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INTERGOVERNMENTAL PANEL ON climate change

Chapter 1

Renewable Energy and Climate Change

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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 40 pages: a total of 6 pages over the maximum (13 over the mean, respectively).

Expert reviewers are kindly asked to indicate where the Chapter could be shortened by 4-11 pages in terms of text and/or figures and tables to reach the mean length.

References highlighted in yellow are either missing or unclear.

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.

In addition, all monetary values provided in this document will need to be adjusted for inflation/deflation and then converted to USD for the base year 2005.

Chapter 1: Overview of climate change and renewable energy

CONTENTS

EXECUTIVE SUMMARY

Climate change is a major symptom of the more fundamental problem of unsustainable development. Utilizing the atmosphere as a dumping ground for heat trapping greenhouse gases (GHGs) such as carbon dioxide from burning fossil fuels, and methane from coal mining, production of natural gas and petroleum and natural gas transport and use is responsible for raising the temperature of the earth. Efforts to improve wellbeing through sustainable economic and social development will be severely compromised if they ignore the present and future economic impacts of acute climatic events (such as cyclones or floods) on economies, infrastructure and livelihoods, and the chronic effects of climate change on agriculture, fisheries, health, human settlements and other human activities.

IPCC AR4 demonstrated that climate change due to human activity (emissions of greenhouse gases especially carbon dioxide) is accelerating and that the warming 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 below preindustrial values. The AR4 indicates that to achieve this goal will require global GHG emissions to be at least 50% lower in 2050 than in 2000, and to begin declining by 2020. Recent data suggest that global warming is accelerating faster than suggested in AR4, and that additional emission reductions will be needed to avoid exceeding a 2°C target.

Renewable energy (RE) in combination with end use efficiency is one of the few solutions that enable reducing CO_2 output while maintaining energy services and economic growth. Various forms of RE are universally available, and can readily be introduced in both developed and developing countries. However currently RE contributes only 18% of global energy use, of which 13% is from traditional use of biomass (firewood, dung and agricultural waste), much of which is both inefficient and ecologically unsustainable. On the other hand, the use of windpower and solar energy (PV) are both increasing rapidly from a low base: indeed in 2008 the investment in new 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.

The potential energy supply from RE is very large. This report shows that it is economically feasible to develop RE to supply 270EJ by 2050, which is 31% of the global demand under a ‘high-demand’ scenario but 56% under a lower-demand scenario (i.e. one where energy efficiency is pursued more vigorously than has happened to date). However, this requires a shift in development strategy 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, enhancing energy security, employment creation and meeting Millennium Development Goals (MDGs). For example, use of modern energy services from renewable energy can contribute to freeing up household time in developing countries, and reducing smoke related diseases especially for women and children. This time can be reallocated to tending agricultural tasks, improving agriculture productivity, and develop micro-industries to build assets, increase income, and financial well-being of rural communities, thereby helping to alleviate poverty.

1.1 Background

1.1.1 Climate change

The industrial era has been fuelled by the burning of fossil fuels to provide energy for industry, transportation, heat and electric power. The trapping of radiant heat by carbon dioxide released during combustion of these fuels is now understood to be a major contributor to global warming and climate change.

In 2007, the Fourth Assessment Report (AR4) of IPCC expressed very high confidence (>90%) that the global average net effect of human activities since 1750 has been one of warming. There is a measured increase in global average temperature of 0.76°C (± 0.2°C) between 1850-1899 and 2001-2005, and the warming trend has increased significantly over the last 50 years. Although other greenhouse gases (GHGs) contribute to this warming, CO_2 from fossil fuels accounts for some 60% of the underlying radiative climate forcing, and by 2008 concentrations had increased from preindustrial levels of 280 ppm to 385 ppm (Solomon et al, 2009). Recent studies have demonstrated that climate change is accelerating, that the warming may be significantly greater and the consequences more severe and irreversible than previously realized. Solomon et al. report that “climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop.” Additional carbon dioxide and some methane is released from coal mining, oil and gas production and natural gas transmission and distribution leaks, forest clearing and burning and by land use change. Analysis also suggests that additional warming from carbon black may be adding to radiative forcing (Ramanathan, 2009) along with other changes in the albedo or reflectivity of the earth’s surface.

AR4 [WG1] projected that by the end of this century global annual average temperature will have risen by between 1.1 and 6.4°C depending on which of the SRES socio-economic scenarios best fits actual future GHG emissions. More recent projections, by Prinn et al. (Prinn, 2009), indicate a warmer range of 3.5 to 7.4°C. 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 AR4 [WG2]. A very recent report summarizes multiple trends and concludes that climate change is accelerating on every front from glacial melting to temperature and sea level rise (Copenhagen Diagnosos, 2009) The severity of the consequences of reaching irreversible tipping points temperature rises have lead many governments to advocate limiting temperature rises to 2°C above preindustrial values.

It is the total concentration of GHGs in the atmosphere that directly affects the global temperature. GHG emission rates from fossil fuels currently exceed the ability of natural sinks to absorb them, so 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. If global emissions continue to increase (upper curve of Figure 1.1), then global average temperature will increase by 3-5°C by 2100. (The upper curve is the mid-range A1B scenario (IPCC, 2007), but emissions since 1990 are trending above this curve.)

To limit the average temperature increase to 2°C requires emissions to decrease sufficiently to stabilise CO_2 concentration below 450 ppm (lower curve of Figure 1.1). This in turn implies that global emissions will have to decrease by 50-80% below current levels by 2050 and to begin to decrease instead of their current projected rapid increase by about 2020 (IPCC, 2007 AR4 Synthesis Report, Table SPM-6).

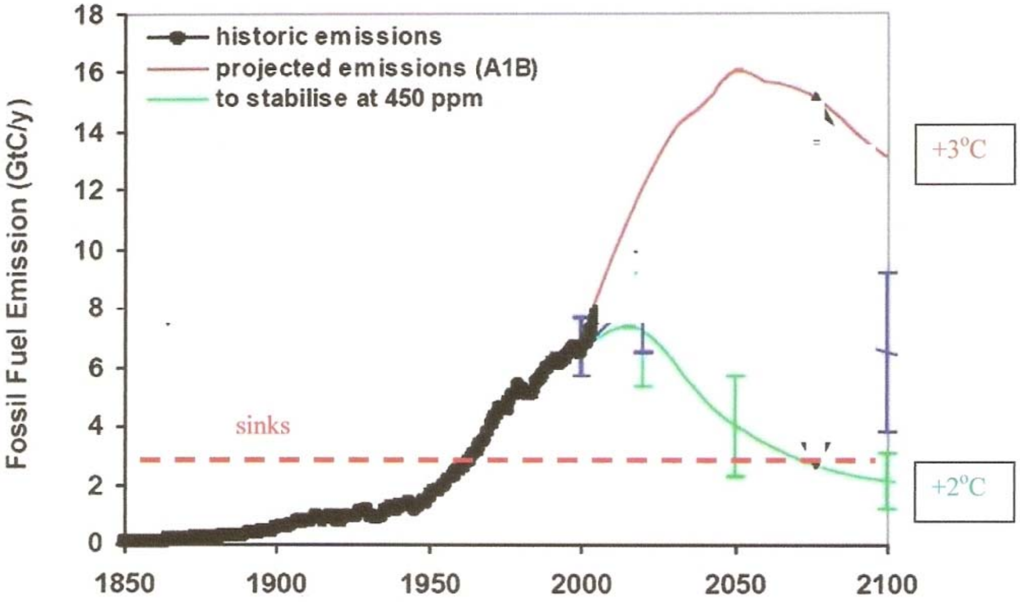


Figure 1.1. Alternative missions scenarios. If global emissions continue to increase as they have done since 1990 (upper curve), then global average temperature will increase by at least 3-5°C by 2100. If emissions decrease sufficiently to stabilise CO_2 concentration at about 450 ppm (lower curve), then the average temperature increase will be limited to ~2°C. (Diagram adapted from IPCC AR4 Synthesis Report Figure SPM-11 and charts from the Global Carbon Project; sinks data from IPCC AR4 WG1 Table TS-1).

Recent analysis of the economic cost of damages and mitigation to avoid those damages has also influenced thinking concerning potential mitigation options (Stern, 2006; 2009; UCS, 2009, McKenzie, 2008). There are many issues in any analysis of mitigation costs including debates over appropriate discount rates (Nordhaus, 2008) whether one utilizes a top down (usually more costly) or bottom up (usually less costly) analysis. The influence of these more recent studies has been to shift the perception that mitigation costs may be less than estimated in earlier studies or may in fact lead to significant direct and indirect savings for many sectors (Ackerman, 2009).

The main renewable energy (RE) technological options for reducing the growth of greenhouse gases in the atmosphere are described in sec. 1.1.4, and in the appropriate chapters of this report.

1.1.2 What is renewable energy and what is its role in addressing climate change?

Renewable energy (RE) is any type of energy produced from geophysical or biological sources that are naturally replenished. As long as the rate of extraction of this energy does not exceed the natural energy flow rate, then the resource is sustainable. 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 in which case, these “renewable” resources are unsustainable. By contrast, the rate of utilization of solar energy has no bearing on the rate at which it reaches the earth.

The renewable energy sources examined in this report are categorised as bioenergy (ch.2), direct solar (ch.3), geothermal (ch.4), hydro (ch.5), ocean energy (ch.6) and wind (ch.7).

Most renewable energy technologies have the advantage of not producing any (or very low) carbon dioxide emissions, and can be utilized in a manner which is in principle inexhaustible. Biomass can be utilized so as to be responsible for significant GHGs, or can be a low carbon fuel. Each RE technology does have a specific set of associated environmental impacts, as discussed in the 'technology' chapters of this report. Most of these impacts are very modest compared to those of fossil and nuclear systems, although a few RE technologies can have substantial environmental impact, notably large dams and unsustainable use of biomass.

The use of renewable energy by humans goes back to the discovery of fire and the use of wood for cooking and heating. Beginning with the domestication of animals for motive power and transportation, humans have relied on photosynthesis and the stored energy in green plants to fuel "animal machines." These original forms of renewable energy still provide the principal sources of energy for more than one billion people in the world and account for an estimated 10 percent of world energy use. Vegetable oils were the original choice of Otto Diesel for his early engine and Henry Ford selected grain ethanol to power his first vehicles.

These biofuels were largely replaced by abundant coal, petroleum and natural gas during the 20th century. However, volatile petroleum and natural gas prices, national security concerns about the geopolitical availability of these fuels and the drive to reduce human induced climate change are creating demands for a return to biofuels for the rapidly growing transport sector, which is largely dependent on fossil liquid fuels The discovery that mechanical energy could be extracted from the wind and from the kinetic energy of falling water and ocean tides, waves and currents was made independently in many parts of the world over the past millennium and in modern technological forms are currently experiencing a resurgence of interest and investment. Passive solar energy has been used for heating and light in ancient Greek and Roman buildings and many societies have made use of the heat from natural hot springs, which now produce both heat and electricity. The development of solar photovoltaic panels that can convert sunlight directly into electricity opened new opportunities for producing electricity, while the development of thermal systems now produce both heat and electricity (Moomaw, 2008).

In 2007, Denmark produced 21% of its electricity from wind power, and nearly 20% of their total energy comes from renewables. Brazil met more than half of its non-diesel transportation energy with bioethanol in 2008, and China's installed wind capacity has grown 5-fold between 2005 and 2008, and it will soon exceed its nuclear capacity at current growth rates. China also leads the world in solar domestic hot water installed capacity (Sawin and Moomaw, 2009; REN 21, 2009a,b).

Despite these impressive gains by renewable energy technologies, fossil fuels remain the dominant form of energy production for heat, electric power and transportation, and their use continues to grow rapidly increasing carbon dioxide (Figure 1.1 and Figure **1.2**).

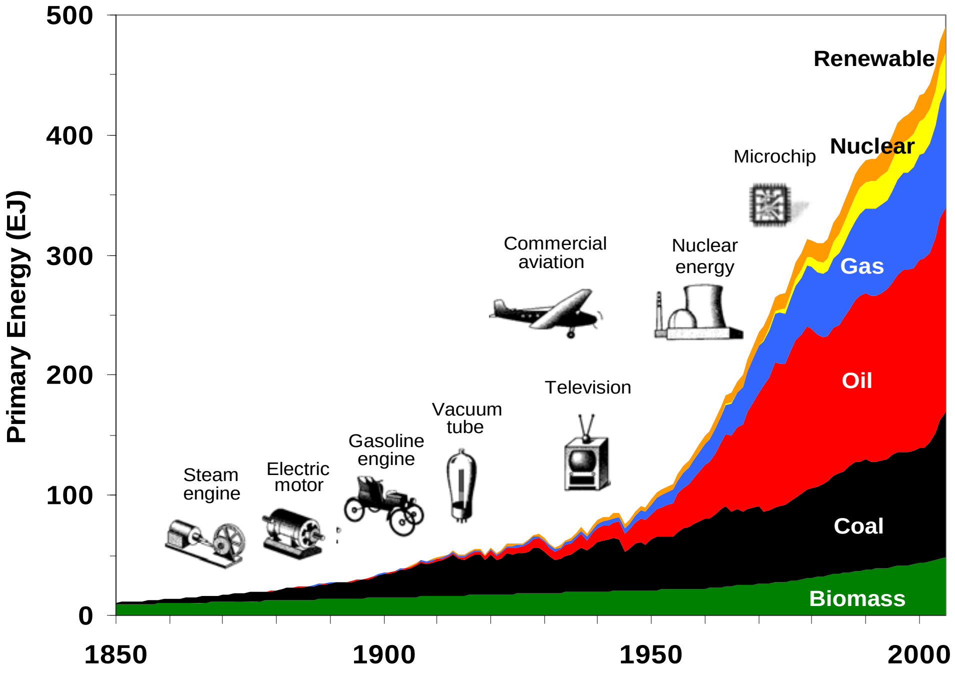
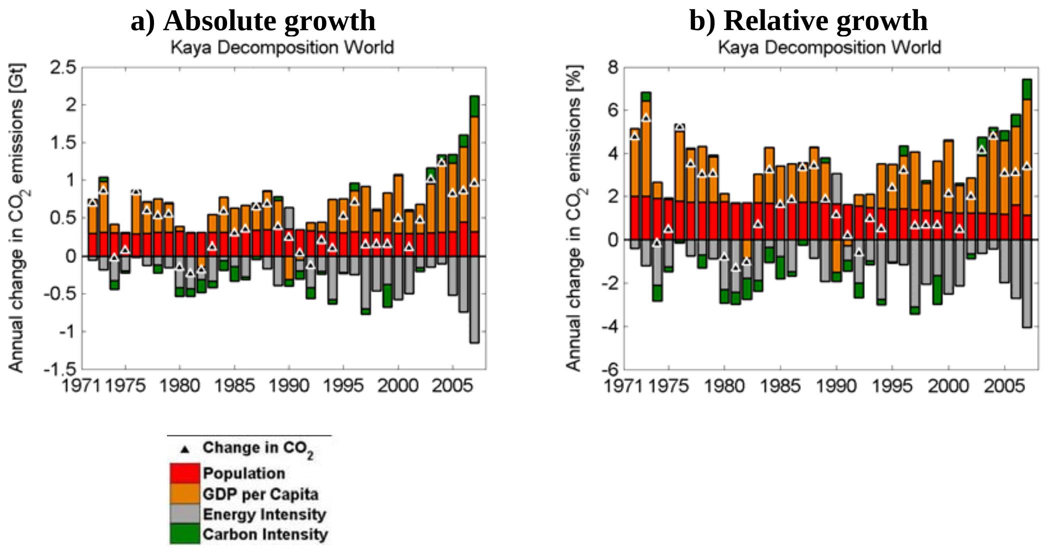


Figure 1.2. Energy supply by source 1850-2005. [TSU: Source?]

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) (Kaya, 1990). The absolute (a) and percentage (b) changes of global CO_2 emissions decomposed into the Kaya factors are shown in Figure 1.3, (Edenhofer et al, 2010).


a) Absolute growth

b) Relative growth

Figure 1.3. Kaya decomposition of global energy related CO_2 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, 2009b.

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. Since the early 2000s the energy supply has become more carbon intense, thereby amplifying the increase resulting from growth in GDP/capita.

It is possible to extend the standard Kaya decomposition so that changes in carbon intensity can be assigned to different energy carriers. Figure 1.4 shows the influence of different energy carriers on emission growth induced by carbon intensity (Edenhofer et al, 2010). 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.

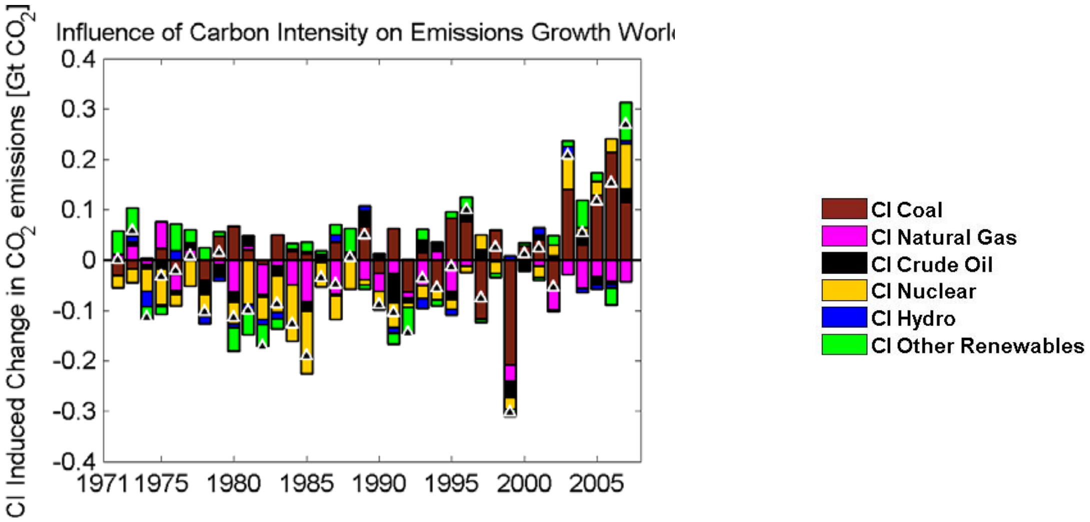


Figure 1.4. The influence of different energy carriers on the carbon intensity induced changes on CO2 emissions. The contribution of carbon intensity to the change in annual CO$_2$ emissions can be attributed to changes in the relative contribution of the energy carriers coal, natural gas, crude oil, nuclear, hydro and other renewables. Note that in case of decreasing shares of carbon-free technologies (renewables, hydro, nuclear), an increase of carbon intensity and thus CO$_2$ emissions is induced. Data Source: IEA (2009b). [TSU: Title partly missing, Cl not defined]

These analyses demonstrate the necessity of shifting from carbon intensive fossil fuels to alternative low carbon sources in the provision of energy services. In order to meet the stringent CO$_2$ emission reduction requirements to 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 renewable energy sources in combination with energy efficiency to meet the GHG reduction goals set by policy makers to reduce the extent of future climate change.

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, in association with energy efficiency, renewable energy sources can make a substantial contribution to climate change mitigation as early as 2030 and an even large contribution 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 broader 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:

Renewable resources by region and impacts of climate change on these resources;
Mitigation potential of renewable energy sources;
Linkages between renewable energy growth and co-benefits in achieving sustainable development by region;
Impacts on global, regional and national energy security;
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. How accelerated deployment might be achieved in a sustainable manner.

1.1.4 Options for mitigation

It is often assumed that economic growth is tied to energy use, and since 85% of primary energy comes from fossil fuels, to CO_2 emissions. Historically, energy consumption per capita has been very roughly proportional to GDP per capita, but this connection was broken in many economies following the oil price shocks of the 1970s. This lowered the energy intensity of economic growth, decreasing the ratio of energy use/ GDP thereby slowed the growth of GHG emissions. Indeed the energy/ GDP ratio declined by 33% between 1970 and 2004 (IPCC, 2007), Fig. SPM-2). Energy supply appears adequate to supply most energy services in most of the developed countries. 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 reduces energy consumption, and with low carbon technologies that minimise CO_2 emissions. All the long-term energy scenarios expect high growth rate of energy consumption in developing countries, so that energy supply with low or zero CO_2 emissions and low energy intensity are indispensable.

We caution against 'mitigation' options that cast climate change as the sole problem when it is really just one symptom of the more fundamental problem of unsustainable development. Thus, 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 which is 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 is likely to increase the amount of 'acid rain' and will not address the increasing acidification of the oceans by CO_2 or the choking of cities by the increasing number of motor cars on the road (Robock et al., 2009).

More constructively, Figure 1.6 shows a potential framework of options for achieving "low carbon growth". These include end use efficiency improvements, more efficient energy conversion technologies, more stringent standards and market based measures, and renewable energy. Renewable energy and energy efficiency represent two of the major options available. Renewable energy in combination with end use efficiency is potentially one of very few solutions that enable the world to actually reduce CO_2 output while maintaining energy services and economic growth.

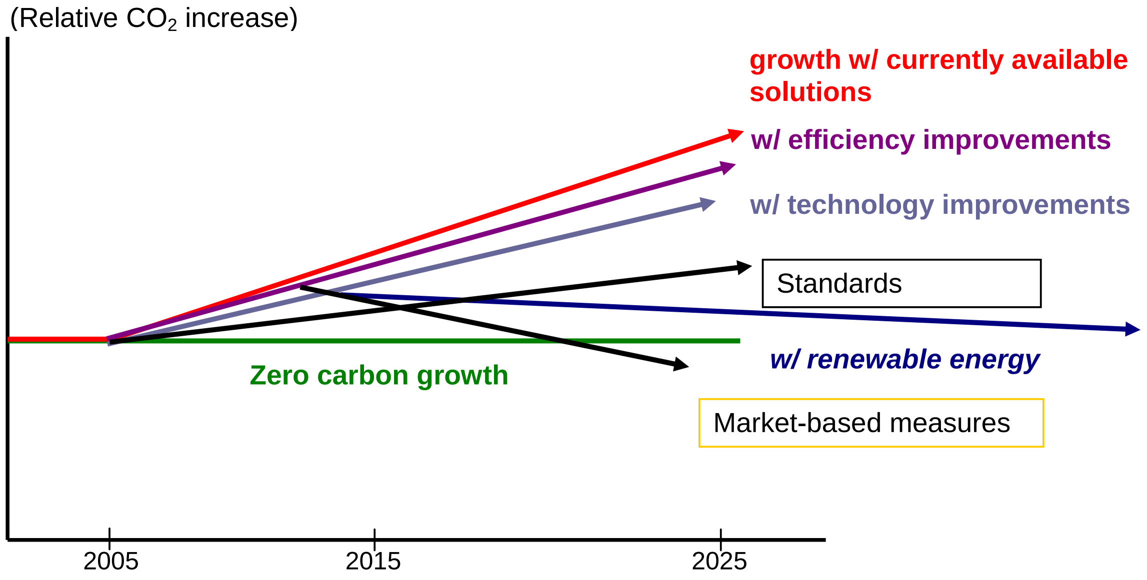


Figure 1.6. A potential framework for reducing carbon output. [TSU:Source?]

There are numerous specific responses to climate change (Pacala and Socolow, 2004; IPCC AR4, 2007), notably

- Renewable energy technology substituting for fossil fuels
- End use energy efficiency gains and production efficiency through newer technologies and/or improved operational practices
- Carbon Dioxide Capture and Storage (CCS) from fossil fuel or biomass combustion
- Fossil fuel switching to lower carbon fuels such as substituting natural gas or biomass for coal
- Nuclear power substituting for coal and natural gas
- Forest, 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)
- Geoengineering such as albedo adjustments, and ocean fertilization

This report will focus on the first of these options: the role that renewable energy can play in reducing the heat trapping gases, carbon dioxide, and methane and will examining the synergies between RE and 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 by up to 50% in many applications. 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, 2009). Avoiding international style glass box construction of high-rise buildings in tropical countries could dramatically reduce emissions at a substantial cost saving for cooling.

Renewable energy 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. Biofuels become more feasible for aircraft as efficiency improves

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. Substantial efficiency gains and CO_2 emission reductions have also been achieved through the use of hybrid electric systems, battery electric systems and fuel cells. The first two are now in production, but fuel cells are still too expensive to be commercially competitive.

Two additional approaches to energy efficiency are combined heat and power systems (Kasten, 2008), and recovery of otherwise wasted thermal or mechanical energy (Bailey and Worrell, 2005).

These principles are also applicable to enhancing the overall delivery of energy from renewable energy as in capturing and utilizing the heat from PV or biomass-electricity systems.

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

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

Two primary concerns motivate the consideration of renewable energy: price and environmental effects. The latter is a growing concern, with generally increased public and government expectations for environmental performance. Energy security is also a major driver. For example in the U.S, the military (Secretary of the Air Force, 2009) has led the effort to expand and diversify fuel supplies for aviation and cites improved energy supply security as the major driving force for renewable fuels. Apart from climate change mitigation, renewable energy can play a significant role in meeting sustainable development goals, enhancing energy security, employment creation and meeting Millennium Development Goals (MDGs).

Securing a reliable, constant and sustainable supply of energy requires a diversification of energy sources. Renewable energy offers promise as a possible alternative for replacing petroleum based products; since most of the resources are domestically based, they can be used in any country (German Federal Ministry for Environment 2008). Despite the worldwide economic recession of 2008-2009, oil prices will likely continue to rise with economic recovery in the absence of other market drivers. A diversified and expanded supply of energy may act to lower prices and/or reduce volatility. Increasing the energy supply via production of alternative fuels is expected to have a positive effect for all energy users by reducing the long-run price of all fuels including conventional petroleum products. Associated price reductions could result in significant savings (on the order billions of dollars annually). 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.

Production and utilisation of renewable energy can also spur rural and economic development, providing opportunities for farmers and entrepreneurs to produce feedstocks for renewable energy production and participate as owners of production facilities across all types of renewable energy. Given that 50% of the world’s population is still agrarian, the scale up of renewable energy offers significant economic opportunities for rural communities around the world (WIREC 2008). The opportunities culminate in improved income, job creation, and improved education, health care, distributive computing, telecommunications and public services.

But we must take care to ensure that even an RE “solution” is truly sustainable. For example, when considering biofuels, they should be made from crops that do not take up arable land that could be used to produce food and do not require excessive use of water, chemicals or threaten biodiversity.

Furthermore, renewable energy sources represent an important opportunity for developing countries, since access to energy is a key factor in combating poverty. A large proportion of the population in these countries live in rural areas. The lack of transmission grids makes conventional energy supply impossible in such locations. The decentralised nature of renewable energy means they are able to provide a basic energy supplies through an off grid system (German Federal Ministry for the Environment 2008). In this way, renewable energy 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.

Renewable energy is also central in achieving MDGs and targets. For example, regarding MDG goal 1 of eradicating extreme poverty and hunger, use of modern energy services from renewable energy can contribute to freeing up household time, in particular for women. This time can be reallocated to tending agricultural tasks, improving agriculture productivity and develop micro-industries to build assets, increase income, and financial well being of rural communities (UNDP 2005). Chapter 9 looks at the relation between greenhouse mitigation and sustainable development.

1.1.6 Trends in renewable energy

The international community's role in advancing renewable energy goes back three decades to the fuel crisis of the 1970s, when many countries began exploring alternative energy sources. Since then, various attempts have been made to ensure renewable energy featured prominently on the international environment and development agenda 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;
2. the 1992 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 renewable energy;
4. 2002 World Summit on Sustainable Development (WSSD) in Johannesburg-South Africa, when several Renewable Energy Partnerships were signed;
5. Bonn Renewable Energy Conference 2004, which addressed best practices, research and policy development, energy services, and MDGs;
6. Beijing Renewable Energy Conference (BIREC) 2005;
7. Washington Renewable Energy Conference (WIREC) 2008.

Since 1990, global energy consumption almost doubled, rising to around 503EJ in 2007, with renewable energy's share at 13.0% (IEA 2009). (Figure 1.7)

Global primary energy consumption

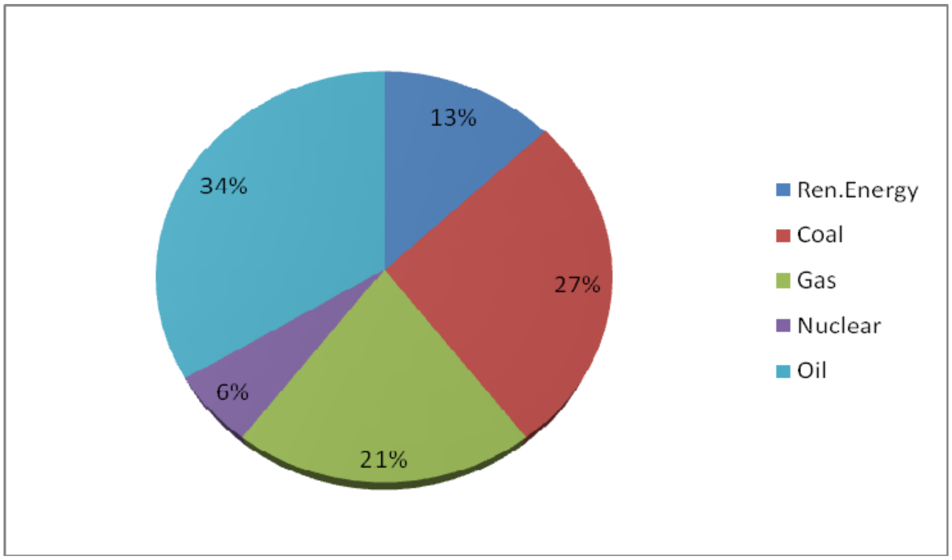


Figure 1.7. Global primary energy consumption(IEA, 2009a).

The 13.0% renewable energy is distributed as solid biomass (9.6%), large hydroelectric power (2.2%), geothermal (0.4%), liquid biomass (0.2%), and new renewables embracing wind solar and marine energy (0.1%). Traditional biomass accounted for the "lion's" share of global primary energy consumption, at 47.0% for Africa, due to its wide spread traditional use particularly in for cooking and lighting. At the global level, on average, renewables have increased by 1.8% per annum between 1990-2007(IEA, 2009b), 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 renewable energy 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, 2009b). Biomass and waste as a share of primary energy consumption is particularly high in Africa (Figure 1.8).

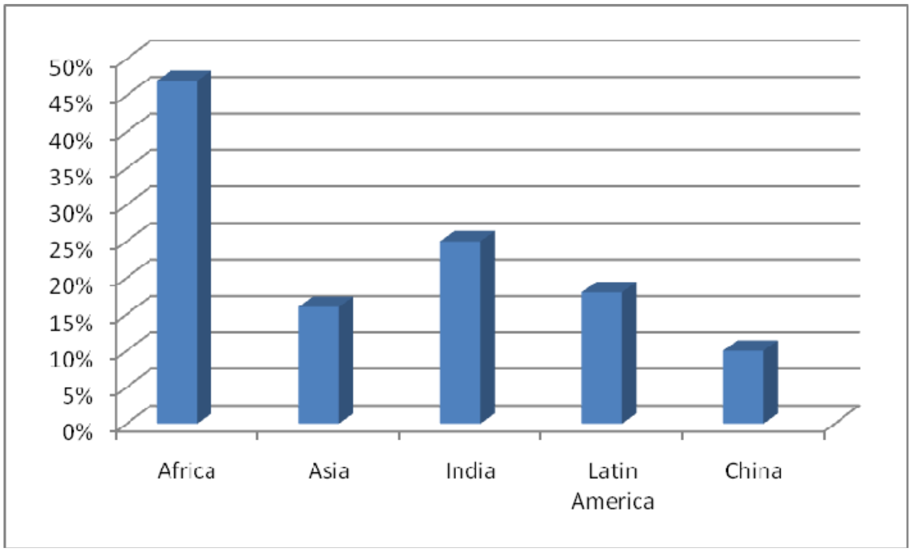


Figure 1.8. Biomass as a share of Primary Energy Consumption (IEA, 2009b)

Africa has a share of 47.0%, Latin America 18.03%, Asia 16.0%, India 25.0% and China 10.0%. Africa's high share is due to traditional use of biomass, which is not sustainable in the long run. Basic forms of cooking and heating impair health through use of open fires, and lead to deforestation (Brew-Hammond, 2008).

UNEP finds that global investment in renewable energy rose 5% and exceeded that for coal and natural gas $140 billion to $110 billion in 2008 despite a decline in overall energy investments. UNEP estimates that an additional $15 billion was invested in energy efficiency during the year (UNEP, 2009). 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 with the U.S. second, Germany third, Spain fourth and India fifth (REN 21, 2009a). In 2008, investment in renewable electric supply exceeded that for coal and natural gas for the first time. Much of this investment was in the United States, China and Europe (UNEP, 2009; REN 21, 2009b)

This investment milestone suggests the possibility that renewable energy could play a much more prominent role in both developed and developing countries over the coming decades. New policies in the United States, China and the EU are supporting this effort, and one country, Germany has proposed a goal of 100% renewable energy by 2050 (German Federal Ministry, 2009).

1.2 Summary of renewable energy resources

1.2.1 Resource advantages of renewable energy

Renewable energy is a resource that is available and is delivered by natural processes to a technological receiver. These resources are far more uniformly distributed among all nations than fossil fuels and uranium. Thus, from an energy security perspective, they are more reliable than other energy resources for fossil-fuel poor countries.

1.2.1.1 Cost certainty and distribution

While distant sources such as off-shore wind and remote wind and hydro will require long distribution limes, distributed systems will not. Renewable technologies such as rooftop solar PV produce electricity that is mostly utilized on site, so even if these distributed systems are grid connected there is no additional transmission or distribution system required and no transmission or distribution line losses. Over half of the capital investment in the electric power sector is in transmission and distribution costs (IEA, 2009b), The cost of renewable energy “fuel” and its delivery to the production site (wind, solar, hydro, geothermal and ocean) is free, and the capital costs for extracting and converting it are known up front, hence there is certainty over future fuel prices. For the world’s poor who utilize wood, dung and crop residues for cooking and heating the biofuels can be gathered with their own labour. As discussed in the next section, more advanced technologies for capturing renewable energy are often capital intensive. Even so, financing systems for technologies such as solar PV for small-scale use in developing countries have been developed that make the cost of improved energy services comparable to kerosene, batteries and oil lamps (Enersol, 2009).

1.2.1.2 Scalability of renewable energy technology

The issue of scaling up particular technologies is an issue, and 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 meet the needs for growing energy demand.

But the rapid introduction of natural gas fired turbines during the past 20 years in North America and Europe suggests an alternative conclusion. The rapid adoption of gas turbines has been due to three factors. The first is that such turbines have become exceptionally efficient (50-60%), the second is that because of economies of scale, their unit cost is low, and thirdly, they can be produced quickly in modules of 50 -100 MW and installed within a short time-frame. This latter aspect has meant low cost of capital, a better match to incremental demand growth and immediate production of incremental power upon installation. Finally, it is interesting to note that the total engine power of vehicles sold in the US each year exceeds the total electric power generation capacity of the country. Another testament to the capacity of modular scaling to produce sufficient modestly sized energy units to meet a large scale demand.

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.

At current rates it appears that wind, solar and biomass have all demonstrated that they can be manufactured at a rate that is comparable to large-scale projects. 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.

1.2.2 Resource disadvantages of renewable energy

One problem with many renewable resources used for electric power is that they are variable and may not always be available for dispatch when needed. Renewable resources may be characterized into two categories: those that have inherent energy storage and those that are variable. The former include hydropower, geothermal, and biomass. Variable sources include solar and wind power. The need for management of variable sources or the use of energy storage systems increases the complexity and cost of these systems. As will be discussed in chapter 8.2 of this report, Germany has recently demonstrated a virtual renewable base load power plant by utilizing a “hybrid” set of renewable sources.

Some sources are matched to demand such as solar electricity and air conditioning loads. Energy services such as water pumping, purification or desalination can be provided whenever the energy source is available. Smart grid advocates including Amory Lovins who was an early proponent, propose utilizing the electricity storage capacity of electric battery vehicles and battery hybrid vehicles to provide interactive storage for solar or wind produced electricity (Moomaw, 1994, RMI, 2008).

The energy density of many renewable sources is relatively low, so that available power levels may be insufficient for meeting certain purposes. These may include very large-scale industrial facilities or dense urban settlements. In most cases, at least some portion of these demands can be met by a combination of renewable energy sources, as will be discussed elsewhere in this report.

The cost of energy capture technology can be quite expensive and it may be difficult to pay for the initial capital investment. Addressing this problem is really no different than meeting the capital costs of other capital-intensive investments such as nuclear power plants and large coal power plants or large scale hydropower facilities.

1.2.3 Resource potential

The theoretical potential for renewable energy 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 renewable energy and a comparison with fossil fuel reserves and annual consumption of approximately 500 Exajoules/year are provided in Table 1.1.

Table 1.1. Renewable energy fluxes

Renewable source	Annual flux or use	Ratio Annual flux or resource/ 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	- - -
Total conventional fossil fuel reserve	396 EJ/y*	104	46,700 EJ

Renewable source	Annual flux or use	Ratio Annual flux or resource/ annual demand	Total reserve
Total unconventional fossil fuel reserve	0.06 EJ/y**	42	18,800 EJ
Total Uranium reserve	31 EJ/y***	6.7 - 23	3,000- 10,500 EJ
Current global energy use	448 EJ/y (2004)* Conv. Biofuels adds ~45 EJ/y	1	- - -

Source: World Energy Assessment, 2000 and 2004, ***IEA, 2006, ** OGJ, 2004.

A summary of the renewable energy supply technical potential estimates in ExaJoules from each of the technical chapters is provided in Table 1.2. Geothermal and wind estimates are assumed to remain constant from the present to 2050. No useful estimate for oceans has been developed. Note that the technical potential exceeds even 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 end use efficiency gains are endogenous ones rather than being policy driven. See Section 1.3 for how a substantial increase in energy efficiency for both supply and demand could lower the total demand even further.

Table 1.2. Technical potential for renewable energy (EJ) The data are a summary of the findings of the technology chapters. See Glossary for a definition of Technical Potential. No consistent method is available for estimating ocean potentials,

Technology	2005	2020	2030	2050
Biofuels	46	530	1,000	1,500
Solar	1,440	17,640	34,200	50,400
Geothermal	661	661	661	661
Electric	30	30	30	30
Thermal	631	631	631	631
Hydropower	12	16	17	23
Oceans	-	-	-	-
Wind	396	396	396	396
Total Renewable production	2,555	19,242	36,274	52,979
Projected global demand, 450 Scenario*	502	586	601	712
Projected global demand, BAU*	502	628	712	928

Source: IEA, 2009c.

1.3 Meeting energy service needs and current status

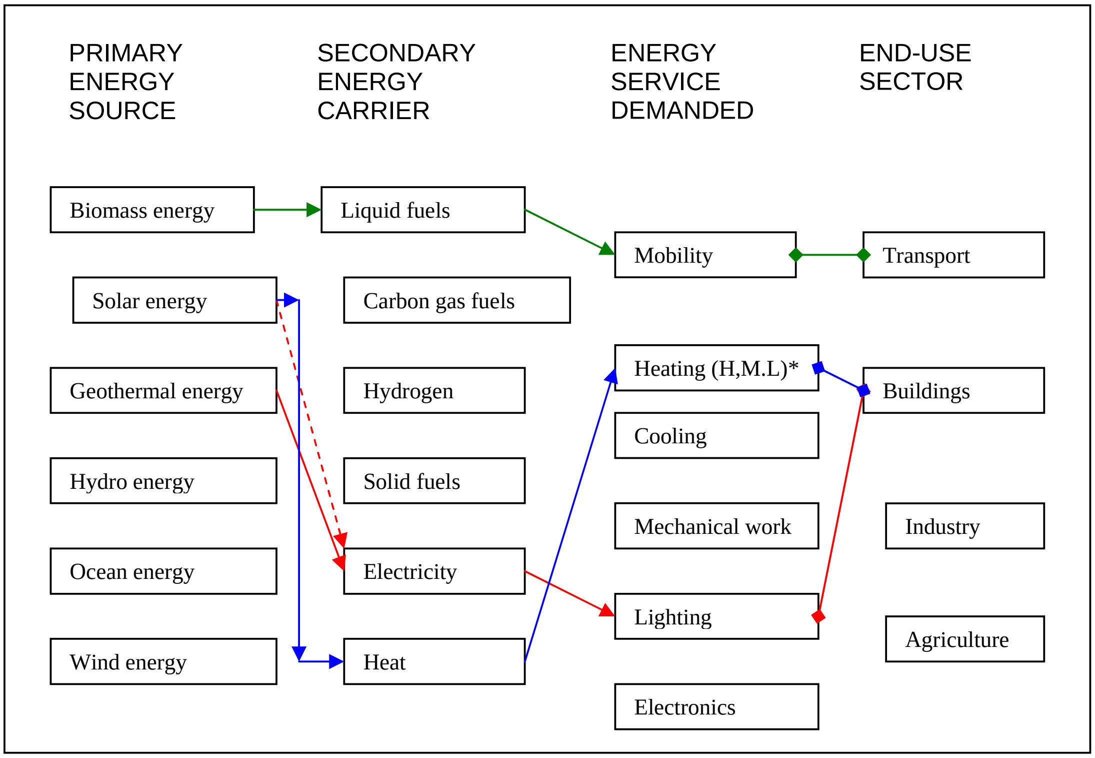
1.3.1 Energy pathways from source to end use

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. Here energy is transformed again by appropriate technologies to provide the service demanded. Renewable energy sources can serve as a primary energy supply.

Analysis of energy flows is described using four different organizing principles: primary energy, secondary energy carriers, energy services and economic sector. Figure 1.9 shows several simplified energy flow pathways of renewable energy from source to end use linking these four parts. Energy transport and storage are often needed to provide a stable energy service to the consumer, making the energy pathway more complicated. These aspects are not shown in the figure. It should be noted that renewable energy can be transformed to appropriate forms of energy to meet the energy services demanded. Selection of the pathway can be made using various criteria such as availability of energy sources, environmental burden, capital cost, life cycle analysis (LCA), matching supply to demand, and other factors, some of which may be regionally specific.

This diagram can be used as an organizing tool for conducting a life cycle assessment of specific energy options to meet alternative energy service needs in different end use sectors. One can identify where energy transformation losses occur and where do environmental impacts occur. Similarly, the LCA 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 or 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 and Mills, 2005).

Figure 1.9. The relationship among primary renewable energy source, Secondary energy carrier, energy service demand and End-use sectors. Some energy pathways are shown from renewable energy source to end-use sector. * H, M, L refer to high, medium and low temperature heat.



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 can be attributed to one of the four end-use sectors shown (in this example, buildings). The diagram indicates the range of sources, carriers, services and sectors examined in this report. Arrows indicate a few of the possible pathways; many others are possible but for simplicity are not shown here. The term ‘carbon gas fuels’ refers to methane, biogas, producer gas, etc, as distinct from pure hydrogen. A given energy service can be met by alternative primary and secondary sources with very different climate and other environmental implications.

1.3.2 Importance of energy end-use efficiency

As discussed in sec.1.1.4, energy efficiency plays a synergistic role with renewables. Because of the relatively low energy density of renewables such as solar energy, it may only be feasible to supply electricity from solar PVs for efficient lighting, or to meet thermal comfort needs if the demand is sufficiently low. End use efficiency has been especially important in meeting energy service needs by renewable energy in developing countries for cost reasons.

It is important to realize that renewable energy need not replace fossil fuel energy on an Exajoule for Exajoule basis. If one measures energy service delivery rather than primary energy, there is a substantial drop in primary energy needs when renewable electric generation replaces inefficient thermal electric conversion systems. One recent study suggests that if all thermal electric systems in the United States were replaced, the demand for primary energy would decrease by 31% for electricity production in 2030 (Jacobson and Delucchi, 2009; Jacobson, 2009).

1.3.2.1 Rebound Effect

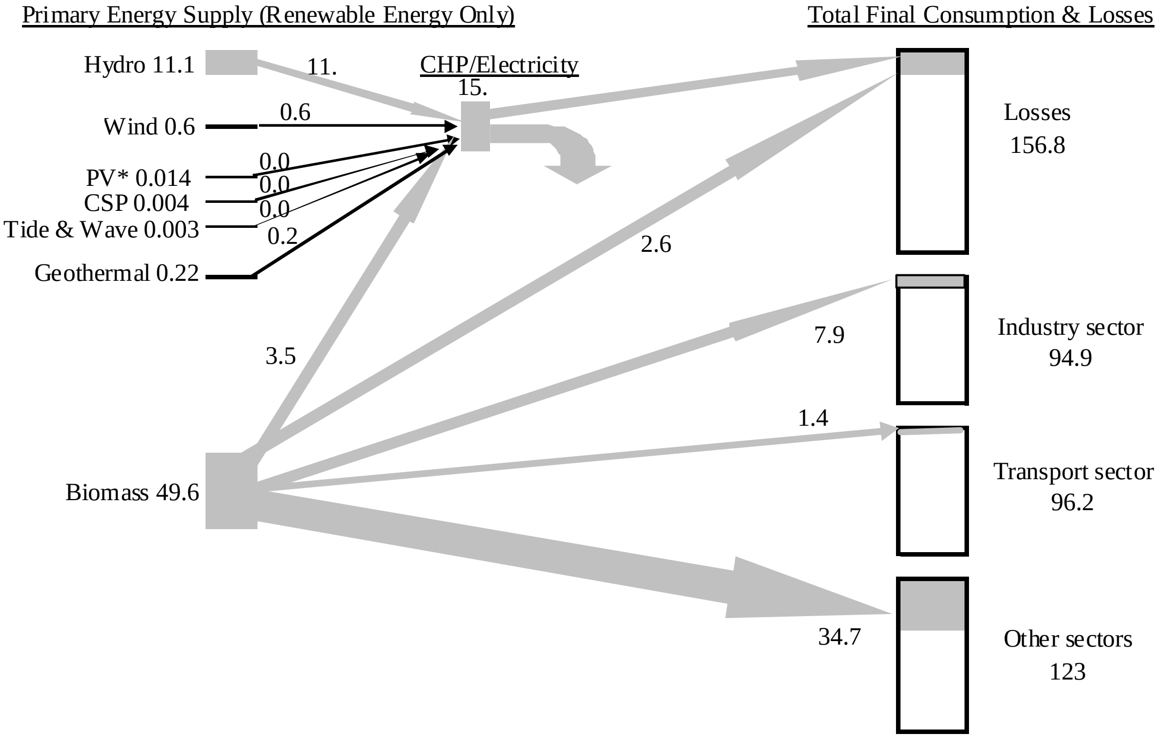
The rebound effect is defined as the failure to achieve full energy savings because the lower cost of providing an energy service with less energy may increase the use of that service. For example, as drivers switch to more efficient vehicles, they may drive more miles because fuel cost is less per mile. Such rebound may partially or, in rare cases, fully negate the expected reduction in GHG emissions when older less efficient devices are replaced. One advantage of shifting to renewable energy is that even if one's energy consumption increases while utilizing the renewable technology, there is no increase in GHG emissions (Sorrell, 2008).

1.3.3 Current status of renewable energy

1.3.3.1 Global energy flows from primary renewable energy

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 [2007, IPCC AR4 WG3]. Figure 1.10, shown here, reflects primary renewable energy only, utilizing the data for 2007 [IEA 2009b]. For that year, the share of renewable energy to total primary energy supply is 13%, about 16% of total final energy consumption. Renewable energy here includes combustible renewables and waste as well as those more commonly included: wind, hydropower, geothermal energy, solar energy, etc. Figure1.10 summarizes global energy fluxes.

Figure 1.10. Global energy flows (EJ in 2007) from primary renewable energy through carriers to end-uses and losses drawn with IEA data



Source: IEA 2009b.

Transport sector includes international aviation and international marine bunkers. Other sectors include agriculture, commercial & public services, residential and non-specified other sectors.

1.3.3.2 Share of renewable energy and its growth rate

Biomass and hydropower are the largest contributors to the sum total of all primary renewable energy at 81% and 18%, respectively. Renewable sources other than biomass and hydro account for less than 1% of the primary energy supply.

Approximate technology shares of 2008 investment were wind power (42 percent), solar PV (32 percent), biofuels (13 percent), biomass and geothermal power and heat (6 percent), solar hot water (6 percent), and small hydropower (5 percent). An additional $40–45 billion was invested in large hydropower, which contributes the largest share (86%) (Ren21, 2009a). Between 2003 and 2008, solar installations grew at an average annual rate of 56%, Biomass and wind at 25% and hydro by 4%. 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. Germany in 2008 produced 15% of its electricity and 10% of its total energy from renewable sources (Sawin and Moomaw, 2009 and references therein). Table 1.3 summarizes the share of renewable energy in world electricity generation.

Table 1.3. Renewable energy share of world electricity production

	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: REN21, 2009a.

1.3.3.3 Contribution of renewable energy to end users

Biomass is utilized primarily in the buildings sector, particularly for heating, where “Buildings” include residential, commercial, public service and agricultural. The contribution of renewable energy to the industry sector is the second largest, after Buildings, with the transport sector consuming only small amounts of energy from renewable sources. While the total amount of renewable energy consumed in each sector is small, there exist many possible applications. The following applications are examples of various applications for each sector at present and in the future:

Buildings sector:

- hot water supply, heating for air conditioning and for cooking, cooling, geothermal heat pump, lighting

Agriculture sector:

- irrigation, greenhouse heating, agricultural drying, aquaculture pond heating, gaseous (biomethane) and liquid (ethanil and biodiesel) fuelsgasiquid and gaseous fuels for machinery and onsite electricity [TSU: sentence unclear]

Industry sector:

- process heat supply, air conditioning, lighting

Transport sector:

- bio-fuels, electricity for Electric Vehicle, hydrogen for Fuel Cell Vehicle

1.3.4 Energy system management

Energy is useful only if available when and where it is wanted. To link the supply and demand, we have to carry energy to the end-users through grids (e.g. hot water, gas pipe, vehicle transportation, and networked electricity) (Twidel and Weir, 2006). Since the end-use demand varies with time on scales of months, days and even seconds, energy storage is also required.

An AC electric power grid is the most convenient and prevailing energy network to transport and distribute energy to the end-users as electricity. Although electric power transported with the grid is generated mainly by centralized power stations such as nuclear, fossil-fired, large hydro and geothermal, the capacity of grid-connected distributed renewable energy sources has recently been increasing rapidly (REN21, 2009b).

The output from wind and solar power is variable, although if it correlates with peak load the value of the electricity produced is higher (for example, solar energy is available at peak hours in California, Japan and Southern Europe). The electric power grid has to be operated to keep the quality of electricity: almost constant voltage and frequency and no failure in secure electricity supply. The rising share of the variable energy sources in electricity generation provides additional costs associated with the integration of these technologies into the power-supply system, including those associated with necessary back-up capacity and operation, and grid access (IEA, 2009b).

Energy storage is without doubt most important key technology for the future energy systems. R&D is under way on various kinds of electric power storage facilities with different storage duration time and capacity: various batteries, compressed air energy storage (CAES), superconducting magnetic energy storage (SMES), etc (Kondoh et al., 2000). Producing hydrogen as an energy carrier from renewable electricity systems can be another form of storage.

Future energy systems would be sort of integrated networks of electric grid, gas (hydrogen) pipeline and hot- and cold-water supply systems. Sophisticated control of the energy system is required in near future to maximize mitigation potential (or to connect as much renewable energy as possible to the energy network) without deteriorating the quality of energy supply as mentioned above. Key technologies to realize such controls are IT, weather and demand prediction, demand response, power electronic devices, and controllable power sources as well as energy storage (Tsuji et al, 2009). Controlling demand-side equipments using “smart-meter” has been proposed (Brown, 2008).

1.3.5 Current status of renewable energy as function of development

1.3.5.1 Rural-urban and developed – developing countries

Access to electricity in developed countries is high and is still increasing but 1.4 billion people in developing countries don’t enjoy electricity supply. Without more energy supply, people can’t get energy services for activities such as electronics and mobility. That said, in some developing countries (Martinot et al., 2002 in Johansson, 2004), various kinds of renewable energy have been introduced to meet the energy service demands as shown in 1.3.5 [TSU: i.e. in this section?].

Figure 1.11 shows the energy consumption per capita for various countries (IEA data). These can be classified into three categories based upon annual per capita energy use: (1) about 8 toe per capita: USA, Canada, (2) about 4 toe per capita: Japan, Korea, Germany and other European countries (3) less than 2 toe per capita: most developing countries. It would appear that developing countries (less than 2 toe per capita), will need more energy and will emit more carbon dioxide unless more efficient and lower emitting technologies provide the desired energy services.

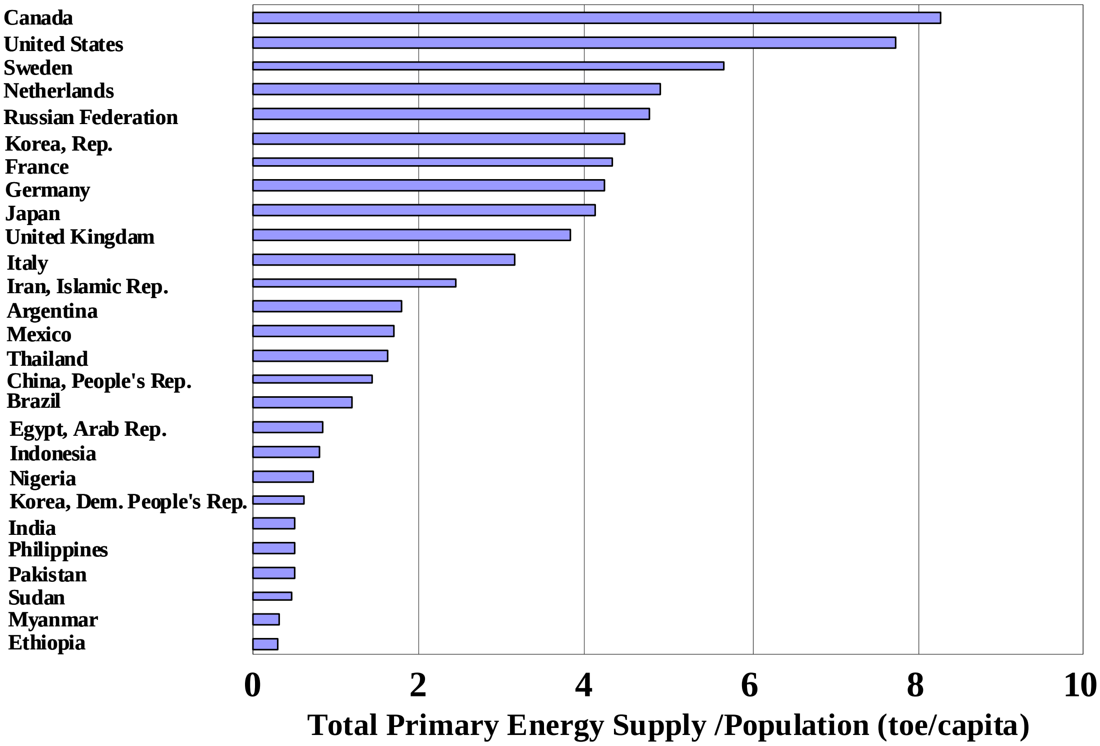


Figure 1.11. Total primary energy supply per population in various countries: 8 toe/capita for USA and Canada, 4 toe/capita for Japan, Korea, Germany, and other European countries, << 2 toe/capita most developing countries (IEA, 2009c).

Biomass is a major source of energy in developing countries. Actually, the percentage of biomass in total primary energy supply is very high in Africa (49%), Asia (25%) and Latin America (18%), whereas that in OECD countries is 3% in 2001 (IEA, 2003 in Karekezi, 2004). In part of Africa, it reaches 90% where it is used for cooking and heating. Table 1.4 shows 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 carbon black, which contributes to global warming. Finding improved energy sources in developing countries would improve health, enhance productivity and lower climate forcing.

Table 1.4. Energy consumption of households in urban and rural areas of China. Non-commercial energy includes combustible renewables such as methane, rice straw, and firewood (National Bureau of Statistics of China).

	Energy consumption GJ/y per capita	Electricity consumption kWh/y per capita
Urban	7.52	3.05
Rural	3.57	1.49
Rural (including non-commercial energy)	14.08	

In urban areas or mega-cities, population density is very high and many energy-consuming activities exist creating demand for high peak power and reliability. Renewable energy supplies for these regions must therefore be capable of responding to the very large demands.

While blackouts are common in many cities in developing countries, they also occur in developed countries as well. These urban centres have become totally reliant on electricity, and cannot function without it. Introduction of very large amount of variable renewable energy supply to the power grids requires energy networks referred to as “Smart grids” to maintain a consistent and reliable supply of electricity. Integration technology of various renewable and distributed energy sources will become more and more important because they can supply electricity at lower cost and with lower carbon dioxide emissions.

Heat pump systems have been penetrating into the market in advanced countries along with the usual renewable technologies such as PV and wind. Heat pump technology captures the thermal energy of air, soil, or river water. The Eco-Cute system of power electric companies of Japan is a hot water supply system based on heat pump technology. Its penetration has been accelerated by electric rate structure, which offers cheap off-peak nighttime electricity. Heat pump technology is being increasingly adopted in North America and in Europe, too. Such modern systems are still too expensive for most residents of developing countries at the moment.

1.3.5.2 Leading countries of renewable energy utilization

Although renewable energy is more evenly distributed than fossil fuels, there are countries or regions rich in specific renewable energy 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 seventy percent of energy is supplied by hydropower and geothermal energy in Iceland. 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 hydro-power electricity to the total electricity: 65% and 60 %, respectively. Brazil is famous for bio-ethanol production from sugarcane and Malaysia is known for its biodiesel from palm oil, however, the latter is produced at the expense of large carbon emissions associated with deforestation. Sun-belt areas such as desert and the Mediterranean littoral are abundant in solar energy. Many developing countries are located in these areas. Renewable energy is mostly utilized in a distributed manner, but its export from the countries rich in resources will become important as well in the future.

In China, strong needs for solar cooker 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 could become the leading global producer. 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 it has become a major international turbine manufacturer.

1.3.5.3 Unmet demands for energy services

Renewable energy, largely based on off grid energy systems can contribute to poverty alleviation and assist addressing MDGs. This can be achieved through provision of modern energy services to meet unmet demand for cooking, lighting and other small electric needs, process motive power, water pumping, heating and cooking in developing countries with relatively low access to electricity. Sub-Sahara Africa (SSA) in particular can benefit from provision of such energy services in view of its relatively low rural electrification rate of less than 10% compared to North Africa 86%, South Asia 32.0%, China and East Asia (82.0%), and Latin America (60%) (IEA, 2004). Provision of improved energy services for cooking for households, currently dependent on traditional biomass, is being realised through use of improved biomass stoves and biogas from households scale bio digesters and, to some extent, solar cookers.

Improved biomass stoves save 10% to 50% of biomass consumption for the same cooking services and can dramatically improve indoor air pollution, as well as reduce GHGs emissions (Clancy 2003). Improved biomass stoves have been produced commercially to the largest extent in China and India, where governments have promoted their use, and Kenya in Africa, where a large commercial market has been developed. Equally, tremendous progress has been made in India, China, and Nepal towards use of biogas from household scale bio-digesters for cooking (Ren21, 2007). Energy services for lighting, small electric needs (street lighting, telecoms, hand tools, and vaccine storage) and process motive power for small-scale industry is currently being met by an array off grid renewable energy technologies. These technologies include micro/pico hydro, biogas from households scale bio digesters, small gasification systems, village scale mini grids/hybrid system and solar PV. Small scale thermal biomass gasification is a growing commercial technology in developing countries notably China and India.

Electricity generation from solar PV, wind or biomass, often in hybrid combinations including batteries and/or supplementary diesel generators, is slowly providing an alternative to traditional energy supply based on diesel or biomass, mostly in Asia. In addition, solar PV and wind power for water pumping (both irrigation and drinking water) are gaining widespread acceptance (Ren 21, 2007)

1.3.6 Climbing the energy ladder

Renewable energy is available everywhere but its energy density is usually low but appropriate for use in the area where it is obtained. Renewable electricity seems more suitable for distributed applications where there is a grid or in remote or rural areas off the grid.

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) renewable energy 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. Solar PV will hopefully follow the wind energy. The potential of these modern renewable energy 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 bio fuel production. Solar water heating is an established technology that can be manufactured in the developing countries. It should be noted that Spain and USA have recently been developing concentrated solar thermal power plants. In regions with strong direct insulation such as deserts, they can produce electricity with higher conversion efficiency than typical solar PV systems. Most of the developing countries are located in hot regions and are therefore promising for the application of this technology.

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.

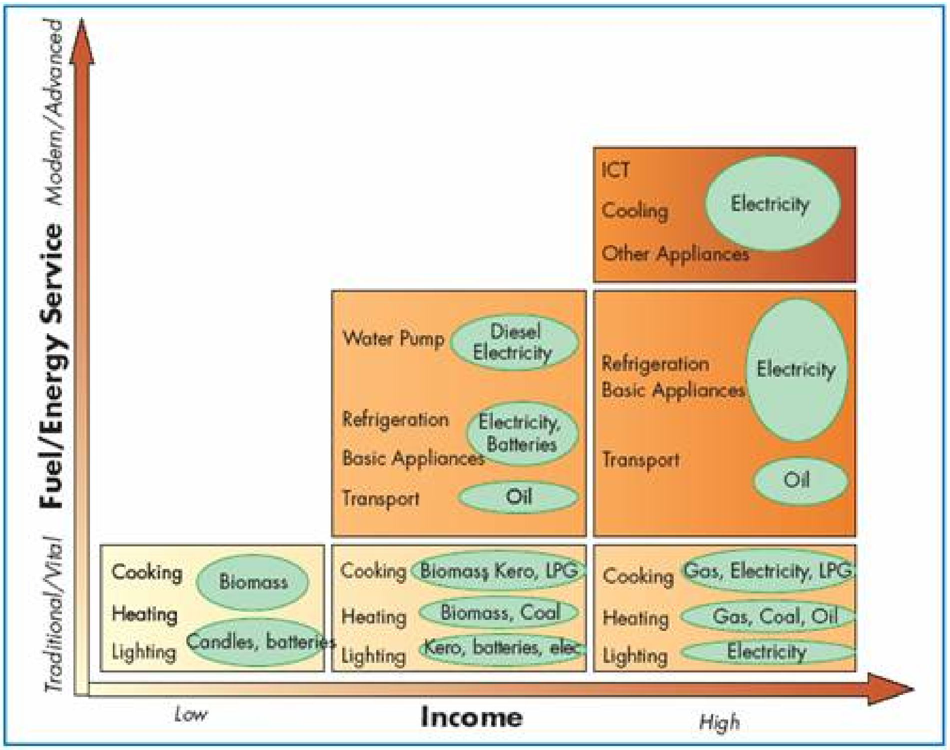


Figure 1.12. Energy Ladder: Household Fuel Transition Source: IEA Analysis, World Energy Outlook 2002.

As per capita incomes increase, the transition to commercial energy sources, which include natural gas, petroleum products and electricity, does not simply represent a substitution of more convenient and expensive fuels for cheaper traditional fuels. 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 and film [TSU: colloquial], which opens rural residents to new information that can instil the idea of change and the potential for self - improvement. Modern liquid fuels permit modern modes of transportation that cut the cost, both monetary and in time, of travel to nearby towns where, again, individuals are exposed to different ways of doing things and different views. Faster and cheaper transportation can increase the reliability of supply of modern fuels, reducing the need to maintain supplies of firewood as a back up and facilitating movements up the energy ladder. Of interest in the energy ladder transition is the need to use some aspects of renewable energy.

Table 1.5 summarizes the progress that has been made in introducing renewable energy 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 renewable energy.

Table 1.5. Progress on Energy ladder and of grid renewable energy 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.

1.3.7 Present status and future potential for developing countries to utilize renewable energy

1.3.7.1 Meeting demands of developing countries through renewable energy leapfrogging

The preceding section 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. India’s advancement in harnessing biomass gasification technology to solve part of its energy is an example of renewable energy leapfrogging. Power levels from 5 kWe to 1 MWe have been field tested and standardized in Africa (Brew-Hammond, 2008).

Malaysia and Indonesia are becoming formidable world players in biodiesel industry. These countries have been able to turn their primary goods/raw materials into finished and semi-finished biofuel products mainly for export in the EU and USA and generating income and employment. The achievements of Brazil through the PROALCOHOL programme in becoming a world-acclaimed consumer and exporter of ethanol thereby generating income within the country.

However, technological development cannot alone contribute to improved energy access in developing countries. Innovative policies, including financing, are required. Provision of affordable financial services for rural areas has been shown to be a key component of achieving sustainable market for energy services. For example, the UNDP project “expanding access to modern energy services-replicating scaling up and mainstreaming at a local level” demonstrated how appropriate financing mechanism contributed to increased access in three case studies in (Kenya, Nepal, Dominican Republic) (UNDP 2006). This mechanism included establishing channels for enabling access to financial services for the suppliers, consumers, and/or institutions that support them.

Another success story for provision of sustainable energy finance is the UNEP’s Rural Energy Enterprise Development (REED) initiative (Usher, 2003). The REED initiative focused on enterprise development and seed financing for clean energy entrepreneurs in Brazil, China and five countries in Africa. A total of US$ 7 million was committed to REED programmes in these countries. REED invests in small and mid size enterprises (SMEs) that deal in clean energy products and services, the sector generally considered too risky to attract conventional sources of financing.

1.3.7.2 Scenarios for renewable energy deployment in the future

There are numerous energy supply and demand scenarios that are referred to in Chapter 10. One of the striking aspects of these scenarios is the wide range of the renewable energy share of the supply. More recent scenarios tend to provide larger contributions from renewable energy and project lower costs than do earlier ones (IEA, McKinsey, Stern).

In 2008, investment in renewable electric supply exceeded that for coal and natural gas for the first time. Much of this investment was in the United States, China and Europe (UNEP, 2009; REN 21, 2009). This event, which is part of a recent trend, suggests the possibility that renewable energy can play an increasing role over the coming decades. New policies in the United States, China and the EU are supporting this effort, and one country, Germany has set a goal of 100% renewable energy by 2050.

There are however very early estimates by Lovins that suggested the possibility of very large penetration of renewable energy accompanied by significant reductions in end use demand. His 1975 estimate for total energy supply in the United States for 2000 of approximately 100 EJ was substantially lower than official government estimates of 150 EJ, but was within 5% of the actual energy use in 2000. However, a larger share of this amount came from efficiency gains than from renewables (Lovins, 1975). His “soft path” scenario has been based upon an examination of current innovations and his more recent analysis projects the potential for very large penetration of renewable energy in a distributed energy system (Lovins, 2008).

Methodologies differ in developing scenarios, and there are no generally agreed upon strategies for determining either costs or for assessing the rate of introduction, the role or rate of introduction of policies or the level of public acceptance. For example scenarios predicting large-scale adoption of nuclear power have consistently overestimated the levels actually achieved. Bottom up scenarios usually find lower costs for renewable and energy efficiency, while top down, macroeconomic models usually predict higher prices. It appears that it is not fruitful to simply project current trends with the current technology and fuel mix, and substitute renewable energy sources for fossil fuels. It seems that a useful approach is to identify alternative futures and then to determine what prices, policies and other factors would be needed to achieve those goals.

Evolving scenarios suggest that a significant portion of future energy needs on the electricity supply on-site heat production and transport fuels could be met by renewables. The major investments in recent years suggest that this trend may continue.

1.4 Barriers and issues

Almost everywhere in the world, one can find a renewable energy resource of one kind or other – e.g., solar radiation, blowing 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 (as described in chapters 2 to 7 of this report). Why then is renewable energy (RE) not in universal use?

Firstly, there are barriers. A barrier was defined in the IPCC Fourth Assessment Report as ‘any obstacle to reaching a goal, adaptation or mitigation potential that can be overcome or attenuated by a policy programme or measure’ (Metz et al., 2007: glossary). 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 (R&D).

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.

In this section, we briefly consider in a general way 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. Some barriers are particularly pertinent to a specific technology; they are 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. 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.

Some of these barriers are directly to do with energy prices, and what ‘externalities’ they do or do not yet take into account. They are examples of the ‘market failures’ that dominate today’s energy markets. Others (e.g., the institutional or informational barriers) would remain barriers to RE even in the economist’s dream world of ‘perfect markets’. [TSU: language]

1.4.1 Informational barriers

1.4.1.1 Deficient data about natural resources

Renewable Energy is widely distributed (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 would be 30% higher on top of a local hill than in the valley a few hundred metres away. 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.

1.4.1.2 Skilled human resources (capacity)

To develop renewable energy 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. In particular, the dispersed nature of RE implies that each user community requires someone to have basic technical training to deal with routine maintenance. This is particularly important, for example, for village-level solar energy in developing countries. Developing the “software” to operate and maintain the renewable energy “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 upon which he or she is depending.

1.4.1.3 Public and institutional awareness

The oil price peaks of 1973, 1989 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 the more ‘obvious’ forms such as 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 Social Reserch Centre, 2008) indicate strong public support for greater use of RE (and for action 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.

It is also the case that, to be fully successful, a program to implement renewable energy technologies requires that there be awareness and support from not only the public, but the government, utilities and industries. In only a few countries has there been a major effort to educate all parts of society about the nature of renewable energy relative to traditional fossil fuels.

1.4.2 Socio-cultural issues

1.4.2.1 Social acceptance

A certain cachet has begun to attach to having solar energy systems on one’s roof, as a mark of the owner’s environmental responsibility. On the other hand, many wind farms have had to battle the ‘not in my backyard’ (NIMBY) attitude before they could be established. Rich owners of holiday homes in remote areas in particular have objected to their view being ‘spoilt’. (The same people would probably object even more vehemently to having a nuclear power station or large coal plant built nearby!) [TSU: language]. See chapters 7 and 11 of this report for more discussion of how such local planning issues impact the uptake of RE.

1.4.2.2 Land use

Farmers on whose land such 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. 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 will insist on being paid for the use of their land for (e.g.) a mini-hydro system of which they are the sole beneficiaries. Unintended consequences, such as displacement of rain forests to grow crops for biofuels must also be avoided.

1.4.3 Technical and structural barriers

1.4.3.1 Resource issues

RE draws on natural environmental flows of energy, most of which by their nature are variable and almost always of lower energy intensity [W per m^3] than the petrol consumption of a motor car or the core of a nuclear reactor (Twidell &Weir 2006). Both these characteristics of the flows imply that different engineering techniques are needed to harness them cost-effectively from those used with fossil or nuclear energy. In particular, to manage energy supply systems for variable supply as well as variable demand requires a systems approach, which may involve 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 dotting electric heaters around the building (See Chapter 3 of this report).

1.4.3.2 Existing infrastructure and energy market regulation

The dispersed, relatively low energy-density, nature of most forms of RE implies that the most effective way to use them may be though dispersed 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. Even when a planned RE application is of a centralized nature, such as the proposed solar concentrating power system in North Africa intended to supply southern Europe, the energy source is usually nowhere near existing supply systems, so that (expensive) new 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. Most of them therefore assume that systems are of high power density and/or high voltage, and are therefore 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). However, such regulations were ‘liberalised’ in several countries in the 1990s, to allow ‘independent power producers’ to operate, although often such producers are still required to be of a big enough scale to exclude many proposed RE projects (See chapters 8 and 11 of this report).

1.4.3.3 Intellectual property issues

Technological development of RE has been rapid in recent years, particularly in photovoltaics and wind power. Many of these new developments are protected by patents. 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. In particular, developing countries fear that the technology transfer referred to in the UN Framework Convention on Climate Change will come not as untied aid but on commercial terms, heavily restricted by intellectual property rights that are too costly for them to acquire.

1.4.4 Economic barriers

Chapter 10 of this report includes a detailed discussion of the current and projected costs of RE systems. Here we merely highlight a few pertinent general features of the economics of RE.

1.4.4.1 Cost issues

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

(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 (sec. 1.4.2.1). 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 vagaries of fossil energy prices - compare the oil price which has varied over the past decade from $11 to 145 USD (2005) per barrel. Such variation makes it very difficult to assess, at the outset of a project, what will be its levelized cost of energy production and hence (for a private investor) its profitability. 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.

1.4.4.2 Availability of capital and financial risk

As just noted, the initial capital cost comprises most of the economic cost of an RE system. The financial viability of an RE system therefore strongly depends on the availability of capital and its cost (interest rates). While the predictability of such costs is an advantage of RE systems, sometimes bankers are reluctant to lend for even sound business propositions (e.g., in the financial crisis of 2008-09).

In the case of developing biofuels for aviation, neither the potential bio jet refiners nor the airlines fully understand 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. The problem was that the ethanol and bio diesel markets had collapsed resulting in project sponsors and their lenders loosing most of their investments. Alternative energy lenders were focused on solar and wind projects that served the electric generating markets, where there are guaranteed revenue streams that ensured the project-generated profits for the participants. Using the electric market as a model, if the airlines want to have sources of alternative fuel, they would have to provide a guaranteed market for the aviation products, which were Green Jet and Green Diesel, or 80% of a hypothetical refineries output. (That left only 20% being subject to market sources.) In addition, the airlines would have to enter into a cost plus arrangement with the refinery because no lender would take the pricing risk for the Green Jet and Green Diesel.

During discussions with banks and with the DOE and USDA, it was found that there were no private lending sources that would lend even with these government guarantees, and that there was only one government entity that might take debt risk on a non-experimental alternative fuel for aviation project. That was the US Department of Agriculture. The Department of Energy provides grant money and the DOD will pay the full cost for “Experimental” projects, but no agency will guarantee alternative energy loans for aviation. (There was no certified fuel until September 2009 and no bank or government will guarantee a loan to produce something that might never get certified – newly certified fuels ease this somewhat.)

If any financings get done, it will be due to the willingness of the airline industry to take bio fuel risks. However, no one will know for certain what is possible until some deals are done. The airlines apparent willingness to assume real risk by signing long term off take agreements that are not tied to spot market prices is a major step forward. This willingness is as important as government guarantees, perhaps more important.

1.4.4.3 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, not least because of their military connections. Only in times of ‘energy crisis’ has there been appreciable spending on RE technologies. (IEA statistics) Tax write-offs for private spending have been similarly biased towards non-renewable energy sources (e.g. in favour of oil exploration or new coal-burning systems) (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 Institutional barriers

1.4.5.1 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 (see Section 1.5.5) [TSU: section 1.4.3.2]. 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 most forms of RE.

In this situation, policy change to the laws and regulations governing energy supply is needed to allow decentralized RE concerns to operate at all, let alone to compete on a fair basis.

Energy businesses are among the largest in any country, industrialised or developing. They have billions of dollars tied up in the existing infrastructure. Many executives of these large concerns belittle the potential contribution of RE to the national energy mix and have the economic clout to lobby – often successfully – against any moves that might threaten their entrenched position, e.g., by adding effective competition from RE. Hamilton (2007) graphically describes such efforts in Australia.

1.4.5.2 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 already access to spare parts requires new infrastructure to be set up.

Because the cost of such systems is largely up-front (see Section 1.5.5) [TSU: section 1.4.4.1], 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 riddled 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 (Wade et al, 2005).

1.4.6 Opportunities and Issues

Some form of renewable energy is available in most parts of the world, and has the advantage of being delivered to the site of use for free. However, the cost of the technology to convert the “free: fuel often places these sources out of economic reach when compared to fossil fuels. In part this is because the environmental and health benefits of RE is seldom calculated into the price, and the health and environmental damages from fossil fuels are seldom assessed. There are also many non-economic barriers (See Section 1.5 and Chapter 11). [TSU: section 1.4]

Research and Development is underfunded globally (UNEP, 2008). Despite this shortfall, there have been significant breakthroughs in solar PV and battery storage technology in recent years by the private sector. As the scale and experience with wind technologies have increased, the cost and reliability of these technologies have improved significantly. Because many renewable technologies are unfamiliar to utility and government decision makers, there needs to be technology transfer from countries that have adopted them to those (especially developing ones) that have not. With the introduction of the new technologies must come the training and capacity building that is essential to operate, maintain and utilize these sources of energy.

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

In situations where one wishes to introduce public change, policy sets the framework, the conditions and often the impetus under which such change can occur. If the advancement of renewable energy in the context of climate change is seen as desirable or necessary, then action on behalf of policy and decision makers will be required. Such policies cover every aspect of the progress of renewable energy 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 development, 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 concessions 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 European feed-in-tariffs has propelled them into the lead in manufacturing at a profit, renewable energy technologies.

1.5.1 Policies for development of technologies

One always faces the question of who should cover the costs associated with the research and development (R&D) of new technologies; 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 renewable energy 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, one sees the private sector 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).

Market barriers exist that prevent the development and penetration of novel renewable energy 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 renewable energy to have qualities and values related to their cleanliness and renewability, the current market attributes no value as such to these characteristics.

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 or to ameliorate the risks faced by R&D products in the market.

1.5.2 Policies to move technologies to commercialization

The importance of technology development and deployment should not be underestimated. Bossetti, 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). Edmonds et al. (2004) consider advanced technology development to be far more important as a driver of emission reductions than carbon taxes. 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. 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.

The failure of many worthy technologies to move from the research and development to commercialization is often the most difficult stage, and has been referred to as the “valley of death” for new products. Attempts to move to renewable technology into mainstream markets following the oil price shocks failed at the time 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 Deployment of policies (supply push vs. demand pull)

The task of policy and decision makers with respect to the market can have a variety of approaches: 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 Research and Development, 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 research and development attempt to create new products through market push. 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. 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. The United States has relied mostly on government R&D subsidies for renewable energy 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.

The use of Renewable Portfolio Standards (RPS) has been moderately successful in some states in the United States. 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 likely soon to become the largest producer of PV technology. Having dropped its domestic incentives for PV technology, Japan has fallen 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. So many governments resort to levelling the playing field by granting similar subsidies to renewable energy technologies.

1.5.4 Integrate policies into sectors

Since all forms of renewable energy capture and production involve spatial considerations, policies need to consider land use, employment, transportation, agricultural and other sector specific issues.

The major focus for renewable energy is the electric power sector where we see a 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.

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.

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 developing 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.

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 renewable energy supply (land use, option values, aesthetic concerns, etc.) as well as review co-benefits associated with the development of that particular form of renewable energy (e.g., reduction in Criteria Air Contaminants, GHG emissions reduction). Current 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 recent 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 et al, 2004; Tobias et al, 2007)

It is also critical to consider the potential of RE to reduce emissions from a life cycle perspective. The fundamental reason that biofuels present the opportunity for lower GHG emissions is that biomass feedstocks absorb CO_2 for growth during photosynthesis in relatively short time scales (in a sense petroleum is a “renewable source – but its CO_2 “absorption” occurred over very long time scales. In general, the growth of biomass feedstocks could offset some, if not all, of the combustion CO_2 emissions, resulting in reduced life cycle GHG emissions. However, direct and indirect land-use changes are important aspects that must be evaluated when considering biofuels. Such changes can include deforestation, conversion of grasslands to agricultural production, or diversion of agricultural production to fuel production. These may result in considerable GHG emissions, and can potentially overwhelm the gains from CO_2 absorption. An illustrative life cycle analyses, featuring expanded boundaries, for aviation is shown in Figure 1.13. The use of different approaches to life cycle analyses can lead to substantially different results. Ultimately, the best one might achieve is to quantify uncertainties and provide policy makers with a range of possible outcomes. Clearly, there are many complexities and global guidance will be needed to ensure a robust accounting of the benefits and negative externalities of RE.

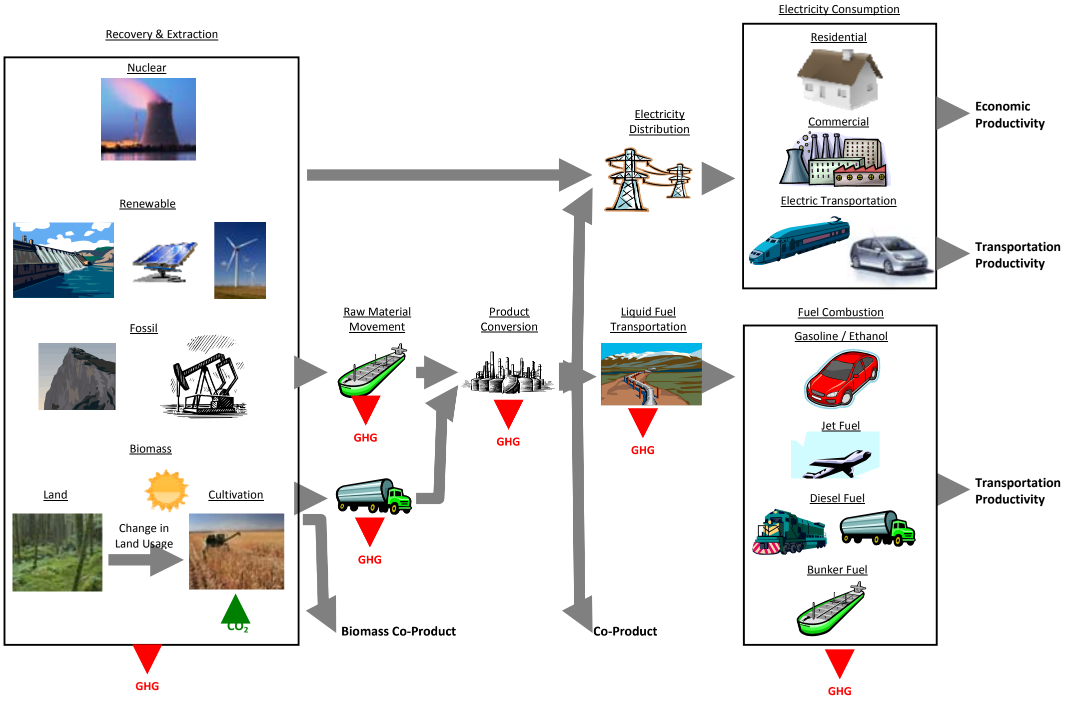


Figure 1.13. Illustrative system for energy production and use illustrating the role of RE along with other production options. A systemic approach is needed to conduct life cycle analysis. [TSU: Source?]

1.5.6 Options are available if policies are aligned with goals

An examination of alternative policies to encourage adoption of renewable energy 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 renewable energy, it has been more effective than renewable portfolio standards (Carpenter, 2009). For example, Germany has moved from having essentially no renewable energy in 1989 to being a leading user and producer of wind and solar power (Sawin and Moomaw, 2009), and the government recently announced a goal to become 100% renewably powered by 2050 (Bundesministerium, 2009). According to David Wortmann, Director of Renewable Energy 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 renewable energy supply into grid system

All renewable energy forms must function within the current system (although many may in fact be stand alone when communities or demand is isolated from the energy system). Institutional or operational barriers may prevent the advent of renewable energy into the system. Utilities in many parts of the world are also focused on all aspects of the energy system and may form monopolies where a broader market representation may in fact be available and be allowed to exist. Most countries have found that there are significant barriers to introducing renewable energy to the grid because of the structure of existing regulations that do not recognize the benefits of these technologies, and favour traditional power sources. Europe and the United States have had to deal with interconnection standards, net metering, issues of variability of power output, discriminatory practices against distributed energy sources of all kinds, and a failure to recognize the benefits to clean air and other environmental quality measures. Where these issues have been addressed the penetration of renewable energy has been greatest.

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