uncertainties surrounding the costs in Table 1.4 and, as with technical potential, the data are meant to provide context for comparison. In viewing the table, one needs also to consider other factors that have an impact on the final cost of the electricity to the consumer: typical capacities, dispatchability, socio-economic conditions, grid requirements, capacity factor variations, etc. These too are addressed in the various chapters.

1.3 Current Status of RE in Meeting Energy Service Needs

1.3.1 Energy Flows and Metrics

1.3.1.1 Energy pathways from source to end-use

In a typical energy system, consumers (the demand side) wish to receive specific services provided by the energy delivered to them by producers (supply side). Energy sources typically require transformation into secondary energy carriers, which then deliver energy to the point of end use. Energy is then transformed by appropriate technologies to provide the service demanded. RE sources can serve as a primary energy supply.

To meet a requirement for an energy service (e.g., lighting) a primary [renewable] energy source (e.g., geothermal energy) is transformed into a secondary energy carrier (e.g., electricity) that can be transformed again into a form (e.g., light) that performs the desired service. Such an end-use is often attributed to one of the four end-use sectors (buildings, transportation, industry, agriculture).

Economies are driven by energy. Over 80% of primary energy comes from the combustion of fossil fuels, which are the source of 60% of GHGs ((IPCC, 2007)). Hydropower, nuclear energy and a portfolio of renewable sources provide the remainder of non-CO_2 emitting energy. To maintain both a sustainable economy that is capable of providing essential goods and services to the citizens of both developed and developing countries, and to maintain a supportive global climate system requires a major shift in how energy is supplied and utilized. There is a multi-step process whereby primary energy is converted into an energy carrier (heat, electricity or mechanical work), and then into an energy service. This is illustrated in Figure 1.6.

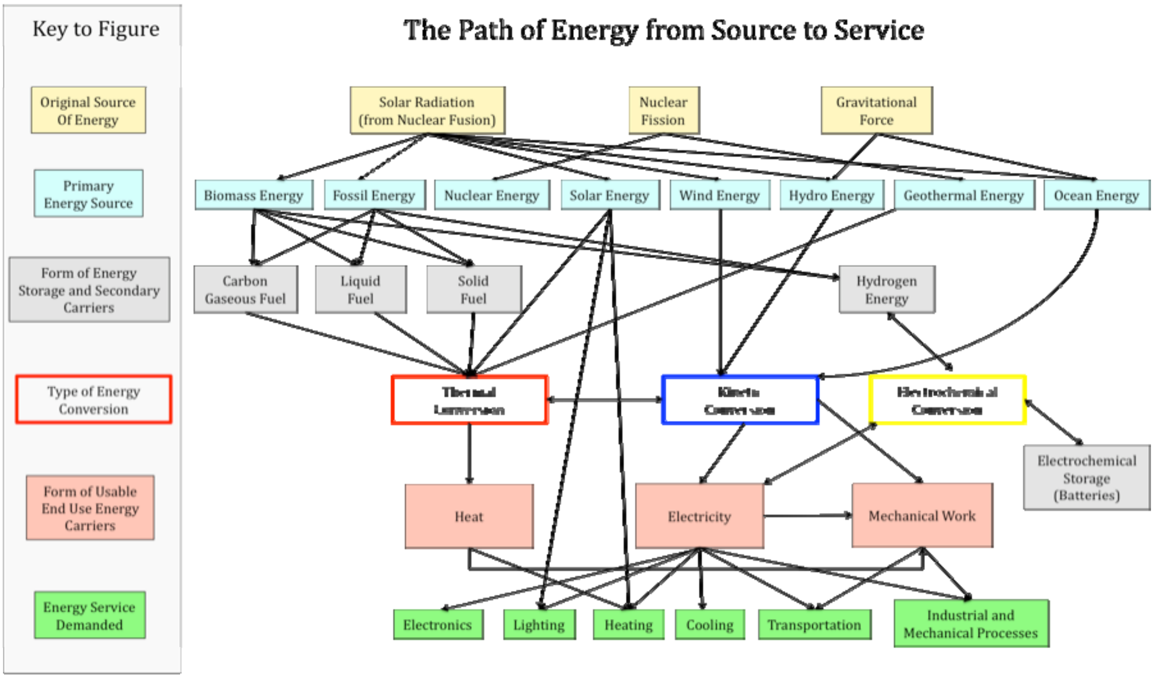

Figure 1.6. The Path of Energy from Source to Service. The Energy services delivered to the users can be provided with differing amounts of end use energy. This in turn can be provided with more or less primary energy from different sources, and with differing emissions of CO2 and other environmental impacts. [TSU: Source?]

Thermal conversion processes to produce electricity (including from biomass and geothermal) suffer losses of approximately 50-90% and losses of around 80% to supply the mechanical energy needed for transport. These conversion losses raise the share of primary energy from fossil fuels, and the wasted heat from fossil fuel combustion is the primary source of CO_2 ((LLNL, 2009); (Sterner, 2009)). Direct energy conversions from solar, hydro, ocean and wind energy to electricity do not suffer these thermal losses. Hence primary energy requirements are much smaller for these forms of RE than for fossil fuel, biomass combustion or for nuclear power. Stored solar heat in the ground, water and air may be efficiently captured utilizing heat pumps, which will not produce CO_2 emissions if powered by a RE source such as wind or solar. Solar direct heating and day lighting are also direct energy transfers without conversion losses, and direct heating from geothermal, biomass and solar thermal systems can also be highly efficient processes. By comparison, CCS requires substantial energy inputs, which would increase the demand for primary energy to supply the same amount of end use energy for energy services. It is important to recognize this when accounting for primary energy using different methodologies (Section 1.3.1.2)

Figure 1.6 can be used as an organizing tool for conducting a life cycle assessment (LCA) of specific energy options to meet alternative energy service needs in different end use sectors. It can help to identify where energy transformation losses and environmental impacts including GHG emissions occur. Similarly, Life Cycle Assessment can become the basis of a systemic analysis of costs, highlighting where economic savings might be achieved. Utilizing this approach can help to identify the most cost effective, most energy efficient and least environmentally damaging strategy for meeting a particular energy service such as lighting, cooking or an industrial process. It is especially helpful in identifying energy savings through reduction of energy transformation losses, and reduction in end use demand ((Huber & Mills, 2005)).

1.3.1.2 Methodology and Units Used in this report

In this report Joules are used (usually ExaJoules = 10^{18} Joules) when discussing and comparing different forms of energy, and Watthours may be used for electricity (Usually TeraWatt hours = 10^{12} Watthours). See the glossary for definitions of terms.

Different energy analyses use a variety of accounting methods that lead to different quantitative outcomes for both reporting of current primary energy use and energy use in scenarios that explore future energy transitions. Energy accounting systems are utilized in the literature often without a clear statement as to which system is being used ((Lightfoot, 2007), (E. Martinot, Dienst, Weiliang, & Qimin, 2007)). A comprehensive overview of differences in primary energy accounting from different statistics has been described ((Macknick, 2009)) and the implications of applying different accounting systems in long-term scenario analysis were illustrated by Nakicenovic *et al.*, ((Nakicenovic, Grubler, & McDonald, 1998).

Three alternative methods are predominantly used to report primary energy. While the accounting of combustible sources, including all fossil energy forms and biomass, is unambiguous and identical across the different methods, they feature different conventions on how to calculate primary energy supplied by non-combustible energy sources, i.e. nuclear energy and all RE sources except biomass. These methods are:

- *the physical energy content method* adopted, for example, by the OECD, the International Energy Agency (IEA) and Eurostat, (IEA/OECD/Eurostat, 2005).
- *the substitution method* which is used in slightly different variants by BP (2009) (Finley, 2009) and the US Energy Information Administration, each of which publish international energy statistics, and
- *the direct equivalent method* that is used by UN Statistics (2010) and in multiple IPCC reports that deal with long-term energy and emission scenarios (Nakicenovic & Swart, 2000); (Morita, et al., 2001); (Fisher, Nakicenovic, & al., 2007).

For non-combustible energy sources, the *physical energy content method* adopts the principle that the primary energy form should be the first energy form used down-stream in the production process for which multiple energy uses are practical (IEA/OECD/Eurostat, 2005). This leads to the choice of the following *primary* energy forms:

- heat for nuclear, geothermal and solar thermal; and
- electricity for hydro, wind, tide/wave/ocean and solar PV.

The *direct equivalent method* counts one unit of secondary energy provided from non-combustible sources as one unit of primary energy. This method is mostly used in the long-term scenarios literature, including multiple IPCC reports ((Watson, Zinyowera, & Moss, 1996); (Nakicenovic & Swart, 2000); (Morita, et al., 2001); (Fisher, et al., 2007)), because it deals with fundamental transitions of energy systems that rely to a large extent on low-carbon, non-combustible energy sources.

In this Special Report, IEA data are utilized, but energy supply is reported using the *direct equivalent method*. The major difference between this and the *physical energy content method* will appear in the amount of energy reported for electricity produced by geothermal heat, concentrating solar thermal, ocean temperature gradients or nuclear energy.

Table 1.5 compares the amounts of primary energy by source and percentages using the *physical energy content*, *the direct equivalent* and a variant of the *substitution method* for the year 2007 based on IEA data (IEA, 2009d).

Table 1.5 Comparison of global total primary energy supply in 2007 using different primary energy accounting methods (data from IEA (2009a)).

	Physical content method		**Direct equivalent method**		**Substitution method**[3]	
	EJ	**%**	**EJ**	**%**	**EJ**	**%**
Fossil fuels	411.09	81.62	411.09	85.27	411.09	79.41
Nuclear	29.69	5.90	9.81	2.04	25.79	4.98
Renewables	62.47	12.40	60.81	12.61	80.40	15.53
Bioenergy	48.31	9.59	48.31	10.02	48.31	9.33
Solar	0.40	0.08	0.40	0.08	0.49	0.10
Geothermal	2.05	0.41	0.39	0.08	0.78	0.15
Hydro	11.08	2.20	11.08	2.30	29.17	5.63
Ocean	0.00	0.00	0.00	0.00	0.01	0.00
Wind	0.62	0.12	0.62	0.13	1.64	0.32
Other	0.39	0.08	0.39	0.08	0.39	0.08
Total	503.64	100.00	482.10	100.00	517.67	100.00

IEA, 2009: Energy Balances of Non-OECD Countries International Energy Agency, 2009 edition.

For the purpose of this report, the direct equivalent method is chosen for the following reasons:

All non-combustible sources are treated in an identical way by using the amount of secondary energy they provide. This allows the comparison of all non-CO_2 emitting RE and nuclear energy sources on a common basis. Primary energy of fossil fuels and biomass combines both the secondary energy and the thermal energy losses from the conversion process. When fossil fuels or biofuels are replaced by nuclear systems or other renewable technologies, the total of reported primary energy decreases substantially (Jacobson, 2009). Energy and emissions scenario literature that deals with fundamental transitions of the energy system to avoid dangerous anthropogenic interference with the climate system over the long-term (50-100 years), has used the direct-equivalent method most frequently ((Nakicenovic & Swart, 2000); (Fisher, et al., 2007)).

Figure 1.7 shows the differences in the three methods when projected to 2050 for a particular scenario that might achieve a stabilization of CO_2 at 550ppm. A more complete discussion of the different methodologies is provided in Appendix II.

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[3] For the substitution method conversion efficiencies of 38% for electricity and 85% for heat from non-combustible sources were used. BP uses the value of 38% for electricity generated from hydro and nuclear. BP does not report solar, wind and geothermal in its statistics for which, here, also 0.38 is used for electricity and 85% for heat.

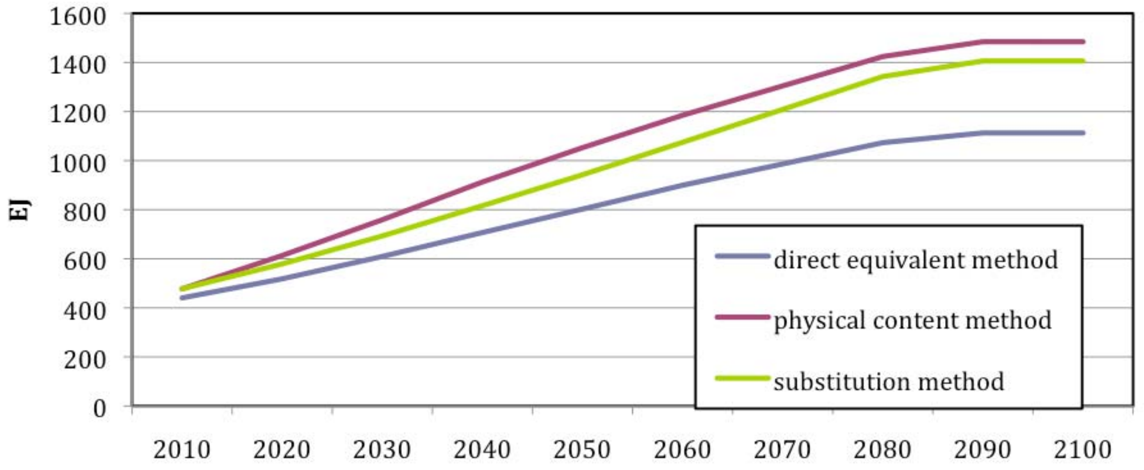

Figure 1.7 Comparison of global total primary energy supply between 2010 and 2100 using different primary energy accounting methods based on a 550 ppm CO2-equivalent stabilization scenario ((Loulou, Labriet, & Kanudia, 2009)). See Chapter 10 and Appendix II for additional information.

1.3.2 Importance of energy end-use efficiency

Often the lowest cost option is to reduce end use energy demand through efficiency measures, which include new technologies and more efficient practices. For example, compact fluorescent or light emitting diode lamps use only about one-fourth to one-sixth as much electricity to produce a lumen of light as does a traditional incandescent lamp. Properly sized variable speed electric motors and improved efficiency compressors for refrigerators, air conditioners and heat pumps can lower primary energy use in many applications (Weizsäcker et al, 2009). Efficient houses and small commercial buildings such as the Passivhaus design from Germany are so air tight and well insulated that they require only about one-tenth the energy of more conventional dwellings ((Passivhaus, 2010). Avoiding international style glass box construction of high-rise buildings in tropical countries could dramatically reduce emissions at a substantial cost saving for cooling.

RE installations (with zero or low GHG emissions) are often more feasible once end use demand has been lowered. For example, if electricity demand is high, the size of the required rooftop solar system might be larger than the roof but, by lowering demand, the size and cost of the distributed solar system may be manageable.

The transportation sector could reduce emissions significantly by shifting to appropriately produced biofuels or by utilizing engineering improvements in traditional internal combustion engines to reduce fuel consumption rather than to enhance acceleration and performance. Biofuels become more feasible for aircraft as efficiency improves. Significant efficiency gains and substantial CO_2 emission reductions have also been achieved through the use of hybrid electric systems, battery electric systems and fuel cells (see sec. 8.3.1). Two additional approaches to energy efficiency are combined heat and power systems ((Casten, 2008)), and recovery of otherwise wasted thermal or mechanical energy (about 19% of US electricity equivalent with no increase in CO_2 emissions and at a few cents/kWh) ((Bailey & Worrell, 2005)). Combined heat and power can significantly reduce emissions by avoiding burning additional fuel for commercial and industrial heat. A residential scale unit that operates on natural gas is also available in Japan and North America.

These principles are also applicable to enhancing the overall delivery of energy from RE such as capturing and utilizing the heat from PV or biomass-electricity systems, which is done frequently in the forest products industry.

Technological improvements can and will continue to make progress reducing GHGs through efficiency. However, technology alone can only take us so far. The forecasted growth in population and the projected demand for energy could well outpace the pace of technological innovation, and emissions will continue to grow without some behavioural changes especially in the richer countries.

1.3.3 Current status of RE

1.3.3.1 Global primary energy consumption and electricity production

Since 1990, global energy consumption almost doubled, rising to around 504 EJ in 2007, with RE's share at approximately 13.0% (12.6%) ((IEA, 2009d)**)** See Figure 1.8.

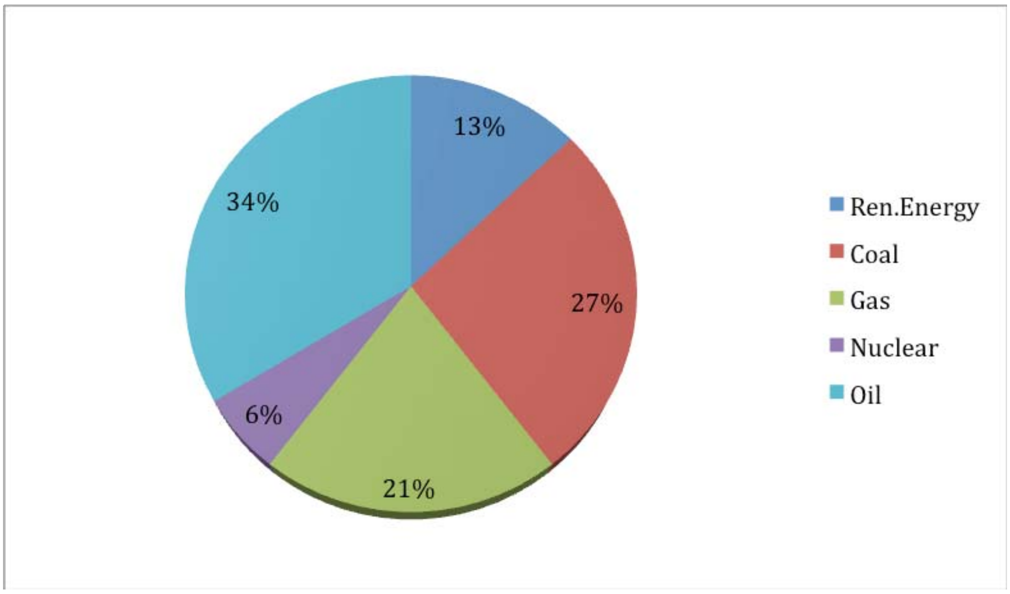

Figure 1.8 Global primary energy consumption 2007 ((IEA, 2009b)).

The 12.6% RE is distributed as solid biomass (9.5%), large hydroelectric power (2.2%), geothermal (0.4%), liquid biomass (0.3%), and new renewables embracing wind solar and marine energy (0.2%). At the global level, on average, renewables have increased by 1.8% per annum between 1990-2007 **(**(IEA, 2009d)**)** only just managing to keep pace with growth in total primary energy consumption (1.9%). Wind energy registered the highest average growth rate of 29.0%, and grid-tied solar PV 70 percent. The capacity of utility-scale solar PV plants 200 kilowatts) tripled during 2008, to 3 GW. Solar hot water grew by 15 percent, and annual ethanol biodiesel production both grew by 34 percent. Heat and power from biomass and geothermal sources continued to grow, and small hydro increased by about 8 percent ((REN21, 2009a)).

Globally, around 55% of RE has been used to supply heat in private households and in the public and services sector. Essentially, this refers to wood and charcoal, widely used in developing countries for cooking. Electricity production stands at 24.0% ((IEA, 2009d)). RE's contribution to electricity generation is summarized in Table1.6.

Table 1.6. RE share of world electricity production 2007

	Electricity TWh	Share of RE supply
Renewable total	3578	1
Biomass	259	0.073

Hydro	3078	0.860
Geothermal	62	0.017
Solar PV	4	0.001
Concetrating Solar Power	1	0.000
Wind	173	0.048
Tide & wave	1	0.000

Source: IEA WEO 2009 ((IEA, 2009d))

1.3.3.2 Regional aspects of RE

As regards biomass as a share of regional primary energy consumption. Africa is particularly high with a share of 47.0%, followed by India 20%, Asia excluding China 16%, and China 10% (Figure 1.9)

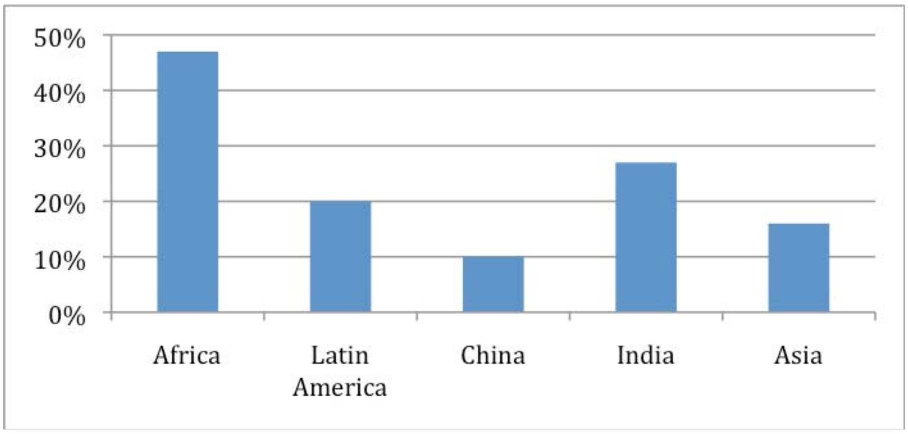

Figure 1.9 Biomass as a share of regional Primary Energy Consumption ((IEA, 2009d)).

UNEP finds that global investment in RE rose 5% and exceeded that for coal and natural gas by $140 billion to $110 billion in 2008 [TSU: needs to be converted into 2005US$] despite a decline in overall energy investments. UNEP estimates that an additional $15 billion [TSU: needs to be converted into 2005US$] was invested in energy efficiency during that year. Much of this investment was in the United States, China and Europe ((UNEP, 2009); (REN21, 2009b)).

In China, growing energy needs for solar cooking and hot water production have promoted their development. China is now the leading producer, user and exporter of solar thermal panels for hot water production, and has been rapidly expanding its production of solar PV, most of which is exported, and has recently become the leading global producer. In terms of capacity, in 2008, China was the largest investor in thermal water heating, second in wind power additions and third in bioethanol production. In terms of renewable power capacity, China now leads the world followed by the U.S., Germany, Spain and India ((REN21, 2009a)). China has been doubling its wind turbine installations every year for the past five years, and could overtake Germany and the U.S. by 2010. India has become a major producer of wind turbines and now is among the top five countries in terms of installation, and has become a major international turbine manufacturer.

These developments suggest the possibility that RE could play a much more prominent role in both developed and developing countries over the coming decades. New policies in the U. S., China and the EU are supporting this effort. European leaders signed up in March 2007 to a binding EU-wide target to source 20% of their energy needs from renewables, including biomass, hydro, wind and solar power, by 2020.

As noted above, RE is more evenly distributed than fossil fuels, there are countries or regions rich in specific RE resources. The share of geothermal energy in the national electricity production is above 15% in four countries: El Salvador (22%), Kenya (19.8%), Philippines (19%) and Iceland (17%). More than 70% of energy is supplied by hydropower and geothermal energy in Iceland. In some years depending on level of precipitation, Norway produces more hydropower electricity than it needs and exports its surplus to the rest of Europe. New Zealand and Canada have also a high share of hydropower electricity to the total electricity: 65% and 60 %, respectively. Brazil is the second largest producer of bio-ethanol, which it produces from sugarcane.

1.3.3.3 Global energy flows of primary RE

Global energy flows from primary energy through carriers to end-uses and losses in 2004 are shown in Figure 4.4 of IPCC AR4 WG3. Figure 1.10, shown here, reflects primary RE only, utilizing the data for 2007 **(**(IEA, 2009d)). 'RE' here includes combustible biomass, forest and crop residues and municipal solid waste as well as the other types of RE considered in this report: wind, hydropower, geothermal energy and solar energy.

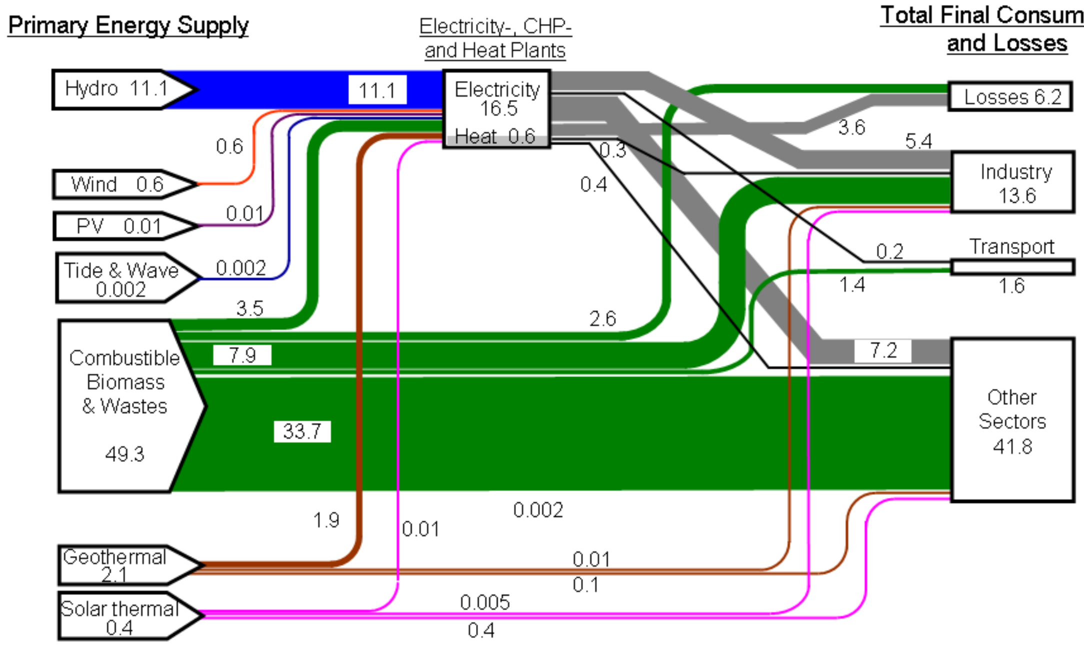

Figure 1.10 Global energy flows (EJ in 2007) from primary RE through carriers to end-uses and losses (based on IEA data). 'Other sectors' include agriculture, commercial and residential buildings, public services and non-specified other sectors. 'Transport sector' includes international aviation and international marine bunkers. **[TSU: Source?]**

In 2007, renewable sources generated 18% of global electricity (19,756 TWh), which consisted of 13% of primary energy (including traditional sources) and 18% of end use energy ((REN21, 2008); (REN21, 2009a)). The flow of biomass, which includes traditional uses, dominates this figure, but there is significant investment in modern RE technologies as noted above and accompanying rapid growth. Approximate technology shares of 2008 investment were wind power at 42%, solar PV 32 %, biofuels 13%, biomass and geothermal power and heat 6%, solar hot water 6% and small hydropower at 5%). An additional $40–45 billion [TSU: needs to be converted into 2005US$] was invested in large hydropower ((REN21, 2009a)). Between 2003 and 2008, solar installations grew at an average annual rate of 56%, biofuels and wind at 25% and hydro by 4%. Germany in 2008 produced 15% of its electricity and 10% of its total energy from renewable sources ((BMU, 2009)).

To integrate large fractions of RE into electric power systems requires improved transmission, distribution and storage technology and greater use of information technology in what is referred to as a smart grid as described in Chapter 8. Fully integrated energy planning for power production, heating, cooling and transportation will require both management of supply and demand, improved end use efficiency and utilizing RE in ways that match its availability and appropriateness to specific tasks.

1.3.4 Current status of RE as function of development

1.3.4.1 Energy consumption and access to electricity

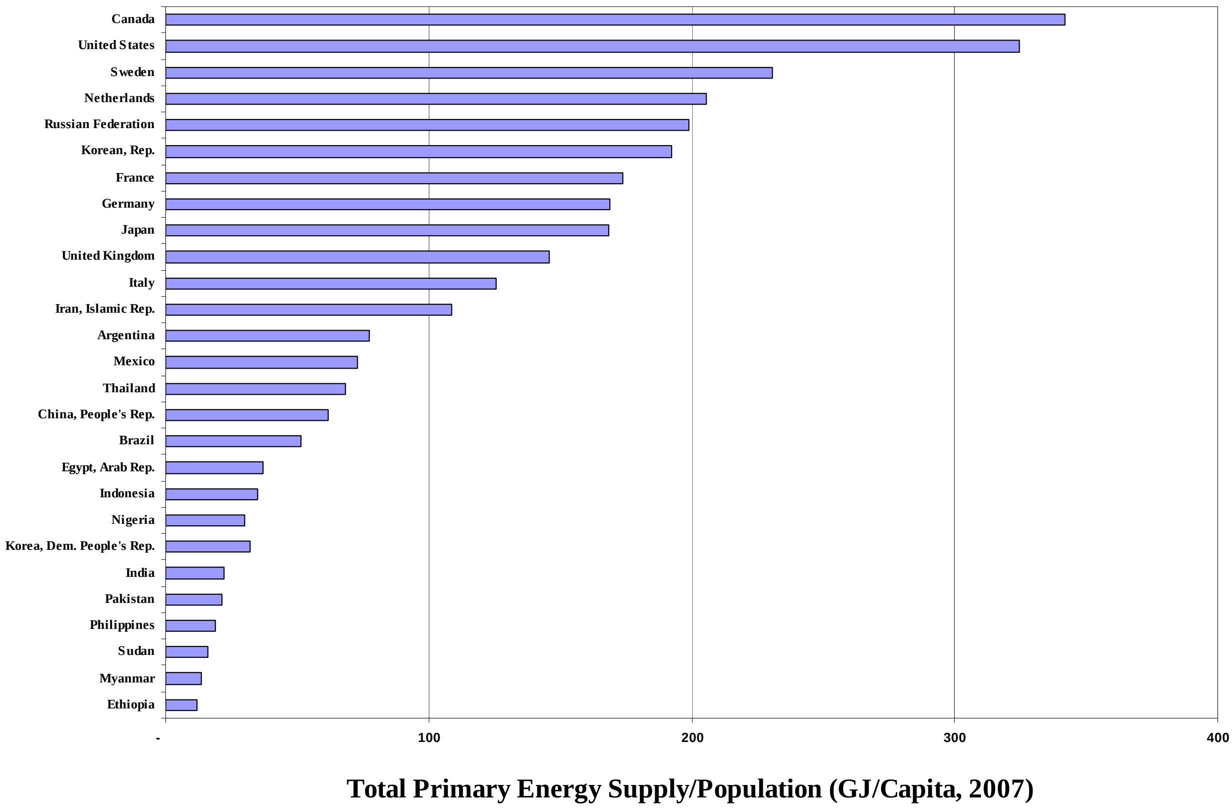

Figure 1.11. Total primary energy supply per person in various countries: > 300 TJ/capita for U.S. and Canada, 100 - 200 TJ/capita for Japan, Korea, Germany, and other European countries, <50 toe/capita most developing countries (adapted from (IEA, 2009b).

Access to electricity in developed countries is high and is still increasing but 1.4 billion people in developing countries still do not have access to electricity. The electrification rate is also different from region to region: North Africa 86%, China and East Asia 82.0%, and Latin America 60%, South Asia 32.0%, Sub-Sahara Africa (SSA) less than 10% (IEA, 2004). Without more electricity supply, people cannot get energy services for activities such as electronics, lighting and productivity enhancing mechanical work such as sewing, carpentry and water pumping or purification. That said, in some developing countries ((E. Martinot, Chaurey, & al, 2002);(Johansson, McCormick-Brennan, & al., 2004) various kinds of RE have been introduced to meet the energy service demands as shown in 1.3.5.

1.3.4.2 Utilization of RE

Biomass is a major source of energy in developing countries. Table 1.7 indicates how inefficient the traditional biomass utilization in rural area is. Although consumption of commercial energy and electricity per capita in urban areas is more than double of that in rural areas (agricultural districts), the total energy consumption, including non-commercial energy, is much higher in rural areas.

Traditional biomass is typically used in inefficient devices, is often accompanied by health issues and is a major source of black carbon, which contributes to global warming. Finding improved energy sources in developing countries would improve health, enhance productivity and decrease climate change.

Table 1.7. Energy consumption of households in urban and rural areas of China. Non-commercial energy includes combustible RE such as methane, rice straw, and firewood. (ChinaStats, 2007)

	Energy consumption GJ/y per capita	Electricity consumption kWh/y per capita
Urban (commercial energy)	7.52	305
Rural (commercial energy)	3.57	149
Rural (non-commercial energy)	10.51	

While blackouts are common in many cities in developing countries, they occur in developed countries as well. Urban centres have become totally reliant on electricity, and cannot function without it. Integration of very large amount of variable RE supply to the power grids raises some technical (systems) issues discussed in chapter 8.

Heat pump systems that extract stored solar energy from the air, ground or water have penetrated the market in developed countries sometimes in combination with renewable technologies such as PV and wind. Heat pump technology is discussed in chapter 4.

Sun-belt areas such as deserts and the Mediterranean littoral are abundant in clear sky solar energy and suitable for concentrated solar thermal power plants. The potential to export solar and wind energy from the countries rich in resources could become important in the future (Desertec, 2010); see case study in chapter 8).

1.3.5 Climbing the Energy Ladder

RE plays an important role in the movement from more traditional to more modern forms of energy supplied to consumers simply because it is typically available locally and can, with the right technologies, advance consumers up the energy ladder. RE based on off-grid energy systems can contribute to poverty alleviation and assist in achieving MDGs by providing unmet energy services, as indicated in section 1.1.5.

In developing countries, energy infrastructures are underdeveloped, but it’s not clear that they should follow a western-style energy system with extensive and costly networks. More evenly distributed underdeveloped (and largely unmapped) RE sources are available in developing countries. Regions and communities without electricity and other modern sources of energy suffer from extreme poverty, limited freedom of opportunities, insufficient health care, etc. Although the energy system will be different from that of developed countries, to raise the electrification rate is indispensible for developing countries. About two thirds of the global hydropower potential is located in the developing countries. In favourable areas, wind energy has become cost competitive with conventional energies, the more so if external costs are taken into account. It has shown rapid development and cost reductions (see chapter 7) . Solar PV is likewise developing rapidly (see Chapter 3). The potential of these modern RE technologies in the developing countries is considerable.

Biomass is the dominant energy source in many developing countries and is increasingly being harvested in an environmentally unsustainable way. To avoid the inefficient traditional biomass utilization for cooking and heating, solar thermal energy utilization is practically useful as well as modern biofuel production. For example, as discussed in chapter 2, improved biomass stoves save 10% to 50% of biomass consumption for the same cooking services and can dramatically improve indoor air quality, as well as reduce black carbon and GHG emissions (Clancy, 2002). Solar water heating is an established technology that can be manufactured in developing countries (China is already the world's largest producer). Many developing countries in desert regions may be suitable locations for solar concentrating power technology (chapter 3).

Progress is being made in developing countries on improving the energy ladder from use of traditional biomass in the form of firewood, cow dung and agriculture residues to more environmentally benign devices/fuels including improved biomass stoves, biogas and, to some extent, solar cookers. Similar progress is being made for provision of modern energy services for productive use of heat and electricity. The energy ladder for household fuel transition is depicted in Figure 1.12.

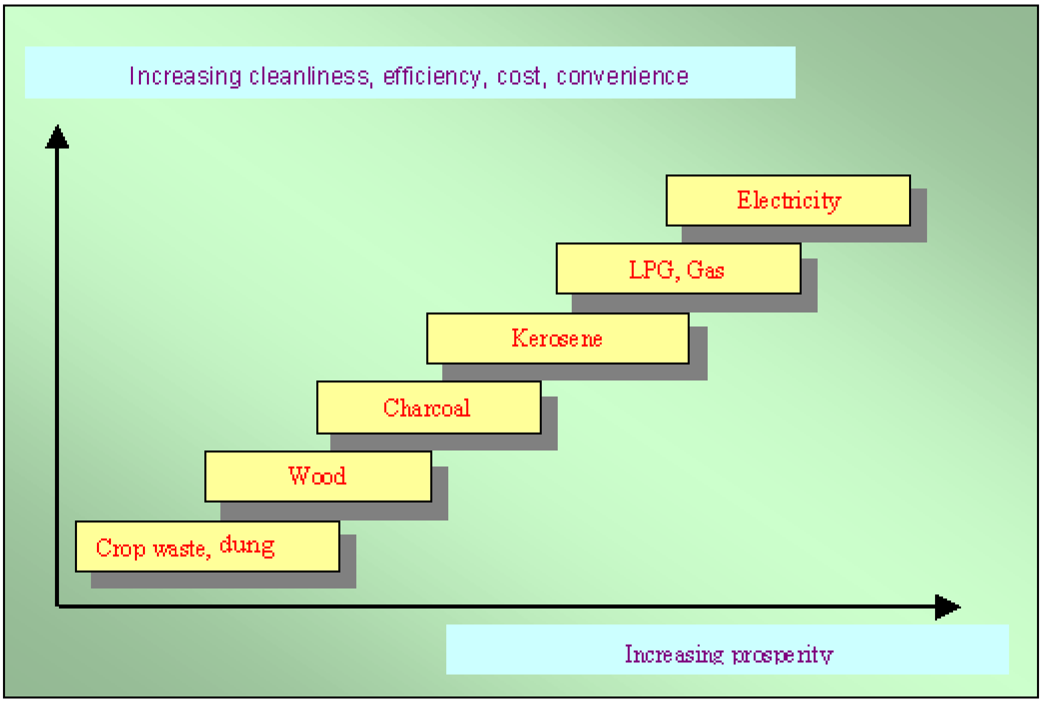

Figure 1.12. Energy Ladder: Household Fuel Transition.
(Source: www.sparknet.info/goto.php/view/1/theme.htm) [TSU: Institution/website & year; link in footnote or reference list]

With development, there is generally a transition up the 'energy-ladder' to fuels that are progressively more efficient, cleaner, convenient and expensive, such as natural gas, LPG and electricity. Commercial energy sources also permit the use of modern technologies that transform the entire production process at the factory level, in agriculture and within the home.

Electricity allows tasks previously performed by hand or animal power to be done much more quickly with electric powered machines. Electric lighting allows individuals to extend the length of time spent on production and hence on income producing activities. It also allows children time to read or do homework and access to television, computer and internet, which opens rural residents to new information that can instil the idea of change and the potential for self -improvement. Of interest in the energy ladder transition is the opportunity to use RE rather than diesel generators for either off or on-grid applications.

Commercial energy sources (in particular modern RE) permit the use of modern technologies that transform the entire production process at the factory level, in agriculture and within the home. Modern liquid fuels (including biofuels) permit modern modes of transportation that cut the cost, both monetary and in time, of travel to nearby towns for trade, education and healthcare. Table 1.8

summarizes the progress that has been made in introducing RE technologies in a number of developing countries that has greatly improved the delivery of energy services by moving up the energy ladder and the scale-up of off grid RE.

Table 1.8. Progress on Energy ladder and of grid RE application

Energy services/ technologies	**Progress**	**Comments**
Improved biomass cookstoves	I. 220 million improved biomass stoves now in use in the world	Increase due to a variety of public programmes over the last two decades. The number can be compared with almost 570 million households world wide that depend on traditional biomass as primary energy
	II. China with 180 million household representing 95% of such households	
	III. India with 34 million representing 25% of such households	
	IV. Africa has 8.0 million with Kenya having the largest number of 3.0 million	
Cooking and lighting	I. About 25 million households worldwide receive energy for lighting and cooking from household scale bio digesters	In addition to providing energy, biogas has improved livelihood of rural household-for example-reduced household time spent on firewood collection
	II. 20 million households in China	
	III. 3 million households in India	
	IV. 150,000 households in Nepal	
Small scale biomass gasification	I. Total capacity of gasifiers in India estimated up to 35MW	Gasifiers used for provision of electricity and heat for productive use e.g. textile and silk production, drying of rubber and bricks before firing
	II. More gasifiers have been demonstrated in the Philippines, Indonesia, Sri-Lanka and Thailand	
Village scale mini grids/ hybrid combinations	I. Tens of thousands of mini grids in China based on small hydro	Mainly from solar PV, wind and biomass, other in hybrid combinations
	II. Thousands in China, Nepal, Vietnam and Sri-Lanka	
	III. Use of wind and solar PV in mini grids and hybrid systems still in order of thousands in China	
Water pumping from wind and solar PV	I. About 1 million mechanical wind pumps in Argentina	Solar PV and wind power (both for irrigation and water pumping) gaining widespread acceptance
	II. Large numbers in Africa: South Africa (300,000), Namibia(30,000), Cape Verde(800), Zimbabwe(650)	
	III. 50,000 solar PV-pumps world wide. India (4000), West Africa (1000)	
	IV. The rest in Argentina, Brazil Indonesia, Namibia, Niger, Philippines, Zimbabwe	

Source: REN21, 2008 and Ren21/GTZ/BMZ 2008 ((REN21, 2008)).

1.3.6 Present status and future potential for RE

1.3.6.1 Meeting demands of developing countries through RE leapfrogging

Table 1.8 shows that technological options exist for providing cleaner cooking fuels and expanding rural electrification delivery –using mainly off-grid power generation. It is clear that successful technological leapfrogging examples are concentrated in Asia and in Brazil, the second largest consumer, and the major exporter of ethanol, which generates income within the country and improves energy security ((Brew-Hammond, Darkwah, & al., 2008)).

However, technological development cannot alone contribute to improved energy access in developing countries. Innovative policies, including financing, are required (see sec 1.4.6.2 and chapter 11).

1.3.6.2 Global Scenarios for RE deployment in the future

Chapter 10 includes a comprehensive analysis of over 100 scenarios of energy supply and demand to assess the costs and benefits of RE options to reduce GHG emissions and thereby mitigate climate change. Even without a push for climate change mitigation, the increasing demand for energy services is expected to drive growth of RE to levels exceeding today's energy usage. There are large uncertainties in projections, including economic and population growth, development and deployment of higher efficiency technologies, the ability of RE technologies to overcome initial cost barriers, preferences, environmental considerations and other barriers.

1.4 Barriers, Opportunities and Issues

Almost everywhere in the world, one can find a RE resource of one kind or other – e.g., solar radiation, wind, falling water, waves, tides and stored ocean heat or heat from the earth - and there are technologies available to harness all of these forms of energy. The opportunities seem great. Then, why is RE not in universal use?

Firstly, there are *barriers*. A barrier was defined in the AR4 as 'any obstacle to reaching a goal, adaptation or mitigation potential that can be overcome or attenuated by a policy programme or measure' ((IPCC, 2007); (Verbruggen, et al., 2010)). For example, the technology as currently available may not suit the desired scale of application. This barrier can be attenuated in principle by a program of technology development (Research &Development).

Secondly, other *issues*, not so amenable to policies and programs, can also impede the uptake of RE. An obvious example is that the resource may be too small to be useful at a particular place: e.g., the wind speed may be consistently too low to turn a turbine or the topography too flat for hydropower.

This section describes some of the main barriers and issues to using RE for climate change mitigation, adaptation and sustainable development. *As throughout this introductory chapter, the examples are illustrative and not comprehensive*. Section 1.5 (briefly) and Chapter 11 [section 11.4] of this report (in more detail) look at policies and financing mechanisms that may overcome them. When a barrier is particularly pertinent to a specific technology, it is examined in the appropriate 'technology' chapters of this report (i.e., chapters 2 to 7).

For convenience of exposition, the various barriers are categorised here as informational, socio-cultural, technical and structural, economic, or institutional (see Table 1.9). This categorization is somewhat arbitrary since, in many cases, barriers extend across several categories. More importantly, for a particular project or set of circumstances it will usually be difficult to single out one particular barrier. They are interrelated and need to be dealt with in a comprehensive manner.

More positively, RE can open opportunities for co-benefits, not least for adaptation to climate change. Some such opportunities are outlined in subsection 1.4.7.

Table 1.9. A categorisation of barriers to RE deployment

Subsection	Type of barrier	Some relevant policy instruments (see chapter 11)
1.4.1	Market failures	Carbon taxes, emission trading schemes, public support for R&D on RE)
1.4.2	Information and awareness barriers	Energy standards, information campaigns
1.4.3	Socio-cultural issues	Improved processes for land use planning
1.4.4	Technical and structural barriers	Enabling environment for innovation, revised technical regulations, international support for technology transfer (e.g. under UNFCCC)
1.4.5	Economic barriers	economic climate that supports investment, carbon taxes, emission trading schemes
1.4.6	Institutional barriers	Microfinance, technical training, liberalisation of energy industries

[TSU: Source?]

1.4.1 Market failures

Many, but not all, barriers are described by economists as *market failures*. With reference to the theoretical ideal market conditions ((Debreu, 1959), (Becker, 1971)), all real-life markets fail to some degree ((Bator, 1958);(Meade, 1971); (Williamson, 1985)), evidenced by losses in welfare. Three major market failures (imperfections) are undersupply of public goods, oversupply of negative externalities and rent appropriation by monopolistic entities. In case of RE deployment, they may appear as:

- Underinvestment in invention and innovation in RE technologies because initiators cannot benefit from exclusive property rights on their efforts ((Margolis & Kammen, 1999); (Foxon & Pearson, 2008)).
- Un-priced environmental impacts and risks of energy use when economic agents have no obligation to internalize the full costs of their actions ((Beck, 1995), (Baumol & Oates, 1998)). GHG emissions and climate change are prevalent examples ((Stern, 2006); (Halsnaes, Shukla, & Garg, 2008), p.135; see also sec.1.4.5.1), but also impacts and risks of some RE projects and of other low-carbon technologies (nuclear, CCS) remain unpaid.
- The occurrence of monopoly or monopsony powers in energy markets limit competition among suppliers or demanders, free market entry and exit (see sec. 1.4.4.2). Monopoly and oligopoly power can be factual by deliberate concentration, control and collusion. Interconnected network industries (for example: electric, gas and heat transmission grids) within a given area, are natural monopolies because network services are least-cost when provided by a single operator ((Baumol, Panzar, & al., 1982)).

Characterizing these imperfections as market failures, with high likelihoods of significant welfare losses and of the impotence of market forces in clearing the imperfections, provides strong economic arguments for public policy intervention repairing the failures ((Coase, 1960); (Bromley, 1986)). On top of imperfections classified as market failures, various factors apart from market prices and budgets affect the behaviour of market agents, and are categorised here as other types of barriers.

1.4.2 Informational and awareness barriers

1.4.2.1 Deficient data about natural resources

RE is widely distributed (e.g. the sun shines everywhere) but is site-specific in a way that 'conventional' fossil-fuel systems are not. For example, the output of a wind turbine depends strongly on the wind regime at that place, unlike the output of a diesel generator. While broad-scale data on wind is reasonably well available from meteorological records, it takes little account of local topography, which may mean that the output of a particular turbine could be 10-50 % higher on top of a local hill than in the valley a few hundred metres away ((Petersen, Mortensen, Landberg, H¯jstrup, & Frank, 1998)). To obtain such site-specific data requires on-site measurement for at least a year and/or detailed modelling. Similar data deficiencies apply to many other RE resources, but can be attenuated by specific programs to better measure those resources.

1.4.2.2 Skilled human resources (capacity)

To develop RE resources takes skills in mechanical, chemical and electrical engineering, business management and social science, as with other energy sources. But the required skill set differs in detail for different technologies and people require specific training. Developing the skills to operate and maintain the RE "hardware" is exceedingly important for a successful RE project. It is also important that the user of RE technology understand the specific operational aspects and availability of the RE source. One case where this is important is in the rural areas of developing countries (see Section 1.4.6.2). More generally, in some developing countries, the lack of an ancillary industry of RE, (such as specialized consulting, engineering and procurement, maintenance, etc) implies higher costs for project development and is an additional barrier to deployment.

1.4.2.3 Public and institutional awareness

The oil price peaks of 1973, 1980, 1991 and 2008 made the consumer in both industrialised and developing counties search for alternative sources of energy. These events brought broad enthusiasm for RE, especially solar, wind and biomass, but detailed understanding remains more limited about the technical and financial issues of implementation. For instance, opinion polls in Australia (e.g., (ANU, 2008)) indicate strong public support for greater use of RE (and more generally to mitigate climate change). On the technical aspects, many supporters of single household PV energy systems are initially unaware that to be viable such systems require appliances with much greater end-use efficiency than conventional ones. Even professionals often lack awareness of RE possibilities, e.g. architects who specify 'conventional' heating systems instead of renewable ones.

To be fully successful, a program to implement RE technologies requires that there be awareness and support from not only the public, but the government, utilities and industries. Thus, stakeholder consultation is necessary for successful implementation. However, in only a few countries have there been a major effort to educate all parts of society about the nature of RE relative to traditional fossil fuels.

1.4.3 Socio-cultural issues

1.4.3.1 Social acceptance

Social acceptance for RE is generally increasing; having domestic solar energy PV or domestic hot water systems on one's roof has become a mark of the owner's environmental commitment (Bruce, Watt, & Passey, 2009). By contrast, many wind farms have had to battle the 'not in my backyard' (NIMBY) attitude before they could be established, as have nuclear power stations (Pasqualetti, Gipe, & Righter, 2002); (Klick & Smith, 2010); (Webler & Tuler, 2010). See chapters 7 and 11 of this report for more discussion of how such local planning issues impact the uptake of RE. Chapter 11 also includes a wider discussion of the enabling social and institutional environment required for the transition to RE systems.

1.4.3.2 Land use

Farmers on whose land wind farms are built rarely object; in fact they usually see them as a welcome extra source of income either as owners (Denmark) or as leasers of their land (U.S.), as they can continue to carry on agricultural and grazing activities beneath the turbines ((Milborrow, 2001)) Other forms of RE preclude multiple uses of the land; e.g. a dam for hydropower. Land use can be just as contentious in some developing countries. In Papua New Guinea, for example, villagers may insist on being paid for the use of their land for (e.g.) a mini-hydro system of which they are the sole beneficiaries. ((Johnston & Vos, 2005), p.66) Unintended consequences, such as displacement of rain forests to grow crops for biofuels also need to be avoided.

1.4.4 Technical and structural barriers

1.4.4.1 Resource issues

RE draws on natural environmental flows of energy, most of which by their nature are variable and almost always of lower intensity [W per m^2] than the petrol consumption of a motor car or the core of a nuclear reactor (Twidell & Weir, 2006). These characteristics imply that the engineering techniques needed to harness RE cost-effectively differ from those used for fossil or nuclear energy. In particular, to manage energy supply systems for variable supply as well as variable demand requires a systems approach, which will require the use of information technology. For example, to use solar energy to heat a house in winter is best done by architectural design rather than by converting it to electricity and then installing electric heaters around the building (See Chapter 3 of this report).

1.4.4.2 Existing infrastructure and energy market regulation

The dispersed, relatively low energy-density, nature of most forms of RE implies that the most effective utilization may be though distributed applications, rather than through large centralized power systems such as are required by systems based on coal and nuclear energy. Unfortunately much of the existing energy infrastructure is built on the centralized model. When a planned RE application is of a centralized nature, such as the proposed solar concentrating power system in North Africa intended to supply Europe, the energy source is not usually near existing supply systems. This requires that transmission infrastructure has to be constructed, which adds to the financial costs. This is not a new problem in that harnessing remote hydropower has been accomplished and the electricity generated has been transported over very large distances.

Technical regulations and standards have evolved to make the current energy infrastructure fairly safe and reliable. These standards and regulations generally assume that systems are of high power density and/or high voltage and may therefore be unnecessarily restrictive for RE systems of low power density. Most of the rules governing sea lanes and coastal areas were written long before offshore wind power and ocean energy systems were being developed and do not consider the possibility of multiple uses that include such systems (See Chapter 6 of this report).

The regulations governing energy businesses in many countries are still designed around monopoly or near-monopoly providers (especially for electricity). These standards and regulations were ‘liberalised’ in several countries in the 1990s, to allow ‘independent power producers’ to operate, although scales required often exclude many smaller proposed RE projects. There are current regulations that protect the current centralized production, transmission and distribution system and make the introduction of alternative technologies including many renewables difficult. An examination and modification of existing laws and regulations is a first step in the introduction of RE technologies especially into the electric power system (See chapters 8 and 11 of this report).

1.4.4.3 Intellectual property issues

Technological development of RE has been rapid in recent years, particularly in photovoltaics and wind power. Patents protect many of these new developments. Concerns have been raised that this may unduly restrict low-cost access to these new technologies by developing countries, as has happened with many new pharmaceuticals ((Barton, 2007)).

1.4.5 Economic barriers

Chapter 10 of this report includes a detailed discussion of the current and projected costs of RE systems. A few pertinent general features of the economics of RE are highlighted here.

1.4.5.1 Cost issues

Twidell &Weir (2006) point to some key questions that affect an assessment of the economic costs and benefits of an energy system (Twidell & Weir, 2006):

(a) Whose financial costs and benefits are to be assessed: the owners, the end-users, or those of the nation or the world as a whole? The costs of climate change to a nation or the world or even to a local community have in the past been treated as external to the costs of an energy project, as seen by its owners, operators and bankers. The averted costs of climate-related disasters were thus seen as a benefit to the nation but not directly to the project proponents. However such ‘external costs’ can be made internal to a project’s finances by government policies, such as carbon taxes or emission trading schemes, as discussed in Section 10.6 and Chapter 11 of this report.

(b) Which parameters or systems should be assessed: the primary energy sources or the end-use services? The practical importance of this distinction was raised in section 1.3.1.

(c) Where does the assessment apply? The cost of RE at a particular site strongly depends on the resource available. Similarly, adding a PV system near the end of a long power line from a central power station can boost the voltage there much more cheaply than replacing the whole power line by one with lower power losses. Its site-specific value to the grid operator is thus much greater than its financial cost.

(d) When are the costs and benefits to be assessed: at the start of a project or levelized over its working life? In marked contrast to fossil fuel systems, the fuel cost of RE systems is zero (bioenergy excepted). Instead the main cost is the up-front capital cost.

This capital cost may be considerably higher than for a conventional energy system, but it is not subject to the fluctuations of fossil energy prices - compare the oil price that has varied recently from $11 to 145 USD [TSU: needs to be converted into 2005US$]0020per barrel. Such variation makes it very difficult to assess, at the outset of a project, what will be its levelized cost of energy production. In contrast, the capital cost, and hence the levelized cost, of an RE project is known at the outset, or at worst is subject only to the relatively small variation in interest rates over the life of the project. In either case the revenue stream is usually also uncertain (See Appendix II) (Gross, Blyth, & Heptonstall); (Bazilian & Roques, 2008).

1.4.5.2 Availability of capital and financial risk

All power projects carry financial risk because of uncertainty in future electricity prices, regardless of its source, making it difficult for a private or public investor to anticipate future financial returns on investment. Moreover, the financial viability of an RE system strongly depends on the availability of capital and its cost (interest rates) because the initial capital cost comprises most of the economic cost of an RE system. While the predictability of such costs is a relative advantage of RE systems, bankers are still often reluctant to lend for almost any purpose (e.g. in the financial crisis of 2008-09) **(**(Wright, van der Heijden, Burt, Bradfield, & Cairns, 2008)).

An example of financial risk from an RE system outside the power sector is the development of biofuels for aviation. In 2009 neither the potential bio-jet refiners nor the airlines fully understood how to structure a transaction that is credit worthy and as a result might get financed if there were financial institutions interested in these types of transactions ((Slade, Panoutsou, & Bauen, 2009)).

A socially important case where capital availability can be a barrier to modern energy services is in the rural areas of developing countries (see section 1.4.6.2).

1.4.5.3 Allocation of government financial support

Since the 1940s, governments in industrialized countries have spent considerable amounts of public money on energy-related research development and demonstration (RD&D). However, by far the greatest proportion of this has been on nuclear energy systems. Usually, only in times of ‘energy crisis’ has there been appreciable spending on RE technologies (IEA, 2008). See also section 10.5 of this report). However, following the financial crisis of 2008-09, some governments used part of their ‘stimulus packages’ to encourage RE or energy efficiency. Tax write-offs for private spending have been similarly biased towards non-RE sources (e.g., in favour of oil exploration or new coal-burning systems), notwithstanding some recent tax incentives for RE (GAO, 2007). The policy rationale for government support for developing new energy systems is discussed in section 1.5 and chapter 11 of this report.

1.4.5.4 Trade barriers

There are tariff barriers (import levies) in some countries that render uneconomic some trade in bioenergy that might otherwise be of mutual benefit (see chapter 2 of this report, sec. 2.4.7).

1.4.6 Institutional barriers

1.4.6.1 Industry structure

The energy industry in most countries is based on a small number of companies (sometimes only one in a particular segment such as electricity or gas supply) operating a highly centralized infrastructure. The institutional and personal skills and the mindset that this structure encourages do not fit well with the model of multiple dispersed supplies that characterizes many forms of RE. And even the more centralised forms of RE will usually entail transmission lines from new locations. In this situation, changes to the laws and regulations governing energy supply may be needed to allow RE concerns to operate at all, let alone to compete on a fair basis. Chapter 8 deals with this and other ‘integration’ issues.

Energy businesses are among the largest in any country, industrialised or developing. They have billions of dollars tied up in the existing infrastructure. Although some big businesses in Brazil and

Norway have already embraced RE, and others elsewhere are starting to do so, some incumbent energy suppliers have lobbied against RE for decades. Hamilton (2007) graphically describes such efforts in Australia (Hamilton, 2007). The World Business Council for Sustainable Development presents the more positive view of some other large energy businesses (e.g., (WBCSD, 2008)).

1.4.6.2 Technical and financial support (especially for scattered users)

Technical support for dispersed RE, such as photovoltaic systems in the rural areas of developing countries, requires many people with basic technical skill rather than a few with high technical skill as tends to be the case with conventional energy systems. Training such people and ensuring that they have ready access to spare parts requires new infrastructure to be set up.

Because the cost of such systems is largely up-front, it would be unaffordable to most potential customers, especially in developing countries, unless a financial mechanism is established to allow them to pay for the RE energy service month by month as they do for kerosene. Even if the initial equipment is donated by an overseas agency, such a financial mechanism is still needed to pay for the technical support, spare parts and eventual replacement of the system. The developing world is filled with examples of systems abandoned for lack of such follow-through mechanisms. Failure to have these institutional factors properly set up has been a major inhibitor to the use of RE in the Pacific Islands, where small-scale PV systems would appear to be a natural fit to the scattered tropical island communities (Johnston & Vos, 2005).

1.4.7 Opportunities opened by RE, including for adaptation

Section 1.1.4 has pointed out that the wider use of RE brings benefits not only for climate mitigation but co-benefits in energy security, economic development that is both more sustainable and more potentially more equitable than current patterns. In particular, RE with its dispersed resource and scalable technologies can assist development in the rural areas of developing countries and thereby lessen the urban drift of population with its attendant social problems ((Gupta, 2003); (Cherni & Hill, 2009)). And in both developed and developing countries, some types of RE systems create considerably more new jobs than do ‘conventional’ fossil-based or nuclear-based systems, which tend to be much more centralised and mechanised (Wei, et al., 2010). Chapter 9 of this report elaborates on many of these issues.

Since a degree of climate change is now inevitable, adaptation to climate change is an essential component of sustainable development (IPCC-Synthesis, 2007). AR4 includes a chapter on the linkage between climate mitigation (reducing emissions of GHGs) and climate adaptation (Klein, et al., 2007). A co-benefit of some forms of RE which has not received much attention in the literature, despite that chapter, is the potential to assist adaptation to climate change, as in the following examples.

- Active and passive solar cooling of buildings [chapter 3] helps counter the direct impacts on humans of rising mean temperatures.
- Dams (used for hydro-power) are also important in smoothing out the impacts of droughts and floods, which are projected to be major impacts of climate change. Indeed, this is one of reasons for building such dams in the first place [chapter 5; see also World Commission on Dams ((WCD, 2000)).]
- Water pumps in rural areas, often powered by photovoltaics [chapter 3] or wind [chapter 7] are also important tools for raising agricultural productivity, especially in dry seasons and droughts.

- Tree planting and forest preservation along coasts and riverbanks is a key strategy for lessening the coastal erosion impacts of climate change. With suitable choice of species and silvicultural practice, these plantings can also yield a sustainable source of biomass for energy, e.g. by coppicing. [Chapter 2, section 2.5]

1.5 Role of policy, R&D, deployment, scaling up and implementation strategies

Policy sets the framework, the conditions and often the impetus under which publicly induced change can occur. If the advancement of RE in the context of climate change is seen as desirable or necessary, then actions will be required. Such actions cover every aspect of the progress of RE as a primary part of the energy system. The components of this advancement include development, testing, deployment, commercialization, market preparation, market penetration, maintenance, monitoring, etc. Chapter 11 reviews the various antecedents, policy developments, implementation and other conditions that allow for the appropriate policies to be put in to place.

The growth of RE systems in industrialised countries in the last decade or two has been greatest where it has been supported by policies such as feed-in tariffs, mandatory RE targets, or tax concessions for RE investment. But having such support switch on and off at short intervals, as the tax credits have done in the USA, results in bursts of quickly conceived projects followed by periods of inactivity as business are reluctant to invest because of uncertainty as to whether the support policy will continue. By contrast, the long-term certainty inherent in German feed-in-tariffs has propelled them into the lead in manufacturing RE technologies.

1.5.1 Policies for development of technologies

The debate surrounding technology development, its costs and its deployment is rich. The benefits and costs of R&D or of research, development and deployment (RD&D) involve discussions of two factor learning curves, where R&D expenditures are related to investment costs of technologies, mobilizing funds that includes coverage of deployment (RD&D) **(**(Sonntag-O'Brien & Usher, 2004)**),** the role of carbon pricing policies in technology development and more ((Bosetti, Carraro, & al., 2009)).

The question of who should cover the costs associated with the R&D for new technologies is complex. Should this be public funds or private, or some mixture of both? Ostensibly, commercial or economic benefits of the advancement in an existing technology or some more novel approach to capturing RE exist; these benefits should accrue to the investor. Historically, private enterprise has invested and consequently received the benefit while society has gained from advances made. Logically, one assumes that the bulk of the R&D should fall on the shoulders the firm / company / utility and it can be argued that public funds in R&D should be minimal or none. Others argue that the development and advancement of a new technology requires an initial impetus from foresighted planners and continued support to ensure commercialization in the future. Currently, the private sector is leading R&D of technologies that are close to market deployment, while public funding is essential for the longer term and basic research ((Fisher, et al., 2007), Section 3.4.2). Chapter 11.2.2 addresses these issues.

Market barriers exist that prevent the development and penetration of novel RE technologies into the energy system. Renewable supply companies are under sometimes significant disadvantages (risks) associated with the development of a new technology or service, especially when the market playing field is not level. For example, while many perceive RE to have qualities and values related to their cleanliness and renewability, the current market attributes no value as such to these characteristics. New technologies also face regulatory barriers that support existing systems, which by their nature discriminate against distributed energy sources such as rooftop solar PV or against wind and solar because of their variable nature.

Sufficient investment will be required to ensure that the best technologies are brought to market in a timely manner. These investments, and the resulting deployment of new technologies, provide an economic value and can act as ‘hedging’ strategies in addressing climate change. However, there remains significant uncertainty, in part due to a paucity of data, that enables one to link ‘inputs’ (R&D and market stimulation costs) to ‘outputs’ (technology improvements and cost reductions) ((Fisher, et al., 2007), Section 3.4.2). The role of the policy maker is important, whether to invest in R&D, to ameliorate the risks faced by R&D products in the market or to develop the pilot and demonstration projects so necessary for market acceptance.

1.5.2 Policies to move technologies to commercialization

The importance of policies to enhance technology development, described above, is crucial to the advancement of RE supply there is also a need for policies to drive deployment. (Bosetti, *et al.*, 2009), in their gaming analysis using the WITCH model, argue that the establishment of enduring and consistent carbon pricing policies are themselves sufficient to stimulate R&D and deployment (without affecting R&D in other areas; i.e., it was not a diversion of funds) (Bosetti, et al., 2009) Edmonds *et al*., 2004) consider advanced technology development to be far more important as a driver of emission reductions than carbon taxes (Edmonds, Clarke, Wise, Pitcher, & Smith, 2008). Weyant (2004) concluded that GHG stabilization will require the large-scale development of new energy technologies, and that costs would be reduced if many technologies are developed in parallel and there is early adoption of policies to encourage technology development (Weyant, 2004). Both statements speak to the need to ensure that newly developed technologies can move from the pilot/development state to the production/commercialization state. Costs of piloting and ultimate commercialization of a new technology/process can be very high and firms often find the greatest expense and the greatest risk in this area. Many institutional support mechanisms were and are available to move RE technologies into the market, e.g. grants, tax relief, feed-in tariffs and the like. The failure of many worthy technologies to move from R&D to commercialization has been coined the “valley of death” for new products (Markham, 2002); (Murphy & Edwards, 2003); Murphy, *et al*., 2003) .This is discussed in Ch. 11.5 Attempts to move renewable technology into mainstream markets following the oil price shocks failed in most developed countries. Many of the technologies were not sufficiently developed or had not reached cost competitiveness and, once the price of oil came back down, interest in implementing these technologies faded. Solar hot water heaters were a technology that was ready for the market and with tax incentives many such systems were installed. But once the tax advantage was withdrawn, the market largely collapsed.

1.5.3 Implementation of policies (supply push vs. demand pull)

Policy and decision makers approach the market in a variety of ways: level the playing field in terms of taxes and subsidies, create a regulatory environment for effective utilization of the resource, internalize externalities of all options or modify or establish prices through taxes and subsidies, create command and control regulations, provide government support for R&D, provide for government procurement priorities or establish market oriented regulations, all of which shape the markets for new technologies. Some of these, such as price, which modify relative consumers’ preference, provide a demand-pull and enhance utilization for a particular technology. Other such as government supported R&D attempt to create new products through market push (Dixit & Pindyck, 1994); (Freeman & Soete, 2000); (Moore, 2002) (Dixit and Pindyck, 1994; Freeman and Soete, 2000; Moore, 2002). Requirements that set either technology or performance standards through regulation may also move in a direction that enhances the penetration of the product/service in the market.

There is now considerable experience with several types of policies designed to increase the use of renewable technology. Denmark became a world leader in the manufacture and deployment of large-scale wind turbines by setting long-term contracts for renewably generated electricity production. The Danes also made it relatively easy for farmer cooperatives to invest in wind turbines and used their domestically produced machines in their foreign assistance program. The Danish government left R&D to the private sector (Sawin, 2001). Germany has used a similar market pull mechanism through its feed-in-tariff that assured producers of wind, solar and other renewable sources of electricity that they would receive a higher rate for each kilowatt-hour of renewably generated electricity for a long and certain time period. Germany is the world's leading installer of solar PV, and until 2008 had the largest installed capacity of wind turbines (REN 21, 2009a). The U.S. has relied mostly on government R&D subsidies for RE technologies and this supply push approach has been less successful. Early attempts by the state of California to encourage wind power in the 1980s by an investment tax credit failed to produce an enduring wind turbine environment. Some form of a production tax credit has resulted in much more production of zero carbon electricity (Sawin, 2001).

The use of Renewable Portfolio Standards (RPS) has been moderately successful in some states in the U.S. China has encouraged renewable technology for water heating, solar PV and wind turbines by investing in these technologies directly. China is already the leading producer of solar hot water systems for both export and domestic use, and is now the largest producer of PV technology (REN 21, 2009a). After dropping its domestic incentives for PV technology, Japan fell behind as a major producer of PV technology. It has proven very difficult to take away existing subsidies to other technologies including fossil fuels and the construction of nuclear power plants in most countries. Governments may resort to levelling the playing field by granting similar subsidies to RE technologies.

1.5.4 Integrate policies into sectors

Since all forms of RE capture and production involve spatial considerations, policies need to consider land use, employment, transportation, agricultural, water, food security, trade concerns and other sector specific issues.

A major focus for RE is the electric power sector's need to introduce new technologies and to rebuild the transmission and distribution grid. The grid must be more compatible with a system that incorporates both large central power plants and a very distributed system of small renewable and other suppliers. Such a system must harmonize conventional and biofuel plants that utilize the otherwise lost heat associated with power production, rooftop solar PV, and mid-to-large scale hydro, wind, concentrated thermal solar and geothermal power plants. Many current regulations and laws support the structure and reliability of the current centralized grid locking in these technologies, and prevent the wide-scale introduction of renewable electric generating technology.

For the transport sector, there are major questions of developing the infrastructure for either biofuels, renewably generated hydrogen or battery and hybrid electric vehicles that are "fuelled" by the electric grid or from off-grid renewable electrical production (Tomic & Kempton, 2007).

The agriculture sector presents unique opportunities for capturing methane from livestock production and using manure and other crop wastes to provide on-farm fuels. There are now examples of farms that utilize methane from livestock to heat buildings including greenhouses, run electric generators and tractors. Brazil has been especially effective in establishing a rural agricultural development program around sugar cane. Bioethanol produced from sugar cane in Brazil is currently responsible for about 40% of the spark ignition travel and it has been demonstrated for use in diesel buses and even in a crop duster aircraft. The bagasse, which is otherwise wasted, is gasified and used to operate gas turbines for electricity production while the "waste" heat is used in the sugar to bioethanol refining process (Pousa, 2007).

1.5.5 Policies to avoid negative externalities

Any change in energy systems will alter the status quo of presently used fuels and technologies. No development stands on its own and policy makers need to critique and incorporate into any assessment all aspects of the impacts of a policy designed to enhance renewable fuels. It is necessary to incorporate externalities of a switch to RE supply (land use, alternative values, aesthetic concerns, etc.) as well as review co-benefits associated with the development of that particular form of RE (e.g., reduction in air pollutants, GHG emissions reduction). Some producers of fossil fuels are concerned that any policies that encourage a move away from the use of fossil fuels will adversely affect their markets. Two analyses of implementation of oil reductions concluded that the major impact would be on unconventional oil sources that produce high CO_2 emissions from oil shales, oil tars and heavy bitumen much more than conventional supplies (Barnett, Dessai, & Webber, 2004); (Persson, Azar, Johansson, & Lindgren, 2007). It is also critical to consider the potential of RE to reduce emissions from a life cycle perspective, an issue that each of the following technology chapter addresses. While the use of biofuels can offset GHG emissions from fossil fuels, direct and indirect land use changes must be also be evaluated in order to determine net benefits.[4] Such changes can include deforestation, conversion of grasslands to agricultural production, or diversion of agricultural production to fuel production. These may even result in increased GHG emissions, potentially overwhelming the gains from CO_2 absorption. An illustrative life cycle analyses, featuring expanded boundaries is shown in Figure 1.13.

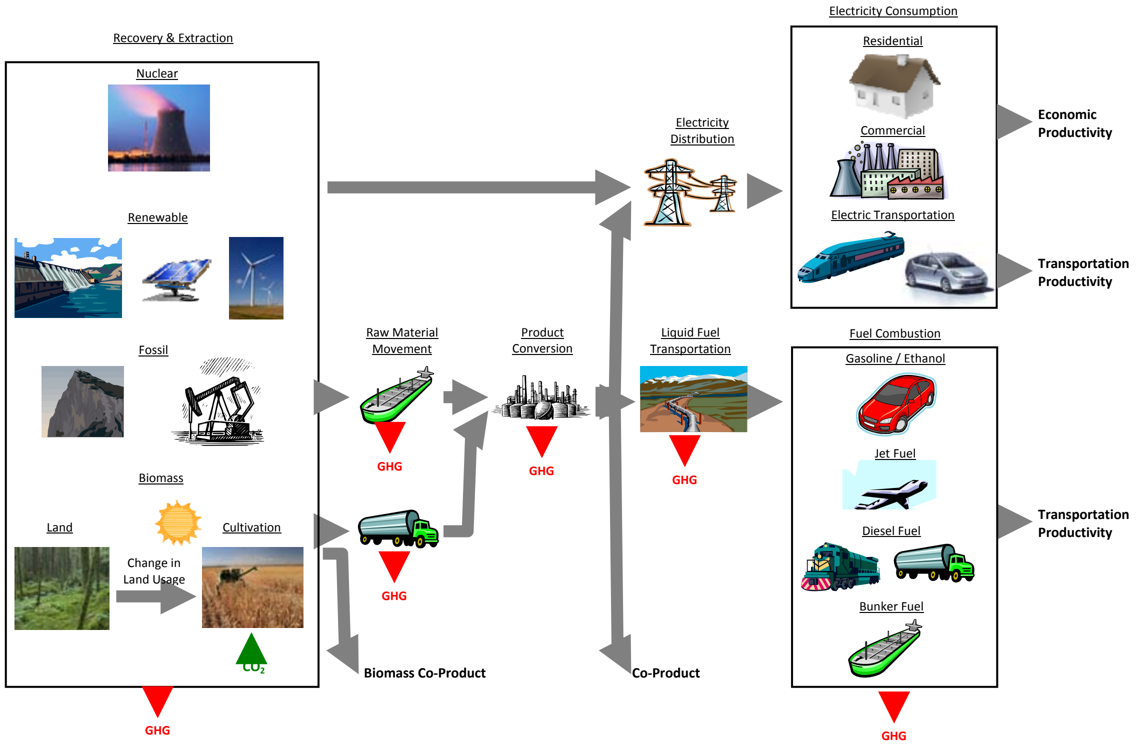

Figure 1.13. Illustrative system for energy production and use illustrating the role of RE along with other production options. A systemic approach is needed to conduct life cycle systems analysis.

1.5.6 Options are available if policies are aligned with goals

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[4] Note that such land use changes are not restricted to biomass based RE. For example, wind generation and hydro developments as well as surface mining for coal and storage of combustion ash also incur land use impacts.

An examination of alternative policies to encourage adoption of RE demonstrates that demand-pull policies are generally more effective than supply-push policies (Sawin, 2004). A recent analysis of alternative policies has found that wherever feed-in-tariffs are utilized to provide long-term certainty for higher production prices to RE, it has been more effective than renewable portfolio standards (Carpenter, 2009).

Germany, has proposed a goal of 100% RE by 2050 (BMU, 2009). According to David Wortmann, Director of RE and Resources, Germany Trade and Invest has stated, "The technical capacity is available for the country to switch over to green energy, so it is a question of political will and the right regulatory framework. The costs are acceptable and they need to be seen against the huge costs that will result if Germany fails to take action to cut its carbon emissions." (Burgermeister, 2009). Ultimately, we will need a basket of incentives to companies to develop the processing and refining capacity, and positive fiscal and legal frameworks to advance the economic viability of RE.

1.5.7 Integration of RE supply into the existing energy system

Our current energy system is the consequence of a set of energy choices often made in the absence of renewable supply (except for large hydro sources). As a result, institutional or operational barriers may hinder or prevent the advent of RE into the system. There still exist utilities that exhibit monopolies in all supply aspects – generation, transmission and distribution – and often maintain conditions that retain out-of-date transmission regulations, favour traditional power sources, do not recognize the benefits associated with new renewable supply sources and prevent the transition of the energy system to a more sustainable form.

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