INTERGOVERNMENTAL PANEL ON climate change

Technical Summary

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The Technical Summary has been allocated a total of 102 pages in the SRREN. The actual length is 134 pages (excluding cover page), a total of 32 pages over target. Government and expert reviewers are kindly asked to indicate where the chapter could be shortened in terms of text and/or figures and tables.

All monetary values provided in this document will need to be adjusted for inflation/deflation and then converted to US$ for the base year 2005.

Please note that the Technical Summary should not contain any references in the text; only figures and tables are referenced. In addition, section numbers should be provided in brackets, indicating where the original text can be found in the chapters.

SRREN – TECHNICAL SUMMARY

CONTENTS

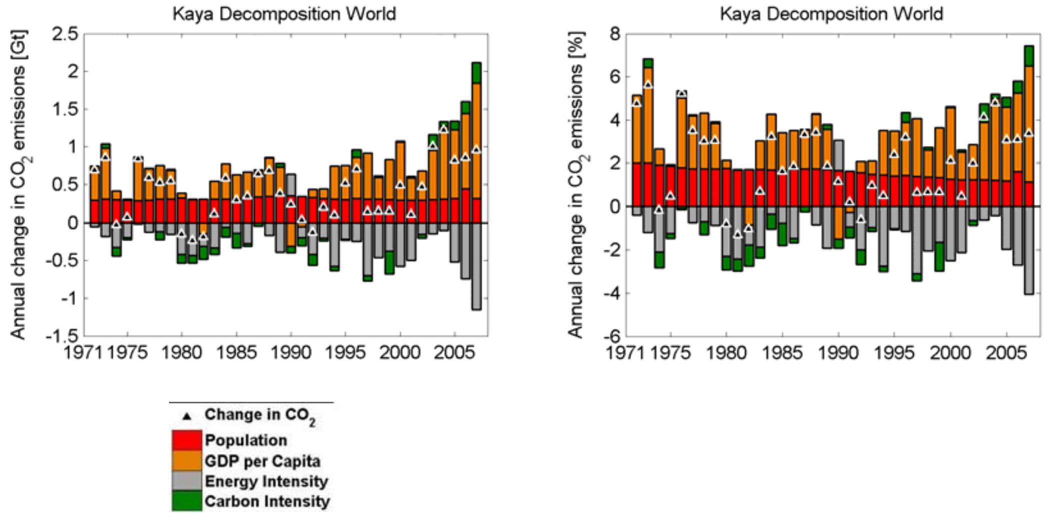
Renewable Energy and Climate Change

Climate Change

A primary driver of the industrial era has been the burning of fossil fuels to provide energy for industry, transportation, heat and electric power. The trapping of radiant heat by carbon dioxide (CO_2) released during combustion of these fuels is now understood to be a major contributor to global warming and climate change. In 2007, the IPCC’s Fourth Assessment Report (AR4) expressed very high confidence (>90%) that the global average net effect of human activities since 1750 has been one of warming. The AR4 projected that global annual average temperature will rise over this century by between 1.1 and 6.4°C depending on which of the socio-economic scenarios best fits actual future GHG emissions.

To develop strategies for reducing CO_2 emissions, we can use the Kaya identity (Figure TS 1.1) which 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).

$$CO_2 = \text{Population} \times (\text{GDP/population}) \times (\text{TPES/GDP}) \times (CO_2/\text{TPES})$$



a) Absolute growth **b) Relative growth**

Figure TS 0.1. 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. In recent years (2000 – 2007), increases in carbon intensity have mainly been driven by the expansion of coal use in both developed and developing countries, demonstrating the need of shifting from carbon intensive fossil fuels to alternative low carbon sources for energy services. Renewable energy technologies have an important role to play in reducing emissions of CO_2.

The Role of renewable energy in addressing Climate Change

The challenge is to find a way to continue providing energy and other services in a sustainable manner that does not impact climate. There are multiple means for lowering the heat trapping emissions from energy sources, while still providing energy services. The AR4 identified renewable energy (RE) along with efficiency improvements as major contributors toward reducing anthropogenic emissions that impact climate.

The following mitigation options related to energy supply are relevant:

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

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

While the low density and disbursed distribution of many forms of RE may not be suitable to some applications (such as energy intense industry), the use of RE and its decentralised nature incurs a number of co-benefits. Apart from climate change mitigation, RE can play a significant role in meeting sustainable development goals, enhancing energy security, employment creation and meeting Millennium Development Goals (MDGs). Production and utilisation of RE can also spur rural and economic development, providing opportunities for farmers and entrepreneurs to produce feedstocks for RE production and participate as owners of production facilities across all types of RE.

This Special Report on RE explores the potential for low carbon renewable energy sources in combination with energy efficiency to meet GHG reduction goals. It provides information for policy makers, the private sector and civil society on:

I. Renewable resources by region and impacts of climate change on these resources;
II. Mitigation potential of RE sources;
III. Linkages between RE growth and co-benefits in achieving sustainable development by region;
IV. Impacts on global, regional and national energy security;
V. Technology and market status, future developments and projected rates of deployment;
VI. Options and constraints for integration into the energy supply system and other markets, including energy storage options;
VII. Economic and environmental costs, benefits, risks and impacts of deployment;

VIII. Capacity building, technology transfer and financing in different regions;
IX. Policy options, outcomes and conditions for effectiveness; and
X. How accelerated deployment might be achieved in a sustainable manner.

Summary of Renewable Energy Resources and Potential

The theoretical potential for renewable energy exceeds current and projected global energy demand by far, but the challenge is to capture and utilize it to provide the desired energy services in a cost effective manner. Since 1990, global energy consumption almost doubled, rising to around 441 EJ in 2007. Various forms of RE are universally available, and can readily be introduced in both developed and developing countries. The technical potential for RE exceeds the estimated 'business as usual' demand by a factor of 50 by 2050.

Renewable resources are far more widely distributed among all nations than are fossil fuels and uranium. Thus, from an energy security perspective, they are more reliable than other energy resources for fossil-fuel poor countries. In most cases, the costs of RE technology are known and, while there will be local variation, there is considerable certainty over future energy prices, which for many renewables is zero. Reducing price volatility is important for all economies, but especially for poorer nations.

There may be potential resource disadvantages but these can be addressed. Variability may be overcome by using multiple RE technologies with differing variability timing and frequency, matching demand to supply (solar energy and space cooling), decoupling demand and supply as in water pumping or desalination, and through demand side management and energy storage systems. These approaches increase complexity and information management requirements and raise the cost of RE systems. Higher initial capital investment can be addressed by financing systems similar to meeting capital costs of other capital-intensive investments.

The theoretical potential for renewable energy significantly exceeds the global demand but the challenge is to capture and utilize RE to provide the desired energy services in a cost effective manner. Still, Table TS **1**1.1 shows that even the technical potential exceeds the estimated business as usual demand by at least a factor of 10 by 2050. The table provides a perspective for the reader to understand the relative sizes of the RE resources in the context of demand for energy in the future. Both the technical potentials and future demand are highly uncertain; any further refinement of the values adds little to the discussion.

Table TS 1.1 Technical potential for renewable energy (EJ/y)

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

1. Technical potential estimates for 2020, 2030, and 2050 are based on a review of studies in (Krewitt, et al., 2009); data presented in Chapters 2-7 may disagree with these figures due to differing methodologies.

2. Range of estimates comes from studies reviewed by (Krewitt, et al., 2009)as revised based on data presented in Chapters 2-7.

3. Estimates for PV and CSP from (Krewitt, et al., 2009) for 2020, 2030, and 2050 are based on different data and methodologies, which tend to significantly understate the technical potential for PV relative to CSP.

4. Primary energy from biomass could be used to meet electricity, thermal, or transportation needs, all with a conversion loss from primary energy ranging from roughly 20% to 80%.

5. Even the high-end estimates presented here take into account key limitations with respect to food demand, water availability, biodiversity and land quality.

6. IEA (2009)

7. DLR (2008)

Meeting Energy Service Needs and Current Status

Renewable energy can supply the same energy services to users as conventional primary energy sources, and in some cases without the thermal losses to which combustible fuels are subject. The same energy services can also be provided with differing amounts of end-use energy. Economies are driven by energy, and over 80% of primary energy comes from the combustion of fossil fuels, which is the source of 60% of GHGs. Hydropower, nuclear energy and a portfolio of renewable sources provide the remainder of non carbon dioxide emitting energy.

There is a multi-step process whereby primary energy is converted into an energy carrier, and then into end use energy (total final consumption) to provide energy services for the various economic sectors. Since it is the ultimate energy services of electronics, lighting, heating, cooling, transportation or industrial and mechanical processes, careful design can minimize the amount of energy required to accomplish those services, and extract the required energy from renewable and other low GHG emitting sources. This is illustrated in Figure TS 1.2.

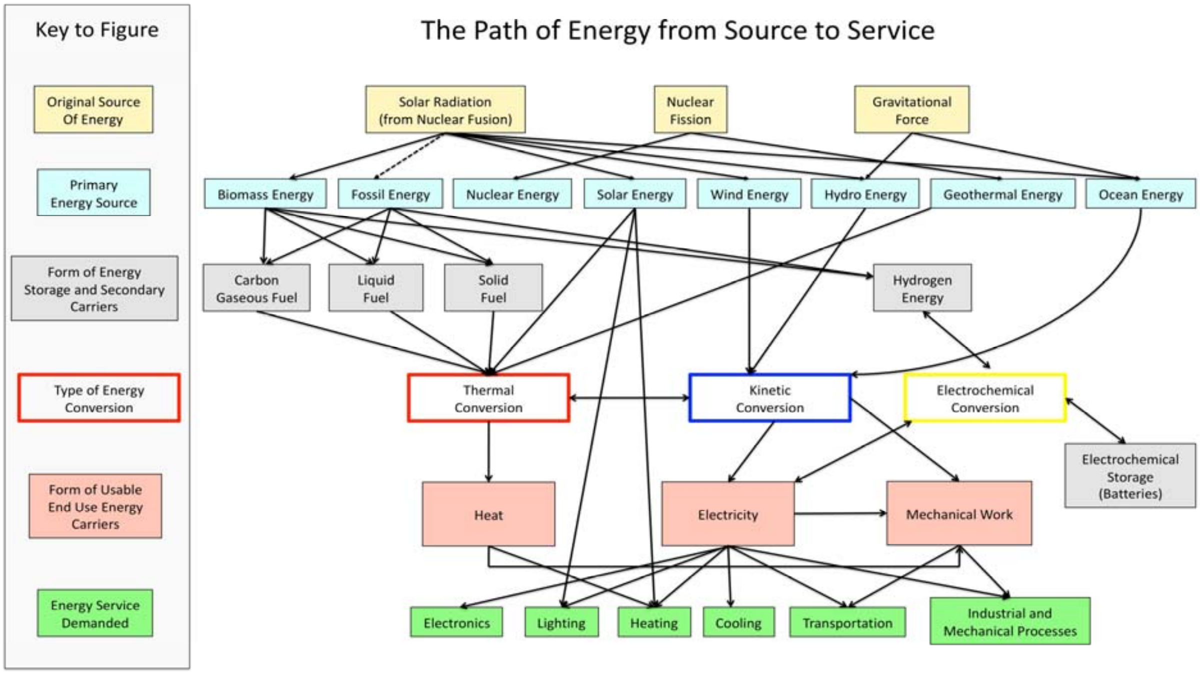


Figure TS 1.2 The Path from Source to Service. The energy services delivered to the users can be provided with differing amounts of end use energy. This in turn can be provided with more or less primary energy and with differing emissions of carbon dioxide and other environmental impacts. [TSU: reference missing]

Thermal conversion processes to produce electricity (including from biomass and geothermal) suffer losses of approximately 50-90% and losses of around 80% to supply the mechanical energy needed for transport. Direct energy conversions from solar, hydro, ocean and wind energy to electricity do not suffer these thermal losses. Direct heating from geothermal, biomass and solar thermal systems can also be highly efficient processes. By comparison, CCS requires substantial energy inputs, which would increase the demand for primary energy to supply the same amount of end use energy for energy services [1.3.1.1].

Global energy flows and investment in primary RE

UNEP data indicates that global investment in RE 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, 2009; REN 21, 2009b). UNEP estimates that an additional $15 billion was invested in energy efficiency during the year. Approximate technology shares of 2008 investment were wind power at 42%, solar PV 32 %, biofuels 13%, biomass and geothermal power and heat 6%, solar hot water 6% and small hydropower at 5%). An additional $40–45 billion was invested in large hydropower ((REN21, 2009a)).

In recent years, RE has contributed 23% of added capacity. Traditional biomass accounted for the majority of global primary energy consumption due to its wide spread traditional use particularly for cooking and lighting in developing countries.

Between 2003 and 2008, solar installations grew at an average annual rate of 56%, biofuels and wind at 25% and hydro by 4%. Germany in 2008 produced 15% of its electricity and 10% of its total energy from renewable sources. The developing world is particularly ripe to adopt evolving RE technologies as it can often leapfrog adaptation in developed economies. 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 RE.

Figure TS 1.3 reflects primary RE only, utilizing the data for 2007. ‘RE’ here includes combustible biomass, forest and crop residues and municipal solid waste as well as the other types of RE considered in this report: solar energy, hydropower, oceans, geothermal and wind.

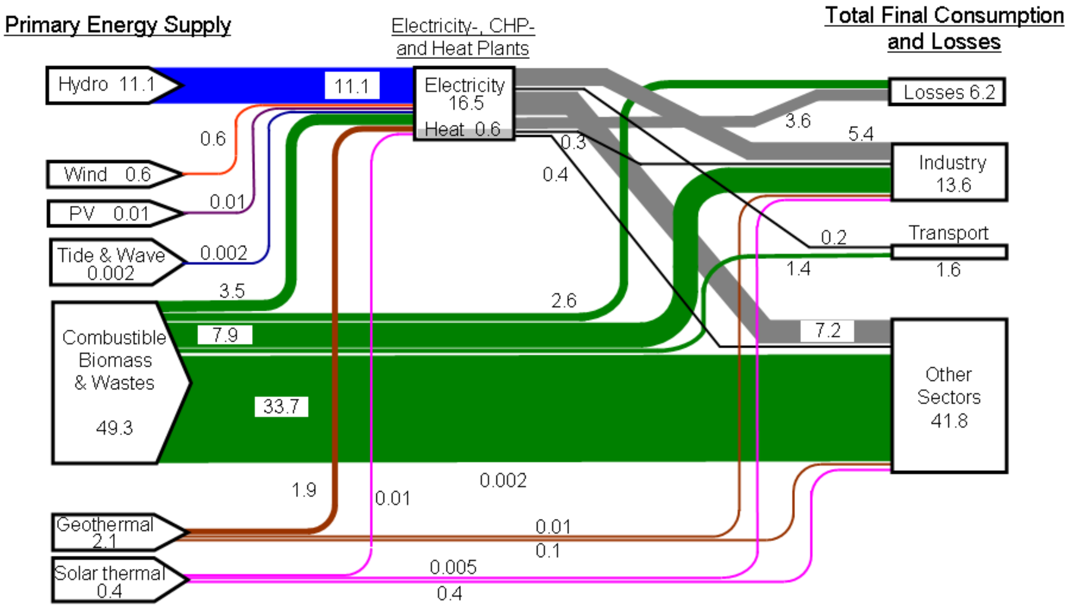


Figure TS 1.3 Global energy flows (EJ in 2007) from primary RE through carriers to end-uses and losses (based on IEA data). ‘Other sectors’ include agriculture, commercial and residential buildings, public services and non-specified other sectors. ‘Transport sector’ includes international aviation and international marine bunkers.

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. The flow of biomass, which includes traditional uses, dominates this figure, but there is significant investment in modern RE technologies as noted above and accompanying rapid growth.

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

Economic, social, and ecological benefits are further motivating governments and individuals to adopt RE because they offer the potential to simultaneously realise multiple goals in relation to sustainable development [11.3] The key drivers of RE policy are: climate change mitigation; enhanced access to energy services, in particular for the poor as a basic aspect of poverty reduction and achievement of the MDGs; improved health, education and environmental living conditions; higher security of energy supply at stable prices; diversity of energy sources; and economic development and domestic job creation. The relative importance of the drivers, opportunities and benefits of RE varies from country to country and over time as changing circumstances affect economies, attitudes and public perceptions [10.6, 11.3].

RE generation replaces conventional energy generation reducing local pollutants. See Figure TS 1.4. For energy production technologies based on combustion, impacts and external costs arise largely from emissions of particulates and gases to air [10.6.2]. RE technologies have significant benefits for reducing air and water pollution, and damage to land from mining, subsidence and oil spills [1.1.6].

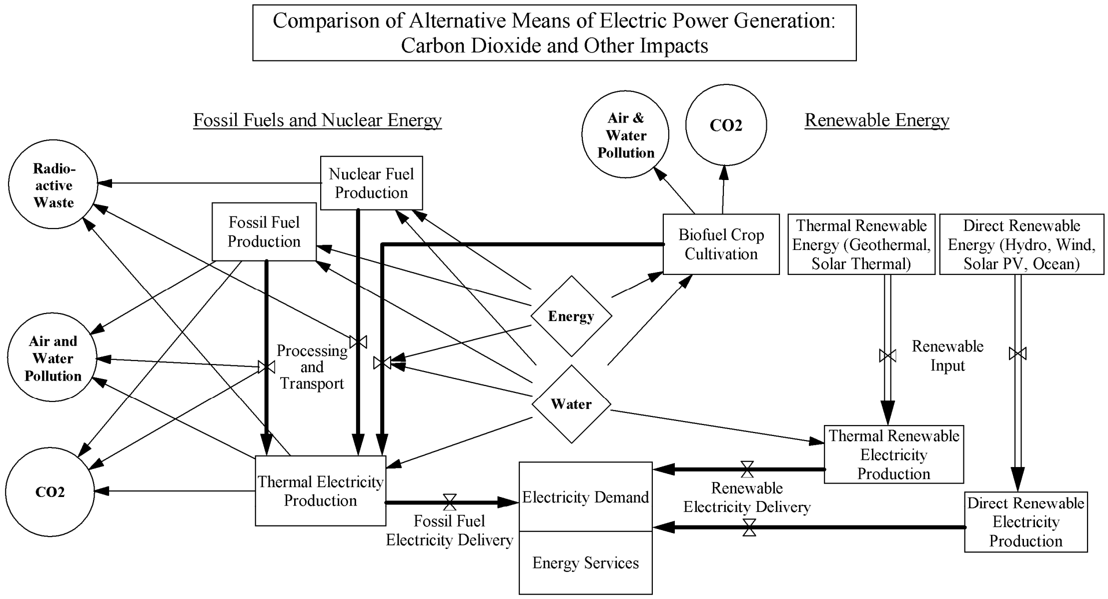


Figure TS 1.4. Comparison of co-benefits, water use and CO_2 emissions associated with primary energy sources for electricity production. Not included are land impacts from surface mining of coal, land clearance for bioenergy and hydro reservoirs or methane leakage from coal natural gas and petroleum production and use or damage from oil spills and coal ash storage [1.1.6]. [TSU: reference missing]

Climbing the Energy Ladder in Developing Countries

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

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 may be different from that of developed countries, to raise the electrification rate is indispensible for developing countries.

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

With development, there is generally a transition up the 'energy-ladder' to fuels that are progressively more efficient, cleaner, convenient and expensive, such as natural gas, LPG and electricity. Electricity allows tasks previously performed by hand or animal power to be done much more quickly with electric powered machines. Of interest in the energy ladder transition is the opportunity to use RE rather than diesel generators for either off or on-grid applications. Commercial energy sources also permit the use of modern technologies that transform the entire production process at the factory level, in agriculture and within the home.

Barriers and Issues

Almost everywhere in the world, one can find a RE resource of one kind or other. Then, why then is RE not in universal use?

Firstly, there are *barriers*, 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'. The various barriers can be categorised as informational, socio-cultural, technical and structural, economic, or institutional. More importantly, however, they are interrelated and need to be dealt with in a comprehensive manner. Some of these barriers relate directly to energy prices and not accounting for the 'externalities' they do or do not address. Others (e.g., the institutional or informational barriers) would remain barriers to RE even in the presence of 'perfect markets'. A summary of barriers and potential policy instruments to overcome these barriers is shown in Table TS1.2.

Table TS 1.2. A categorisation of barriers to RE deployment

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

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.

As for every type of energy technology, environmental and social impacts exist for each of the RE technologies, and will need to be carefully managed to ensure sustainable growth of supply. Because of the diversity of RE sources and technologies and their reliance on differing and sometimes-diffuse energy resources, the impacts and their potential mitigation will vary by technology. Such social and environmental impacts affect deployment opportunities for RE as well as conventional energy sources.

Role of Policy, R&D, Deployment, Scaling Up and Implementation Strategies

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. In particular, the long-term certainty inherent in European feed-in-tariffs has proven successful in creating a manufacturing industry for renewable energy technologies. 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. Sufficient investment will be required to ensure that the best technologies are brought to market in a timely manner. However, market barriers exist that prevent the development and penetration of novel renewable energy technologies into the energy system. Therefore, 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.

There are a variety of approaches to facilitate the introduction of RE to the market. 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.

The major focus for renewable energy is the electric power sector where there is a need to introduce new technologies and to rebuild the transmission and distribution grid. 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.

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. It is also critical to consider the potential of RE to reduce emissions from a life cycle perspective.

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. Where these issues have been addressed, the penetration of renewable energy has been greatest.

Bioenergy

Introduction Current Pattern of Bioenergy Use and Trends

Chapter 2 discusses biomass, a primary source of fibre, food, fodder and energy. Estimating the future mitigation potential of bioenergy presents unique analytical challenges compared to other renewable energy sources, given the many existing and rapidly evolving bioenergy sources; complexities of physical, chemical, and biological conversion processes; variability in site specific environmental and socio-economic conditions; the many interlinkages between bioenergy and other land-based activities, such as food and fibre production, forest protection, and more, and political interests triggered by the rapid evolution in production and use of liquid biofuels. Methodological and practical challenges are overcome by undertaking an integrated and comprehensive global review of the mitigation potential of bioenergy up to the year 2030.

Since society began biomass is the most important renewable energy source, providing about 10% (46 EJ) of the annual global primary energy demand. A major part of this biomass use (37 EJ) is related to charcoal, wood and manure used for cooking and space heating, generally by the poorer part of the population in developing countries called traditional bioenergy. Modern bioenergy use (for industry, power generation, or transport fuels) is already making a significant contribution of 9 EJ, and this share is growing.

Currently, modern bioenergy chains involve a range of feedstock, conversion processes and end-uses. Feedstock types include dedicated crops or trees, residues from agriculture and forestry and related transformation industries, and various organic waste streams. Their economics and yields vary across world regions and feedstock type/conversion processes, with costs ranging from 5 to 80 US$/GJ biofuels, from 5 to 20 US$/GJ for electricity, and from 1 to 5 US$/GJ for heat from solid fuels or waste. There are several important competitive bioenergy systems today, most notably sugar cane based ethanol production and heat and power generation from residual and waste biomass. Depending on energy prices and specific market conditions, smaller scale applications (for power heat and biofuels) can compete, such as Jatropha oil production in rural settings.

Resource Potential

The assessment of the biomass potential renders a range of estimates from different sources as well as the opportunities and limitations from the potential competition for land, water and other resources. Narrowing the biomass resource potential to distinct numbers is not possible. But it is clear that several hundred EJ per year can be provided for energy in the future, given favourable developments. It can also be concluded that:

- Biomass use for energy can already today be strongly increased over current levels based on increased use of forestry and agricultural residues [2.2.5]
- The medium and longer term energy crop potential depends strongly on productivity increases that can be achieved in food production and environmental constraints that will restrict energy crop cultivation on different land types. [2.2.5]
- The cultivation of suitable lignocellulosic crops can allow for higher potentials by making it possible to produce bioenergy on lands where conventional food crops are less suited and would lead to larger soil carbon emissions. [2.2.5]
- Water constraints may limit production in regions experiencing water scarcity. The use of suitable drought tolerant energy crops can help adaptation in water scarce situations. Assessments of biomass resource potentials need to more carefully consider constrains and opportunities in relation to water availability and competing use. [2.2.5]

While recent assessments employing improved data and modelling capacity have not succeeded in providing narrow distinct estimates of the biomass resource potential, they have advanced the understanding influential parameters. Some of the most important parameters are inherently uncertain and will continue to obscure long term biomass supply potentials. However, insights from resource assessments can improve the prospects for bioenergy by pointing out crucial development areas. [2.2.5]

The expected deployment of biomass for energy on medium to longer term differs considerably between various studies. Large scale biomass deployment is largely conditional: deployment will strongly depend on sustainable development of the resource base and governance of land-use, development of infrastructure and on cost reduction of key technologies. Based on the current state-of-the-art analyses, the upper bound of the biomass resource potential halfway this century can amount over 400 EJ. This could be roughly in line with the conditions sketched in the IPCC SRES A1 and B1 storylines, assuming sustainability and policy frameworks to secure good governance of land-use and improvements in agricultural and livestock management are secured. [2.8.3]

If the right policy frameworks are not introduced the expansion of biomass use can lead to significant conflicts in different regions with respect to food supplies, water resources and biodiversity. Supply potential may then be constrained to a share of biomass residues and organic wastes, some cultivation of bioenergy crops on marginal and degraded lands and some regions where biomass is evidently a cheaper energy supply option compared to the main reference options (which is the case for sugarcane based ethanol production). Biomass supplies may then remain limited to an estimated 100 EJ in 2050. [ES]

Technology

Feedstock production or recovery. Feedstock types may be classified as dedicated crops or trees (i.e., plants grown specifically for energy purposes), primary residues from agriculture and forestry, secondary residues from agro and forest industries, and organic waste from livestock farming, urban, or industry origin. Biomass may be harvested several times a year (for forage-type feedstock such as hay or alfalfa), once a year (for annual species such as wheat or perennial grasses), or every 2 to 50 years or more (for short-rotation coppice and conventional forestry, respectively). Problems arise if fuelwood extraction and wood extraction for commercial purposes exceeds forest regeneration capacity, which occurs in many parts of the world. [2.3.1.1]

The intensity in the use of production factors (inputs, machinery, labour or land) may vary across world regions for a similar species. Within a given region, similar yield levels may be reached through a variety of cropping systems and production intensities. [2.3.1.1]

Recoverability of **primary residues** is 25 and 50 % for logging residues and 33 and 80% of processing residues (plant materials that remain on the farm after removal of the main crop produce). **Secondary residues** are by-products of post-harvest processing of crops, namely, cleaning, threshing, sawing, sieving, crushing, etc. Although modes and volumes of agricultural residue production may differ by production area, the rates of production of residues relative to crop marketable yield are reported as 140% for rice, 130% for wheat, 100% for corn, and 40% for rhizomic crops. There are several alternative uses of agricultural residues (e.g., animal feed, soil erosion control, animal bedding, and fertilizers). Residue availability is difficult to predict and varies seasonally. [2.3.1.1]

Residues and waste streams are a coveted resource since their apparent costs only include collection, pre-conditioning and transport. Their export has to be carefully managed to avoid jeopardizing soil organic matter content and fertility in the long-run, which typically brings down their theoretical availability by 70% to 80%. Nutrient exports should also be compensated for, possibly by recycling residual ash, stillage or digestate from the bioenergy conversion process. [2.3.1.1]

Bioenergy feedstock interactions with the agriculture, food & forest sectors. Energy feedstock production may compete with the food, feed, fibre and forest sectors directly for land or for a stream of biomass (e.g., cereal straw for cattle bedding material vs. energy production). The outcome of these competition effects hinges on the economics of supply and demand for the various sectors and markets involved, at regional to global scales. At a local scale, synergistic effects may also emerge between competing usages. For instance, integrated agroforestry enables land use for both food and energy purposes with mutual benefits for the associated species, integrated agriculture for food, feed, and various types of energy products is already taking place including grazing reductions requirements in several cases. Double cropping and mixed cropping are strategies to maximize the output of land. [2.3.1.2]

Perennial species create positive externalities such as erosion control, improved fertilizer use efficiency, reduction in nitrate losses and water stress, and provision of habitat for biodiversity and biological control of pests. According to Practical Action Consulting (2009) bioenergy feedstock does not affect local staple food security provided feedstock benefits are distributed to local communities. [2.3.1.2]

Logistics and supply chains. Most non-woody biomass is available in loose form with low bulk densities, causing handling, transportation and storage problems. Shredded biomass residues may be densified by briquetting or pelletizing. Briquettes and pellets can be renewable substitutes for coal, lignite and fuelwoodthat have consistent quality, size, better thermal efficiency, and higher density than loose biomass. Chips, a by-product of conventional forestry, require less processing and are cheaper than pellets. Charcoal has double the calorific value of the original feedstock, burns without smoke, and is used widely. In Africa, illegal charcoal production is seen as a primary threat to remaining wildlife habitats. [2.3.2.1] Charcoal making is an enterprise for rural populations to supply urban markets. Crop residues and dung are normally used by the owners as a seasonal supplement to fuelwood. [2.3.2.2]

Conversion technologies. Biomass feedstocks can be converted through a variety of existing and evolving conversion processes to products for a variety of end-use summarized in Table TS 2.1. Many types of integrated biomass refineries are entering markets worldwide in various scales. [2.3.3]

One thermochemical process is biomass combustion, used by about 2.4 billion people in developing countries, who use firewood in inefficient traditional open fire cook stoves in poorly ventilated kitchens leading to major health problems. Major efforts launched to improve efficiency and reliability of cook stoves have reached 800 million people so far over the past ten years (WHO, 2009). Simultaneously, large-scale combustion and cogenerationof more than one form of energy from one source are reaching combined efficiencies of 90% in Nordic and other countries and used in district heating. [2.3.3.1]

Bioenergy Systems and Chains: Description of existing state of the art systems. Liquid biofuels are mainly used in the transport sector and ethanol costs are usually lower than biodiesel for commercial systems (based on rapeseed, soya and oil palm). Conversion efficiency (from feedstock to end-use product) is modest, from a little over 50% to around 10% for co-products of food production. Solid biomass, mostly used for heat, power and heat & power usually has lower production costs than liquid biofuels. Unprocessed solid biomass is less costly than pre-processed (via densification), but for the final consumer the transportation and other logistic costs have to be added, which justify the existence of a market for both types of solid biomass. [2.3.4]

Table TS 2.1. Main routes for converting biomass to a range of possible end-uses

Process	Type of Feedstock	Example of Conversion Technology	End use from conversion technologies
Thermo-chemical conversion	Lignocellulosic crops, wood , primary and secondary residues, aquatic biomass	Combustion Cogeneration Pyrolysis Gasification Liquefaction	Cooking/heating/electricity/ cogeneration Last three also provide liquid fuels such as ethanol, other alcohols, ethers, hydrogen, methane, hydrocarbon fuels. Also monomers for polymers and chemicals
Chemical	Oil crops or aquatic biomass, waste	Hydrolysis/ Transesterification Catalytic processing	Electricity /liquid biofuels (biodiesel)/ chemicals Renewable hydrocarbon fuels
Biochemical	Starch, sugar, lignocellulosic crops, wood, residues, organic waste, aquatic biomass	Anaerobic digestion Pretreatment/Hydrolysis followed by Fermentation or Biological synthesis or Catalytic upgrading	Cooking/heating/ power /liquid biofuels for vehicles Ethanol, butanol, direct diesel and jet fuel replacements. Monomers for plastics or biobased products

Source: E4tech, 2009, Cherubini et al.,2009, IEA Bioenergy: ExCo: 2007:02

Global and Regional Status of Market and Industry Development

We provide the global and regional status of market and industry development in bioenergy. For local markets the use of bioenergy technologies provides a simple, local and renewable solution for energy related to cooking, heating and lighting mainly in rural areas. Widespread dissemination of these technologies may be limited by purchasing power, availability, and access to the biomass resource. Lack of education, awareness and motivation are among the prime factors that hinder regional penetration.

The amount of traditional biomass used is very uncertain because fuels are often not purchased commercially and therefore must be estimated indirectly in most cases. Modern bioenergy use (for industry, power generation, or transport fuels) is making already a significant contribution of 10 EJ and this share is growing. Today, biomass (mainly wood) contributes some 10% to the world primary energy mix, and is still by far the most widely used renewable energy source (Figure TS 2.1).

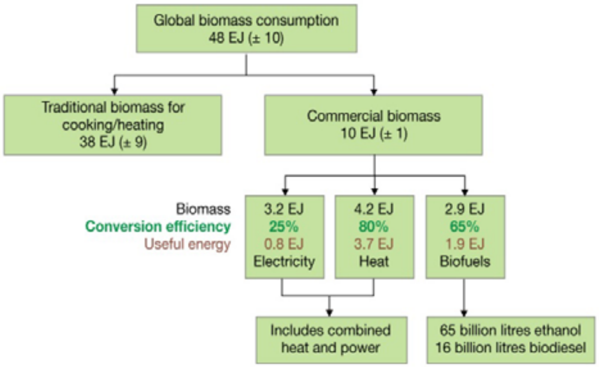


Figure TS 2.1 Global biomass consumption for bioenergy and biofuels in 2008. Source: based on IEA 2009 update of 2007

One of the fastest-growing applications of biomass is the production of biofuels based on agricultural crops –global biofuels preliminary supply estimates are at 1.9 EJ (2008), a significant growth from1.43 EJ in 2007, when it accounted for 1.5% of total road-transport fuel. Most of the increase in the use of biofuels in 2007 and 2008 occurred in the OECD, mainly in North America and Europe.

Review of developments in biomass use, markets and policy shows acceleration of efforts over the past years. Bionergy use is growing, in particular, in biofuels with an increase of 37% from 2006-2009.Significant overcapacity was built because the global economic situation deteriorated, but is projected to recover. Projections from IEA, but also many national targets, count on biomass to deliver a substantial share of projected renewable energy increases. According to the 2009 World Energy Outlook scenarios, biofuels may contribute 5.7 to 11.6 EJ to the global transport fuel demand, meeting about 5% to 11% of total world road-transport energy demand, up from about 2% today (IEA, 2009). In the 450 Scenario, biomass consumption also increases and in 2030 is 14.7 EJ higher than in the Reference Scenario.

International trade of biomass and biofuels has also become much more important over time, with roughly 10% of biofuels and a third of all pellet production for energy producing trade internationally (Junginger et al., 2010). The latter has proven to be an important facilitating factor in both increased utilisation of biomass in regions where supplies are constrained as well as mobilising resources from areas with reduced demand, creating economic development opportunities for both. Many barriers remain in developing well working commodity trading of biomass and biofuels that meet sustainability criteria.

The policy context for bioenergy in many countries changed rapidly and dramatically with rapid increases in food prices in 2007 reaching a peak in 2008 and then falling rapidly again to now down 13% for the year while non-food agricultural commodities are up 20%. The debate on food vs. fuel competition and the growing concerns about other conflicts have resulted in a strong push for the development and implementation of sustainability criteria and frameworks as well as changes in temporization of targets for bioenergy and biofuels. Furthermore, the support for advanced biorefineries and second generation biofuel options does to drive bioenergy to more sustainable directions.

Leading modern biomass use nations like Brazil, Sweden, Finland and the US, have shown that persistent policy and stable policy support is a key factor in building biomass production capacity and working markets, the required infrastructure and conversion capacity that gets more competitive over time, and generates considerable economic activity.

Countries differ in their priorities, approaches, technology choices and support schemes bioenergy development. On one hand policies are complex, but this is a reflection of the many aspects that affect bioenergy deployment; agriculture and land-use, energy policy & security, rural development and environmental policies. Priorities, stage of development and physical potential and resource availability differ widely from country to country and for different settings.

Environmental and Social Issues

The effects of bioenergy on social and environmental issues – ranging from health and poverty to biodiversity and water quality – may be positive or negative depending upon local conditions, the specific feedstock production system and technology paths chosen, how criteria and the alternative scenario are defined, and how actual projects are designed and implemented, among other variables. Perhaps most important is the overall management and governance of land-use when additional biomass is produced for energy purposes on top of meeting food and other demands from agricultural production (as well as livestock).

In case biomass production is in balance with improvements in agricultural management undesirable (i)LUC effects can be avoided, while unmanaged, conflicts may emerge. The overall performance of bioenergy production systems is therefore interlinked with management of land-use. Such processes are shown in Figure TS 2.2, along with benefits and risks, and how biomass production can be influenced by interactions and feedbacks among land use, energy and climate in scales that range from field level up to global market effects. Tradeoffs between environmental, social, and economic dimensions exist and need to be resolved by appropriate strategies. Such strategies are currently emerging due to many efforts targeting the deployment of sustainability frameworks and certification for bioenergy production, setting standards for GHG performance, addressing land use change (LUC) effects, environmental issues, social aspects, etc., but these are by no means finalized and fully implemented. The main challenge is to interlink land use management and the agricultural sector at large with (gradual) development of the potential biomass resource potential.

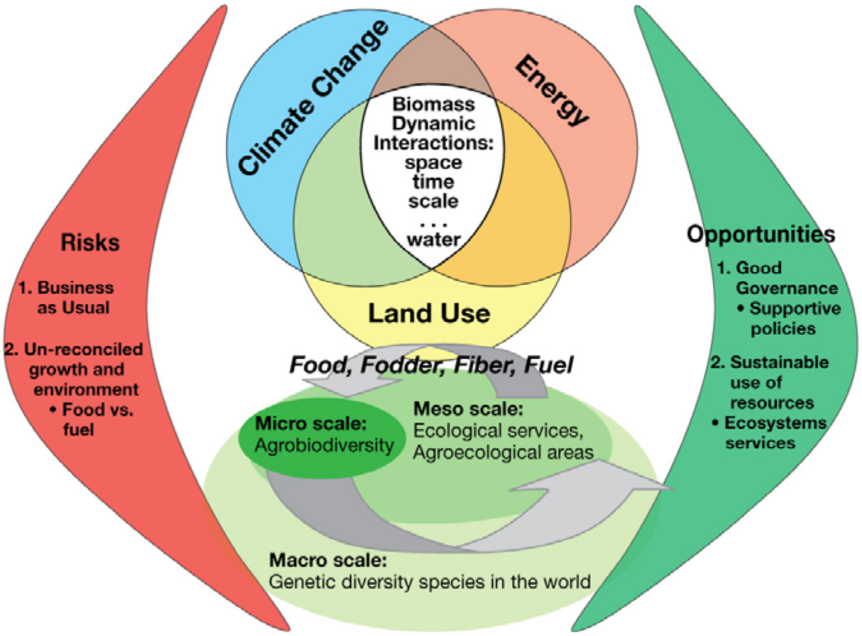


Figure TS 2.2 Climate Change-Land Use-Energy Nexus. Adapted from Dale et al., submitted and van Dam et al., 2009.

GHG impacts of bioenergy systems are well quantified in state-of-the-art literature. Recent assessment of GHG performance of key biofuel production systems deployed today and possible 2^{nd} generation biofuels using different calculation methods (see, Hoefnagels et al., 2010) conclude that well managed bioenergy production and utilization chains can deliver high GHG mitigation percentages (80-90%) compared to their fossil counterparts,especially lignocellulosic biomass used for power generation, and when commercially available 2nd generation biofuels. Generally residues and organic wastes used for energy result in good performance. Most current biofuel production systems have positive GHG balances, without iLUC effects incorporated. Sugar cane based ethanol typically already shows good GHG performance (with reductions over 80%) and most biofuel production from corn and rapeseed, when managed properly, shows reductions in the 35%- 50% range. (i)LUC can strongly affect those scores and when conversion of land with large carbon stocks takes place directly or indirectly, emission benefits can shift to negative levels. Extreme carbon emissions are obtained if peatlands are drained and converted to oil palm rather than established on marginal grasslands with lower carbon stocks than the plantation itself, then overall negative GHG emissions can be achieved (Wicke et al., 2008). The GHG mitigation effect of biomass use for energy (and materials) strongly depends on feedstock choice, location (in particular avoidance of converting carbon rich lands to carbon poor cropping systems) and avoiding iLUC (see below). In contrast, perennial cropping systems can store large amounts of carbon and enhance sequestration on marginal and degraded soils in addition to replacing fossil fuels. Governance of land-use and proper zoning and choice of biomass production systems is key to achieve good performance.

Other key environmental impacts cover water use, biodiversity and other emissions. Just as for GHG impact, proper management determines emission levels to water, air and soil. Development of standards and criteria pushes bioenergy production to low emission management. Description of specific biofuel production (and use) with many functionalities enables an appropriate assessment of trade-offs for the use of land and water, and the type(s) of bioenergy products suited for specific projects. An illustrative case study is a prospective impact analysis of alternate Argentinean land-use strategies and cropping systems guiding future development of food, feed, and biofuel (van Dam et al., 2009a,b). Location is the key driver. Environmental impact assessments more broadly quantify environmental, ecological, health impacts, landscape habitat and response, and generate an economic analysis of benefits and impacts.

Water is a critical issue that needs better analysis on a regional level to understand the full impact of vegetation and land-use management changes. Recent studies indicate (Dornburg et al., 2008; Berndes, 2003; Rost et al, 2010) that considerable improvements can be made in water use efficiency in conventional agriculture and biomass crops. Depending on location and climate, perennial cropping systems in particular can achieve benefits in terms of improved water retention and lowering direct evaporation from soils. Without proper management, increased biomass production could come with increased competition for water in critical areas, which is highly undesirable.

Similar remarks can be made with respect to biodiversity, although more scientific uncertainty exists due to ongoing debate on quantification methodologies. Large scale monocultures clearly occur at the expense of nature area biodiversity (for example highlighted in CBD, 2007). In contrast, establishing mixed cropping systems (e.g. agroforestry) as monocultures replacements could increase biodiversity. This is highly location specific and dependent on land-use planning, zoning and depending on biomass production systems. This is also an area that deserves considerably more research, as well as proper monitoring.

As bioenergy production grew rapidly in the past ten years in concert with rising oil and food prices, the consequences of bioenergy development in terms or land use and impacts on the global economic system were questioned. Initial LCA tools were coupled to a variety of macroeconomic/econometric models and to biophysical models or data to assess the consequences of fuel levels proposed by legislation in several countries to agriculture, forestry, and related sectors economic systems. Assessment of the available literature showed that initial models were lacking in geographic resolution leading to higher proportions of assignments of land use to deforestation than necessary because of the lack of lands such as pastures in Brazil. The early paper of Searchinger claimed an iLUC factor of 1 (losing one hectare of forest land for each hectare of land used for bioenergy), later macro-economic model based studies tuned that down to 0.3 – 0.15 and more detailed evaluations of e.g. (Lapola et al., 2010 and IFRI (Al-Fiffai et al, 2010) acknowledge that iLUC effects strongly or even fully depends on the rate of improvement in agricultural and livestock management and the rate of bioenergy production deployment. This balance in development is the basis for the recent European biomass resource potential analysis, for which expected gradual productivity increments in agriculture are the basis for possible land availability as reported in (Fischer et al, 2010 and Wit & Faaij, 2010) and take avoidance of competition with food (or nature) as a starting point. Increased model sophistication to adapt to the complex type of analysis required and improved data on the actual dynamics of land distribution in the major biofuel producing countries is now producing results that are converging to lower overall land use change impacts and acknowledgement that land use management at large is key [2.5.3.1].

Estimates of (i)LUC effects require value judgments on the temporal scale of analysis, land use under the assumed “no action” scenario which has been the basis for most studies , expected uses in the longer term, and allocation of impacts among different uses over time. A system that ensures consistent and accurate inventory and reporting on carbon stocks is considered an important first step toward LUC carbon accounting. Key is that (i)LUC can be avoided and this can be used as starting point for developing bioenergy resources with interlinked integral governance of land use, land use planning and zoning, development of agriculture and livestock [2.5.3.1].

Social impacts from large expansions of bioenergy are complex and difficult to quantify. Generally bioenergy options have a larger positive impact on job creation in rural areas than other energy sources. Rationalized conventional agriculture ‘frees up land’’ for bioenergy providing for increased employmentt and value added in rural regions (see e.g.. Wicke et al., 2009). For many developing countries, the potential bioenergy has for generating employment and economic activity in rural areas is a key driver. Expenditures on fossil fuel (imports) can also be (strongly) reduced. Whether such benefits end up with rural farmers depends largely on production chain organization and land-use governance. Rapid bioenergy deployment could compete with food production. Increases in food prices can be significant especially for poor people as shown by many recent studies that focused on implications of rapid expansion of first generation biofuels produced from food crops. It is acknowledged in many analyses that when such competition is avoided, and value chains are properly organized (e.g, with cooperatives with proper ownership structures and using agroforestry systems), farmers and local economies can be major beneficiaries of additional biomass production for energy (see, e.g., Wiskerke et al., 2010) [2.5.5].

Bioenergy is a component of much larger agriculture and forestry systems of the world, and land and water resources need to be properly managed in concert with the type of bioenergy most suited to the specific region and its natural resources and economic development situation. Bioenergy has the opportunity to contribute to climate mitigation, energy security, diversity goals, and economic development in developed and developing countries. The effects of bioenergy on environmental sustainability may be positive or negative depending upon local conditions, how criteria are defined, how actual projects are designed and implemented, among many other factors.

Prospects for Technology Improvement, Innovation and Integration

Increasing land productivity is a crucial prerequisite for realizing large scale bioenergy potentials. Most increases in agricultural productivity over the past 50 years came through plant breeding and improved agricultural management including irrigation, fertilizer and pesticide use. The adoption of these techniques in the developing world is most advanced in Asia, where it entailed a strong productivity growth during the past 50 years. Considerable potential exists for extending the same gains to other regions, like Sub-Saharan Africa, Latin America, Eastern Europe and Central Asia where adoption has been slow. Recent long-term foresight by the FAO expects global agricultural production to rise by 1.5 percent a year for the next three decades, significantly faster than projected population growth. Major food staple crop’s maximum yields may increase by more than 30% by switching from rain-fed to irrigated and optimal rainwater use production. Moving from intermediate to high input technology may result in 50% increases in tropical regions and 40% in subtropical and temperate regions. One should note that environmental tradeoffs may be involved under strong agricultural intensification. [2.6.1]

Conversion technologies & bioenergy systems. Advanced cultivation techniques could be taken up to increase the production of biomass for energy purposes all over the world. Various developments in technologies are also being explored to improve the conversion efficiencies and for the development of multiple products for various end use applications. In particular, with advances in science and technology of the past ten years, the portfolio of biofuels that now can be produced from biomass has expanded to include a variety of higher energy density fuels that have properties similar to those of diesel and jet fuels, in addition to traditional biofuels (see Table TS 2.1).This progress rests, in part, in the development of key intermediaries from lignocellulosic biomass – mixture sugars, synthesis gas, and pyrolysis oils – that have the potential to reach cost competitiveness with fossil fuels. Processing to fuels is taking advantage on one hand of engineering microbes and enzymes, using biological synthesis to design specific products and on the other hand of advances in catalysis and engineering, and molecular understanding of bio and chemical processes. Similarly, biobased materials are emerging as full replacements or partial replacements of fossil fuel-derived plastics and materials. [2.6.3]

Cost Trends

Cost trends and technological learning in bioenergy systems have long been less well described compared to other solar and wind energy technologies. Recent literature gives more detailed insights on the experience curves and progress ratios of various bioenergy systems. Table TS 2.2 summarizes analyses that have quantified learning (e.g., expressed by progress ratios) and experience curves for the systems (i) sugarcane based ethanol production (Van den Wall Bake et al.; 2009), (ii) corn based ethanol production (Hettinga et al., 2009), (iii) wood fuel chips and CHP in Scandinavia (Junginger et al., 2005 and a number of other sources). PR denotes the progress ratio, expressing the rate of unit cost decline with each doubling of cumulative production. For example, a PR of 0.8 implies that after one doubling of cumulative production, unit costs are reduced to 80% of the original costs, i.e. a 20% cost decrease. The definition of the ‘unit’ may vary. The absolute performance of the two major commercial ethanol systems is illustrated in terms of a variety of functional units related to climate impact and fossil energy, as a function of time [2.5, and Table 2.5.1].

There is clear evidence that further improvements in power generation technologies, supply systems of biomass and production of perennial cropping systems can bring down the costs of power (and heat) generation to attractive cost levels in many regions, especially when competing with natural gas. If 20-30 U$/tonne carbon taxes were deployed (or CCS), biomass can be competitive with coal based power generation. There is evidence that technological learning and related cost reductions occur with comparable progress ratios as other renewable energy technologies. This is true for cropping systems (following progress in agricultural management when annual crops are concerned), supply systems and logistics (as clearly observed in Scandinavia, as well as international logistics) and in conversion (ethanol production, power generation, biogas and biodiesel).

With respect to second generation biofuels, recent analyses have indicated that the improvement potential is large enough to make them compete with oil prices of 60-70 U$/barrel. Currently available scenario analyses indicate that if R&D and market support on shorter term is strong, technological progress could allow for this around 2020. Several short term options can deliver and provide important synergy with longer term options, such as co-firing, CHP and heat production and sugar cane based ethanol production. Development of working bioenergy markets and facilitation of international bioenergy trade is another important facilitating factor to achieve such synergies.

Table TS 2.2 Overview of experience curves for biomass energy technologies / energy carriers. Cost/price data collected from various sources (books, journals, press releases, interviews) PR = Progress Ratio, R2 is the correlation coefficient of the statistical data

Learning system	PR (%)	Time frame	Region	n	R^2
Feedstock production					
Sugarcane (tonnes sugarcane) Van den Wall Bake et al.; 2009	68±3	1975-2003	Brazil	2.9	0.81
Corn (tonnes corn) Hettinga et al, 2009	55±0.02	1975-2005	USA	1.6	0.87
Logistic chains					
Forest wood chips (Sweden) Junginger et al., 2005	85-88	1975-2003	Sweden / Finland	9	0.87-0.93
Investment & O&M costs					
CHP plants (€/kW$_e$) Junginger et al., 2005	75-91	1983-2002	Sweden	2.3	0.17-0.18
Biogas plants (€/m^3 biogas/day) Junginger et al., 2006a	88	1984-1998		6	0.69
Ethanol production from sugarcane Van den Wall Bake et al.; 2009	81±2	1975-2003	Brazil	4.6	0.80
Ethanol production from corn (only O&M costs) Hettinga et al, 2009	87±1	1983-2005	USA	6.4	0.88
Final energy carriers					
Ethanol from sugarcane Goldemberg et al., 2004	93 / 71	1980-1985	Brazil	~6.1	n.a.
Ethanol from sugarcane Van den Wall Bake et al., 2009	80±2	1975-2003	Brazil	4.6	0.84
Ethanol from corn Hettinga et al., 2009	82±1	1983-2005	USA	6.4	0.96
Electricity from biomass CHP Junginger et al., 2006a	91-92	1990-2002	Sweden	~9	0.85-0.88
Electricity from biomass IEA, 2000	85	Unknown	EU (?)	n.a.	n.a.
Biogas, Junginger et al., 2006a	85- 100	1984-2001	Denmark	~10	0.97

Data availability is limited for production of biomaterials and biochemicals, bio-CCS concepts and algae. Recent scenario analyses indicate that advanced biomaterials (and cascaded use of biomass) and bio-CCS may become attractive mitigation options on medium term. Algae may have potential to produce liquid or gaseous fuels with minimal land-use, but deployment is uncertain and may not be significant before 2030.

Potential Deployment

Bioenergy at large has a significant GHG mitigation potential, provided resources are developed sustainably and provided the right bioenergy systems are applied. Perennial cropping systems and biomass residues and wastes are in particular able to deliver good GHG performance in the range of 80-90% GHG reduction compared to the fossil energy baseline. For estimates of the potential future deployment of bioenergy see Figure TS 2.3.

Biomass potentials are influenced by and interact with climate change impacts but the detailed impacts are still poorly understood; there will be strong regional differences in this respect. Climate change impacts on bioenergy feedstocks production are real but do not pose serious constraints if temperature raise is limited to 2°C. Bioenergy and new (perennial) cropping systems also offer opportunities to combine adaptation measures (e.g. soil protection, water retention and modernization of agriculture) with production of biomass resources.

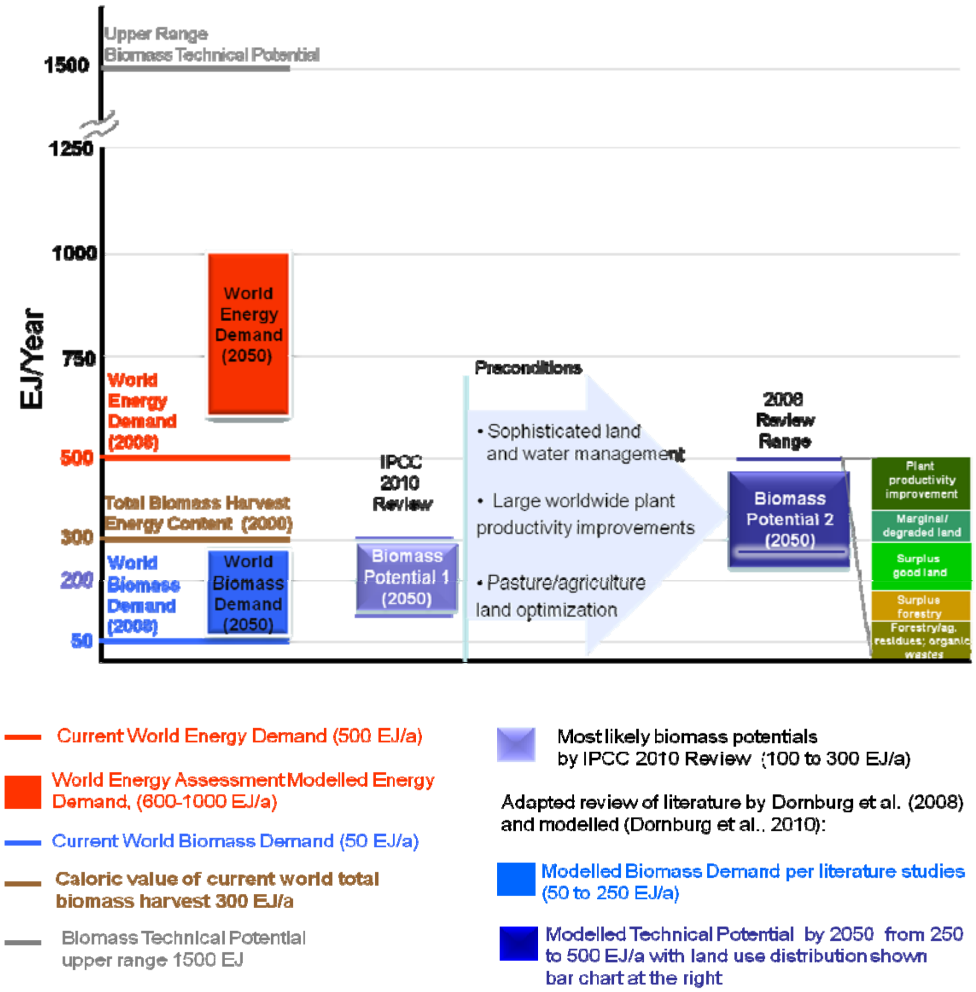


Figure TS 2.3 Upper technical biomass supply potentials, most likely biomass potential (IPCC review, this Chapter), modelled biomass potential (Dornburg et al., 2010), expected demand for biomass (primary energy) based on global energy models and expected total world primary energy demand in 2050. The Biomass Potential 2 scenario incorporates some key limitations and criteria with respect to biodiversity protection, water limitations, soil degradation, and considers developments in agricultural management between A2 versus A1/B1 scenario conditions. The breakdown consist of: (i) Residues: Agricultural and forestry residues; (ii) Forestry: surplus forest material (net annual increment minus current harvest); (iii) Exclusion of areas: potential from energy crops, leaving out areas with moderately degraded soils and/or moderate water scarcity; (iv) No exclusion: additional potential from energy crops in areas with moderately degraded soils and/or moderate water scarcity; (v) Learning in agricultural technology: additional potential when agricultural productivity increases faster than historic trend. Adapted from Dornburg et al. (2008) and Dornburg et al. (2010) based on several review studies.

The recently and rapidly changed policy context in many countries, in particular the development of sustainability criteria and frameworks and the support for advanced biorefinery and second generation biofuel options does drive bioenergy to more sustainable directions. There is consensus on the critical importance of biomass management in global carbon cycles, and on the need for reliable and detailed data and scientific approaches to facilitate more sustainable land use in all sectors. Table TS 2.3 describes key preconditions and impacts for two possible extreme biomass scenarios.

Table TS 2.3 Two opposing storylines and impacts for bioenergy on long term Adapted from Dornburg et al. (2008) and Dornburg et al. (2010).

Storyline	Key precyonditions	Key impacts
- High biomass scenario		
Largely follows A1/B1 SRES scenario conditions,	Assumes: - well working sustainability frameworks and strong policies - well developed bioenergy markets - progressive technology development (biorefineries, new generation biofuels, - successful deployment of degraded lands.	- Energy price (notably oil) development is moderated due to strong increase supply of biomass and biofuels. - Some 300 EJ of bioenergy delivered before 2050; 35% residues and wastes, 25% from marginal/degraded lands (500 Mha), 40% from arable and pasture lands 300 Mha). - Conflicts between food and fuel largely avoided due to strong land-use planning and aligning of bioenergy production capacity with efficiency increases in agriculture and livestock management. - Positive impacts with respect to soil quality and soil carbon, negative biodiversity impacts minimised due to diverse and mixed cropping systems.
Low biomass scenario		
Largely follows A2 SRES scenario conditions, assuming limited policies, slow technological progress in both the energy sector and agriculture, profound differences in development remain between OECD and DC's.	- High fossil fuel prices expected due to high demand and limited innovation, which pushes demand for biofuels for energy security perspective - Increased biomass demand directly affects food markets	- Increased biomass demand partly covered by residues and wastes, partly by annual crops. - Total contribution of bioenergy about 100 EJ before 2050. - Additional crop demand leads to significant iLUC effects and impacts on biodiversity. - Overall increased food prices linked to high oil prices. - Limited net GHG benefits. - Socio-economic benefits sub-optimal.

Key messages and policy recommendations from chapter 2

- Biomass resource potential, even when key sustainability concerns are incorporated, is significant (up to 30% of the world's primary energy demand in 2050) but conditional. A large part of the potential biomass resource base is interlinked with improvements in agricultural and forestry management, investment in infrastructure, good governance of land, smart land use and introduction of effective sustainability frameworks and land-use monitoring.
- If the right policy frameworks are *not* introduced, expansion of biomass use can lead to significant conflicts with respect to food supplies, water resources and biodiversity. Conflicts can also be avoided and synergize with better management of land and other natural resources, (e.g. soil carbon enhancement and restoration, water retention functions) especially agriculture and livestock management to contributing to rural development. Logically, such synergies should explicitly be targeted in comprehensive policy frameworks.
- Bioenergy largely has a significant GHG mitigation potential, provided resources are developed sustainably and provided the right bioenergy systems are applied. Perennial cropping systems

and biomass residues and wastes are able to deliver good GHG performance of 80-90% GHG reduction compared to the fossil energy baseline.

- Optimal use and performance of biomass production and use is regionally specific. Policies need to take regional conditions into account and incorporate the agricultural and livestock sector into good land-use governance and rural development.
- The recent and rapidly changing policy context in many countries drives bioenergy to more sustainable directions. Particularly the development of sustainability criteria and frameworks that support advanced biorefinery and second generation biofuel.
- Lignocellulose based biofuel technology and other advanced bioelectricity options (e.g. carbon capture and storage and advanced biorefieries) are expected to offer fully competitive technologies in the future. Several short term options can provide important synergy with longer term options, such as co-firing, CHP and heat production and sugarcane based ethanol production. Development of working bioenergy markets and facilitation of international bioenergy trade is an important synergy facilitating factor.
- Biomass potentials are influenced by and interact with climate change impacts but the detailed impacts are still poorly understood; there will be strong regional differences in this respect. Bioenergy and new (perennial) cropping systems also offer opportunities to combine adaptation measures (e.g. soil protection, water retention and modernization of agriculture) with production of biomass resources.

DIRECT SOLAR ENERGY

Introduction

Solar energy is an abundant energy resource. Indeed, in just one hour, the solar energy intercepted by the Earth exceeds the world's energy consumption for the entire year. Drawing its energy from a nuclear fusion reaction in the sun's core and constituting the heat radiation emitted by the sun's surface at 5800 K, solar energy consists of a flow of photons or electromagnetic waves that range in wavelengths to cover the ultraviolet, visible, and infrared spectra. Just outside Earth's atmosphere, the magnitude of solar energy is about 1368 watts (W) per square meter of surface facing the sun. But at ground level, this energy is attenuated by the atmosphere to about 1000 W/m^2 on a clear occasion within a few hours of noon (a condition called "full sun")—and to about 500 W/m^2 at a similar time on a day of average atmospheric makeup, and to about 100 W/m^2 on a completely overcast occasion. The use of solar energy embraces a family of technologies classified here under four categories: solar thermal, which includes both active and passive heating of buildings, domestic and commercial solar water heating, swimming pool heating, and process heat for industry; electricity generation via direct conversion by photovoltaic (PV) cells; electricity generation by concentrating solar energy to obtain high temperature and then using that energy to drive heat engines and electrical generators; and finally, solar fuels production methods, which use solar energy to produce useful fuels.

Resource Potential

The *theoretical* potential of solar energy is estimated at 10.8×10^8 TWh per year, but producing this energy would require the full use of all available land area, at 100% conversion efficiency. Determining the *technical* potential requires assessing the fraction of land that can practically be used as well as a realistic conversion efficiency. Estimates for this quantity range from 0.44×10^6 TWh (1580 EJ) per year to 1.4×10^6 TWh (5122 EJ) per year—that is, from 3.1 to 10.2 times the world's primary energy consumption rate in 2007 [3.2.1]. The available energy is spread over the world, so every country and region has a sizeable solar resource that can contribute substantially to its energy base. Part of solar radiation consists of rays arriving directly from the sun without being scattered in the atmosphere: this is the so-called beam or direct solar radiation that is used by concentrators and is most available in desert-like areas. A wide network of solar radiation measurement stations spans the globe [3.2.2], and has yielded (typically hourly) data of solar radiation on a horizontal surface at ground level over the last 40 years or more for many locales. Supplementary data are obtained from measurements from an array of Earth-orbiting satellites. The results are available for solar designers who can use the data to project what energy will be delivered on average by their solar conversion devices in the future. Figure TS 3.1 shows two maps of global solar flux at the Earth's surface.

In the following, we review each of the four solar technologies under various headings.

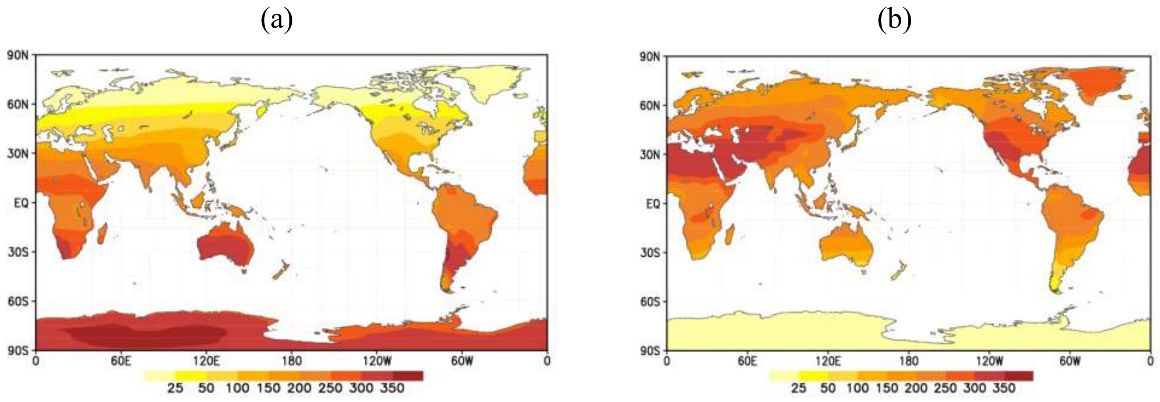
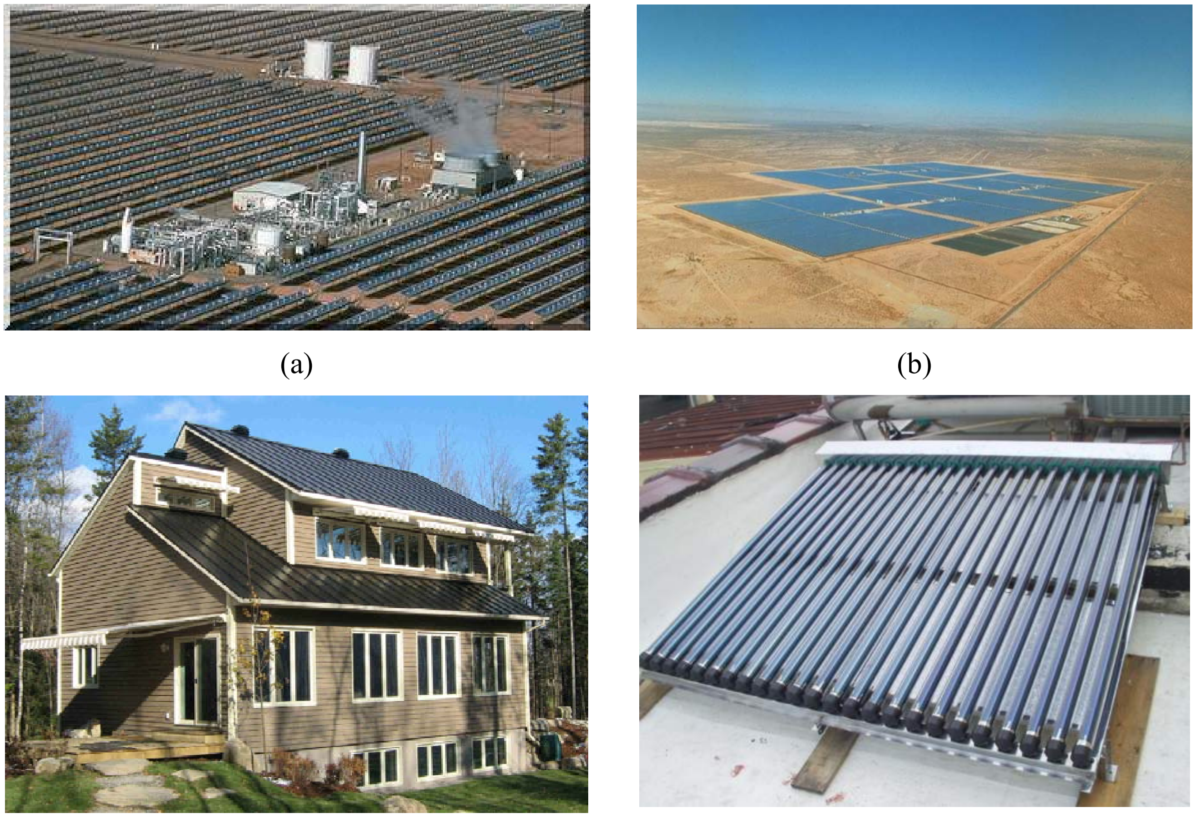


Figure TS 3.3 The global solar flux (in W m^{-2}) at the Earth's surface—derived from the European Centre for Medium-Range Weather Forecasts Re-Analysis (ERA)—averaged over two 3-month periods: (a) December-January-February and (b) June-July-August.

Technology and Applications

1. Solar Thermal: The key component in "active" thermal solar systems is the solar collector. The flat-plate solar collector consists of a blackened plate exposed to the sun, with conduits—either integral to it or attached to it—through which the fluid to be heated passes into and out of the collector. The fluid then passes to other components, such as a domestic hot-water tank, releasing its heat before being returned to the collector. The flat-plate collector may be classified as 1) unglazed, which is suitable for delivering heat at temperatures a few degrees above ambient temperature, 2) glazed, which has a sheet of glass or other transparent material placed parallel to the plate and spaced a few cm above the plate, making it suitable for delivering heat at temperatures of about 30°C to 60°C, or 3) evacuated, which is like the glazed, but the space between the plate and the glass cover is evacuated, making it suitable for delivering heat at temperatures of about 50°C to 120°C. (To withstand the vacuum, the plates of an evacuated collector are put inside glass tubes, which now constitute both the collector's glazing and container; thus, evacuated collectors are often referred to as tubular collectors.) The typical efficiency of a solar collector when used in its proper temperature range extends from about 40% to 70% at full sun. To obtain heat at higher temperatures, the solar rays are concentrated by mirrors. A common application for the flat-plate collector (and sometimes for the evacuated collector) is heating water for domestic and commercial use (e.g., for washing). They can also be used in active solar heating to provide comfort heat for buildings. Solar cooling uses solar collectors to provide heat in a particular refrigeration cycle called the absorption refrigeration cycle. Other applications for solar-derived heat are industrial process heat, agricultural applications such as drying of crops, and for cooking. Much effort has gone into developing special methods for storing solar-derived heat over longer periods than that provided by the water tanks commonly used to store heat over the day/night period or short periods of cloudy weather. Systems have been proven in the field that can store from summer to winter and ultimately can permit solar-heating systems to provide essentially 100% of the heat demand, compared to the 40% to 60% normally provided by systems with short-term storage [3.3.2]. Passive solar thermal, another way of providing comfort heating for buildings, has proven to be very popular. In passive solar heating, the building itself—particularly its windows—acts as the solar collector and natural methods are used to distribute and store the heat. The basic elements of passive heating architecture are high-efficiency equatorial-facing windows, thermal mass, protection elements, and occasionally, reflectors. The building should be well insulated before passive solar strategies are undertaken.



(a) (b)

(c) (d)

Figure TS 3.2 (a) one of the original SEGS plants in California built by LUZ, operating for 20 years, showing the parabolic trough collectors and steam turbine plant; (b) aerial view of the five SEGS III-VII plants at Kramer Junction, California; (c) Equatorial-facing triple-glazed window area the EcoTerra^{TM} demonstration solar house is 9.1% of heated floor area; (d) evacuated-tube thermal solar collector. [TSU: reference to figure in text is missing]

Studies have shown that using these strategies in new buildings in northern Europe or North America can reduce the building heating demands by up to 40%. For existing, rather than new, buildings retrofitted with passive heating concepts, reductions in the order of up to 20% are achievable [3.3.1].

2. Photovoltaic Electricity Generation: In photovoltaic generation, a plate of a semi-conductor material, such as silicon, is placed in the sun. Semiconductors contain valence electrons, which are bounded tightly to the positive nuclei of the atoms, and conduction electrons, which are more energetic and free to move throughout the material. The relative amount of each type of electron can be altered by introducing certain impurities into the semiconductor, in a process called "doping." N-type doping produces a relative excess of conduction electrons, whereas p-type doing produces a relative deficit. The semiconductor plate exposed to the sun actually consists of two layers: an n-type layer and a p-type layer. External electrical leads are attached to the plate, now called a cell, one to the n-type layer, the other to the p-type layer, and an electrical load (e.g., an electric motor) is connected to these leads. The contacting of the two layers produces a natural voltage or junction potential across the interface, but in the absence of solar rays, the junction potential cannot deliver electrical power at the leads. However, when the solar photons strike the cell, valence electrons can be promoted to conduction electrons. After crossing the junction, the newly formed conduction electrons can move toward the external electrical leads. This creates a flow of external electrons, or an electrical current, and electrical power is thereby delivered to the load (motor). A first distinction in the various forms of the silicon type of PV cells is based on the type of silicon: monocrystalline, multicrystalline, or amorphous. The best efficiency achieved by the cells is 25% for monocrystalline, 20.4% for multicrystalline, and 10.1% for amorphous silicon; amorphous silicon cells compensate for their lower efficiency by their ease of manufacturing. A hybrid of multicrystalline and amorphous layers has achieved an efficiency of 23%. Mono- and multicrystalline silicon cells are the dominant technologies on the PV market, with a 2009 market share of about 80%. Research on improving solar cells has concentrated on raising the efficiency and lowering the cost. An upper bound for the efficiency of the single-junction silicon cell is 31%, so efforts for higher efficiency have focused on using different semiconductor materials with higher junction potentials and introducing additional junctions, the latter strategy permitting a greater fraction of solar photons to generate conduction electrons. Solar cells, usually of the high-efficiency and expensive variety, can be placed at the focus of an optical concentrator; these concentrating photovoltaic (CPV) systems are being given high priority. As with concentrating solar power systems, the CPV systems work best in clear-sky locales. There has also been an effort to minimize the amount of silicon used; silicon is still the preferred material because of its abundance and low price, but because of the purity required, its cost still represents a significant portion of the cost of the cells. The thickness of crystalline layers (or wafers) were roughly halved from 1990 to 2009, to less than 200 micrometers. The wafer area has doubled over the same period, to over 100 cm^2. A group of cells are mounted side by side under a transparent sheet (usually glass) and connected in series to form a “module,” typically with dimensions of up to about 1 m by 1 m. In considering efficiencies, it is important to distinguish between cell efficiencies (quoted above) and module efficiencies; the latter are typically 50% to 80% of the former. Modules have expected lifetimes of 20 to 30 years. The application of PV for useful power involves more than just the cells; the PV system, for example, may include an inverter (to convert the DC power from the cells to AC power to be compatible with common networks and devices) and, for off-grid applications, the system may include storage devices such as batteries. Work is ongoing to make these devices more reliable and to extend their lifetime to be comparable with that of the modules. The applications of the PV-derived electricity can be categorized as either “stand-alone” or “grid-connected.” In the latter, the cells are connected to be another energy source on a conventional electrical grid of mains electricity, supplementing the other sources and reducing the power required to deliver to the load. In the former, the cells constitute the single source on a grid, and batteries are generally required to cover periods when the sun is not shining [3.3.3].

3. CSP Electricity Generation: Concentrating solar power (CSP) technologies produce electricity by concentrating the sun’s rays to heat a liquid or gas that is then used in a heat engine process (steam or gas turbine) to drive an electrical generator. CSP uses only the direct-beam component of solar radiation, and so its use tends to be restricted to a limited geographical range. The concentrator brings the solar rays to a point (point focus) as in central-receiver or dish systems or to a line (line focus) as in trough or linear Fresnel systems. In trough concentrators, long rows of parabolic reflectors that track the movement of the sun concentrate the sun on the order of 70 to 100 times, onto a heat-collection element (HCE) mounted along the reflector’s focal line. The HCE comprises a blackened inner pipe and a glass outer tube, with an evacuated space between the two. In current designs, a heat-transfer oil is circulated through the steel pipe and is heated to about 400°C. Linear Fresnel reflectors work in much the same way. The central-receiver (also called the “power tower”) system uses an array of mirrors (heliostats) on the ground, each tracking the sun along two axes to redirect the sun’s rays onto a point focus on top of a tall tower. At the focus is the receiver, a fixed inverted cavity in which the heat-transfer fluid circulates. It can reach a higher temperature (up to 1000°C) than achieved in the line-focus types, meaning that the heat engine can convert more of the collected heat to power. Temperatures of ~900°C are achieved in the other point-focus system, the dish system, in which just one paraboloid-shaped reflector (as opposed to an array of reflectors) is used for each heat engine. The dish redirects the solar rays onto a receiver that is not fixed but moves with and is connected to the dish, being only about one dish diameter away. In one popular realization of this concept, a Stirling engine driving an electrical generator is housed within the receiver housing. Each of the dish units just described is relatively small, producing 10 to 25 kW_e, but many units can be combined in a field to realize very large power output. All four CSP systems have been built and demonstrated, some delivering energy to the grid. The earliest commercial CSP plants were the Solar Electric Generating Stations (SEGS) in California, producing 354 MW of power; installed between 1985 and 1991, they are still in operation today. Time will tell which of the four systems will be most widely adopted. Introducing energy storage into these systems has a shorter history, and methods are still being developed. In contrast to PV electricity production, CSP does not need to store the electrical energy itself. Rather, the plan for CSP technologies (except for dishes) is to store thermal energy (or heat) after it has been collected at the receiver and before going to the heat engine—an approach generally considered more straightforward than storing electricity. Storage media considered include molten salt, steam accumulators (for short-term storage only), solid ceramic particles, high-temperature phase-change materials, graphite, and high-temperature concrete. Sizes of storage range from 1 hour (achievable now) to 7.5 hours and are either in operation or in the planning stage [3.3.4].

4. Solar Fuel Production: Solar fuel technologies convert solar energy into chemical fuels, such as hydrogen. The fuels derived can then replace fossil fuels, with a corresponding saving in greenhouse gas (GHG) production. The fuels can then be used in the myriad of applications common to most fuels: they can be directly burned to generate heat, which may then be converted into electrical or mechanical work via heat engines, say for transportation. They can also be used to generate electricity directly in fuel cells and for upgrading fossil fuels. Thus, they can give solar energy the transportability and flexibility that make fossil fuels particularly valuable. There are four basic routes to solar fuels, which can work alone or in combination: the electrochemical, photochemical/photo-biological, thermochemical, and solar fuel synthesis from solar hydrogen and CO_2. In the first, hydrogen is produced by an electrolysis process driven by solar-derived electrical power that has been generated by PV or CSP systems. Electrolysis of water is an old and well-understood technology, typically achieving 70% conversion efficiency from electricity to hydrogen. In the photochemical/photo-biological route, solar photons are used to drive photochemical or photo-biological reactions whose products are fuels: that is, they mimic what plants and organisms do. In the third route, the thermo-chemical route, high-temperature solar-derived heat (like that obtained at the receiver of a central-receiver CSP plant) is used to drive an endothermic chemical reaction whose output is a fuel. Here, the reactants can include combinations of water, carbon dioxide, coal, biomass, and natural gas, and the products, which constitute the solar fuels, can be any (or combinations) of the following: H_2, syngas, methanol, dimethyl ether (DME), and synthesis oil. Of course, in the case of a fossil fuel being used as a reactant, overall calorific values of the products will exceed those of the reactants, so that less fossil fuel needs to be burned for the same energy release. Solar fuel can also be synthesized from solar hydrogen and CO_2 by producing hydrocarbons compatible with existing energy infrastructures such as the natural gas network or conventional fuel supply structures.

Installed Capacity and Generated Energy

1. Solar Thermal: Service hot-water heating for domestic and commercial buildings is now a mature technology growing at a rate of about 16% per year and employed to various extents in most countries of the world. The world installed capacity of thermal power from these devices is estimated to be 200 GW_{th}, with a capacity factor of about 10%. The global market for solar thermal totaled an estimated 19 GW_{th} per year in 2008, of which 92.5% was for glazed flat-plate and evacuated-tube collectors; unglazed collectors, used principally for swimming pool heating, accounted for most of the rest. China accounted for about 80% of the new installations in 2008; the European Union accounted for about 10%. Other leading countries were Turkey (3.5%), Brazil

(1.5%), India (1%), and the United States, Australia, and Japan at 0.5%. The rate of rise in the solar thermal installations varies among the different countries. In Europe, the market size more than tripled between 2002 and 2008. The biggest push came from the German market, which more than doubled its capacity. China's growth rate in 2007 was 16%. Despite the above-noted gains in Europe, solar thermal still only accounts for a relatively small portion of the demand for hot water. For example, in Germany, with the largest market, only about 5% of one- and two-family homes are using solar thermal energy. One measure of the market penetration is the per capita annual usage of solar energy. The lead country in this regard is Cyprus, where the figure is 61 kW_{th} per 1 000 people. In Austria, which has one of the highest figures in Europe, it is 29 kW_{th} per 1 000 people [3.4.1].

2. Photovoltaic Electricity Generation: PV production is growing at a rate of about 40% per year, making it one of the fastest-growing energy technologies. Currently, it claims an installed capacity power production of about 22 GW, with a capacity factor estimated at about 11%. The rate of installation in 2009 is estimated to be between 6.6 and 7.9 GW per year. More than 90% of this capacity is installed in three leading markets: the EU with 73% of the total, Japan with 12%, and the USA with 8%. Roughly 95% of the PV installed capacity in the OECD countries is grid connected, the remainder being off-grid. The high rate of growth can no doubt be attributed primarily to the various government incentives, including the feed-in tariffs implemented in Germany and Spain, and the buy-down incentives coupled with investment tax credits implemented in the United States. The top seven PV markets through 2009 included Germany (9800 MW installed), Spain (3500 MW), Japan (2630), USA (1650 MW), Italy (1140 MW), Korea (460 MW), France (370 MW), and PR China (300 MW). Spain and Germany have seen, by far, the largest amounts of solar installed in recent years, with Spain seeing a huge surge in 2008 and Germany having experienced steady growth over the last five years [3.4.1].

3. Concentrating Solar Power (CSP): CSP has now reached a cumulative installed capacity of about 0.65 GW, with another 1.8 GW under construction. The capacity factors for CSP are expected to be quite high, in the range of 35% to 40%. Following the 354 MW of solar trough technology finished in 1991, there had been a slow period for CSP. But since about 2004, there has been a strong growth in planned capacity. The bulk of the current operating capacity consists of trough technology, but central-receiver technology comprises a growing share. By 2010, only about 60% of planned capacity was in the U.S., the remaining capacities being in Spain (30%), Abu Dhabi (6%), Algeria, Egypt, Australia, and Morocco [3.4.1].

4. Solar Fuel Production: Currently, solar fuel production is in the pilot-plant phase. Pilot plants in the power range of 300–500 kW have been built for the carbo-thermic reduction of ZnO, steam methane reforming of methane, and steam gasification of pet-coke. A 250-kW steam-reforming reactor is operating in Australia [3.4.1].

Industry Capacity and Supply Chain

1. Solar Thermal: Currently, flat-plate collector manufactures are producing about 27 million m^2 per year of solar collectors, a scale large enough to adapt to mass production, even though production is spread among a large number of companies around the world. Indeed, large-scale industrial production levels have been attained in most parts of the industry. In the manufacturing process, a number of readily available materials—including copper, aluminium, stainless steel, and thermal insulation—are being applied and combined through different joining technologies to produce the absorber plate and container box, and this is topped by the cover glass, which is almost always low-iron glass, now readily available. Most production is in China and is aimed at internal consumption; for that country, evacuated collectors are starting to dominate the market. Once a small part of the market, evacuated tubular collectors are now gaining in market share. Much of the export market occurs in total solar hot-water heating systems, rather than solar collectors *per se.* The largest exporters of solar water heaters are Australia, Greece, the USA, and France. Australian exports constitute about 50% of its production. In passive solar heating, part of the industry capacity and the supply chain lies in people: namely, the engineers and architects, who must systematically collaborate to produce a passively heated building. Close collaboration between the two disciplines has often been missing in the past, but the dissemination of systematic design methodologies issued by different countries has improved the design capabilities. Windows and glazing are an important part of passively heated buildings and the availability of a new generation of highly efficiency (low-emissivity, argon-filled) windows is having a major effect on solar energy's contribution to buildings heating requirements. These windows now constitute the bulk of the new windows being installed in most northern countries, although their part in the whole building stock is still relatively small. There does not appear to be any industrial capacity or supply-chain issues relating to the adoption of better windows. Another feature of passive design is adding mass to the building's structure. Concrete and bricks, the most commonly used storage materials, are readily available; phase-change materials (e.g., paraffin), considered the storage materials of the future, are not expected to have supply-chain issues [3.4.2].

2. Photovoltaic Electricity Generation: The compounded annual growth rate in manufacturing production from 2003 to 2009 was more than 50%. The current production rate of about 11 GW_{peak} per year is split between several countries and regions: China has about 37% of world's production; Europe has about 17%; Japan and Taiwan have about 14% each; and the U.S. has about 5%. Worldwide, some 200 factories produce silicon wafer-based solar cells and more than 300 produce solar modules. In 2009, silicon-based solar cells and modules represented about 80% of the worldwide market (Figure 3.21). The total market share of wafer-based silicon is expected to decrease over the next few years, whereas thin-film module production is expected to gain market share. Manufacturers are moving to original design manufacturing units and are moving parts of the module production closer to the final market. Between 2004 and early 2008, the demand for crystalline silicon (or polysilicon) outstripped supply. This led to a price hike, and with the new price, ample supplies have become available, the PV market now driving its own supply of polysilicon [3.4.2].

3. Concentrating Solar Power (CSP): Within just a few years, the CSP industry has gone from negligible activity to over 1,400 MW being either commissioned or under construction. More than ten different companies are now active in building or preparing for commercial-scale plants. They range from start-up companies to large organizations with international construction management expertise, and include utilities, such as Florida Power & Light. None of the supply chains for construction of plants is limited by the availability of raw material. Expanded capacity can be introduced with a lead time of about 18 months [3.4.2].

4. Solar Fuel Production: Solar fuel technology is still at an emerging stage, and there is no supply chain in place at present for commercial applications. Solar fuels will comprise much of the same solar-field technology as being deployed for other high-temperature CSP systems, in addition to downstream technologies similar to those in the petrochemical industry [3.4.2].

Impact of Policies

Direct solar energy technologies face a range of potential barriers to achieve wide-scale deployment, and policies to advance markets generally target three issues: 1) accelerating technology improvements by using incentives in the near-term, 2) streamlining planning and permitting processes, and 3) harmonizing global codes and standards. Solar water heating is supported by tax credits, grants and soft loans, and a few renewable electricity standards. For electricity-producing technologies, longer-term support for enabling technologies (e.g., storage and smart grids) is being pursued. Direct financial support for PV is driving the growth in PV markets. Feed-in-tariffs (FITs) set a legal framework for utilities in more than 40 countries to purchase PV-generated electricity at premium rates. Tax credits and soft loans are another set of direct financial tools that are frequently used, as are policies (most common in the United States) that obligate power suppliers to provide a specified fraction of electricity from renewable energy technologies [3.4.3].

Environmental and Social Impacts

Environmental Impacts: Land use is one form of environmental impact. For roof-mounted solar thermal and PV systems, this is not an issue, but it can be an issue for central-station PV. On the other hand, a recent study has shown that the central-station PV life cycle actually involves less land disturbance (in the southwest U.S.) than both fossil fuel and nuclear energy life cycles. The emission of CO_2 and pollutants emitted during the production and decommissioning of the PV modules is another environmental impact. Life-cycle GHG emissions for silicon-based PV modules have been determined to be about 32 g of CO_2-eq/kWh, very much less than that for burning fossil fuels, and this figure is expected to be reduced in the future. (This corresponds to an energy payback period of 2.0 to 2.5 years.) Although the PV industry uses some toxic materials, any release of these materials can be reduced to acceptable levels by strict controls. Moreover, the recycling of PV modules is already economically viable. The land use for CSP is expected to be less than that for PV because the CSP plants are generally more efficient, provided they are set up in clear-sky areas, which generally will be the case. One difference with CSP vis-à-vis PV is that it needs a method to cool the working fluid. Although such cooling often involves the use of scarce water, local air as the coolant is a totally viable option, even though it could involve a slight drop (2%–10%) in plant efficiency. Life-cycle GHG emissions for CSP modules have recently been estimated to be to be about 14 g of CO_2-eq/kWh. With regard to thermal solar, one of the few available studies found that the environmental impact of large-scale solar water-heating adoption in the UK would be very small, showing up mainly in the appearance of the solar collectors on the roofs [3.6.1].

Social Impacts: Apart from its benefits in GHG reduction, the use of solar energy over fossil fuels reduces by a large margin the release of pollutants—particulates and noxious gases—that lead to illnesses and deaths: an estimated 0.8 million deaths yearly are caused by exposure to urban air pollution. Not only would many lives be saved, but public health expenditures would also be drastically reduced if there were wide-scale adoption of direct solar energy. Job creation can be another benefit; it has been shown that at 0.87 job-years per GWh, solar PV had the greatest job-generating potential of any energy technology. Close behind is CSP with 0.23 jobs per GWh, both being well ahead of fossil technologies. When properly put forward, these arguments plus careful planning have been shown to accelerate social acceptance and increase public willingness to tolerate any disadvantages of solar energy, such as visual impacts. It is expected that next-generation PV panels will be so well integrated into the building structure that onlookers will hardly be aware of their presence. The positive benefit in the developing world provides arguments for their use. About 1.6 billion people do not have access to electricity. Solar home systems and local PV-powered community grids can provide economically favourable electricity to many areas for which connection to a main grid is too costly by other means. The impact of electricity on the local population is shown through a long list of important benefits: the replacement of kerosene lamps and similar indoor-polluting light sources, increased reading light levels and qualities leading to increased reading with all the benefits that go with that, street lighting for security and greater community involvement, and communications devices (e.g., televisions, radios) that provide a myriad of benefits in improving the lives of people [3.6.2].

Prospects for Technology Improvements and Innovation

1. Solar Thermal: In buildings of the future, solar panels—including PV panels thermal collector panels, and combined PV-thermal panels—will make up the viewed components of the roof and façades. They will be integrated at the earliest stages of building planning. These buildings will be put in place not just through the whims of individual builders/owners, but will be mandated, at least in some areas. For example, the vision of the European Solar Thermal Technology Platform is to establish the "Active Solar Building" as a standard for new buildings by 2030, where an Active Solar Building covers 100% of its demand for heating (and cooling, if any) with solar energy. Also expected in the future is that solar heating for industrial processes (SHIP), which is currently at a very early stage of development, will become cost-competitive. This will allow solar to move into an area that represents a sizeable fraction of the energy demands of developed countries, about 28% for the EU27 countries. It will be accomplished through a number of technological improvements, principally by developing solar collectors that can function efficiently at higher temperatures [3.7.2]. In highlighting the foreseen advances in passive solar, we can distinguish between two climates: those that are dominated by the demand for heating and those dominated by the demand for cooling. For the former, one can see a wider-scale adoption of the following items: evacuated glazing, dynamic exterior night-time insulation, and translucent glazing systems that can automatically change solar/visible transmittance and that also offer improved insulation values. For the latter, there is the expectation of 1) cool-roof technologies, 2) heat-dissipation techniques such as use of the ground and water as a heat sink, 3) methods that improve the microclimate around the buildings, and 4) solar control devices that allow penetration of the lighting, but not the thermal, component of solar energy. For both climates, there is the expectation of improved thermal storage to be embedded in building materials and also improved methods for distributing the absorbed solar heat around the building and/or to the outside air, perhaps even using active methods such as fans. Finally, improved design tools are expected to facilitate these various improved methods [3.7.2].

2. Photovoltaic Electricity Generation: Although currently a relatively mature technology, PV is still hampered by low efficiency and high cost; but following the trends of other semiconductor industries, steady improvements are expected in the future. Further technological efforts are being taken up in a large framework of intergovernmental cooperation, complete with roadmaps. At the cell level, four broad technological categories that require specific R&D approaches have been identified: 1) cell efficiency, stability, and lifetime, 2) high productivity and manufacturing, 3) environmental sustainability, and 4) applicability, which includes standardization and harmonization. Recognized as part of the first approach are the differences among three major classes of cells: the current class of cells; emerging cells considered to be medium risk and having a mid-term (10–20-year) timeline; and high-risk cells aimed at 2030 and beyond, which are considered to have extraordinary potential but involve new technologies. Examples of the emerging cells are multiple-junction polycrystalline thin films and crystalline silicon in the sub-100-micrometer-thickness range. Examples for the high-risk cells are biomimetic devices and quantum dots that have the potential to increase the maximum efficiency by up to 66%. Finally, there is the important work on the balance of systems (BOS), which looks at inverters, storage, charge controllers, system structures, and the energy network [3.7.3].

3. CSP Electricity Generation: Although CSP is now a proven technology at the utility scale, it is yet to be optimized, and further cost reductions can be expected. There is much scope for improving the heat-engine efficiency, which, for example, in trough plants is estimated to be 37%. To increase efficiency, alternatives to the use of oil as the heat-transfer fluid—such as water (boiling in the receiver) or molten salts—are being developed, permitting higher operating temperatures. For central-receiver systems, the overall efficiencies (including all component systems) are higher because the operating temperatures are higher, and further improvements are expected to achieve peak efficiencies of 35%. Trough technology will benefit from continuing advances in solarselective surfaces, and central receivers and dishes will benefit from improved receiver/absorber designs that allow collection of very high solar fluxes. Capital cost reduction is expected to come from the benefits of mass production, economies of scale, and learning from previous experience [3.7.4].

4. Solar Fuel Production: Solar electrolysis using PV or CSP is available for niche applications, with estimated production costs at 1.5 to 2 times oil at US$100/bbl. Many paths are being pursued to develop the technology that will reduce the cost of solar fuels: the photoelectrochemical (PEC) cell (which combines all the steps in solar electrolysis to a single unit), producing biofuels from modified photosynthetic microorganisms (which has the potential to have solar energy conversion efficiencies much better than those based on field crops), and the so-called “SOLAR-H2” process (which integrates two frontline research topics: artificial photosynthesis in man-made biomimetic systems, and photo-biological H_2 production in living organisms) [3.7.5].

Cost Trends

1. Solar Thermal: Most solar thermal processes require an auxiliary—generally, a conventional—energy source, so the demand for energy is met by a combination of the two. Typically, between 20% to 80% of the demand is covered by the solar component. Solar equipment generally represents a high first cost to the user which must be amortized over the years of service and then added to the operating cost to determine the unit cost of energy. A European study established the current cost of solar thermal energy (mainly for hot water heating) as ranging from 5 to 17 €-cent per kWh for the regions of central and southern Europe. The same study projected the corresponding cost for 2030 to be 2 to 6 €-cent per kWh. At the latter prices, which are much less than energy from conventional sources, it is expected that solar thermal will extend into active heating of buildings, cooling, and process heat, creating a mass market. Over the last decade, for each 50% increase in installed capacity of solar water heaters, investment costs have fallen 20%. Of the high first cost mentioned above, the solar collectors themselves represent the main cost, with their installed costs ranging from 200 to 500 €/m^2 for flat-plate collectors to 450 to 1,200 €/m^2 for evacuated-tube collectors. The financial payback time required for a solar water heating system in southern Australia has been estimated to be 2 to 2.5 years [3.8.1,2].

2. PV Electricity Generation: The price for PV is often expressed as $ per W, which is the price of a PV module divided by the number of watts that the module will deliver in full sun. Obtaining the unit price of energy (cents per kWh) from a PV system will require first adding the BOS and installation costs, then using a method for amortizing the first cost over the energy delivered over the life of the panel, which will require knowledge of the capacity factor. Despite its simplicity, the $ per W figure gives a useful basis for comparison for both PV and CSP. The current average global price for PV modules with greater than a 75-W rating is just under 2 US$/W, which can be compared to the corresponding 1990 price of 9.30 US$/W. The PV module learning curve (price vs. cumulative production) shows a tight correlation, with the price being reduced by 20% for every doubling of cumulative sales. Prices are projected to continue to drop and are expected to be at or below 1.50 USD/W for all major PV technologies by 2015. This is the price of the modules. After adding in the price of the BOS and installation, a figure of 7.6 US$/W was found to apply in the U.S. in 2007; slightly lower costs have been experienced in Japan and Germany. By 2015, the U.S. Department of Energy projects the price of PV-generated electricity to range from 5 to 10 ¢ US per kWh, depending on the end-user [3.8.3].

3. CSP Electricity Generation: Currently, the average cost for installing a CSP plant is roughly 4 US$/W. The current cost of the energy delivered is estimated to be 12 to 14 ¢ US per kWh, and research projects in the U.S. and Europe are expected to reduce this to 7 to 10 ¢ US per kWh by 2015 and to less than 7 ¢ US per kWh, with 12 to 17 hours of storage by 2020 [3.8.4].

Potential Deployment

Given the capabilities of direct solar energy summarized above, it is appropriate to ask: What role can direct solar energy play on the world energy stage in the not too distant future? No doubt the role will depend on the amount of funding that the technologies will receive to drive the necessary R&D and establish the plants. It is not our goal to lay out new scenarios here. Rather, we summarize findings from previous studies, as taken from the literature, covering the years out to 2050. Only summary figures of those studies are presented in this Technical Summary. Table TS 3.1 below gives the summary data. Each entry in the second to fifth columns contains a single value and a range. The former are averages of values reported by differing literature sources for different funding levels; the latter are the standard deviations of these various values. Sources for the tabulated data are the following: Greenpeace (Revolution scenario); International Energy Agency (IEA), including both the ACT and Blue Maps; and Shell, including both the Scramble and Blueprints scenarios. The Shell data are limited to solar thermal technologies. The column on the right gives the necessary investment costs in RD&D needed between 2005 and 2030 to meet the given GW values, according to the IEA scenarios. The costs after 2030 were considered by the IEA as commercial investment costs.

Table TS 3.1 Evolution of the Cumulative Direct Solar Installations until 2050, by Technology

Technology	2010	2020	2030	2050	Investment Cost, $\$\times10^9$
	Cumulative Installations in GW or GW_{th}				
Solar Thermal (GW_{th})	192 ± 107	988 ± 640	4500 ± 850	9130 ± 5730	255 to 280
PV (GW)	18.5 ± 6.3	160 ± 100	700 ± 550	2100 ± 1300	180 to 222
CSP (GW)	5	91 ± 8	253 ± 41	980 ± 660	260 to 315

With regard to the solar thermal entries, note that passive solar contributions are not included in these data; although this technology certainly reduces the demand for energy, it is not part of the supply chain considered by the usual energy statistics [3.9].

Potential deployment scenarios range widely—from a marginal role of direct solar energy in 2050 to one of the major sources of energy supply. Although it is true that direct solar energy provides only a very small fraction of the world energy supply, it is undisputed that this energy source has the largest potential and a promising future.

Reducing cost is a key issue in making direct solar energy more cost competitive. This can only be achieved if the solar technologies reduce their costs along their learning curves, which depend primarily on market volumes. In addition, continuous R&D efforts are required to ensure that the slope of the learning curves (see Fig. TS 3.3 for an example) do not flatten too early.

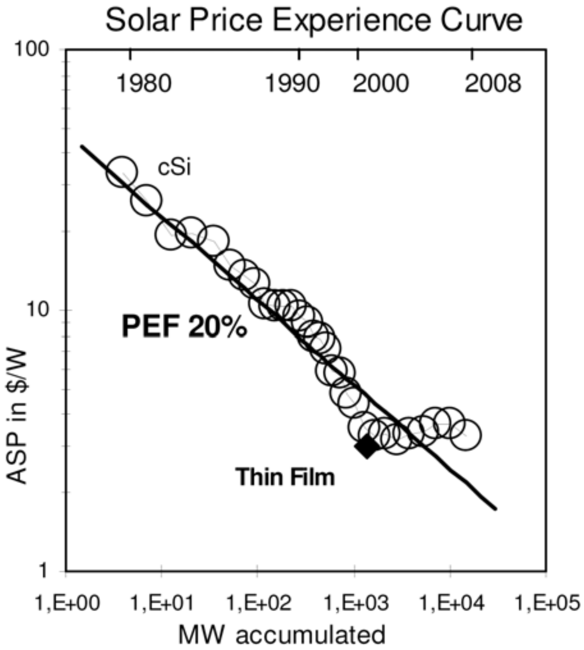


Figure TS 3.3 Solar price experience or learning curve for PV modules (Hoffmann *et al.*, 2009).

The true costs of implementing solar energy are still unknown because the main implementation scenarios that exist today consider only a single technology. These scenarios do not take into account the co-benefits of a renewable/sustainable energy supply via a range of different renewable energy sources and energy-efficiency measures.

Potential deployment depends on the actual resources and availability of the respective technology. However, to a large extent, the regulatory and legal framework in place can foster or hinder the uptake of direct solar energy applications. Minimum building standards with respect to building orientation and insulation can reduce the energy demand of buildings significantly and can increase the share of renewable energy supply without increasing the overall demand. Transparent, streamlined administrative procedures to install and connect solar power source to existing grid infrastructures can further lower the cost related to direct solar energy.

Geothermal Energy

Resource Potential

Geothermal resources consist of thermal energy stored at depth within the Earth in both rock and trapped steam or liquid water, and are used to generate electric energy in a thermal power plant or in other domestic and agro-industrial applications requiring heat [ES, 4.2.1]. It originates within the Earth and differs from "ground source heat" that is stored solar energy in soils and ground water [SRREN Glossary]. The theoretical potential for geothermal energy is estimated to be 105-400 x 10^6 EJ within 10 km depth, 65-140 x 10^6 EJ within 5 km depth, and 35-43 x 10^6 EJ within 3 km depth [4.2.1].

The geothermal technical potentials for electric generation and direct uses are presented in Figure TS 4.1. All of these estimates are lower than the AR4 estimate (5000 EJ/y) and are within the estimates from Krewitt et al. (2009).

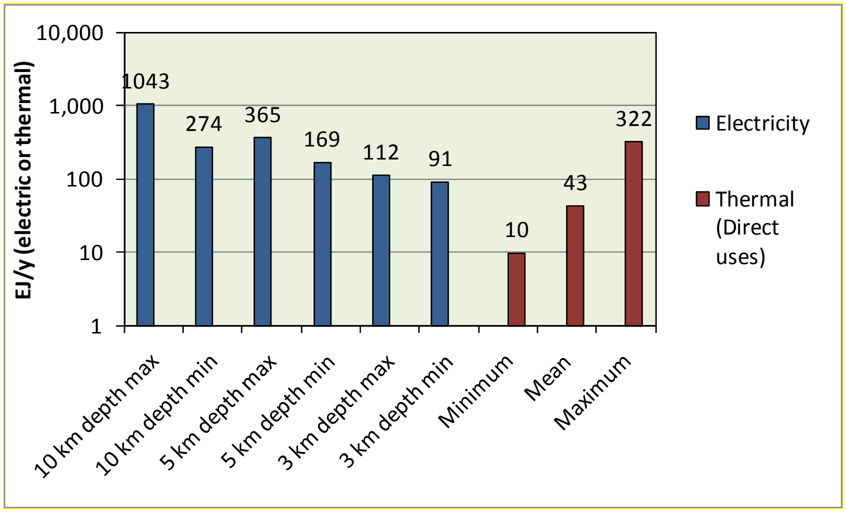


Figure TS 4.1 Geothermal technical potentials for electricity and direct uses (heat) [4.2.1] [TSU: reference is missing]

The technical potentials are presented on a regional basis in Table TS 4.1. The original regional assessment of theoretical potential was conducted by the Electric Power Research Institute in 1978 (EPRI, 1978), based on a detailed estimation of the thermal energy stored inside the first 3 km under the continents accounting for regional variations in the average geothermal gradient and the presence of either a diffuse geothermal anomaly or a high enthalpy region, associated with volcanism or plate boundaries. The values in Table TS 4.1 follow the EPRI approach for each region and applied to the minimum and maximum technical potentials mentioned before at 3, 5 and 10 km depth. The separation into electric and thermal (direct uses) potentials is somewhat arbitrary in that most higher temperature resources could be used for either or both in combined heat and power applications depending on local market conditions [4.2.2].

Table TS 4.1 Geothermal technical potentials for the IEA regions (prepared with data from EPRI, 1978, and the global technical potentials described) [4.2.2]

IEA REGION	Technical potential in EJ/y (electric) at depths to:						Technical potential in EJ/y (heat for direct uses)		
	3 km		5 km		10 km				
	Min	Max	Min	Max	Min	Max	Min	Mean	Max
1. OECD North America	18.7	23.1	37.0	79.7	58.1	221.7	2.1	9.3	69.5
2. Latin America	10.4	12.8	21.3	45.9	32.9	125.5	1.2	5.5	40.9
3. OECD Europe	4.7	5.8	8.4	18.1	13.8	52.7	0.8	3.6	26.8
4. Africa	14.5	17.9	25.5	55.0	42.4	161.7	1.4	6.1	45.8
5. Transition Economies	17.2	21.2	29.5	63.6	49.6	189.1	1.5	6.8	51.1
6. Middle East	3.2	4.0	5.7	12.2	9.4	36.0	0.3	1.4	10.2
7. Developing Asia	7.3	9.1	14.6	31.5	22.9	87.2	0.8	3.7	27.6
8. India	2.4	3.0	4.0	8.7	6.9	26.1	0.2	1.0	7.2
9. China	6.4	7.9	12.9	27.7	20.1	76.6	0.7	3.3	24.5
10. OECD Pacific	5.9	7.3	10.4	22.4	17.3	65.9	0.6	2.5	19.0
Total	**90.8**	**112.1**	**169.3**	**364.9**	**273.5**	**1042.6**	**9.8**	**43.0**	**322.6**

Technology and Applications (electricity, heating, cooling)

Geothermal heat is extracted using wells that produce hot fluids contained in hydrothermal reservoirs with naturally high permeability and porosity or by artificial fluids pathways in Enhanced Geothermal Systems (EGS). The principle of EGS is as follows: in the subsurface where temperatures are high enough for effective utilisation, a fracture network is created or enlarged to act as fluid pathways. Water is passed through this deep reservoir using injection and production wells, and heat is extracted from the circulating water at the surface. The extracted heat can be used for power generation and for district heating [4.3.5]. Once at surface, fluids can be indirectly used to generate electric energy in a power unit, and/or in a direct way in several applications requiring heat.

Geothermal energy is independent of climatic conditions [4.2.3]; it can be dispatched and used to meet peak demand. Hence, geothermal electric power can complement intermittent electricity generation [4.1].

Electric power from geothermal energy is especially suitable for supplying base-load power in an economical way due to the high average capacity factor of currently 71%, with newer installations above 90% [ES].

Since geothermal resources are underground, exploration methods (including geological, geochemical and geophysical surveys) have been developed to locate and assess them. The objectives of geothermal exploration are to identify and rank prospective geothermal reservoirs prior to drilling, and to provide methods of characterising reservoirs that enable estimations of geothermal reservoir performance and lifetime, focusing in the underground temperature distribution, the Earth's stress field and potential fluid bearing structures [4.3.2].

For drilling of geothermal wells over a range of depths up to 5 km, conventional rotary drilling methods are used similar to those for accessing oil and gas reservoirs. Advanced drilling technologies allow for high temperature operation and provide directional capability [4.3.2]. Monitoring, analyzing and modelling of the chemistry and thermodynamics of geothermal fluids, along with mapping their flow and movement in geothermal reservoirs allows for better sizing of power plant and pro-active management of the reservoir's development [4.3.3].

Geothermal power plants either make direct use of the steam from geothermal reservoirs or they deploy heat exchangers (binary cycle plants) that transfer the heat to another working fluid. Binary cycle plants allow for use of lower temperature reservoirs and are often constructed as linked modular units of a few MWe in capacity. Combined or hybrid plants comprise two or more of the above basic types to improve versatility, increase overall thermal efficiency, improve load-following capability, and efficiently cover a wide resource temperature range (200-260°C) [4.3.4].

Under appropriate conditions, high, intermediate and low temperature geothermal fields can be utilised for both power generation and the direct use of heat [4.3.1]. Direct use provides heating and cooling for buildings including district heating, fish ponds, greenhouses and swimming pools, water purification/desalination and industrial and process heat for agricultural products and mineral drying [4.3.7]. Geothermal heat pumps (GHP) are a subset of direct use that can be utilized anywhere in the world for heating and cooling [4.1] and are based on the relatively constant ground or groundwater temperature in the range of 4°C to 30°C. GHP can be of the closed loop or of the open loop type [4.3.8].

Prospects for Technology Improvement, Innovation, and Integration

Successful development and deployment of geothermal technologies will mean significantly higher energy recovery, longer field lifetimes and much more widespread availability of geothermal energy. Achieving that success will require sustained support and investment into technology development from governments and private sectors for the next 10 to 20 years. With time, better technical solutions are expected to improve power plant performance and reduce maintenance down-time. More advanced approaches for resource development, including advanced geophysical surveys, reinjection optimization, scaling/corrosion inhibition, and better reservoir simulation modelling, will help reduce the resource risks by better matching installed capacity to sustainable generation capacity [4.6.1].

In exploration, R&D is required for hidden geothermal systems and EGS prospects. Rapid reconnaissance geothermal tools will be essential to identify new prospects, especially those with no surface hot springs. Satellite-based hyper-spectral, thermal infra-red, high-resolution panchromatic and radar sensors are most valuable at this stage, since they can provide data inexpensively over large areas [4.6.2].

In order to improve access to reservoirs special research is needed in large diameter drilling through plastic, creeping or swelling formations such as salt or shale. The objectives of new-generation geothermal drilling and well construction technologies are to reduce the cost and increase the useful life of geothermal production facilities through an integrated effort. Ultimately a larger portion the geothermal resource would be economically accessible if drilling costs could be substantially reduced by developing improved technology, e.g. thermal, particle-assisted abrasives, and chemically-assisted drilling techniques [4.6.3].

Reservoir engineering, particularly in the case of EGS, need to be refined to significantly enhance the hydraulic productivity, while reducing the risk of seismic hazard. Imaging fluid pathways induced by hydraulic stimulation treatments through innovative technology would facilitate this. New visualisation and measurement methodologies (imaging of borehole, permeability tomography, tracer technology, coiled tubing technology) should become available for the characterisation of the reservoir [4.6.3].

The efficiency of the surface system components can still be improved, especially for low-enthalpy power plant cycles, cooling systems, heat exchangers and production pumps for the brine. New and cost-efficient materials are also required for pipes, casing liners, pumps, heat exchangers and for other components [4.6.4].

Enhanced Geothermal Systems (EGS)

While conventional, high-temperature, naturally-permeable geothermal reservoirs are profitably deployed today for power production and direct uses, the success of the EGS-concept would lead to widespread utilization of lower grade resources. EGS projects are currently at a demonstration and experimental stage. The key technical and economic challenges for EGS over the next two decades will be to achieve efficient and reliable stimulation of multiple reservoirs with sufficient volumes to sustain long term production, with low flow impedance, limited short-circuiting fractures, and manageable water loss (Tester et al., 2006) [4.6.1]. This requires, for instance, better understanding of how cracks form and propagate in different stress regimes and rock types and the ability to create multiple fracture zones from a single borehole [4.6.2].

Submarine geothermal power

Submarine geothermal power is still at the conceptual stage. In theory, submarine devices could make use of existing hydrothermal vents (without drilling) at mid-ocean ridges to generate electricity. Among others, critical challenges for these resources include the distance from shore and off-to-onshore grid-connection costs and the potential impact on unique marine life around hydrothermal vents [4.3.6].

Global and Regional Status of Market and Industry Development

Geothermal technologies from conventional geothermal resources are mature with established markets around the world. Geothermal-electric generation accounts for one century of commercial experience with 10.7 GW of installed capacity in 24 countries (Fig. TS 4.2) providing 10% to 30% of their electricity demand in six of them. There are also 50 GW thermal of geothermal direct applications operating in 78 countries, including space heating and cooling with GHP.

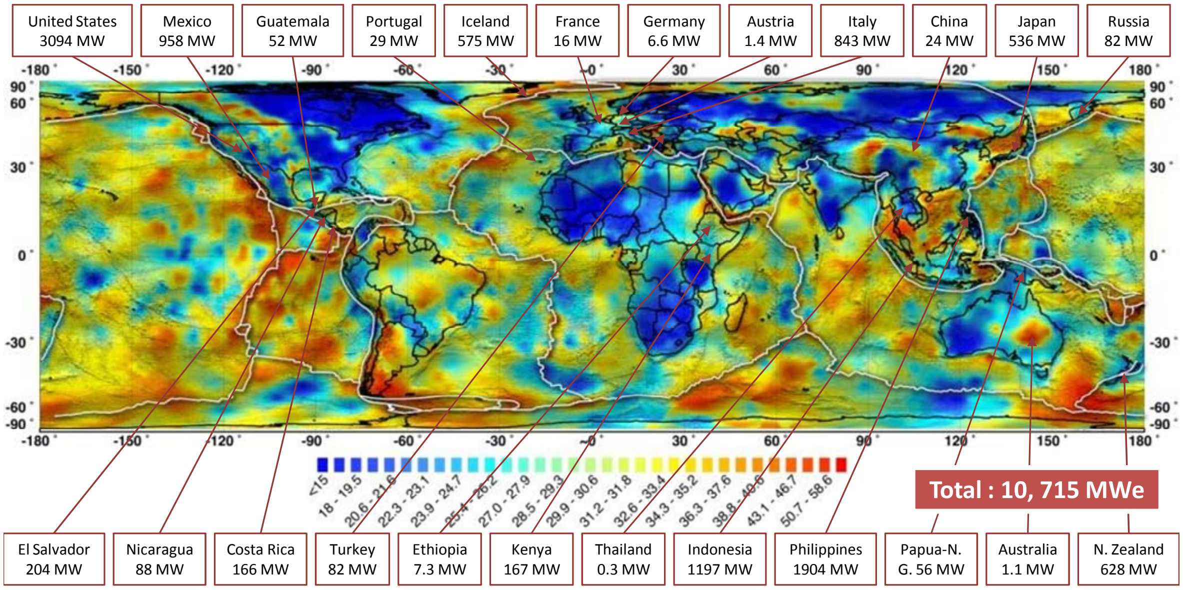


Figure TS 4.2 Geothermal-electric installed capacity by country in 2009. Figure shows worldwide average temperature gradients in °C/km and tectonic plates boundaries (data from Bertani, 2010).

The worldwide use of geothermal energy for power generation (predominantly from conventional hydrothermal resources) was 67.2 TWh/year in 2008 with a worldwide CF of 71% (Bertani, 2010). Conventional geothermal resources currently used to produce electricity are of high-temperature

(>180°C), utilised through steam turbines (condensing or back-pressure, flash or dry-steam), and of low-intermediate temperature (<180°C) used by binary-cycle power plants [4.4.1].

The average annual growth of worldwide geothermal-electric installed capacity over the last five years (2005-2010) is 4.7%, and over the last 40 years (1970-2010) is 7.0%. For geothermal direct uses (heat applications) the world average annual growth in 2005-2010 is 16.1%, and 11% in the last 35 years (1975-2010) [4.4.1].

EGS are still in the demonstration phase in Europe, the US and Australia, with two pilot projects already in operation in Germany and one commissioned in France. In Australia considerable investments of US$ 248 million by year-end 2008 have been made by private sector companies, and there are government grants to co-fund drilling, geophysical surveys and research totaling US$ 267 million. The US in its recent clean energy initiatives has included large EGS research, development, and demonstration components as part of a revived national geothermal program [4.4.2].

The world installed capacity of geothermal direct use is currently estimated to be 50.6 GWt (Table 4.2), with a total thermal energy usage of about 121.7 TWh_t/y (0.438 EJ/y), distributed in 78 countries, with an annual average capacity factor of 27.8%. The main types (and relative percentages) of direct applications in annual energy use are: space heating of buildings (63%, of which three quarters are from heat pumps), bathing and balneology (25%), horticulture (greenhouses and soil heating) (5%), industrial process heat and agricultural drying (3%), aquaculture (fish farming) (3%) and snow melting (1%) (Lund et al., 2010) [4.4.3].

Cost Trends

Geothermal projects have typically high up-front costs (mainly due to the cost of drilling wells) and low operational costs. These operational costs vary from one project to another due to size and quality of the geothermal fluids, but are relatively predictable in comparison with power plants of traditional energy sources which are usually subject to market fluctuations in fuel price [4.7].

The capital cost (capex) of a typical geothermal-electric project is composed of the following components: a) Exploration and resource confirmation (10-15% of the total), b) Drilling of production and injection wells (20-35% of the total), c) Surface facilities and infrastructure (10-20% of the total), and d) Power plant (40-80% of the total). Current capex vary between 1800 and 5300 US$ (2005) per kWe [4.7.1].

Current geothermal-electric Operation and Maintenance (O&M) costs, including make-up wells, have been calculated to be between 19 and 30 (2005) US$/MWh. The present levelized costs (LCOE) of geothermal electricity are calculated to be 43-84 (2005) US$/MWh using the lowest (3%) and highest (10%) discount rates, which make it competitive in most power markets. There are no actual LCOE data for EGS, but some projections obtained values of 100-175 (2005) US$/MWh for relatively high-grade EGS resources (250-330°C, 5 km depth wells) assuming a base-case present-day productivity of 20 kg/s per well [4.7.2].

By 2050 LCOE are expected to low 15% (Fig. TS 4.3) due to a decreasing drilling cost derived from better technologic practices in the drilling industry and from economic competition resulting from a greater availability of drilling rigs, and an increasing worldwide average capacity factor (80% for 2020, 85% for 2030 and 90% for 2050 [4.7.3]). Projected LCOE values for EGS assuming improvements in technology and productivity are expected to low around 50% by 2050 [4.7.4].

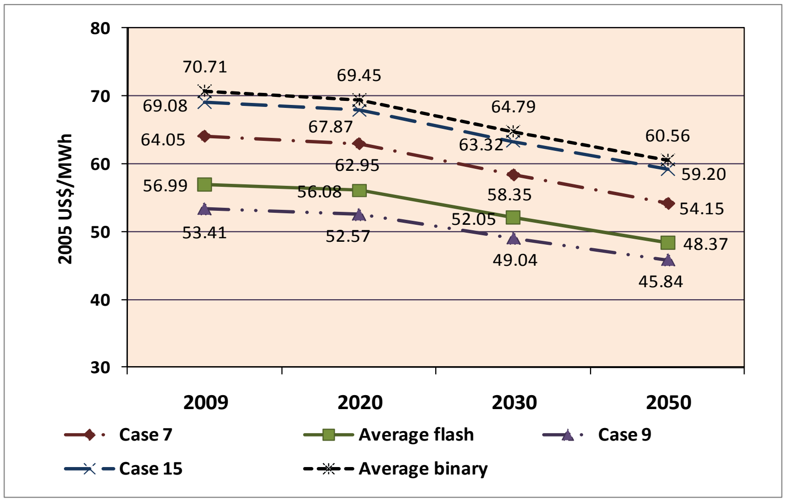


Figure TS 4.3 Present and projected LCOE in 2005 US$ for typical geothermal-electric plants at discount rate of 7% [Refer to 4.7.2 and 4.7.2 for explanation of cases 7, 9 & 15]. [TSU: reference?]

Cost of direct-use projects have a wide range, depending upon the specific use, the temperature and flow rate required, the associate O&M and labour costs, and the income from the product produced. In addition, costs for new construction are usually less than cost for retrofitting older structures. However, current costs of geothermal direct uses are also competitive and calculated to be between 75 (2005) US\$/kW$_{th}$ for aquaculture ponds to 3900 (2005) US\$/kW$_{th}$ for individual space heating. Current LCOE costs go from 35 (2005) US$/MWh (thermal) for aquaculture ponds to 170 (2005) US$/MWh (thermal) for individual space heating [4.7.5].

Environmental and Social Impacts

Geothermal is a renewable resource as the tapped heat from an active reservoir is continuously restored by natural conduction and convection from surrounding hotter regions, and the extracted geothermal fluids are replenished by natural recharge and by reinjection of the exhausted fluids. If managed properly, geothermal systems can be sustainable for the long term. Geothermal systems are natural phenomena, and typically discharge gases mixed with steam from surface features, and minerals dissolved in water from hot springs.

Direct CO_2 emissions average 120 g/kWh$_e$ for currently operating conventional flash and direct steam electric power plants and less than 1 g/kWh$_e$ for binary cycle plants with total reinjection. Corresponding figures for direct use applications are even lower.This emission is from natural CO_2 releases into the atmosphere, not created by any combustion process [ES, 4.5.1]. Over its full life-cycle, the CO_2-equivalent emissions range from 23-80 g/kWh$_e$ for binary plants and 14-202 g/kWh$_{th}$ for district heating systems and GHP [4.5.2].

Local hazards arising from natural phenomena, such as micro-earthquakes, hydrothermal steam eruptions and ground subsidence may be influenced by the operation of a geothermal field. Pressure or temperature changes induced by stimulation, production or re-injection of fluids can lead to geo-mechanical stress changes and these can then affect the subsequent rate of occurrence of these natural phenomena. Even though no buildings or structures within a geothermal operation or local community have been significantly damaged (more than superficial cracks) by shallow earthquakes originating from either geothermal production or injection activities, geological risk assessments can help avoid or mitigate these hazards [4.5.3].

Land use requirements range from 160 to 290 m^2/GWh/y excluding wells and up to 900 m^2/GWh/y including wells. Specific geothermal impacts on land use include effects on outstanding natural features such as springs, geysers and fumaroles. Despite good examples of unobtrusive, scenicallylandscaped developments (e.g. Matsukawa, Japan), and integrated tourism/energy developments (e.g. Wairakei, New Zealand and Blue Lagoon, Iceland), land use issues in many settings (e.g. Japan, the US and New Zealand) can be a serious impediment to further expansion of geothermal development [4.5.5].

The successful realization of geothermal development projects often depends on the level of acceptance by the local people. Prevention or minimization of detrimental impacts on the environment, and on land occupiers, as well as the creation of benefits for local communities, is indispensable to obtain social acceptance. One of these benefits is that geothermal development often creates job opportunities for locals since drilling and plant construction must be done at the site. This can be helpful for poverty alleviation in developing countries, particularly in Asian, Central and South American, and African developing nations where geothermal developments are often located in remote mountainous areas [4.5.4].

Geothermal resources are environmentally advantageous and the net energy supplied more than offsets the environmental impacts of human, energy and material inputs. A good example of this is the city of Reykjavik, Iceland, which has eliminated heating with fossil fuels, significantly reducing air pollution, and avoided about 100 Mt of cumulative CO_2 emissions (i.e., around 2 Mt annually). Other examples are at Galanta in Slovakia, Pannonian Basin in Hungary, and Paris Basin in France [4.5.4].

Potential Deployment

Geothermal energy can contribute to near- and long-term carbon emissions reduction. In 2008 the worldwide geothermal-electric generation was 67.2 TWh_e [4.4.1, 4.7.3] and the heat generation from geothermal direct-uses was 121.7 TWh_t [4.4.3]. These amounts of energy are equivalent to 0.24 and 0.44 EJ/y, respectively, for a total of 0.68 EJ/y (direct equivalent method). This represents only ~0.13% of the global primary energy demand in 2007. However, on a global basis, by 2050 geothermal could supply 2.5-4.1% of the global electricity demand and almost 5% of the global demand of heat-cooling [4.8].

In the near-term (2015) and taking into account the geothermal-electric projects under construction or planned in the world, it is expected to reach 18,500 MWe of installed capacity (Bertani, 2010). For geothermal direct uses (heat applications) it is expected an annual growth rate between their historic average rate (11%) and the rate of the last 5 years (2005-2010: 16.1%), which results in 13.5% to reach 95,300 MW_{th} [4.8.1].

In the long-term (2050), it is assumed for electric power deployment that the average annual rate growth for 2015-2030 will be the historic rate (7%), and for 2030-2050 an annual rate growth of 5.9% is expected, including EGS projects deployment. For direct uses deployment, the assumed average annual rate growths are: 11% for 2015-2020 (historic rate 1975-2010), 9% for 2020-2030, 5.5% for 2030-2040 and 2.5% for 2040-2050 [4.8.2]. Thus, the expected deployments by regions in the near and long term are presented in Table TS 4.2, which is a compound of tables 4.10 and 4.12 of chapter 4 [4.8.1, 4.8.2].

Table TS 4.2 Regional near- and long-term forecasts of installed capacity for geothermal power and direct uses (heat) and global forecast of electric and direct uses (heat) generation [4.8.1, 4.8.2]. [TSU: Sources of tables 4.10 and 4.12 are missing]

REGION	Current capacity (2010)		Forecast capacity (2015)		Forecast capacity (2050)	
	Direct (GWt)	Electric (GWe)	Direct (GWt)	Electric (GWe)	Direct (GWt)	Electric (GWe)
1. OECD North America	13.893	4.052	30.7	6.6	234.5	45.4
2. Latin America	0.808	0.509	1.2	1.1	10.2	8.5
3. OECD Europe	20.357	1.551	36.6	2.1	305.9	25.3
4. Africa	0.13	0.174	2.5	0.6	18.4	7.0
5. Transition Economies	1.063	0.082	1.8	0.2	10.2	4.8
6. Middle East	2.362	0	3.1	0.0	7.1	2.2
7. Developing Asia	0.052	3.158	2.1	6.1	20.4	35.2
8. India	0.265	0	1.2	0.0	10.2	2.8
9. China	8.898	0.024	12.3	0.1	127.5	13.7
10. OECD Pacific	2.755	1.165	3.7	1.8	86.7	15.7
TOTAL	**50.583**	**10.715**	**95.3**	**18.5**	**831.1**	**160.6**
Generation (current or expected, thermal and electric) in:	TWh_t/y	TWh_e/y	TWh_t/y	TWh_e/y	TWh_t/y	TWh_e/y
	121.7	67.2	250.4	121.6	2184.0	1266.4
	EJ/y	EJ/y	EJ/y	EJ/y	EJ/y	EJ/y
	0.44	0.24	0.90	0.44	7.86	4.56

For power, practically all the new power plants expected by 2015 will be conventional (flash and binary) in hydrothermal resources, with only a marginal contribution of EGS projects. In general terms, the worldwide trends in development of EGS are estimated to be slow in the next 5-10 years, and then present an accelerated growth. In the long-term (2050) it is expected that half of the geothermal power plants in the world (160 GWe) will be of EGS type.

Projections of geothermal energy contribution to the global primary energy supply span a very broad range: up to 11.9 EJ/y in 2020, 21.3 EJ/y in 2030 and 50.1 EJ/y in 2050, taking the more stringent carbon mitigation policies (300-440 ppm in all years), and are sensitive to the carbon policy assumed by each projected year. Medians of all those scenarios are also sensitive to the carbon policy, ranging 0.39-0.68 EJ/y by 2020, 0.22-1.2 EJ/y by 2030 and 1.09-3.85 EJ/y by 2050, in all cases considering the baseline (600-1000 ppm) and the 300-440 ppm scenarios. These amounts are not completely comparable with the IPCC AR4 estimate by 2030, since this included only geothermal-electric generation without reference to the geothermal contribution for heat supply. But even so, it is clear that the 2.28 EJ/y of electric generation estimated by the AR4 by 2030 results well above the medians considered by 2030, but lies in the 25-75% percentile for the more restricted scenario [4.8.2]. It is clear, also, that the medians of all scenarios considered by Chapter 10 are feasible for 2020, 2030 and 2050 and even result conservative compared to the estimates provided in Table 4.2. What's more, even the highest estimates for long-term contribution of geothermal energy to the global primary energy supply (50.1 EJ/y by 2050), are well within the technical potentials (91 up to 1043 EJ/y for electricity and 10 up to 322 EJ/y for heat). Thus, technical resource potential is not likely to be a barrier to reach the most aggressive levels of geothermal deployment (electricity and direct uses) in a global or regional basis [4.8.2].

Evidence suggests that the global and regional availability of geothermal resources is enough to meet the results of the modelled scenarios, and also that projected market penetration seems to be reasonable. With its natural thermal storage capacity, geothermal is especially suitable for supplying base-load power, and thus is uniquely positioned to play a key role in climate change mitigation strategies [4.8.3].

Hydropower

Resource Potential

Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations. The annual global and *technically* feasible potential for hydropower generation is 14,368 TWh with a corresponding estimated total capacity potential of 3,838 GW; five times the current installed capacity. Undeveloped capacity ranges from about 70 percent in Europe and North America to 95 percent in Africa indicating large and well distributed opportunities for hydropower development worldwide (see Table TS 5.1). (5.2.1) Substantial potential is also available at existing weirs, barrages, canals and ship locks.

Table TS 5.1 Regional technically feasible, annual hydropower potential (TWh/yr) and capacity potential (GW) compared to annual generation in 2005/2006 (TWh) and installed capacity (GW); also shown are undeveloped capacity potential and average capacity factors in percent (%) (Source: (IJHD, 2005, 2007).

	Technical Potential (TWh/Yr)	Capacity Potential (GW)	Annual Generation 2005/2006 (TWh)	Installed Capacity (GW)	Undeveloped Capacity Potential (%)	Capacity Factor [=Generation/ (Capacity*8760hrs)] (%)
North America	1510	357	625	148	71	48
Latin America	2968	600	674	136	81	56
Europe	1140	360	539	170	68	36
Africa	1750	399	983	21	95	50
Asia	6800	1652	1061	258	87	47
Australasia/ Oceania	200	67	40	13	83	34
Total	14368	3845	3032	746	79	46

While the average capacity factors are in the order of 50%, the value for Europe (36%) and Australasia/Oceania is low probably due to the way hydro is used in the energy mix (more peaking than base-load). Increases in generation achievable by equipment renovation, uprates and operation optimization have generally not been assessed. (5.2.1)

The resource potential for hydropower may change due to a changing climate; both increasing and decreasing effects have been found in local and regional studies (5.2.2). Global effects on existing hydropower systems will probably be small, even if individual countries and regions could have significant positive or negative changes in precipitation and runoff (ES): Annual power production capacity for the present (2005) hydropower system in 2050 could increase by 2.7 TWh in Asia under the A1B scenario, and decrease by 0.8 TWh in Europe. (5.2.2.1.7)

Technology and Applications

Hydropower plants (HPP) are often classified in three main project types according to operation and type of flow: run of river (RoR), reservoir based and pumped storage type. (5.3.1)

RoR HPP only have small intake basins with no storage capacity. Some RoR HPP also have small storage and are known as pondage-type plants. Power production therefore follows the hydrological cycle in the watershed. For RoR HPP the generation varies as per water availability from rather intermittent in the small tributaries to base-load in large rivers with continuous water flow. Hydropower projects with a reservoir, alternatively called storage hydropower, deliver a broad range of energy services such as base load, peak, energy storage and act as a regulator for other sources. In addition they often deliver services that are going far beyond the energy sector such as flood control, water supply, navigation, tourism and irrigation. Pumped storage delivers its effect mainly on peaking consumption. (5.3.1, 5.4.4). Pumped storage is the largest-capacity form of grid energy storage now available. (5.3.1.3) Hydropower projects are usually designed to suit particular site conditions, and are classified by project type, head (i.e. the vertical height of water above the turbine), purpose (single or multi-purpose) and size (installed capacity). Size wise categories are different worldwide due to varying development policies in different countries.

Hydropower has the best conversion efficiency of all known energy sources (about 90% efficiency, water to wire). It also has the highest energy payback ratio (see Figure TS 5.1), considering the amount of energy required to build, maintain and fuel a hydropower plant compared with the energy it produces during its normal life span. (5.1.3) However, sedimentation is a problem that needs to be managed as it has a number of negative effects on HPP performance: depletion of reservoir storage capacity over time; increase in downstream degradation; increased flood risk ,; generation losses due to reduction in turbine efficiency, increased frequency of repair and maintenance; and reductions in turbine life-time and in regularity of power generation. The sedimentation problem may ultimately be controlled through land-use policies and the protection of vegetation coverage. The application of technical measures, such as the reduction of sediment load to the reservoirs, the removal of sediment from the storage reservoirs, and the design and operation of hydraulic machineries to resist effects of sediment, may also help to deal with the problem. (5.3.3)

Normally the life of hydro-electric power plant is 40 to 80 years. Electro-mechanical equipment may need to be upgraded or replaced after 30-40 years, while civil structures like dams, tunnels, etc usually function longer before it requires renovation. Uprating of hydropower plants calls for a systematic approach as there are a number of factors (hydraulic, mechanical, electrical and economic) that play a vital role in deciding the course of action. From a techno-economic viewpoint, uprating should be considered along with renovation & modernization/Life extension measures. Hydropower generating equipment with improved performance can be retrofitted, often to accommodate market demands for more flexible, peaking modes of operation. Most of the 746 GW of hydropower equipment in operation today will need to be modernised by 2030. Having existing hydropower plants refurbished will usually result in increased hydropower capacity and production both where present capacity is being renovated and/or uprated and where existing infrastructure (like barrages, weirs, dams, canal fall structures, water supply schemes) is being reworked to add new hydropower facilities. (5.3.4)

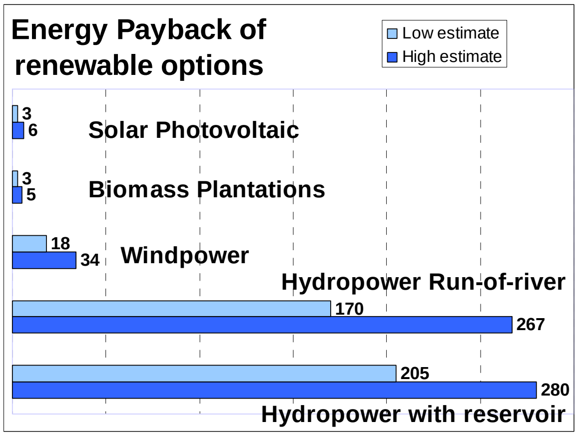


Figure TS 5.1 Energy Pay back Ratio (Source: Gagnon 2008).

Global and Regional Status of Market and Industry Development

Hydropower is a mature, predictable and price competitive technology. (ES) It currently provides approximately 16% of the world's total electricity production and 87% of electricity from renewable sources. (5.4.1) While hydropower contributes to some level of power generation in 159 countries, five countries make up more than half of the world's hydropower production: China, Canada, Brazil, the USA and Russia (5.4.1). The importance of hydroelectricity in the electricity matrix of these countries differs, however, widely. On one hand Brazil, Canada are heavily dependent on this source having a percentage share of the total of 83.2% and 58% respectively, whereas other hand, United States has a share of 7.4% only from hydropower. In Russia, the share is 17.6% and 15.2% in China. (5.4.1)

Hydropower projects are one of the main contributors to carbon credits. As of March 2010, 562 hydropower projects out of total 2062 projects are registered under CDM, representing 27% of CDM projects. A significant portion of these projects are based in China (67%), India (9%) and Brazil (6%). So far only 12 projects have been rejected by the CDM Executive Board on the grounds of not fulfilling the additionality criterion. However, there is uncertainty at present of the value of the Certified Emission Reductions (CERs) gained within the EU Emission Trading Scheme (ETS). With EU Member States having interpreted the conditions on the use of these credits differently in the past, European carbon exchanges have refused to offer the CERs for trade on their platforms as they may not be fully fungible. Initiatives to harmonise this procedure are underway. (5.4.5)

Carbon credits benefit hydropower projects by helping to secure financing and to reduce risks. As financing is a most decisive step in the entire project development, additional funding from carbon credit markets could be a significant financial contribution to project development (increase in return on equity and improve internal rate of return) which can be observed in several ways: 1) additional revenues from the credits, and 2) higher project status as a result of CDM designation (enhanced project's attractiveness for both equity investors and lenders). (5.4.5)

Many economically feasible hydropower projects are financially challenged. High up-front costs are a deterrent for investment. Also, hydropower tends to have lengthy lead times for planning, seeking various permits, and construction. In the evaluation of life-cycle costs, hydropower often has the best performance, with annual operating costs being a fraction of the capital investment and the energy pay-back ratio (= total energy produced during system's normal lifespan/ energy required to build, maintain and fuel the system) being extremely favourable because of the longevity of the power plant components. (5.4.6.1)

The development of more appropriate financing models is a major challenge for the hydropower sector, with optimum roles for the public and private sectors. The main challenges for hydropower relate to creating private-sector confidence and reducing risk, especially prior to project for seeking permits. Green markets and trading in emissions reductions will undoubtedly give incentives. Also, in developing regions, such as Africa, being emerging markets interconnection between countries and the formation of power pools is building investor confidence in these. Feasibility and impact assessments carried out by the public sector, prior to project execution, will ensure greater private-sector interest in future projects. (5.4.6.1)

Most of countries differentiate between small scale and large scale hydropower. There are different incentives used for small scale hydropower (feed-in tariffs, green certificates, easy permits and bonus) depending on the country, but no incentives are used for large scale hydro. For instance, France currently applies a legislation which provides a financial support scheme for renewable energy based on feed-in tariffs (FIT) for power generation. For renewable energy installations up to 12 MW, tariffs depend on source type and may include a bonus for some sources (rates are corrected for inflation). For hydropower the tariff duration is 20 years, and the FIT is 60.7 €/MWh, plus 5 to 25 €/MWh for small installations, plus up to 16.8 €/MWh bonus in winter for regular production. (5.4.6.2)

Integration into Broader Energy Systems

As the generating units of hydropower can be started or stopped almost instantly, it is the most responsive energy source for meeting peak demands and balancing unstable electricity grids. Techniques such as seasonal/multi seasonal storage or daily/weekly pondage can be used in many cases to make the distribution of stream flow better suitable to power demand patterns. (5.5.5) Storage hydropower is therefore ideal for backing up and regulating variable renewable sources like wind, solar and waves, thus allowing for a higher deployment of these sources in a given grid. The flexibility and short response time of hydropower could also facilitate nuclear and thermal plants to operate at their optimum steady state level thereby reducing their fuel consumption and emissions. (ES) Hence, in an integrated system, the hydropower plant is used as the peaking plant with thermal units functioning as base loads. (5.5.1) As such, hydropower has the potential to increase the output of power systems and smooth the output from variable output technologies. (5.5.) It can help to ensure reliable supplies and may help eliminate brownouts and blackouts caused by partial or total power failures. (5.5.4) Therefore, hydropower generation provides numerous ancillary services such as voltage regulation, operating reserves, black-start capability and frequency control, helping to maintain a reliable operation of the transmission system and to increase energy security. (5.5.6.4)

Hydropower can be served through the national and regional electric grid, mini grid and also in isolated mode. There are several hydro projects which are for captive use and have been since the very beginning of hydropower development. Water mills in England, Himalayan countries and many other parts of the world, for grinding the cereals, for water lifting and for textile industry constitute early instances where hydropower has been used as captive power in mechanical as well as electrical form. The tea and coffee plantation industry have used and still are using hydropower for their captive needs in isolated areas. (5.5.2) There has been a growing realisation in developing countries that small scale hydropower schemes have an important role to play in the socioeconomic development of remote rural, especially hilly, areas specially to provide power for industrial, agricultural and domestic uses. Small scale hydropower based rural electrification in China has been one of the most successful examples, building over 45,000 small scale hydro plants of 50,000 MW, producing 150 Billion kWh annually, and benefitting over 300 Million people (up to 2007). (5.5.3)

Environmental and Social Impacts

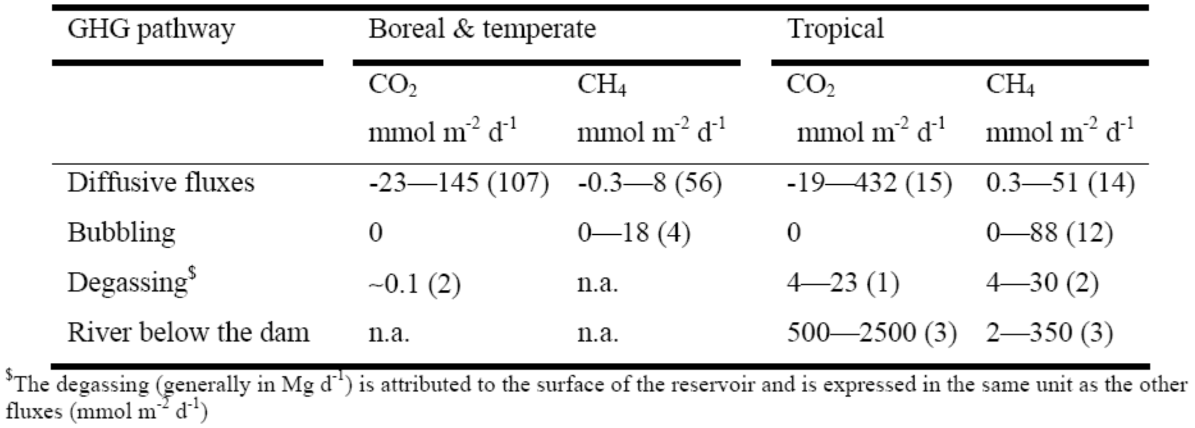
Like all other energy and water management options, hydropower projects do have up and down sides. On the environmental side, hydropower offers advantages on the macro-ecological level, but shows a significant environmental foot print on the local and regional level. With respect to social impacts, a hydropower scheme will often be a driving force for socio-economic development, yet a critical question remains on how these benefits are shared. (5.6)

Most environmental impacts of hydropower generation will be related to changes in the hydrological regime of the river, i.e. the physical and biological changes caused by variations in flow and water level. The magnitude of these changes can be mitigated by proper power plant operation and discharge management, regulating ponds, information and warning systems as well as access limitations. There is also a trend to incorporate ecological minimum flow considerations into the operation of water control structures as well as increasing needs for flood and drought control. Major changes in the flow regime may entail modifications in the estuary, where the extent of salt water intrusion depends on the freshwater discharge. Another impact associated with dam construction is decreased sediment loading to river deltas downstream from large reservoirs for example the Nile delta.

While not all hydropower plants do have a reservoir, it is the impoundment of land which has the most important adverse impacts. Water quality may be affected, with the absence of oxygen contributing, especially in warm climates, to the formation of methane in the first years after impoundment. Impacts on biological diversity and migratory fish species also require careful consideration during the project planning phase. For example, improvements in turbine design, spillway design or overflow design have proven to successfully minimize fish injury or mortality rates.

One of hydropower's main environmental advantages is that it creates no atmospheric pollutants or waste. Over its life cycle, a hydropower plant generally emits much less CO2 than most other sources of electricity. (5.6) Lifecycle assessments that evaluate GHG emissions of HPP during construction, operation and maintenance, and dismantling, estimate the amount of CO2 – equivalent emitted to be between 11-15g CO2eq/kWh. Such emission estimates, stemming from mainly temperate and Nordic reservoirs, rank very low compared to those of thermal power plants, which would typically be in the range of 500-1000 g CO2eq /kWh. However, all freshwater systems, whether they are natural or man made, emit greenhouse gases such as CO2 and methane (CH4) due to decomposing organic material (Table TS 5.2). While some natural water bodies and freshwater reservoirs may even absorb more GHG than they emit there is a definite need to properly assess the net change in GHG emissions induced by the creation of such reservoirs. The challenge is to improve the understanding of reservoir induced impacts, excluding unrelated anthropogenic sources as well as natural GHG emissions from the watershed. (5.6.3)

Table TS 5.2 Range of gross CO2 and CH4 emissions from hydroelectric freshwater reservoirs. Numbers in parentheses are the number of studied reservoirs (UNESCO-RED, 2008).



GHG pathway	Boreal & temperate		Tropical	
	CO_2 mmol m^{-2} d^{-1}	CH_4 mmol m^{-2} d^{-1}	CO_2 mmol m^{-2} d^{-1}	CH_4 mmol m^{-2} d^{-1}
Diffusive fluxes	-23—145 (107)	-0.3—8 (56)	-19—432 (15)	0.3—51 (14)
Bubbling	0	0—18 (4)	0	0—88 (12)
Degassing[$]	~0.1 (2)	n.a.	4—23 (1)	4—30 (2)
River below the dam	n.a.	n.a.	500—2500 (3)	2—350 (3)

[$] The degassing (generally in Mg d^{-1}) is attributed to the surface of the reservoir and is expressed in the same unit as the other fluxes (mmol m^{-2} d^{-1})

Hydropower has been a catalyst for economic and social development of several countries. According to the World Bank, large hydropower projects can have important multiplier effects creating an additional 40-100 cents of indirect benefits for every dollar of value generated. Hydropower can serve both in large centralized and small isolated grids. Small scale hydro can easily be implemented and integrated into local ecosystems and might be one of the best options for rural electrification for instance in isolated grids, while large urban areas and industrial scale grids need the flexibility and reliability of large scale hydro.

Thus on the positive side, hydropower often fosters socio-economic development, not only by generating electricity but also by facilitating through the creation of freshwater storage schemes along with other multiple water-dependent activities, such as irrigation, navigation, tourism, fisheries or sufficient water supply to municipalities and industries while protecting against floods and droughts. Yet, inevitably questions arise about the sharing of these revenues among the local affected communities, government, investors and the operators. Key challenges in this domain are the fair treatment of affected communities and especially vulnerable groups like indigenous people, resettlement if necessary and public health issues, as well as appropriate management of cultural heritage values. (5.6)

Each hydropower plant is a unique product tailored to the specific characteristics of a given geographical site and the surrounding society and environment. Consequently, the magnitude of environmental and social impacts as well as the extent of their positive and negative effects is rather site dependent. For this reason the mere size of a hydropower plant is not a relevant criterion to anticipate impacts. (5.6) Good experience gained during past decades in combination with new sustainability guidelines, innovative planning based on stakeholder consultations and scientific know-how is promising to secure a high sustainability performance in future hydropower projects. Transboundary water management, including hydropower projects, establishes an arena for international cooperation that may contribute to promote peace, security and sustainable economic growth. Ongoing research on technical and environmental issues may ensure continuous improvement and enhanced outcomes for future projects.

Prospects for Technology Improvement and Innovation

With hydropower being a mature technology, most components have been tested and optimised during long term operation. Large hydropower turbines are now close to the theoretical limit for efficiency, with up to 96% efficiency. Older turbines can have lower efficiency by design or reduced efficiency due to wear from sediments. It is therefore a potential to increase energy output by retrofitting new equipment with improved efficiency and usually also with increased capacity. Most of the existing hydropower equipment in operation today will need to be modernized during the next two decades, opening up for improved efficiency and higher power and energy output. (5.7)

There is much ongoing research aiming to extend the operational range in terms of head and discharge, and also to improve environmental performance, reliability and reduce costs. Some of the promising technologies under development are variable speed and matrix technologies, fish-friendly, hydrokinetic and abrasive resistant turbines, and tunnelling and dam technologies. Most of these new technologies under development aim at utilizing low (< 15m) or very low (< 5m) head, opening up many sites for hydropower that have not been possible to use by conventional technology. As most of the data available on hydropower potential is based on field work produced several decades ago, when low head hydro was not a high priority, existing data on low head hydropower potential may not be complete. (5.7)

Cost Trends

Hydropower requires relatively high initial investment, but has the advantage of very low operation costs and a long lifespan. Its life-cycle costs are deemed low and it is a cost competitive renewable energy source. For comparison to other energy sources (renewable and thermal) the Levelized Cost of Energy (LCOE) can be used.

The most important parameters for determining LCOE are: 1) Investment cost, 2) Load factor, 3) Operation and maintenance cost, 4) Depreciation period and 5) Interest rate. Investment costs are very site specific and ranges from as low as 500 \$/kW to more than 5 000 \$/kW.

Once built and put in operation, hydropower usually requires very little maintenance and operation costs can be kept low. O&M costs are usually given as % of investment cost per kW and may be taken typically as 2.5%. The load factor will depend on hydrological characteristics and regulation (storage) capacity, and values vary from below 40% to near 60%.

Depreciation period is the number of years (“Lifetime”) the station is expected to be fully operational and contributing to production and income. For hydropower, and in particular large hydropower, the largest cost components are civil structures with very long lifetime, like dams, tunnels, canals etc. Electrical and mechanical equipment, with much shorter lifetime, usually contributes less to the cost. For large hydro a typical lifetime ranges from 40 to 80 years.

Interest rate on investment is a critical parameter, in particular for renewable technologies where the initial investment costs dominates in the calculation of LCOE.

There is still a large untapped potential for new hydropower development up to the assumed economic potential of ca. 9000 TWh/year. It is reasonable to assume that in general projects with low cost will be developed first, and as the best projects have been developed, increasingly costly projects will be used. Very expensive project will usually have to wait and possibly be used at a later stage.

Considering the investment cost structure distribution for mostly large projects and mixture of small and medium size projects (5.8.1), it seem reasonable to assume a gradually increasing cost from today and up to 2050. A typical investment cost can be 1500 $/kWh in 2010 (range 1000 to 2000 $/kW), increasing to 2000 $/kWh in 2030 and 2500 $/kWh in 2050, as the more favorable projects have been developed. A summary of the results are given in Table TS 5.3 below:

Table TS 5.3 [TSU: Table caption missing].

Interest rate/Depreciation period	Investment cost in US$/kW	O&M cost in %	Full load hours	LCOE cent/kWh	Comments
3% interest rate 40 year depreciation period	1500 $/kW in 2010 2000 $/kW in 2020 2500 $/kW in 2050	2.5% 2.5% 2.5%	3950 3950 3950	2.6 3.5 4.3	Projects with lowest cost implemented first Increasing cost for remaining projects
7% interest rate 40 year depreciation period	1500 $/kW in 2010 2000 $/kW in 2020 2500 $/kW in 2050	2.5% 2.5% 2.5%	3950 3950 3950	3.8 5.1 6.3	Projects with lowest cost implemented first Increasing cost for remaining projects
10% interest rate 40 year depreciation period	1500 $/kW in 2010 2000 $/kW in 2020 2500 $/kW in 2050	2.5% 2.5% 2.5%	3950 3950 3950	4.8 6.4 8.1	Projects with lowest cost implemented first Increasing cost for remaining projects

These values are well within the range of cost estimates given by WEO 2000/2004 and the various analyses published by IEA and other (Table 5.6 in 5.8.1).

For hydropower stations serving multi-purpose like irrigation, flood control, navigation, roads, drinking water supply, fish, and recreation, the cost, especially for the reservoir, should be shared with the other users/purposes. Many of the purposes cannot be served alone due to consumptive nature and different priority of use. (5.8.2, 5.10)

Potential Deployment

In addition to mitigate global warming, hydropower with storage capacity can also mitigate freshwater scarcity by providing water security during lean flows and drought in dry regions of the world. By 2035, it is projected that 3 billion people will be living in conditions of severe water stress. Water, energy and climate change are inextricably linked. Water storage facilities have an important role in providing energy and water for sustainable development. It is anticipated that climate change will lead to modifications of the hydrological regimes in many countries, introducing additional uncertainty into water resources management. In order to secure water and energy supply in a context of increasing hydrological variability, it will be necessary to increase investment in infrastructure sustaining water storage and control.

Renovation, modernisation & upgrading (RM&U) of old power stations is cost effective, environmentally friendly and requires less time for implementation(5.3.4). There is a substantial potential for adding hydropower generation components to existing infrastructure like weirs, barrages, canals and ship locks.

So far, only one third of the economically feasible hydropower potential has been developed across the world (e.g. 3 000 TWh/year out of ~9 000 TWh/year). The different long term prospective scenarios propose a significant increase for the next decades. For the near-time projections (2015) it is estimated a growth to between 3692 and 3887 TWh/year. For 2030, the global hydropower generation capacity is projected between 4 680 TWh to more than 6 454 TWh as an annual generation, depending on assumptions regarding carbon mitigation scenarios. For 2050, estimates of potential deployment of new hydropower range from 3000 to 6000 TWh/year, compared to present level (5.9.2).

The European Union has developed most of its feasible potential but there are however several possibilities to increase its hydropower capacity: rehabilitation and refurbishment of the existing units, development of small hydropower, and possible new large plants to fulfil the EU RES targets. In Eurasia the remaining potentials are mostly located in Russia and Turkey. (5.9.4)

In North America, even though a large amount of the feasible potential has been developed so far, Canada (and also United States of America) is likely to continue to develop their potential considering national laws on RES, and GHG constraints. In South and Central America**,** the growth will be mainly driven by Brazil, but also several other countries such as Peru, Ecuador, Chile and Colombia will contribute to the increase. (5.9.4)

In Africa, less than 10% of the feasible potential has been developed. The development will rely mainly on countries such as the Democratic Republic of Congo, Ethiopia, Cameroon, Sudan, Uganda, Zambia and Mozambique. In the Asia Pacific region, growth will be mainly driven by China and India. There will also be a significant increase in the Mekong basin (Laos, Myanmar, etc.) and in the Himalaya area (Bhutan and Nepal). (5.9.4)

To achieve these levels there are no real technical and markets challenges, compared to other non mature RES technologies. Even the highest estimates for long-term hydro production are within the global resource estimates presented in section 5.2, suggesting that technical resource potential is unlikely to be a barrier to hydro deployment. On a regional basis, however, higher deployment levels may begin to constrain the most economical resource supply in some regions. (5.9.4).

While efforts may be required to ensure an adequate supply of labour and materials during a long period (for instance more than 40 GW were installed in 2008, which is equivalent to the highest annual long-term IEA forecast scenario in its 450 ppm scenario WEO-2008), no fundamental long-term constraints to materials supply, labour availability, or manufacturing capacity are envisioned if policy frameworks for hydro are sufficiently attractive. (5.9.5)

Integration into water management system

Water, energy and climate change are inextricably linked. These issues must be addressed in a holistic way and it is not practical to look at them in isolation. Providing energy, food and water for sustainable development requires global water governance. As it is often associated with the creation of water storage facilities, hydropower is at the crossroads of these stakes and has a key role to play in providing both energy and water security. Therefore hydropower development is part of water management systems as much as energy management systems, both of which are increasingly climate driven. (5.10)

In order to increase security of supply for water and energy, both within the current climate and in a future with increasing hydrological variability, it will be necessary to increase investment in infrastructure for water storage and control. This is stated in one of the main messages in the World Bank Water Resources Sector Strategy. The need for climate driven water management is often repositioning hydro development as a component of multipurpose water infrastructure projects. (5.10.1)

Creating reservoirs is often the only way to adjust the uneven distribution of water in space and time that occurs in the unmanaged environment. Reservoirs add great benefit to hydropower projects, because of the possibility to store water (and energy) during periods of water surplus, and release the water during periods of deficit, making it possible to produce energy according to the demand profile. This is necessary because of large seasonal and year-to-year variability in the inflow. Such hydrological variability is found in most regions in the world, and it is caused by climatic variability in rainfall and/or air temperature. Most reservoirs are built for supplying seasonal storage, but some also have capacity for multi-year regulation, where water from two or more wet years can be stored and released during a later sequence of dry years. The need for water storage also exists for many other types of water-use, like irrigation, water supply, navigation and for flood control. Reservoirs, therefore, have the potential to be used for more than one purpose. About 75% of the existing 45,000 large dams in the world were built for the purpose of irrigation, flood control, navigation and urban water supply schemes. Only about 25% of large reservoirs are used for hydropower alone or in combination with other uses, as multi-purpose reservoirs (5.10.2).

Since the majority of dams do not have a hydropower component, there is a significant market for increased hydropower generation in many of them. A recent study in the USA indicated some 20 GW could be installed by adding hydropower capacity to the 2500 dams that currently have none. New technology for utilizing low heads also opens up for hydropower implementation in many smaller irrigation dams (5.10.2).

Ocean Energy

Resource Potential

Ocean Energy can be defined as energy derived from technologies, which utilize sea water as their motive power or harness the chemical or heat potential of sea water. The renewable energy resource in the ocean comes from five distinct sources, each with different origins and each requiring different technologies for conversion. These resources are:

Wave energy – derived from wind energy kinetic energy input over the whole ocean. The total theoretical wave energy resource is 32,000 TWh.

Tidal rise and fall – derived from gravitational forces of the earth-moon-sun system. The world theoretical tidal power potential is in the range of 1 -3 TW located in relatively shallow waters (Charlier and Justus, 1993). The world's largest ocean energy power plant is the 240 MW La Rance Barrage in Brittany. A 254 MW tidal barrage is due to open at Sihwa Lake in the Republic of Korea later in 2010. At least 21 GW of tidal barrage developments are under consideration worldwide.

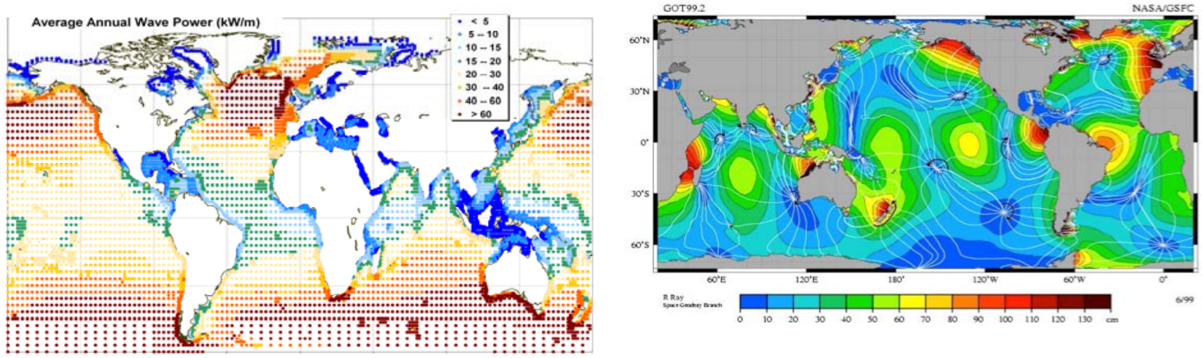
Tidal and ocean currents – derived from tidal energy or from wind driven (thermo-haline) ocean circulation. A total of 106 promising locations for utilization of tidal currents have been identified in Europe alone and it was estimated that, using present-day technology, these sites could supply 48 TWh/y to the European electrical grid network. In China it has been estimated that 7,000 MW of tidal current energy are available. Locations with high potential have also been identified in the Philippines, Korea, Japan, Australia, Northern Africa and South America. The best-characterized system of ocean currents is the Gulf Stream, of which the Florida Current has potential for 25 GW of electricity generation.

Ocean thermal energy conversion (OTEC) – derived from solar energy stored as heat in ocean surface layers centres. An optimistic estimate of the global resource is 30,000 to 90,000 TWh. Submarine geothermal energy – hydrothermal energy at mid-ocean ridges - may be a future source of ocean heat energy.

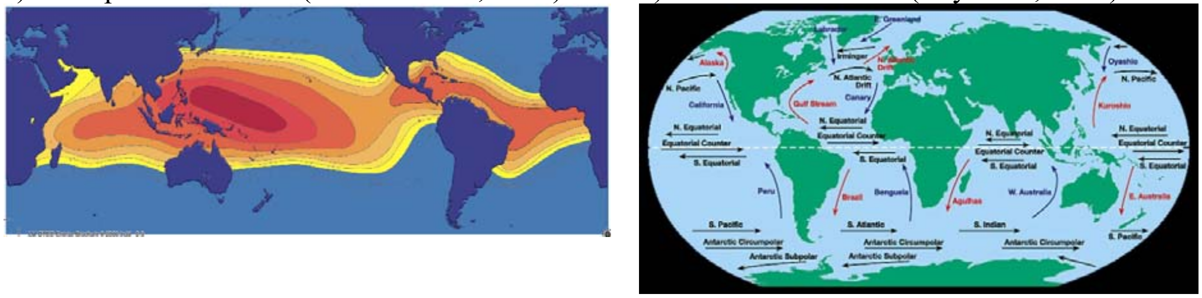
Salinity gradients – derived from salinity differences between fresh and ocean water at river mouths (also called 'osmotic power'). The annual generation potential of osmotic power has been calculated as 1,650 TWh. In Europe alone there is a potential to generate 180 TWh (6.1, 6.2).

The energy resources contained in the world's oceans easily exceed present human energy requirements and the energy could be used not only to generate and supply electricity but also for direct potable water production. Some potential ocean energy resources, such as ocean currents or osmotic power from salinity gradients, are globally distributed, other forms have a complementary distribution. Ocean thermal energy is principally distributed in the Tropics around the Equator (0° - 35°), whilst the highest annual wave power occurs between latitudes of 40° - 60°. Wave power in the Southern Hemisphere undergoes smaller seasonal variation than in the Northern Hemisphere. Ocean currents, ocean thermal energy, osmotic power and, to some extent, wave energy are consistent enough to generate base load power.

The following maps the description of global annual spectral wave power (in kW/m of wavefront, global energy distribution, global tidal rise and fall, global ocean thermal energy resources (in °C) and distribution of global surface ocean currents (Figures TS 6.1a-d).



a) Wavepower in kW/m (Barstow et al., 2008) b) Tidal Rise and Fall (Ray et al., 2009)



c) Ocean Thermal Energy (Lockheed-Martin, 2009) d) Ocean Currents – warm in red, cold in blue (UCAR, 2009)

Figure TS 6.1 Description of a) global annual wavepower, b) global energy distribution, c) global ocean thermal energy resources and d) global ocean currents distribution.

Technology and Applications

There is presently no convergence on a single design for ocean energy converters due to botht he range of different resources, immaturity of present technologies and a fundamental lack of operating experience (6.3.1). Given the range of options for harnessing different forms of ocean energy, there will never be a single device design, as there is for wind energy.

Wave energy technologies can be classified into three groups: oscillating water columns (shore-based, floating), oscillating body (surface buoyant, submerged), and overtopping devices (shore-based, floating). Oscillating water columns use wave motion to trap a volume of air and compress it in a closed chamber, where then exhausts through a specialized air turbine generating electricity. Oscillating bodies are commonly devices, which use swell wave movements to generate differential motions between two bodies of different mass, from which motion power can be generated. Overtopping devices collect surging waves into a water reservoir at a level above the free water surface, which then drains down through a conventional low-head hydraulic turbine (6.3.2).

Tidal rise and fall energy can be harnessed by the adaptation of river-based hydroelectric dams to estuarine situations, where a barrage encloses an estuary, which creates a single basin reservoir behind it. The barrage may generate electricity on both the ebb and flood tides. Some future barrages may have multiple-basin mode to enable continuous generation. The most recent technical advances are stand-alone offshore "tidal lagoons" (6.3.3).

Technologies to harness power from rivers and tidal/ocean currents are also under development but tidal energy converters are more advanced. Some of the tidal/ocean current energy technologies are similar to mature wind turbine generators but submarine turbines must also account for reversing flow, cavitation at blade tips and harsh underwater marine conditions (e.g., salt water corrosion, debris, fouling, etc). Tidal currents tend to be bidirectional, varying with the tidal cycle, and relatively fast-flowing, compared with ocean currents, which are usually unidirectional, slow-moving but continuous. The main difference river and ocean current turbines generally deal with currents flowing in a single direction, whilst tidal current turbines must deal with reversing flow directions two or four times per day during ebb and flood cycles. Usually, they are classified based by their principle-of-operation into axial flow turbines, cross flow turbines and reciprocating devices (6.3.4).

Ocean thermal energy conversion (OTEC) plants use temperature differences of seawater from different depths (warm water from the surface, cool water (from >1,000 m depth) to produce electricity. Open-cycle OTEC systems use seawater as the circulating fluid, whilst closed-cycle systems use heat exchangers and a secondary volative working fluid to drive a turbine. They are believed to present the best solution in terms of thermal performance (6.3.5). Hybrid systems use both open- and closed-cycle systems.

The salinity gradient between freshwater from rivers and seawater can be utilised as a source of power. At least two concepts for converting this energy into electricity are under development: Reversed Electro Dialysis (RED) and Pressure Retarded Osmosis (PRO), also known as ‘osmotic power’. The Reversed Electro Dialysis (RED) process is a concept where the difference in chemical potential between two solutions is the driving force. The PRO or osmotic power process utilises naturally occurring osmosis – a hydraulic pressure potential, caused by the tendency of fresh water to mix with seawater by the difference in salt concentration of salt (6.3.6).

Global and Regional Status of Markets and Industry Development

Excepting tidal barrages, all ocean energy technologies are conceptual or are presently under research and development. The most mature technologies have reached pre-commercial prototype stage. Consequently, there is no present commercial market for ocean energy technologies. Nevertheless, worldwide developments of devices are accelerating with, for instance, well over 100 prototype wave and tidal current devices under development.

The principal investors in ocean energy R&D and deployments are national, federal and state governments, followed by major national energy utilities and investment companies. By contrast, the principal form of device developer is a private small- or medium-scale enterprise (SME). There is encouraging uptake and support from these major investors into the prototype products being developed by the SMEs.

National and regional governments are particularly supportive of ocean energy through a range of financial, regulatory and legislative initiatives to support developments, including:

1. Targets for installed capacity or contribution to future supply
2. R&D funds, capital grants and financial incentives, including prizes
3. Market incentives, including feed-in tariffs and supply obligations
4. Research and testing facilities and infrastructure
5. Permitting/space/resource allocation regimes, standards and protocols (6.4.7).

Presently northwestern European coastal countries lead development of ocean energy technologies with North American, northwestern Pacific and Australasian countries also involved (6.4.2.1).

Industrial development of ocean energy is at a very early stage and there is no true manufacturing industry for ocean energy technologies at present. But the growth of interest may lead to the transfer of capacity, skills and capabilities from related industries, combine with the development of new skills and capabilities (6.4.1.2). One unusual feature of ocean energy is the development of national marine energy testing centres, as exemplified by the European Marine Energy Centre (EMEC)[1]. These centres are becoming foci not only for device testing and certification but also for R&D.

Ocean energy technologies for power production range mostly from the conceptual stage to the prototype stage, but few technologies have matured to commercial availability (Table TS 6.1). Over the past four decades, other marine industries (primarily petroleum industry) have enabled significant advances in the fields of offshore materials, offshore construction, corrosion, undersea cables, data and communications. Ocean energy can directly benefit from these advances (6.3.1).

Table TS 6.1: Selected ocean energy devices in operation/under development [TSU: Reference is missing]

Type of Ocean Energy Technology	Subtype	Size of Device	Name of Device	Device Developer	Country	Operational Since	Notes
Wave Energy	shore-based OWC				Portugal	1999	occasionally operational
			LIMPET	Wavegen	Scotland	2000	almost continously operational
	offshore OWC			Energetech/ Oceanlinx	Australia	2006	prototype scale, one device per company
				OE Buoy	Ireland	2007	prototype scale
	OB	750 kW	Pelamis Wavepower	Pelamis	Scotland/Portugal		most advanced OB, device sold as part of commerical project, next device under development
		40 - 150 kW	Power Buoy	Ocean Power Technologies	Hawaii, US eastern seabord, north Spanish coast		vertical axis type, one device in each location
			Wavebob		Ireland	-	under development
				Wave Energy Technology	New Zealand	-	under development
	OT		Wave Dragon		Denmark		prototype scale
			WavePlane		Denmark		prototype scale
Tide Rise and Fall	estuarine barrage	240 MW	LaRance		France	1996	24 x 10 MW bulb-type turbines
		3.2 MW			China	1980	
		20 MW			Canada	1984	
		0.5 MW			Russia	2004	
		254 MW	Sihwa		Korea	2010 (tbc)	retrofit to an existing 12.7 km sea dyke
	estuarine barrage, tidal lagoon (offshore basin)	5 - 11,400 MW (total over 47 GW)	16 projects		Australia, Canada, India, Korea, Russia, UK	planned	
Tidal and Ocean Currents	tidal turbine		SeaGen		Northern Ireland		most advanced tidal turbine
OTEC	floating OTEC		2 devices		India		mainly fresh water production, fuelled by diesel
	land-based OTEC				Kavaratti, India??		fresh water production
	floating, closed cycle	53 kW (18 kW in operation)	Mini-OTEC		USA	1979	
		1 MW (rated)	OTEC-1		USA	1981 (four month)	no turbine
	open-cycle OTEC	205 kW (peak production 103 kW)			USA (Hawaii)	1993 - 1998	
	closed-cycle (Freon)	120 kW (peak production 31.5 kW)			Japan (Nauru)	for several month	
		several smaller			Japan	not kept operational long-term	
	hybrid OTEC	30 kW			Japan	during 2006	able to produce electricity
	land-based, hybrid OTEC	10 MW		Sea Solar Power			under development, closed-cycle (propylene), open-cycle for fresh water production
	floating, hybrid OTEC	100 MW		Sea Solar Power			under development, closed-cycle (propylene), open-cycle for fresh water production
Salinity Gradient	Osmotic Power			Statcraft	Norway	2009	demonstration plant

Environmental and Social Impacts

General environmental concerns about ocean energy devices include the effects of deployment, operation and maintenance (O&M) and decommissioning on local flora and fauna and the alteration of the physical environment. Noise/vibration and hydrodynamic impacts are more specific issues, as are electromagnetic fields, produced by cables transmitting power to shore (6.5.1).

Ocean energy technologies do not generate greenhouse gases in operation – a substantial benefit for climate change mitigation.

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[1] www.emec.org.uk

The key social impact will be competition for and potential loss of space for other uses around deployment sites, including fishing, navigation and recreational activities (6.5.1, 6.5.3). Each ocean power technology has its own set of environmental and social impacts.

Tidal barrages are usually located across estuaries, which are complex, dynamic and potentially fragile environments. Although the La Rance estuary was closed during construction of the La Rance barrage, biodiversity - comparable to that of neighbouring estuaries - was restored within 10 years after commissioning, thanks to the responsible operating mode at the power station. The environmental impacts of the Sihwa Lake tidal power plant should be limited since the tidal flow will refresh an increasingly brackish lake (6.5.3). A barrage is a massive construction and not easily removed. Coast-attached wave energy devices also face this challenge of reversibility (6.5.1).

A key concern with tidal current technologies is that they have moving parts (blades), which may harm marine life. To date there is no evidence of harm to marine life from such devices, probably due to slow rotational speeds (relative to escape velocities of the marine fauna) and the passive nature of the rotating device.

Full-scale commercial deployments of open-ocean current electric generating systems could present certain environmental risks. These can be grouped into four broad categories: the physical environment (the ocean itself), benthic (ocean-bottom) communities, pelagic marine life (in the water column), and commerce. None of these has been fully evaluated, since no prototype ocean current devices have yet been deployed (6.5.4.2).

The principal environmental impacts of ocean energy thermal conversion (OTEC) plants will be the outflow of significant volumes of exotic cold water (OTEC) from these plants (6.5.1). Other social and environmental impacts from OTEC include: chemical pollution (biocides, working fluid leaks, corrosion), structural effects (on artificial reef, nesting/migration), social effects (6.5.5).

Similarly, the principal environmental impact of osmotic power will be the mixing of freshwater and seawater at the power plant, which are likely to be built at large river mouths, with sufficient volumes of freshwater. However, the volume of mixed brackish water produced osmotic power plants will be considerably smaller than the natural mixing that occurs at river mouths (6.5.6).

The social benefits of ocean energy are potentially high, rejuvenating shipping and fishing industries, supplying electricity and/or drinking water to remote communities at small-scale or utility-scale deployments with transmission grid connections to displace aging fossil fuel generation plants. Social benefits may be national – the creation of new industries, redirection of resources from declining industries; regional – industry rejuvenation, developments of business clusters, and individual - new employment opportunities, training for new skills and development of new capabilities (6.5.1).

Prospects for Technology Improvement, Innovation and Integration

Ocean energy technology developers are keen to gain operating experience, so that engineering practices and technology development can advance. Performance improvements and increased reliability are key for most ocean energy technologies. Future developments are likely to focus on up-scaling to the largest practical machine size, minimizing downtime, operation and maintenance (O&M) efforts, reducing installation and decommissioning costs and limiting mooring and substructure requirements. Device design and materials selection to limit or resist degradation by corrosion, cavitation, water absorption, bio-fouling and debris impacts are of crucial importance (6.6.1, 6.6.3, 6.6.4).

Rotor diameters of ocean and tidal current technologies are likely to increase to maximize swept area and thus power extraction. New operating control strategies will be developed to resist extreme loads and mitigate fatigue damage. Axial-flow water current turbines, which harness energy from water currents have operating principles similar to widely-used horizontal-axis wind turbines (6.6.3). They may have developmental advantage over other designs, e.g., cross-flow turbines or reciprocating devices). Enhancing energy extraction from bidirectional flows directions will improve tidal current turbine performance (6.6.2, 6.6.3).

Tidal rise and fall power projects differ from most other ocean energy technologies because they are based on proven hydroelectric technologies, albeit built and operated in an estuarine rather than a riverine environment. Nonetheless are improvements can still be achieved by:

1. Construction of very large offshore facilities
2. Use of multiple basins to increase the value of projects by reducing the intermittency of generation, and
3. Improvements of general turbine efficiency and, more specifically, generation efficiency in both flow directions.

Technologies may be further improved with gears, permitting different rotation speeds for the turbine and the generator, or with variable frequency generation, creating better outputs for the various operating ways and heads (6.6.2).

The heat exchanger system and cold-water inlet pipe are the most important components of the closed-cycle ocean thermal energy conversion (OTEC) power plants. Most research efforts are directed toward some special subjects related to the heat exchanger, in particular its construction material and working fluid, because its share of total plant cost of 20 - 40%. The cold-water inlet pipe is also critical but experience obtained in the last decade with risers for oil & gas production is being transferred to design of these large diameter pipes (6.6.4).

Research in osmotic power will mainly be focussed on membrane modules, pressure exchanger equipment and power generation equipment (i.e., the turbine and generator) to increase efficiency. There will also be a focus on further development of control systems, water pre-treatment equipment, as well as infrastructure around the water inlets and outlets (6.6.5).

Cost Trends

It is difficult to accurately assess the economic viability of most ocean energy technologies, because none but tidal barrages are mature and very little experience is available for validation of demonstration/prototype devices. Future cost reductions can only be demonstrated theoretically, since there are few operating devices and little operating experience.

Present capex costs can be determined directly from prototypes in the water but these are higher than commercial capex costs (6.7.1). Realistic performance (energy capture) estimates and operation and maintenance (O&M) costs (6.7.2) are difficult to estimate for lack of experience. Levelized cost of energy (LCOE) projections by technology developers are frequently unreliable (6.8.1). Future LCOE estimates rely on learning curve reductions experienced in other sectors, such as the wind energy sector. The following table (Table TS 6.2) shows estimates of the costs of various ocean energy technologies.

Reliable cost estimates for ocean power generation are therefore unavailable. However, cost trends should closely follow that of tidal current technology (6.7.4). Concrete estimates for costs of estuarine barrages, tidal lagoons are also missing. Nonetheless, it can be said that upfront costs are high due to expensive construction in marine environments and long construction times (6.7.3).

Table TS 6.2: Cost estimates from various studies for different ocean energy technologies

		Current Cost Parameters[1]					Future Cost Parameters			
Source of Cost Data	**Type of Ocean Energy Technology**	**Capex (US$/kW)**	**O&M Costs (US$/kW)**	**Discount Rate in %**	**Capacity Factor in %**	**LCOE (US¢/kWh)**	**LCOE (US¢/kWh)**	**Required Cumulative Capacity in MW**	**Learning Rate**	**Notes**
Vega (2002)	OTEC	12,300	NA	-	-	0.22	-	-	-	100 MW closed-cycle, 400 km from shore
SERI (1989)		12,200	NA	-	-	-	-	-	-	40 MW plant planned at Kahe Point, Oahu
Cohen (2009)		8,000 - 10,000	NA	-	-	0.16 - 0.20	0.08 - 0.16	-	-	100 MW early commercial plant
Francis (1985)		5,000 - 11,000	NA	-	-	-	-	-	-	-
Lennard (2004)		9,400	NA	-	-	0.18 (0.11)	-	-	-	10 MW closed-cycle; LCOE in parenthesis apply if also producing potable water
SERI (1989)		7,200	NA	-	-	-	-	-	-	Onshore, open-cycle
Vega (2002)		6,000	NA	-	-	0.10	-	-	-	100 MW closed-cycle, 100 km from shore
Vega (2002)		4,200	NA	-	-	0.07	-	-	-	100 MW closed-cycle, 10 km from shore
Scråmestø et al., 2009	Salinity Gradient Power	High	-	-	70%	5 - 10	-	-	-	
CEC (2009)	Tidal Current	-	-	-	-	10 - 30	-	-	-	Cost estimate for California
Callaghan (2006)		8,571 - 14,286	-	-	-	16.1 - 32.1	0.046	2,800	-	Prototype, cost assessment for UK
Callaghan (2006)	Wave Energy	7,679 - 16,071	-	-	-	21.4 - 78.8	-	-	-	PSrototype and pre-commercial devices, cost assessment for UK
Previsic (2004)		2620	123	7.5	38%	-	13.4 (2020)	-	-	106.5 MW capacity, 213 devices x 500 kW, 20-year life, 95% availability, R&D improvement

[1] Cost estimates for OTEC technologies are in different-year dollars and cover a range of different technologies and locations. Many are also highly speculative.

The Marine Energy Challenge study by the UK Carbon Trust demonstrated that the initial LCOE of tidal stream-generated electricity in the UK could be high with 14.3 US¢/kWh but this cost could reduce to 4.46 US¢/kWh by the time installed capacity had reached 2,800 MW.

Potential Deployment

Full-size floating wave energy prototypes are being deployed at specific test sites in various countries, including Norway, UK, Ireland, France, Spain and Portugal. Government-funded financial support is fundamental to facilitating the construction and testing of full-scale prototypes in open sea (6.8.1).

The world's largest tidal power plant (254 MW) is currently under construction at Sihwa in Republic of Korea. Korea has also announced other larger tidal plants, for example, a 520 MW barrage planned for Garolim Bay. In the United Kingdom the 14 m tidal range in the Severn Estuary has long been considered, as one of the greatest tidal sources to be harnessed. The British Government is currently considering ten proposals from a public call for proposals in May 2008 ranging from 624 MW to 14.8 GW. (6.8.2).

A number of other large tidal stream developments are planned over the next five years, based on 1 to 1.5 MW turbines from different manufacturers. Despite little convergence in design options to harness energy from tidal and ocean streams, submarine current devices are beginning to dominate. The deployment of tidal current devices is likely to be areally restricted. The best locations for such deployments include Canada (Bay of Fundy, Vancouver Island), Scotland (Pentland Firth), Wales (Anglesey), Korea (Uldulmok) and New Zealand (Cook Strait). Ocean currents are much more widespread than tidal currents but generally operate at slower speeds, which may be too slow for most early devices (6.8.3).

For the near-to-mid-term, the potential to use OTEC power is concentrate near appropriate markets, rather than any constraints on the resource. Larger floating-platform OTEC plants sending electricity to shore by submarine cable are likely to be limited to locations with large seawater temperature differentials close to shore and large coastal populations nearby. In the long term, ‘grazing’ plant ships could conceivably begin to approach resource limits but more likely would be limited by ability of economies to utilize ammonia or other “high-energy products” directly or indirectly for transportation fuel or other purposes (6.8.4).

The Statkraft prototype osmotic power plant, which became operational in October 2009, is an important milestone following several years of research & development (R&D). The operational prototype plant will be used as a basis to develop a pilot plant with an installed capacity between 1 - 2 MW within 2 - 5 years, bringing the technology one step nearer to commercialisation and development of full-scale plants. Given continued technology development and declining prices for components, osmotic power is a realistic technology with worldwide potential for renewable energy generation (6.8.5).

Wind Energy

Introduction

Wind energy has been used for millennia in a wide range of applications. The use of wind energy to generate electricity on a commercial scale, however, began in earnest only in the 1970s. Though different wind energy technologies remain available within a range of applications, the primary use of wind energy of relevance to climate change mitigation is to generate electricity from larger, grid-connected wind turbines, deployed either on-shore or off-shore (smaller wind turbines, high-altitude wind electricity, and the use of wind energy in mechanical and propulsion applications are briefly discussed in 7.1). [7.1]

Wind energy offers significant potential for near- and long-term carbon emissions reduction. The wind power capacity installed by the end of 2009 was capable of meeting roughly 1.8% of worldwide electricity demand, and that contribution could grow to in excess of 20% by 2050 if ambitious efforts are made to reduce carbon emissions and to mitigate the other barriers to increased wind energy deployment. On-shore wind energy is already being deployed at a rapid pace in many countries, and no insurmountable technical barriers exist that preclude increased levels of wind energy penetration into electricity supply systems. Moreover, though average wind speeds vary considerably by location, ample technical potential exists in most regions of the world to enable significant wind energy development. In areas with particularly good wind resources, the cost of wind energy can be competitive with fossil generation but, in most regions of the world, policy measures are required to make wind energy economically attractive. Nonetheless, continued advancements in both on- and off-shore wind energy technology are expected, further reducing the cost of wind energy and improving wind energy's carbon emissions mitigation potential.

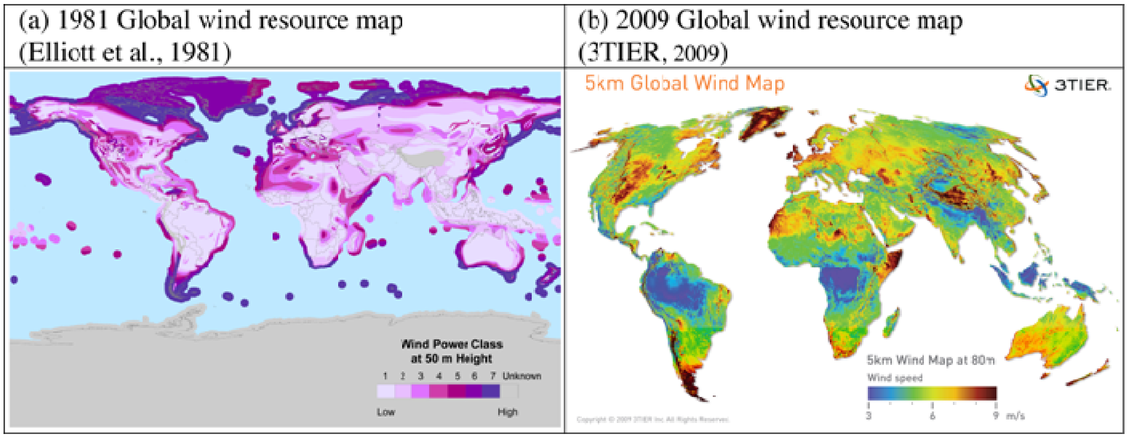
Resource potential

The global resource potential for wind energy is not fixed, but is instead related to the status of the technology, the economics of wind energy, and the assumptions made regarding other constraints to wind energy development. Nonetheless, a growing number of global wind resource assessments have demonstrated that the world's technical potential for wind energy exceeds global electricity demand. [7.2]

The IPCC (2007) has estimated the technical potential for on-shore wind energy at 180 EJ/y, almost three times greater than global electricity demand in 2007. Other estimates of the global technical potential for wind energy range from a low of 70 EJ/y (excluding off-shore) to a high of 1,000 EJ/y (including on- and off-shore); estimates of the potential for off-shore wind energy alone range from 15 EJ/y to 130 EJ/y. This overall range equates to between one and 14 times global electricity demand, and may understate the potential for wind energy due to several of the studies relying on outdated assumptions; the exclusion of off-shore wind energy in a number of the studies; and methodological and computing limitations. As visual demonstration of the impact of advances in assessment methods, Figure TS 7.1 presents two global wind resource maps, one created in 1981 another in 2009. [7.2.1]

Although further advancements in wind resource assessment methods are needed, the technical potential for the resource itself is unlikely to be a limiting factor on global wind energy development. Instead, economic constraints associated with the cost of wind energy, the institutional constraints and costs associated with transmission access and operational integration, and issues associated with social acceptance and environmental impacts are likely to restrict growth well before any absolute global resource limit is encountered. [7.2.1]

In addition, ample technical potential exists in most regions of the world to enable significant wind energy development. The wind resource is not evenly distributed across the globe, however, nor uniformly located near population centres, and wind energy will therefore not contribute equally in meeting the needs of every country. The on-shore wind resource in North America and Eastern Europe/CIS, for example, is often found to be particularly sizable, while some areas of Asia and OECD Europe appear to have more limited on-shore potential. Recent, detailed regional assessments have generally found the actual size of the wind resource to be greater than estimated in previous assessments. [7.2.2]


(a) 1981 Global wind resource map (Elliott et al., 1981)

(b) 2009 Global wind resource map (3TIER, 2009)

Figure TS 7.1 Example global wind resource maps from 1981 and 2009.

There is increasing recognition that global climate change may alter the geographic distribution and/or the inter- and intra-annual variability of the wind resource, or alter the prevalence of extreme weather events that may impact wind turbine design and operation. Though research in this field is nascent and additional research is warranted, it appears unlikely that multi-year annual mean wind speeds and energy densities will change by more than a maximum of ±25% over most of Europe and North America during the present century. As a result, research to date suggests that, while global climate change will alter the geographic distribution of the wind resource, those effects are unlikely to be of a magnitude to greatly impact the global potential for wind energy to reduce carbon emissions. [7.2.3]

Technology and applications

Modern grid-connected wind turbines have evolved from small, simple machines to large, highly sophisticated devices. Scientific and engineering expertise, as well as computational tools and design standards, have supported these technology developments. [7.3.1]

Generating electricity from the wind requires that the kinetic energy of moving air be converted to electrical energy, and the engineering challenge for the wind industry is to design efficient wind turbines to perform this conversion. Though a variety of wind turbine configurations have been investigated, turbine design now centres on horizontal axis machines with 3-blades positioned upwind of the tower. In order to reduce the levelized cost of wind energy, over the past 30 years, average wind turbine size has grown significantly (Figure TS 7.2), with the largest fraction of land-based wind turbines installed globally in 2009 having a rated capacity of 1.5 MW to 2.5 MW. As of 2010, such turbines typically stand on 50-100 meter towers, with rotors that are often 50-100 meters in diameter; even larger machines are in use and under development. As a result of these developments, on-shore wind energy technology is already viable for large-scale commercial deployment. [7.3.2]

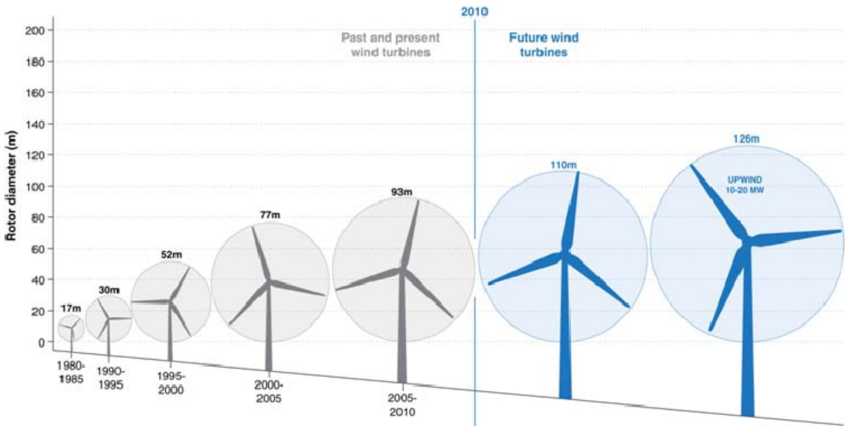


Figure TS 7.2. Growth in size of commercial wind turbines. Source: NREL [TSU: date?]

The off-shore wind energy sector remains relatively immature, but considerable interest exists in the EU and, increasingly, in other regions. This interest is the results of the higher-quality wind resources located at sea; the ability to use larger and more-flexible wind turbine designs; a potential reduction in long-distance, land-based transmission; the ability to build larger power plants; and the potential mitigation of siting controversial. To date, off-shore wind turbine technology has been very similar to on-shore designs, with some modifications and with special foundations. Wind energy technology specifically tailored for off-shore applications will become more prevalent as the off-shore market expands, and it is expected that larger turbines in the 5-10 MW range may come to dominate this market segment. [7.3.2]

Alongside the evolution of wind turbine design, improved testing methods have been codified in International Electrotechnical Commission (IEC) standards. Certification agencies rely on accredited design and testing bodies to provide traceable documentation demonstrating conformity with the standards in order to certify that turbines, components, or entire wind power plants meet common guidelines relating to performance, safety, and reliability. [7.3.3]

From an electric system reliability perspective, an important part of the wind turbine is the electrical conversion system. For new turbines, variable speed machines now dominate the market, allowing for the provision of real and reactive power control and some fault ride-through capability, but no intrinsic inertial response; wind turbine manufacturers have recognized this latter limitation, and are pursuing a variety of solutions. [7.3.4]

Global and regional status of market and industry development

The wind energy market has developed rapidly, demonstrating the commercial and economic viability of the technology and industry. Wind energy deployment has been concentrated in a limited number of regions, however, and further expansion, especially in regions with little wind energy development to date and in off-shore locations, is likely to require additional policy measures. [7.4]

Wind energy has quickly established itself as part of the mainstream electricity industry. From a cumulative capacity of 14 GW by the end of 1999, the global installed capacity increased twelve-fold in ten years to reach almost 160 GW by the end of 2009. The majority of the capacity has been installed on-shore, with off-shore installations focused on Europe and totalling a cumulative 2.1 GW. The countries with the highest installed capacity by the end of 2009 were the United States. (35 GW), China (26 GW), Germany (26 GW), Spain (19 GW), and India (11 GW). Total investment in wind power installations in 2009 alone equalled roughly US$57 billion, while worldwide direct employment in the sector in 2009 has been estimated at 500,000. [7.4.1, 7.4.2]

In both Europe and the U.S., wind energy represents a major new source of electric capacity additions. From 2000 through 2009, wind energy was the second-largest new resource added in the U.S. and EU, while in 2009 roughly 39% of all capacity additions in the U.S. and the EU came from wind energy; in China, 16% of the net capacity additions in 2009 came from wind energy. On a global basis, wind energy represented 11% of net electric capacity additions from 2000 through 2009; in 2009 alone, that figure was likely more than 20%. As a result, a number of countries are beginning to achieve relatively high levels of wind electricity penetration in their respective electric systems. By the end of 2009, wind power capacity was capable of supplying electricity equal to roughly 20% of Denmark's electricity demand, 14% of Portugal's, 14% of Spain's, 11% of Ireland's, and 8% of Germany's. [7.4.2]

Despite these trends, wind generated electricity remains a relatively small fraction of worldwide electricity supply. The total wind power capacity installed by the end of 2009 was capable of meeting roughly 1.8% of worldwide electricity demand. Additionally, though the trend over time has been for the wind energy industry to become less reliant on European markets, with significant recent expansion in the United States and China, the market remains concentrated regionally: Latin America, Africa and the Middle East, and the Pacific regions have installed relatively little wind power capacity (Figure TS 7.3). [7.4.1, 7.4.2]

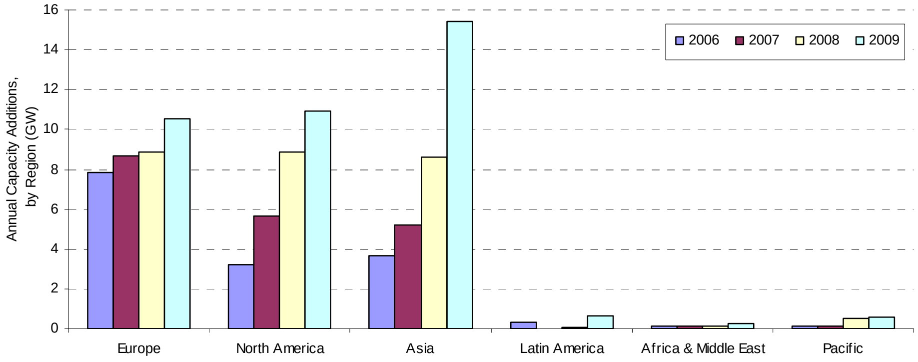


Figure TS 7.3. Annual wind power capacity additions by region (GWEC, 2010a).

The deployment of wind energy must overcome a number of barriers, including: the relative cost of wind energy compared to fossil-fuel generation options; concerns about the impact of wind energy's variability; challenges to building new transmission; cumbersome and slow planning, siting, and permitting procedures; the relative immaturity and therefore high cost of off-shore wind energy technology; and lack of institutional and technical knowledge in regions that have not yet experienced substantial wind energy development. As a result, growth is affected by and responsive to a wide range of government policies. [7.4.4]

Near-term integration issues

As wind electricity penetration levels have increased so too have concerns about the integration of that energy into electric systems. The nature and magnitude of the integration challenge depends on the characteristics of the existing electric system and the level of wind electricity penetration. Nevertheless, the existing literature generally suggests that, at low to medium levels of wind electricity penetration (under 20% of total electricity demand), the integration of wind energy is technically and economically manageable, though institutional constraints will need to be overcome. Concerns about (and the costs of) wind energy integration will grow with wind energy deployment and, even at medium penetration levels, integration issues must be addressed both at the local and system levels through stability and balancing requirements. Even higher levels of penetration may depend on the availability of additional flexible options to maintain a balance between supply and demand. [7.5.1]

Wind energy has characteristics that pose new challenges to electric system planners and operators, including: the localised nature of the wind resource with implications for new transmission; the variability of wind power output; and the lower levels of predictability than is common with conventional power plants. The variability and predictability of wind power output depends, in part, on the degree of correlation in the output between geographically dispersed wind power plants: generally, the output of wind power plants that are further apart are less correlated, and variability over shorter time periods (minutes) is less correlated than variability over longer time periods (multiple hours). Forecasts of wind power output are also more accurate shorter time periods, and when multiple plants are considered together. [7.5.2]

Electric system planners must ensure that generation and transmission are adequate for the reliable operation of the electric system. To do so, planners need computer-based simulation models that accurately characterize wind energy. Additionally, as wind power capacity has increased, so too has the need for wind power plants to become more active participants in maintaining the operability and power quality of the electric system, and minimum interconnection requirements have been implemented to prevent wind power plants from adversely affecting the electric system during normal operation and contingencies. Accurate transmission adequacy evaluations, meanwhile, must account for the location dependence of the wind resource, and significant new transmission infrastructure, both on-shore and off-shore, would be required to access areas with the best wind resource conditions. The institutional challenges of transmission expansion can be substantial. Finally, planners need to account for wind power output variability in assessing the contribution of wind energy toward the long-term reliability of the electric system. The contribution of wind energy to resource adequacy depends on the correlation of wind power output with the periods of time when electric system reliability is at greatest risk, typically periods of high electricity demand. Wind power plants are typically found to have a ‘capacity credit’ of 5-40% of nameplate capacity, with the credit generally decreasing as wind electricity penetration levels rise. The relatively low average capacity credit of wind power plants suggests that electric systems with large amounts of wind energy will also tend to have significantly more total nameplate generation capacity to meet the same peak load than will electric systems without large amounts of wind energy. Some of this generation capacity will operate infrequently, however, and the mix of conventional generation will therefore increasingly shift towards “peaking” resources and away from “baseload” resources. [7.5.3]

[Authors: Need to add some text to explain what the capacity credit means, in layman: something on needing sufficient capacity to serve loads at times of system stress.]

The unique characteristics of wind energy also hold important implications for electric system operations. Because wind electricity is generated with a near-zero marginal operating cost, it is typically used to meet demand when it is available; conventional generators are then dispatched to meet demand minus any available wind energy (i.e., “net demand”). As wind electricity penetration grows, the variability of wind energy results in an overall increase in the magnitude of changes in net demand, and also a decrease in the minimum net demand. As a result of these trends, wholesale electricity prices will tend to decline when wind power output is high, and conventional generating units will be called upon to operate in a more flexible manner than required without wind energy. At low to medium levels of wind electricity penetration, the increase in minute-to-minute variability is expected to be relatively small. The more significant operational challenges relate to the need to manage changes in wind power output over 1 to 6 hours. Incorporating wind energy forecasts into electric system operations can reduce the need for flexibility and operating reserves, but even with high-quality forecasts system operators will need a broad range of strategies to actively maintain the supply/demand balance, including the use of flexible power generation technologies, wind energy output curtailment, and increased coordination and interconnection between electric systems; demand-side management, energy storage technologies, and geographic diversification of wind power plant siting will also become increasingly beneficial as wind electricity penetration rises. Despite the challenges, actual operating experience in different parts of the world demonstrates that wind energy can be reliably integrated into electric systems, and in some countries wind energy already supplies in excess of 10% of annual electricity demand. [7.5.4]

In addition to actual operating experience, a number of high-quality studies of the increased transmission and generation resources required to accommodate wind energy have been completed. The results of these studies demonstrate that the cost of integrating up to 20% wind electricity into electric systems is, in most cases, modest but not insignificant. Specifically, at low to medium levels of wind electricity penetration, the literature suggests that the additional costs of managing electric system variability and uncertainty, ensuring resource adequacy, and adding new transmission to accommodate wind energy will generally not exceed 30% of the generation cost of wind energy. The technical challenges and costs of integration are found to increase with wind electricity penetration. [7.5.5]

Environmental and social impacts

Wind energy is already reducing net GHG emissions, and has the potential for far greater emissions reductions. Moreover, attempts to measure the relative impacts of various electricity supply technologies suggest that wind energy generally has a comparatively small environmental footprint. As with other industrial activities, however, wind energy has the potential to produce some detrimental impacts on the environment and on human beings, and many local and national governments have established planning, permitting, and siting requirements to minimize those impacts. [7.6]

Although the major environmental benefits of wind energy result from displacing electricity generated from fossil-fuel based power plants, estimating these benefits is somewhat complicated by the operational characteristics of the electric system and the investment decisions that are made in new power plants. In the short-run, increased wind energy will typically displace the operations of existing fossil plants. In the longer-term, however, new generating plants may be needed, and the presence of wind energy will influence future plant selection. The emissions arising from the manufacture, transport, installation, and decommissioning of wind turbines should also be considered, and have been estimated by a number of studies to be small compared to the energy generated and emissions avoided over the lifetime of wind power plants (the carbon intensity of wind energy is estimated to range from 4.6 to 27 gCO_2/kWh, whereas energy payback times are between 3 to 9 months). Similarly, managing the variability of wind power production has not been found to significantly degrade the carbon emissions benefits of wind energy. [7.6.1]

Other studies have considered the local ecological impacts of wind energy deployment. Specifically, the construction and operation of both on- and off-shore wind power plants impacts wildlife through bird and bat collisions and through habitat and ecosystem modifications, with the nature and magnitude of those impacts being site- and species-specific. Bird and bat fatalities through collisions with wind turbines are among the most publicized environmental concerns. Though much remains unknown about the nature and population-level implications of these impacts, avian fatality rates have been reported at between 0.95 and 11.67 per MW per year; raptor fatalities, though much lower in absolute number, have raised special concerns in some cases. Bat fatalities have not been researched as extensively, but fatality rates ranging from 0.2 to 53.3 per MW per year have been reported; the impact of wind power plants on bat populations is of particular contemporary concern. Wind power plants can also impact habitats and ecosystems through avoidance of or displacement from an area, habitat destruction, and reduced reproduction.

The impacts of wind power plants on marine life have moved into focus as offshore development has increased. Potential negative impacts include underwater sounds, electromagnetic fields, physical disruption, and the establishment of invasive species. The physical structures may, however, create new breeding grounds or shelters and act as artificial reefs or fish aggregation devices. Additional research is warranted on these impacts, but they do not appear to be disproportionately large compared to on-shore wind energy. [7.6.2]

Surveys have consistently found wind energy to be widely accepted by the general public. Translating this broad support into increased deployment, however, often requires the support of local host communities and/or decision makers. To that end, in addition to ecological concerns, a number of concerns are often raised about the impacts of wind power plants on local communities. Perhaps most importantly, modern wind energy technology involves large structures, so wind turbines are unavoidably visible in the landscape. Other impacts of concern include land and marine usage, proximal impacts such as noise, flicker, health, and safety, and property value impacts. Appropriate siting of wind turbines is important in minimizing the impact of wind energy development on local communities, and engaging local residents in consultation during the planning stage is often an integral aspect of the development process. Though some of the concerns can be readily mitigated, others - such as visual impacts - are more difficult to address. In part as a consequence, complicated and time-consuming planning and siting processes are key obstacles to wind energy development in some countries and contexts. Efforts to better understand the nature and magnitude of the remaining impacts, together with efforts to minimize and mitigate those impacts, will therefore need to be pursued in concert with increasing wind energy deployment. [7.6.3]

Prospects for technology improvement and innovation

Over the past three decades, innovation in the design of grid-connected wind turbines has led to significant cost reductions, while the capacity of individual turbines has grown markedly. Public and private R&D programmes have played a major role in the technical advances seen in wind energy over the last decades, leading to system and component-level technology advancements, as well as improvements in resource assessment, technical standards, grid integration, wind energy forecasting, and other areas. From 1974 to 2006, government R&D budgets for wind energy in IEA countries totalled \$3.8 billion, representing around 10% of RE R&D budgets, and just 1% of total energy R&D expenditure. [7.7.1]

Though on-shore wind energy technology is reasonably mature, continued incremental advancements are expected to yield improved design procedures, increased reliability and energy capture, reduced O&M costs, and longer component life. In addition, as off-shore wind energy gains more attention, new technology challenges arise, and more-radical technology innovations are possible. Sophisticated design approaches are required to systematically evaluate and optimize wind turbine concepts, and studies have identified a number of areas where technology advancements could result in changes to the capital cost, annual energy production, reliability, O&M, and grid integration of wind energy. [7.7.2]

At the component level, a range of opportunities are being pursued, including: (1) advanced tower concepts that reduce the need for large cranes and minimize materials demands; (2) advanced rotors and blades through better designs, coupled with better materials and advanced manufacturing methods; (3) reduced energy losses and improved availability through advanced turbine control and condition monitoring; (4) advanced drive trains, generators, and power electronics; and (5) manufacturing learning improvements. [7.7.3]

In addition, there are several areas of possible advancement that are more-specific to off-shore wind energy, including O&M strategies, installation and assembly schemes, support structure design, and the development of larger turbines, possibly including new turbine concepts. Foundation structure innovation, in particular, offers the potential to access deeper waters, thereby increasing the potential wind resource available. Off-shore turbines have historically been installed in relatively shallow water, up to 30 m, on a mono-pile structure that is essentially an extension of the tower, but gravity-based structures have become more common. These approaches, as well as other concepts that are more appropriate for deeper water depths, including floating platforms, are depicted in Figure TS 7.4. [7.7.3]

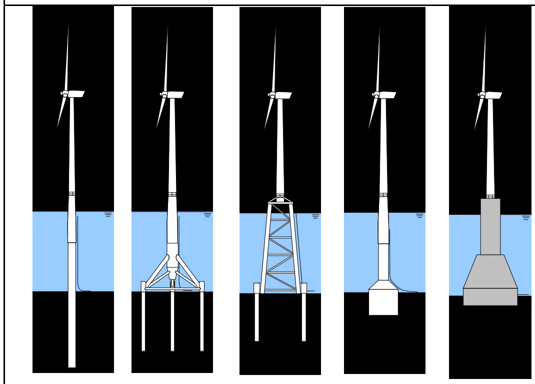
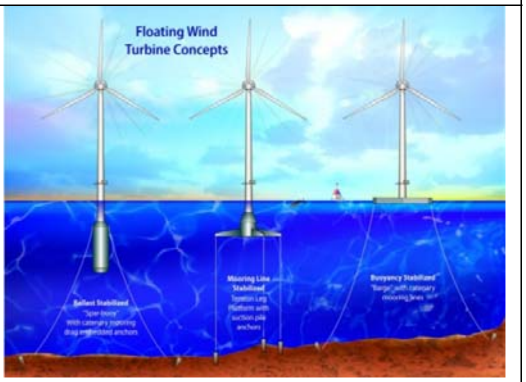
(a) Near-term off-shore foundation concepts	**(b)** Floating off-shore turbine concept
	
Source: UpWind.eu [TSU: date?]	Source: NREL [TSU: date?]

Figure TS 7.4. Off-shore wind turbine foundation designs.

Wind turbines are designed to withstand a wide range of conditions with minimal attention. Significant effort is therefore needed to further advance the fundamental knowledge of the wind turbine operating environment in order to assure a new generation of reliable, safe, cost-effective wind turbines, and to further optimize wind power plant siting and design. Research in the areas of aeroelastics, unsteady aerodynamics, aeroacoustics, advanced control systems, and atmospheric science, for example, can lead to improved design tools, and thereby increase the reliability of the technology and encourage further design innovation. Fundamental research of this nature will be essential for improving: wind turbine design, wind power plant performance estimates, wind resource assessments, short-term wind energy forecasting, and estimates of the impact of large-scale wind energy deployment on the local climate, as well as the impact of potential climate change effects on wind resources. [7.7.4]

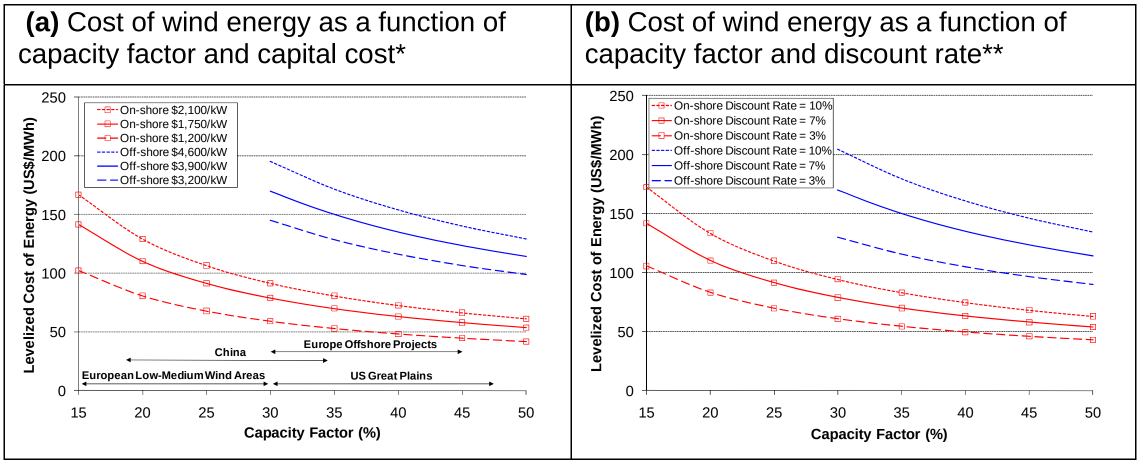
Cost trends

Though the cost of wind energy has declined significantly since the 1980s, in most regions of the world, policy measures are required to make wind energy economically attractive. In areas with particularly good wind resources or particularly costly alternative forms of power supply, the cost of wind energy can be competitive with fossil generation. Moreover, continued technology advancements are expected, supporting further cost reduction. [7.8]

The cost of both on-shore and off-shore wind energy is affected by five fundamental factors: annual energy production, installation costs, O&M costs, financing costs, and the assumed economic life of the power plant. [7.8.1]

From the 1980s to roughly 2004, the installed capital cost of on-shore wind power plants dropped. From 2004 to 2009, however, capital costs increased, the primary drivers of which were: escalation in the cost of labour and materials inputs; increasing profit margins among turbine manufacturers and their suppliers; the relative strength of the Euro currency; and the increased size of turbine rotors and hub heights. In 2009, the average cost for on-shore wind power plants installed worldwide was roughly US$1,750/kW, with a typical range of US$1,200-2,100/kW. The installed costs of off-shore wind power plants have historically been 50% to more than 100% higher than for on-shore plants; O&M costs are also greater for off-shore plants. Recently built or planned off-shore plants have ranged in cost from roughly US$3,200/kW to $4,600/kW. The performance of wind power plants is primarily governed by local wind conditions, but is also impacted by wind turbine design optimization, performance, and availability, and by the effectiveness of O&M procedures. Performance therefore varies by location, but has also generally improved with time. Off-shore wind power plants are often exposed to better wind resources. [7.8.2, 7.8.3]

The resulting levelized cost of on- and off-shore wind energy in 2009 varies substantially, depending on assumed capital costs, energy production, and discount rates (Figure TS 7.5). For on-shore wind energy, levelized costs in good to excellent wind resource regimes average US$50-100/MWh, and can reach US$150/MWh in lower resource areas. Off-shore wind energy is generally more expensive than on-shore, with typical levelized costs that range from US$100/MWh to US$200/MWh; where the exploitable on-shore wind resource is limited, however, off-shore plants can sometimes compete with on-shore plants. [7.8.3]


(a) Cost of wind energy as a function of capacity factor and capital cost*

(b) Cost of wind energy as a function of capacity factor and discount rate**

* Discount rate assumed to equal 7%

** On-shore capital cost assumed at US$1,750/kW, and off-shore at US$3,900/KW

Figure TS 7.5 Estimated levelized cost of on-shore and off-shore wind energy, 2009.

Based on a review of the learning curve and engineering literature, it is estimated that continued R&D, testing, and operational experience could yield reductions in the levelized cost of on-shore wind energy, relative to 2009 levels, of roughly 7.5-25% by 2020, and 15-35% by 2050. The available literature suggests that off-shore wind energy has greater potential for cost reductions: 10-30% by 2030 and 20-45% by 2050. The levelized cost of on-shore wind energy is therefore projected to range from roughly US$30-110/MWh by 2050, depending on the wind resource, installed cost, and the speed of cost reduction. Off-shore wind energy is likely to experience somewhat deeper cost reductions, with a range of expected levelized costs of US$60-140/MWh by 2050. [7.8.4]

Potential deployment

Given the commercial maturity and cost of on-shore wind energy technology, increased utilization of wind energy offers the potential for significant near-term carbon emission reductions: this potential is not conditioned on technology breakthroughs, and related integration challenges are manageable. As a result, in the near-term, the rapid increase in wind power capacity from 2000-2009 is expected by many studies to continue. [7.9.1]

Moreover, a number of studies have assessed the longer-term potential of wind energy in the context of carbon mitigation scenarios. Based on a review of this literature, and as summarized in Figure TS 7.6, wind energy could play a significant long-term role in reducing global carbon emissions. By 2050, the median contribution of wind energy in the two carbon stabilization scenarios across a wide range of studies is 22-26 EJ/y, increasing to 45-50 EJ/y at the 75th percentile, and to more than 100 EJ/y in the highest study. To achieve this contribution would require wind energy to deliver around 13% of global electricity supply in the median case, and 21-26% at the 75th percentile. Other scenarios published by wind energy and RE organizations are consistent with this median to 75th percentile range. [7.9.2]

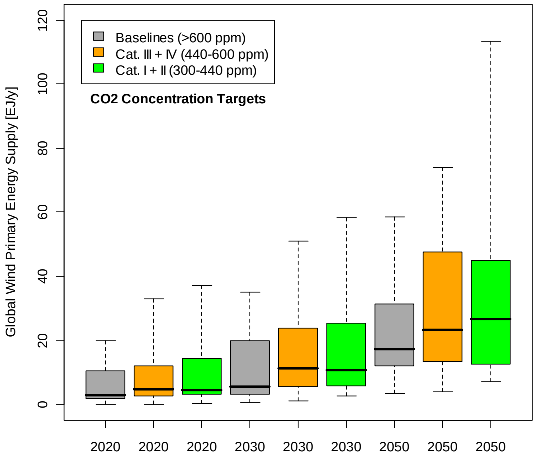


Figure TS 7.6 Global total primary energy supply of wind energy in carbon stabilization scenarios (median, 25th to 75th percentile range, and absolute range).

Achieving the higher end of this range of global wind energy utilization would likely require not only economic support policies of adequate size and predictability, but also an expansion of wind energy utilization regionally, increased reliance on off-shore wind energy in some regions, technical and institutional solutions to transmission constraints and operational integration concerns, and proactive efforts to mitigate and manage social and environmental concerns. Though R&D is expected to lead to incremental cost reductions for on-shore wind energy, enhanced R&D expenditures may be especially important for off-shore wind energy technology. Finally, for those markets with good wind resource potential but that are new to wind energy deployment, both knowledge and technology transfer may help facilitate early wind power installations. [7.9.2]

Integration of Renewable Energy into Present and Future Energy Systems

Integration of renewable energy into supply systems

To enable RE systems to provide a greater share of heating, cooling, transport fuels and electricity will require the modification of conventional energy supply systems so that they can accommodate greater supplies of RE than at present (Figure TS 8.1).

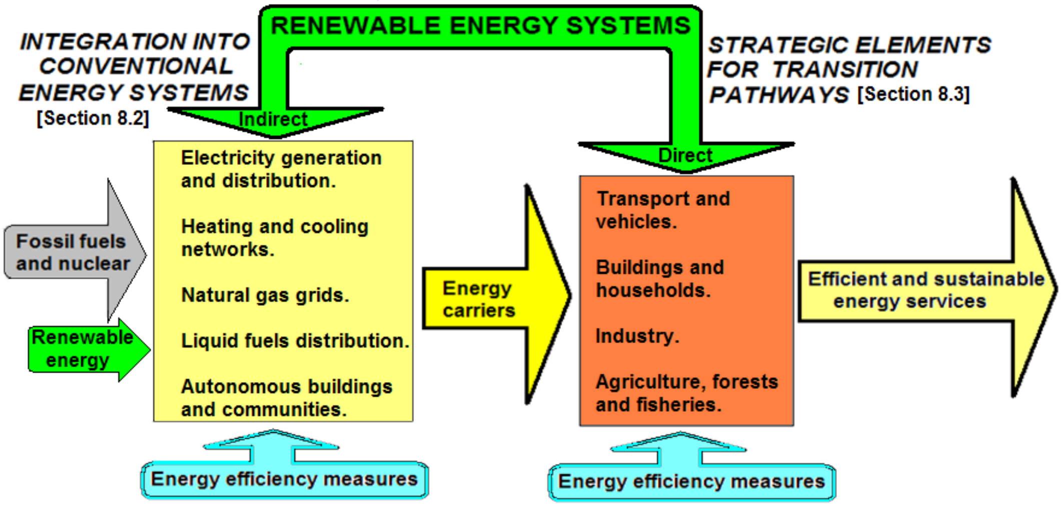
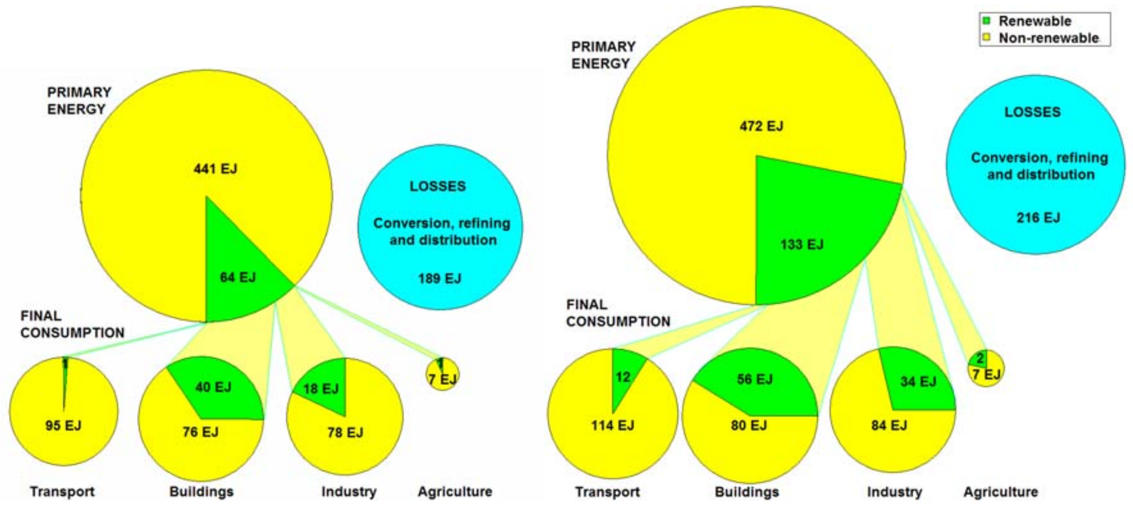


Figure TS 8.1 RE sources, additional to those presently being utilised in conventional energy systems, can be deployed *indirectly* through enhanced integration into energy carriers or *directly* on site by end-use sectors.

Conventional energy systems have evolved over many decades to enable efficient and cost-effective distribution of energy carriers so as to provide useful energy services to end-users. Increasing the deployment of RE systems requires their integration into existing systems by overcoming the associated technical, economic, environmental and social barriers. The various energy systems operating in countries and regions around the world differ markedly and are complex. RE integration approaches will vary as a result. In some regions, electricity systems could possibly become the backbone of future RE-based energy supply if the heating and transport sectors increase electricity demand due to the substitution of coal, natural gas and oil products by "green" electricity.

In order to achieve GHG atmospheric concentration stabilisation around 450 ppm, global energy supply will need to undergo a major transition. As part of this, RE technologies will all need to continue to increase market shares out to 2030. The necessary transition can be illustrated by many scenarios (Chapter 10), the one used here as an example being the IEA's "450 Policy Scenario" (Figure TS 8.2). This would require the rate of increase in annual deployment of primary RE to double from today's level to around 3.0 EJ/yr by 2030.



2007 **2030**

Figure TS 8.2 RE shares of primary energy and final consumption in the transport, buildings, industry and agriculture sectors in 2007, and an indication of the increasing shares needed by 2030 in order to aim for a 450 ppm stabilization target (based on IEA, 2009a). Notes: Area of circles approximately to scale. “Non-renewable” energy includes coal, oil, natural gas (with and without CCS by 2030) and nuclear power. Energy efficiency improvements included in the 2030 projection. RE in the buildings sector includes traditional solid biomass fuels used for cooking and heating as used, along with coal, by 3 billion people in developing countries (UNDP, 2009). Traditional biomass may be replaced, at least in part, by more modern bioenergy systems by 2030.

In order to gain greater RE deployment in each of the sectors, strategic elements need to be better understood, as do the non-technical issues. Transition pathways for each technology could facilitate a smoother integration of RE with the conventional energy systems. Multiple benefits for energy end-users should be the ultimate aim.

RE technologies have continued to evolve and there has been increased deployment due to improved cost-competitiveness, more supporting policies, and increased public concerns at the threats of energy security and climate change. For each sector, the current status of RE use will vary as will possible integration pathways to enhance increased adoption; transition issues yet to be overcome, and future trends. There are also regional variations, particularly for the building sector where deploying RE technologies is vastly different in commercial high-rise buildings and apartments in mega-cities compared with small towns of mainly individual dwellings; in wealthy suburbs compared with poor urban areas; in established districts compared with new sub-divisions; and in farming and fishing communities in OECD countries compared with small village settlements in developing countries that have limited access to energy services.

The aims of the Integration chapter (8.1) are to provide a good understanding of current global energy supply systems and to develop a coherent integration framework in preparation for higher levels of RE penetration. Conventional power supply systems, natural gas grids, heating/cooling schemes and petroleum transport fuel supply and distribution networks as well as vehicles, can be adapted to accommodate greater supplies of RE than at present, ranging from mature technologies to those at the early-concept demonstration stage. They rely on improved cost-effectiveness, social acceptance, reliability, and political support at national and local government levels in order to gain greater market share. The optimum combination of technologies and social mechanisms to enable RE integration at high levels of penetration varies with the limitations of specific site conditions, available RE resources, and local energy demands. How conventional energy supply and demand systems can be adapted and developed to accommodate high penetration of RE, particularly for the electricity sector, together with the additional costs involved for RE integration, remain unclear and further study is required.

Taking a holistic approach to the whole energy system can be a prerequisite for efficient and flexible RE integration. It includes achieving mutual support between different energy sectors, and an intelligent control strategy, together with coherent long-term planning, that would enable electricity, heating, cooling and mobility to be inter-linked.

Electric Power Systems

A feature of RE power generation is greater variability as most RE resources have variable characteristics (Figure TS 8.3.). Since an electric power system has to remain in supply/demand balance at all times, this variability makes achieving a high penetration of RE cost-effectively a significant technical, but not insurmountable, challenge for many transmission system operators (TSOs). To maintain reliability could require fundamental changes to be made in the ways that generation plants, grids and electrical loads are designed and operated.

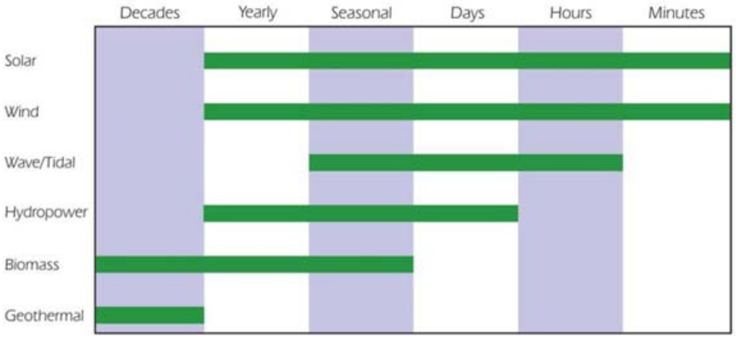


Figure TS 8.3 Time-scale of the natural variability cycles of some RE sources (IEA, 2008).

Within a power supply system, some RE technologies (such as reservoir hydro, bioenergy, geothermal) are dispatchable whereas others (such as wind, solar PV, concentrating solar power (CSP) without storage, small and run-of-the-river hydro, tidal and wave energy systems) are non-dispatchable[2] as their potential output fluctuates with the local RE resource flux. Efficient integration of large shares (above 30%) of these variable RE sources into an existing system will require a paradigm shift rather than minor adjustments. It will require a transition from a conventional system (with zero or limited shares of variable generation and an inflexible load demand), to a more innovative system encompassing flexible generation and demand. For any given system, increasing the penetration[3] of RE varies with the existing plant and infrastructure, operation, flexibility and market design.

In the electricity sector, international experience with the integration of variable RE, mainly wind, shows that high levels of penetration are feasible and can be economically beneficial. Integration is facilitated by strong networks, interconnection, and by methods and investments that increase the flexibility of conventional power supply such as system control and operation over the network, demand-side response, energy storage, more flexible thermal power plants and an enabling

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[2] The term non-dispatchable should be interpreted with care. In this report it denotes the characteristics of a variable RE source that at the system level can be dispatched to a major extent only by decisions of the system operator (for delivering positive and negative regulating power) if primary energy (wind or solar) is spilled (not used). Equally, if variable RE resources are not used in a must-run mode, primary energy will be spilled. There is always, however, a portion of “non-dispatchable” sources that can be dispatched, especially when used at a large scale, due to the correlation between load demand and the resource.

[3] Penetration of RE in a power system is the share it provides of the total gross annual electricity consumption.

electricity market framework. Base load options are feasible using mature and relatively non-variable hydro, geothermal and bioenergy combined heat and power (CHP) technologies.

It is difficult to standardise on a transition strategy to move from a traditional electricity system to a highly flexible one as each system, large or small, has its own particular governance, inter-connection, technology, market and commercial issues to deal with. To increase the penetration of RE resources, stakeholders associated with a given electricity system will probably need to determine their own future pathway, whether the industry serves a village or a continent. The transition to an increased share of RE will need to be carefully managed over many years which could be a challenge for countries without long-term political stability. On a system wide level, RE plants generate electricity just like any other power plant, but many have distinctive features compared to conventional generation.

- *Planning and operation.* Power systems should be designed to provide a reliable supply of electricity for minimal costs. One approach is by using a large number of different generation sources. The benefits of aggregation that this permits are obtained by means of a strong network of transmission/distribution lines and a communication infrastructure that allows for the transfer of power and coordination throughout the network. To avoid voltage fluctuations and blackouts, the system must be able to maintain supply/demand balance even with RE variability and a degree of unpredictability in both demand and generation. In real-time operations, to maintain a near-instantaneous supply/demand balance TSOs, or equivalent market processes, commit and schedule flexible generation capacity and responsive demand to provide reserves that can be available in minutes to compensate for possible loss of generation or transmission or inaccurate forecasts or schedules. When planning ahead, power system planners or participants in equivalent market processes use complex models of the current operation and expected evolution of the system to evaluate the need for investment in generation, network or responsive demand resources.

- *Variability and predictability.* The outputs of variable RE generation can be predicted with various levels of accuracy but may not correlate well with the fluctuating power demand. Depending on the share of the total demand covered by variable RE, the increased variability and uncertainty in the power system may necessitate changes in system operation (8.2.1.3, 8.2.1.4). Over large areas, the correlation of output among variable RE plants is often small due to variations in the RE resource at any given moment. As a consequence the aggregated output of multiple RE generators usually fluctuates less in fractional terms than that of individual plants (8.2.1.2). Experience has shown that integration and accommodation of variable RE resources in a system can become more manageable from the technical and economic perspectives if methods of predicting variability over short time scales (from a few hours to a few days ahead) are sufficiently accurate.

- *Resource location.* The locations of RE sources have consequences for distribution and transmission network infrastructure (8.2.1.3). Small-scale RE systems can often be installed at or near the location of demand. Such distributed generation can bring some advantages for networks if near capacity, but can also pose new challenges that could be resolved by better controls, smart meters and intelligent grids. In other cases, the RE resource can be remote such as for large scale solar PV and CSP plants located in deserts so that substantial new transmission infrastructure may be required.

- *Electrical characteristics.* Electrical conversion of variable RE systems differs from conventional constant speed, synchronous generator systems, but as RE generation designs evolve, the differences are narrowing in terms of power quality characteristics. New technology and innovation enable wind and other variable RE power plants to function more like conventional power plants by meeting a major part of the control requirements made on traditional power plants, and by delivering ancillary services. The cost of delivering a specific ancillary service, or, more generally, to participate in the power market, can be a constraint. Experience shows that RE generators can contribute to sound power system operation, especially by the grouping of small generation plants to create a virtual power plant (VPP) (8.2.1.6). Understanding these characteristics and their interaction and impacts with other parts of the power system, is the basis for proper system integration of RE.

Short-term and long-term impacts. Short-term effects can be caused by balancing the system at the operational time scale (minutes to hours), and by the interaction of variable RE systems with grid voltage and stability. Long-term effects are related to the contribution that RE can make to the adequacy of the system in terms of its capability to meet peak load situations with high reliability. Impact studies on various power systems, both in time and scale, have been undertaken, mainly represented by wind but with more general applicability (Figure TS 8.4). For any given power system, the ability to integrate higher levels of RE depends upon whether the impacts can be identified in advance and successfully dealt with (8.2.1.3).

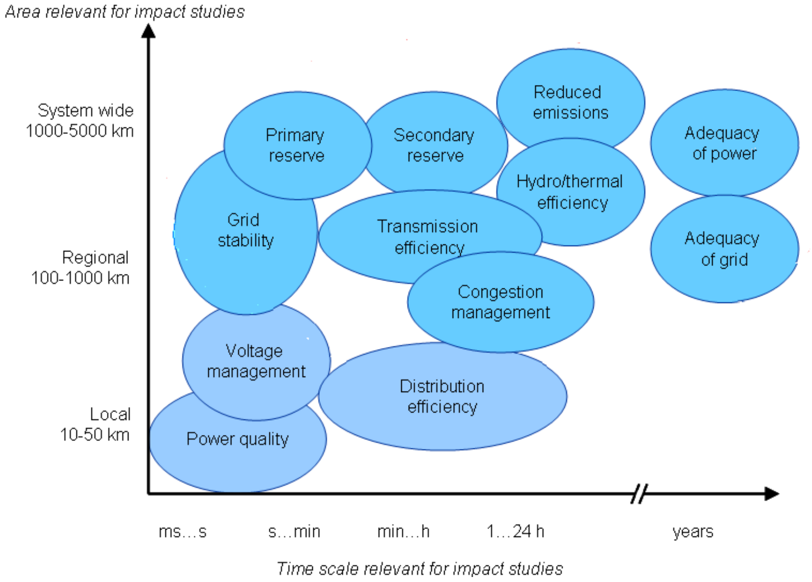

Figure TS 8.4 Impacts of wind power penetration on power systems by time scale and geographic area (Holttinen, 2009a), are representative of similar impacts from other variable renewables.

Analyzing and forecasting RE variability on different time scales, at different levels of geographical aggregation (3.5.4, 7.5.2, 8.2.1.2) and for different RE technology portfolios is necessary to understand and deal with RE impacts on the power system. There is practical experience of large power systems with wind penetration levels of up to 20% and integration issues up to 50% levels have been analysed in system studies. Better controls, smart meters and intelligent grids can help reduce impacts. These impacts identify the challenges of integrating variable and distributed RE systems and highlight the need to address specific aspects of a power system. The main experience with wind energy has relevance to other variable RE sources because it represents a challenging case in view of its relatively high variability and high penetration levels. There remains, however, a knowledge gap on integration issues, particularly for RE penetration levels higher than 20-30%.

From experience to date, the main technical, economic, management and institutional challenges are to be found in:

- power system design, stability and operation, including frequency and voltage regulation;
- network reinforcement, extension and interconnection of national and regional networks;

- network connection requirements for RE generation;
- system adequacy with high penetration of RE due to the low capacity value[4] of several variable RE technologies; and
- electricity market design and corresponding market rules.

Facilitating RE integration. Options to facilitate integration include making power systems more flexible and interconnected (8.2.1.4). Specific engineering approaches that could help solve integration issues include:

- alleviation of the overloading of transmission components through an appropriate combination of power system operation, system expansion, voltage regulation and power flow regulation technologies;
- consideration of energy storage requirements, although this option is likely to be more cost-effective in isolated power systems with high variable RE penetration than those interconnected;
- the time-shifting of power demand in response to an institutional incentive to improve the demand/supply balance as a response to variations in RE generation; and
- more effective energy management at the centralized or decentralized system level, including variable RE generation analysis and forecasting to support more frequent and wider variations of RE generation, better monitoring of the system, the realization of more robust power system controls, and improving system performance including recovery from various system disturbances.

Policy-level initiatives to facilitate RE integration include the review of electricity industry decision-making frameworks (governance, security, commercial and technical regimes) to assess their effectiveness at high levels of RE penetration. They include traditional long-term energy planning of a regulated, monopoly electricity industry, whereas in a competitive industry, such investment decisions may be delegated to a commercial regime with long-term derivative markets supported by advisory functions. In either type of industry, systematic and coherent institutional decision-making can facilitate the integration of high-levels of RE generation.

Costs and benefits. The investment and operating costs associated with integration of RE generation arise from network augmentation to accommodate fluctuating electricity flows associated with variable RE generation. Network extension to connect new RE power plants add costs as does investment in, and operation of, complementary electricity generation, storage and end-use technologies that can respond in a flexible and efficient manner to the additional fluctuating energy flows associated with non-storable RE forms (8.2.1.5). There is a lack of information in the literature on the costs of large-scale RE grid integration other than for wind power which is the most advanced in this regard.

Carefully chosen policies and commercial incentives may be required to bring forward an appropriate mix of “complementary resources” including generation, networks, storage and flexible end-uses, and to maximise the benefits that non-storable RE resources can bring whilst minimising the integration costs. For any given power supply system, the resulting generation mix, and the effectiveness of such a strategy, will be context-specific and evolve over time.

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[4] The capacity value (also known as capacity credit) of variable RE generation in a power system is equal to the amount of conventional generation capacity that can be replaced by this capacity without diminishing the security of supply level (Giebel, 2007).

Future power supply systems. In the long term, the aim to develop a truly sustainable energy supply system could see electricity becoming the main energy carrier, including for the heat and transport sectors. The necessary transition will be in the context of increasing demand for energy services, partly driven by bringing populations within developing countries out of poverty. Integration of electricity from RE sources could become a dominant component of this transition. If so, challenges to the sector will be way beyond current knowledge or experience (8.2.1.6).

A number of speculative approaches to future power system design and operation have been suggested (8.2.1.7). These commonly involve a combination of more highly connected power systems with greatly extended transmission infrastructure; ensuring loads are temporally responsive to supply availability; making greater use of distributed data, communications and controls; employing adapted unit commitment, economic dispatch methods and short-term forecasts; and modifying market structures to combine balancing solutions and to provide incentives for flexible generation in the necessary time frames. The concept of 'intelligent grids' still needs clearer definition, analysis and demonstration but several approaches for the design and operation of such future electricity systems dominated by RE generation have been examined in the literature. These range between large-scale, grid-integrated systems using high voltage direct current (HVDC) transmission over distances of 1000s of kilometres to small-scale distributed generation (DG) embedded in the local, low-voltage network, or to building-integrated systems with the power produced either for use on-site or export. The possibility of DG completely taking over from centralised generation is unlikely to happen even in the long term, but integration of DG into an existing supply system could be technically feasible, as could small autonomous DG mini-grids in remote rural areas or small islands. Depending on the further development of the technologies and associated cost reductions, DG could make a substantial contribution to future total global power generation.

Integration of renewable energies into heating and cooling networks

A district heating (DH) or district cooling (DC) network allows multiple energy sources to be connected to many energy consumers by pumping hot or cold water energy carriers, and sometimes steam, through insulated underground pipelines (8.2.2). Occupiers of buildings connected to a network can avoid operation and maintenance of individual heating/cooling equipment and rely on a professionally managed central system. Several high latitude countries have a district heating market penetration of 30-50%, although in Iceland, the share using geothermal resources, has reached 96%. World annual district heat deliveries have been estimated at around 11 EJ but heat data and statistics are uncertain.

Centralised heat production can facilitate the use of low cost and/or, low grade RE heat sources such as from geothermal, solar thermal, or combustion of a variety of biomass (including refuse-derived fuels and waste by-products) that are not suitable for use in individual heating systems. Waste heat from CHP generation and industrial processes can also be used. This flexibility facilitates competition among various heat sources, fuels and technologies. Centralised production also facilitates application of cost-effective measures to reduce local air pollution.

DH systems can also provide electricity, through CHP system designs. Demand response options also facilitate increased integration of RE in power systems. This includes using electricity for heat pumps and electric boilers for DH schemes, with thermal storage used where excess electricity is generated. Thermal storage systems can bridge the gap between variable, discontinuous or non-synchronised heat supply and demand (8.2.2.3). For short term storage (hours and days) the thermal capacity of the distribution system itself can be used for storage. The capacities of thermal storage systems using different materials and corresponding storage mechanisms, range from a few MJ up to several TJ; the storage time from hours to months; and the temperature between 20°C and 1000°C. Combined production of heat, cold and electricity (trigeneration), as well as the possibility for diurnal and seasonal storage of heat and cold, mean that high overall energy efficiency can be obtained.

There are many geothermal and biomass heating or CHP plants integrated into DH systems that are successfully operating under commercial conditions. Several large scale solar thermal systems with collector areas of around 10,000 m^2 have also been built (e.g. in Denmark). The best mix of heat and cold sources, and heat transfer technologies, depends strongly on local conditions, including demand patterns. As a result, the energy supply mix varies widely between different countries and also between systems.

Modern building designs and uses have tended to increase the demand for cooling but reduced the demand for heating. This trend has been amplified by recent warmer summers in many areas that have increased the cooling demand to provide comfort (8.2.2.4). Cooling load reductions can be achieved by the use of passive cooling options and active RE solutions. As for DH, the uptake of energy efficiency, deployment of other cooling technologies and structure of the market will determine the viability of developing a DC scheme. Modern DC systems from 5 to 300 MW_{th} have been operating successfully for many years using natural aquifers, waterways, the sea or deep lakes as the source of cold, and therefore are classed as a form of RE.

Establishing or expanding a DHC scheme involves high up-front capital costs for piping networks. Distribution costs alone represent roughly half of the total DH cost but are subject to large variations depending on heat density and the local conditions for building the insulated piping network. Network capital costs and distribution losses per unit of heat delivered are lower in areas with high heat densities. Corresponding heat distribution losses can range from less than 5% to more than 30%. The extent to which losses are considered a problem, however, depends on the source and cost of the heat.

DH schemes have typically been developed in situations where strong planning powers have existed, e.g., centrally planned economies, American university campuses, Western European countries with multi-utilities, and urban areas controlled by local municipalities. Expanding the use of DHC systems could facilitate a higher share of RE sources such as deep geothermal and biomass CHP that often require a large heat sink to be viable. Some countries are therefore supporting investments in DH networks as well as providing incentives for using RE.

Integration of renewable energies into gas grids

The gas grid system consists of gas production plants, transmission and distribution pipelines, gas storage, and industrial or private gas consumers. The basic design of a gas system depends on the type and source of energy, the location of demand, and the desired heating value, pressure, and purity depending on the use. Bio-methane or synthesis gas (8.2.3) can be injected into existing gas pipelines for distribution on a national, regional or local level. Large local and regional differences in existing infrastructure (and in gas production and consumption) make planning difficult for RE integration.

Over the past 50 years large integrated natural gas networks have been developed in several parts of the world including USA, Europe, and Japan. Over the past decade there has been an increased interest to “green” existing natural gas grids. Gaseous fuels from RE sources originate largely from biomass and may be produced either thermo-chemically to give synthesis gas (mainly H_2 and CO) or by anaerobic digestion (AD) to produce biogas (mainly CH_4 and CO_2) (8.2.3.1). Gas utilisation can be highly efficient when combusted directly for heat, or converted to a range of liquid fuels using various processes, or used in gas engines or turbines to produce heat and electricity. For example, biomethane, from biogas or landfill gas, can be combusted on-site to produce electricity and/or heat, or after cleaning and upgrading to natural gas quality, distributed to filling stations for use in dedicated or dual gas-fuelled vehicles, or fed into natural gas grids (Figure TS 8.5). Most of the biogas produced around the world has been distributed either in local gas systems primarily dedicated for heating purposes, or, in some cases transported via trucks to filling stations for gas vehicles. However, the biogas business is growing rapidly and several large gas companies are now making plans to upgrade large quantities of biogas and feed them at the required quality into national/regional transmission gas pipelines. As the heating value of synthesis gas is less than that of biomethane, the existing natural gas grid would need modifying to accept synthesis gas directly due to its different flow and combustion properties.

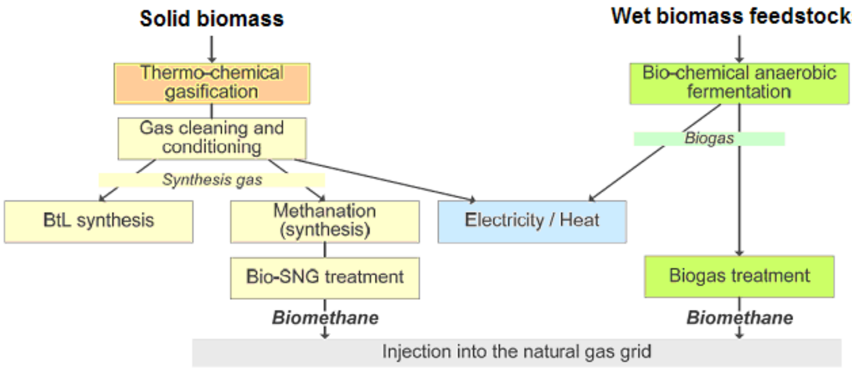


Figure TS 8.5 Injection into the natural gas grid of RE gases produced from solid or wet biomass feedstocks such as green crops or organic wastes (Müller-Langer et al., 2009).

Technical challenges relate to gas source, composition, and quality. Only gases of a specified quality can be injected directly into existing natural gas grids hence gas clean-up is a critical step for both biogas and syngas use. This process removes water, carbon dioxide (thereby increasing the heating value) and additional products from the gas stream. The cost of upgrading varies according to the scale of the facility (3-6% of the energy content).

RE gas systems are likely to require significant storage capacity to account for variability and seasonality of supply. The size and shape of storage facilities and the required quality of the gas will depend on the primary energy source of production and its end use.

Hydrogen may be produced from RE by several routes including the reformation of biogas or water electrolysis. The potential RE resource base for hydrogen is greater than for biogas or biomass-derived syngas. Future production and distribution of hydrogen will depend significantly on the interaction with existing electricity systems. For the short term, blending of hydrogen with natural gas (up to 20%) and transporting it long-distances in existing natural gas grids could be an option, while, in the long term, the construction of pure hydrogen pipelines would require different steels to reduce leakage. The rate limiting factors for deploying hydrogen are likely to be the capital and time involved in building a new hydrogen infrastructure and the added cost for storage when incorporating variable RE sources.

In order to blend RE gases into the gas grid, the gas source needs to be located near to the existing system to avoid high costs. In the case of remote biogas plants it may be better to use the methane on-site to avoid the need for transmission. Similar considerations apply to hydrogen and syngas produced from biomass (8.2.3.5).

Integration of renewable energies into liquid fuels

Most of the projected demand for liquid biofuels is for transport purposes, though industrial demand could emerge for bio-lubricants and bio-chemicals, such as methanol, used in chemical industries. In addition, large amounts of traditional solid biomass used for cooking and heating could eventually be replaced by more convenient, safer and healthier liquid fuels such as dimethyl ether (DME) or ethanol gels.

The biomass-to-liquid fuel process comprises production (agricultural phase), preparation and conversion (industrial phase), distribution, and final consumption (Figure TS 8.6). Biofuels can take advantage of existing infrastructure components already used by the petroleum-based fuels for storage, blending, distribution and dispensing (8.2.4.1) although sharing oil-product infrastructure (storage tanks, pipelines, trucks) with biofuels, especially ethanol, can give problems of water contamination and corrosion, and may require new materials to preserve the lifetime of the equipment.

Decentralized biomass production, seasonality and remote agricultural locations not necessarily near existing oil refineries or fuel distribution centres can impact on the logistics and storage of biofuels (8.2.4.3). The type of fuel storage and delivery system will vary depending with the properties of the biofuel and its compatibility with the existing petroleum fuel system. Technologies continue to evolve to produce biofuels that are more compatible with the existing petroleum infrastructure. Quality control procedures need to be implemented to ensure that biofuels meet all applicable product specifications (8.2.4.4).

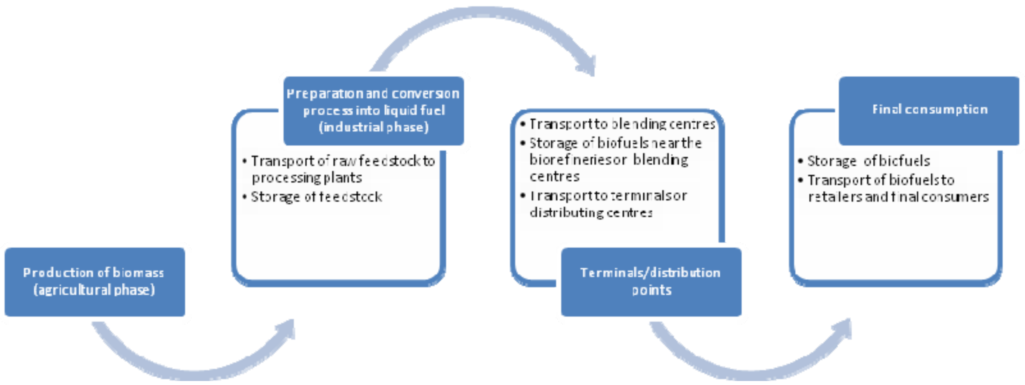


Figure TS 8.6 The typical biofuel process, blending and distribution system [TSU: Reference is missing]

Integration issues are challenging for biofuels. For example, replacing a substantial proportion of gasoline with blends of neat ethanol requires investment in infrastructure including additional tanks and pumps at the service stations. Although the cost of delivery is a small fraction of the overall cost, the logistics and capital requirements for widespread expansion could present many hurdles if they are not well planned. Ethanol and ethanol/gasoline blends cannot be easily stored, transported and delivered in the existing petroleum infrastructure because of the incompatibility of some materials and water absorption by ethanol in the pipelines (8.2.4.1). Moreover, ethanol has only around two-thirds of the volumetric energy density of gasoline, so larger storage systems, more rail cars or vessels, and larger capacity pipelines would be needed to store and transport the same amount of energy, thereby increasing the fuel storage and delivery cost. Although pipelines would, in theory, be the most economical method of delivery, and trial pipeline shipments of ethanol have been successfully achieved, a number of technical and logistical challenges remain. Current ethanol demand volumes are usually considered too low to justify the cost and operational challenges (8.2.4.3).

Autonomous systems

In order to be sustainable, and depending on whether the energy carrier is electricity, hydrogen, or liquid, gaseous or solid fuels, an energy system needs to maintain the demand-supply balance over various time frames. When a system is small, the demand-supply balance problem readily emerges so that the energy system has autonomy for balancing (8.2.5.1). The integration of several RE conversion technologies, energy storage options and energy use technologies in a small-scale energy system depends on site-specific availability of RE resources and the energy demand due to geology, climate, and lifestyle. This creates several types of autonomous power supply systems including: 1) on an island (often including fossil fuel generators as part of a small, mini-grid system); 2) in rural areas of a developing economy (generally a hybrid RE system for remote, off-grid, communities); 3) for individual buildings (including zero-emission designs) that could generate more electricity and heat energy than they consume through the use of energy efficient technologies and on-site heat and power generation.

An autonomous RE power system could involve the limited deployment of a single type of RE generation technology such as solar power, or incorporate a portfolio of technologies. The capacity of the RE generation can be increased by the addition of more generation units of similar type, or by adding other types of RE generation technologies to enhance operational flexibility. Fossil fuel generation to maintain the desired supply reliability and flexibility of system operation could, in the future, be displaced by increased flexibility and the integration of energy storage (8.2.5.2).

Energy storage and efficient utilization technologies could become essential where the integration of RE technologies changes from a niche to a major role. Major constraints can arise from the difficulty of appropriate planning, designing, construction and maintenance of autonomous systems (8.2.5.3). In order to avoid these factors, establishing standardization and certification of the products, integrating planning tools, developing a database and capacity building are important, as are building local capacity and market establishment for low capital and operation costs.

Electricity generated in an autonomous system is usually more costly than that from an existing network where grid connection is available. However, integration of different kinds of RE may improve the economy and reliability of the supply and the economic viability should be evaluated including factors such as the possible future constraints of fossil fuel supplies, avoidance of infrastructure construction, technology innovation and projected cost reductions.

Strategic elements for transition pathways

Since the IPCC 4th Assessment Report in 2007, RE technology developments have continued to evolve and there has been increased deployment due to improved cost-competitiveness, increased public concern at the threats of energy security and climate change, and more supporting policies, including public R&D investment particularly for the transport and building sectors. In order to achieve greater RE deployment in these sectors as well as industry and agriculture (that includes forestry and fishing) (Fig. y.y), both technical and non-technical issues have a role to play.

For each sector, the current status of RE use, possible pathways to enhance increased adoption, the transition issues yet to be overcome and future trends are discussed (8.3). Regional variations exist due to differences in the energy system and related infrastructure currently in place as well as varying national and local ambitions and cultures.

Transport

The direct combustion of fossil fuels for transport consumes around 19% of global primary energy use and produces around 23% of GHG emissions, plus a significant share of air pollutant emissions. Light duty vehicles (LDVs) account for over half of transport fuel consumption worldwide, with heavy duty vehicles (HDVs) 24%, aviation 11%, shipping 10%, and rail 3%. Demand for mobility is growing rapidly with the number of motorized vehicles projected to triple by 2050 and a similar growth in air travel. Energy supply security is therefore a serious concern for the transport sector with about 94% of transport fuels presently coming from petroleum, mostly as imported products.

Improving the efficiency of the transport sector, and decarbonising it, have been identified as being critically important to achieving long-term, deep reductions in carbon emissions. The approaches to reducing transport-related energy use, and hence GHG emissions, are a reduction of travel demand, increased vehicle efficiency, shifting to more efficient modes of transport, and replacing petroleum-based fuels with alternative low or near-zero carbon fuels including biofuels, electricity or hydrogen produced from low carbon primary energy sources (8.3.1.1). Recent scenario studies strongly suggest that a combination of approaches will be needed to accomplish 50-80% reductions in GHG emissions by 2050 (compared to current rates) while meeting the growing transport energy demand.

There are a number of possible fuel/vehicle pathways beginning with the primary energy source, conversion to an energy carrier (or fuel) and use including in advanced internal combustion engine vehicles (ICEVs), electric battery vehicles (EVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and hydrogen fuel cell vehicles (HFCVs) (Figure TS 8.7) (8.3.1.2).

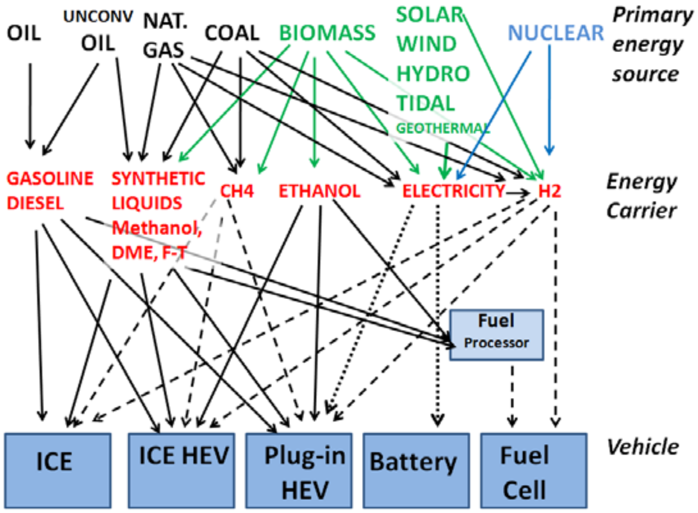


Figure TS 8.7 Possible fuel/vehicle pathways, from primary energy sources (top), through energy carrying fuels (red) to vehicle options (bottom) showing renewable resources (green). Notes: F-T= Fischer-Tropsch process. ICE= internal combustion engine. HEV=hybrid electric vehicle. [TSU: Reference is missing]

Present use of RE in transport is only a few per cent of the total demand, mainly through electric rail and blending liquid biofuels with petroleum products. Millions of LDVs capable of running on liquid biofuels are already in the fleet and biofuel technology is commercially mature (as is the use of compressed biomethane). Costs and lifetimes of present battery technologies are a major barrier to both battery only EVs and PHEVs. The latter are undergoing rapid development, spurred by recent policy initiatives worldwide, and several companies have announced plans to commercialize them starting in 2010. Consumer acceptance associated with battery range and recharging time is also an issue. One strategy is to introduce PHEVs initially while developing and scaling up battery technologies. Many hydrogen fuel cell vehicles have been demonstrated, but are unlikely to be commercialized until at least 2015-2020 due to barriers of fuel cell durability, cost, on-board hydrogen storage and hydrogen infrastructure availability.

Transition issues vary for biofuels, hydrogen, and electric vehicles (Table TS 8.1). No one option is seen to be a clear "winner" and all will take several decades to implement at the large scale.

Table TS 8.1 Transition issues for biofuels, hydrogen, and electricity (Bandevedakar et al., 2008)

Technology Status	**Biofuels**	**Hydrogen**	**Electricity**
Vehicles	Millions of flex-fuel vehicles using ethanol, but conventional vehicles still limited to low concentration blends of ethanol (< 10%) or biodiesel (< 5%)	Demonstration HFCVs. Commercial HFCVs: 2015-2020	Limited current use of EVs. Demonstration PHEVs, Commercial PHEVs :2010-15. Commercial EVs: 2015-2020.
Fuel production	1st generation: Ethanol from sugar and starch crops, biomethane, biodiesel. 2nd generation: ethanol / diesel/green fuels from cellulosic biomass, biowastes, bio-oils, and algae - after at least 2015.	Fossil H_2 commercial for large-scale industrial applications, but not competitive as transport fuel. Renewable H_2 generally more costly.	Commercial power available. RE electricity generally more costly.
Cost (vs. gasoline vehicles) Incremental vehicle price compared to future gasoline ICEV (USD2005) Fuel cost (USD /km)	Similar vehicle cost to gasoline. Fuel cost per km competes, if biofuel price per unit energy ~ gasoline price per unit energy.	HFCV experience price increment compared to gasoline ICEV >USD 5300 (2035) Fuel cost per kg for H_2 at \$3-4/kg (target for mature H_2 infrastructure; may prove optimistic) used in HFCV competes with gasoline at USD 0.40-0.53/l used in gasoline ICEV, assuming HFCV has 2x fuel economy of gasoline ICEV. Renewable H_2 at least 1.5-3x more expensive.	Experience price increment compared to gasoline ICEV >USD 5900 (2035) (PHEVs) >USD 14,000 (2035) (EVs). Electricity cost per km competes with gasoline cost per km for electricity costs \$0.10-0.30/kWh when gasoline costs \$0.3-0.9/l (assuming EV has fuel economy 3x gasoline ICEV)
Compatibility with existing infrastructure	Partly compatible with existing petroleum distribution system. Separate distribution and storage infrastructure can be needed for ethanol.	New H_2 infrastructure needed, as well as renewable H_2 production sources. Infrastructure deployment must be coordinated with vehicle market growth.	Widespread electric infrastructure in place. Need to add in-home and public chargers, RE generation sources, and upgrade transmission and distribution (especially for fast chargers).
Consumer acceptance	Fuel cost: alcohol vehicles have shorter range than gasoline. Potential cost impact on food crops and land use. Land and water issues can be a factor.	Vehicle and fuel costs. Safety of on-board gaseous H_2 storage. Fuelling station availability in early markets.	Vehicle initial cost. High electricity cost of charging on-peak. Limited range unless PHEV. Modest to long recharge time, but home recharging possible. Significantly degraded performance in extreme climates (cold winters, hot summers).
Existing and potential primary resources	Sugar, starch, oil crops. Cellulosic crops; forest, agricultural and solid wastes. Algae and other biological oils.	Fossil fuels, nuclear, all RE-potential RE resource base is large but inefficiencies and costs of converting to H_2 an issue.	Fossil fuels, nuclear, all RE – potential RE resource base is large.
GHG emissions	Depends on feedstock, pathway and land use issues. Low for fuels from waste residues, and sugarcane. Near-term can be high for corn ethanol. 2nd generation biofuels lower.	Depends on H_2 production mix. Compared to future hybrid gasoline ICEVs, WTW GHG emissions for HFCVs using H_2 from natural gas are slightly more to slightly less depending on assumptions used. WTW GHG emissions can approach zero for RE pathways.	Depends on grid mix. Using coal-dominated grid mix, EVs, and PHEVs have WTW GHG emissions similar or higher than gasoline HEV. With larger fraction of RE and low carbon electricity, WTW emissions are lower.

Petroleum consumption	Low	Very low	Very low
Environmental and sustainability issues			
Air pollution	Similar to gasoline. Additional issues for ethanol due to permeation of volatile organic compounds (VOCs) through fuel tank seals. Aldehyde emissions.	Zero emission vehicle	Zero emission vehicle.
Water use	More than gasoline depending on feedstock and irrigation needs.	Potentially very low but depends on pathway.	Potentially very low but depends on pathway.
Land use	Might compete with food- for cropland.	Depends on pathway.	Depends on pathway.
Materials use		Platinum in fuel cells. Neodymium and other rare earths in electric motors.	Lithium in batteries. Neodymium and other rare earths in electric motors.

Note: Costs quoted do not always include payback of incremental first vehicle costs.

An advantage of liquid biofuels is their relative compatibility with the existing liquid fuel infrastructure (8.3.1.2). They can be blended with petroleum products and most ICE vehicles can be run on blends or some even on 100% biofuel. They are similar to gasoline or diesel in terms of vehicle performance and refuelling times, though have limits on the concentrations that can be blended and typically cannot be easily distributed using existing fuel pipelines without modifications. Although liquid biofuels would likely need their own distribution and storage systems, this would be less of a radical change than the supply chains required to provide either electricity, hydrogen or even biomethane where such a network is not yet in place. Sustainable biomass resource availability is, however, a serious issue for some biofuels (Chapter 2).

For RE electricity to serve large transport markets, several innovations must occur such as development of batteries and low cost supply available at the time of recharging EVs. With night-time off-peak recharging, new capacity would not be needed and there may be a good temporal match with wind or hydropower resources, although not necessarily to solar. Energy storage may also be needed to balance vehicle electric demand with RE sources.

Hydrogen has the potential to tap vast new energy resources to provide transport with zero or near-zero emissions (8.3.1.2). Hydrogen from RE sources has near-term cost barriers rather than technical feasibility or resource availability issues. Initially RE and other low carbon technologies will likely be used to generate electricity, a development that could help enable zero-carbon hydrogen that might be co-produced with electricity in future energy complexes. Unlike electricity, natural gas, gasoline and biofuels, hydrogen is not widely distributed to consumers today. Electricity is used more efficiently in an EV or PHEV but hydrogen might be preferred where a larger vehicle with a longer range and faster refuelling time is needed. Bringing hydrogen to large numbers of vehicles would require building a new refuelling infrastructure that could take several decades to construct. The first steps to provide hydrogen to test fleets and demonstrate refuelling technologies in mini-networks have begun.

It is also possible to lower emissions and introduce RE options in other transport sectors including HDVs, aviation, maritime and rail. The use of biofuels is key for increasing the share of RE but engines would probably need to be modified to operate on high biofuel blends above 80% (8.3.1.5). Compared to other transport sectors, aviation has less potential for fuel switching due to safety needs and to minimize fuel weight and volume. Various aircraft have flown demonstration test flights using several biofuel blends, but significantly more processing is needed than for road fuels to ensure that stringent aviation fuel specifications are met. For rail transport, as 90% of the industry was powered by diesel fuel in 2005, greater electrification and the increased use of biodiesel are the two primary options for introducing RE.

Recent trends and projections show strong growth in transport demand, including a strong projected growth in number of vehicles. Meeting this demand whilst achieving a low carbon, secure energy supply will require strong policy initiatives, rapid technological change, monetary incentives and, or, the willingness of customers to pay additional costs. Many uncertainties and cost reduction challenges remain concerning future technologies, source of the energy carriers and the related infrastructure. Given these uncertainties and the long timeline for change, it is important to maintain a portfolio approach that includes behavioural changes (to reduce vehicle km travelled or km flown), more efficient vehicles, and a variety of low-carbon fuels.

Buildings and households

The buildings and household sector in 2007 accounted for ~116 EJ, or about 30 % of total global final energy demand. Around 40 EJ of this total was from combustion of traditional biomass for cooking and heating. By 2030, the total demand could rise to ~136 EJ. The sector is paramount for providing a variety of energy services to support the livelihoods and well-being of people living in both developed and developing countries.

The present use of fossil fuels to provide heating and cooling can be replaced economically in many regions by RE systems using e.g., district heating and cooling, modern biomass and enclosed stoves, ground source heat pumps, or solar thermal and solar sorption systems. Building-integrated electricity generation technologies provide the potential for buildings to become energy suppliers rather than energy consumers. Integration of RE into existing urban environments, combined with efficient "green building" designs, is key to further deployment. For household and commercial building sub-sectors, energy vectors and energy service delivery systems vary depending on the local characteristics of a region and its wealth.

In *urban settlements in developed countries*, most buildings are connected to electricity, water and sewage distribution schemes (8.3.2.1). The features and conditions of energy demand in an existing or new building and the prospects for RE integration differ with location and from one building design to another. Assuming a low stock turnover of buildings of around 1% per year, retrofitting of existing buildings will play a significant role for energy efficiency and RE integration. Where buildings are connected to electricity grids, gas grids or district heating and cooling systems it facilitates indirect integration of RE to provide energy services. Many energy efficiency and RE technologies, although economically viable, involve relatively high up-front investments and long pay-back periods. Examples include district heating and cooling systems, solar water heaters and ground source heat pumps. This barrier can be overcome through planning and regulation as well as economic incentives and financial arrangements.

In *urban settlements in developing countries*, energy consumption patterns often include the non-rational use of biomass, particularly from forest resources located close to urban consumption centres. In some areas, grid electricity is available, although limited. A major challenge is to reverse the current consumption patterns by providing access to modern energy carriers and services, while increasing the share of RE.

Energy consumption patterns in *rural settlements in developed countries* greatly resemble those in urban areas (8.3.2.3). In such areas there are good opportunities for local RE resources to be developed to meet local demand and, in some cases, to generate surplus electricity that can be delivered to the grid. Financial and institutional barriers, including lack of awareness, are among key barriers to mobilizing RE on a large scale in rural areas.

Only a small fraction of *rural settlements in developing countries* have access to modern energy services, which is also a major constraint to eradicating poverty (8.3.2.4). Rural households rely on traditional biomass (mainly crop residues, fuel-wood and charcoal) for their basic cooking and heating energy needs. Lighting demands is often met by kerosene lamps, torches and candles. The key challenge for rural communities is to improve energy access and quality through deploying a range of modern RE technologies for providing basic energy services.

Industry

Manufacturing industries account for about one-third of global energy use although the share differs markedly between countries. The sector is highly diverse but perhaps 85% of industrial energy use is by energy intensive industries: iron and steel, non-ferrous metals, chemicals and fertilizers, petroleum refining, minerals, and pulp and paper. Key measures to reduce carbon dioxide emissions include energy efficiency, materials recycling, CCS, in addition to integrating higher shares of RE and substitute fossil feedstock. In addition, industry can provide demand-response facilities that are likely to achieve greater prominence in future electricity systems with more variable supply.

There are no severe technical limits to the increased direct and indirect use of RE in industry in the future. But integration in the short term may be limited by factors such as space constraints or demands for high reliability and continuous operation. The main opportunities for RE integration in industry include:

- direct use of biomass derived fuels and residues for on-site biofuels, heat and CHP production and use (Chapter 2);
- indirect use of RE through increased use of RE-based electricity, including electro-thermal processes;
- indirect use of RE through other purchased RE-based energy carriers, e.g., liquid fuels, biogas, heat and hydrogen (section 8.2.3);
- direct use of solar thermal energy for process heat and steam demands (Chapter 3); and
- direct use of geothermal for process heat and steam demands (Chapter 4).
- The current direct use of RE in industry is dominated by biomass in the pulp and paper, sugar and ethanol industries where biomass by-products are important sources of co-generated heat and electricity mainly used for the process. Biomass is also an important fuel for many small/medium enterprises (SMEs) such as brick-making, notably in developing countries (8.3.3.1). Industry is not only a potential user of RE but also a potential supplier as a co-product.

Possible pathways for increased use of RE in *energy-intensive industries* vary between different industrial sub-sectors (8.3.3.2). Biomass can replace fossil fuels in boilers, kilns and furnaces and there are alternatives for replacing petro-chemicals through switching to bio-based chemicals and materials. However, due to the scale of operations, access to sufficient volumes of biomass may be a constraint (Chapter 2). Direct use of solar technologies is constrained for the same reason. For many energy-intensive processes the main option is indirect integration of RE through switching to electricity and hydrogen. The broad range of options for producing carbon neutral electricity and its versatility of use implies that electro-thermal processes could also become more important in the future for replacing fuels in a range of processes.

Non-energy intensive industries, although numerous, account for a smaller share of total energy use than energy-intensive industries (8.3.3.3). They include food processing, textiles, light manufacturing of appliances and electronics, automotive assembly plants, wood processing, etc. Much of the energy demand in these industries is for installations similar to energy use in commercial buildings such as lighting, space heating, cooling and ventilation and office equipment.

In general, they are more flexible and offer greater opportunities for the integration of RE than energy-intensive industries.

The potentials and costs for increasing the direct use of RE in industry are poorly understood due to the complexity and diversity of industry and various geographical and climatic conditions. Improved utilisation of processing residues and CHP in biomass-based industries and substitution for fossil fuels offer near-term opportunities. Solar thermal technologies are promising but further development of collectors, thermal storage, back-up systems and process adaptation and integration is needed. Indirect integration using electricity generated from RE sources and facilitated through electro-technologies may have the largest impact both in the near and long-term. Direct use of RE in industry has difficulty competing at present due to relatively low fossil fuel prices and low or zero energy and carbon taxes for industry. RE support policies in different countries tend to focus more on the transport and building sectors than on industry and consequently potentials are relatively un-charted.

Agriculture, forestry and fishing

Whether large corporate-owned farms or subsistence farmers, agriculture is a relatively low energy consuming sector, with pumping of water for irrigation and indirect energy for the manufacture of fertilisers accounting for the greatest consumption.

RE sources including wind, solar, crop residues and animal wastes, are often abundant for the landowner to utilise locally or to earn additional revenue from exporting useful energy carriers such as electricity or biogas off the farm. In many regions, land under cultivation could simultaneously be used for RE production (8.3.4.2). Multi-uses of land for agriculture and energy purposes is becoming common, such as wind turbines constructed on grazing land, on-farm biogas plants used for treating pig manure and recycling the nutrients, streams used for small- and micro-hydropower systems, straw residues collected and combusted for heat and power, and crops grown and managed specifically to provide both food or fibre and liquid biofuel co-products (8.3.4.3).

Despite barriers to greater deployment including high capital costs, lack of available financing and remoteness from energy demand, it is likely that RE will be used to a greater degree by the global agriculture sector in the future to meet energy demands for primary production and post-harvest operations at both the large and small scales, using a wide range of conversion technologies. Since RE resources often abound in rural areas, their capture and integration into traditional farming operations to become an additional form of revenue for landowners has good future potential.

Conclusions

RE has the potential in the longer term to provide a much greater share of global energy than at present. Indeed some communities are already close to achieving 100% RE supply, including for local transport. Over the long-term and through measured system integration, there are few, if any, technical limits to the level of penetration of RE in the many parts of the world where abundant RE resources exist. In the future RE could provide the full range of energy services to large and small communities in both developed and developing countries. However, the necessary transition to a low carbon future will require considerable investments in new technologies and infrastructure, including flexible and intelligent electricity grids, energy storage, novel transport methods and distributed energy systems, as well as improved energy efficiency on both the supply-side and during final end-use consumption.

In the short-term, integration of higher shares of RE in the present energy supply systems than at present can enhance system reliability, energy security, electricity and gas network security, GHG mitigation, sustainable development and access to energy services for all. The full range of RE sources could become available for integration by end-use sectors, including electric vehicles, building integrated solar systems, industry use of bioenergy co-fired with coal, and small wind and small hydro projects for agriculture. Integration strategies that could increase the deployment of RE in both urban and rural areas will depend upon the local and regional RE resources, energy demand patterns, project financing methods and existing energy markets.

The general and specific requirements for better integration of RE into heating and cooling networks, electricity grids, gas grids, transport fuel supply systems and autonomous buildings or communities are reasonably well understood. However, analysis of the additional costs for integration of RE options has not been found in the literature and therefore future research is needed including to provide accurate data for modelling scenarios. For example, how the possible projected trend towards decentralised energy supply systems might affect future costs and demand for large, centralised systems has not been assessed. Other risks and impacts involving the integration and deployment of RE in a sustainable manner, including the increased use of materials, capacity building, technology transfer, and financing, also need further analysis.

Regardless of the energy systems presently in place, whether in energy-rich or energy-poor communities, increased RE integration with the existing system is desirable. The rate of penetration will depend on an integrated approach, including policy framing, life-cycle analysis, comparative cost/benefit evaluations, and recognition of the social co-benefits that RE can provide.

Renewables in the Context of Sustainable Development

Introduction

Development is a concept frequently associated with economic growth, still in many cases disregarding income distribution, physical limits from the environment and the external costs of impacts caused by some and borne by others. Climate change is one of these most relevant impacts, with externalities present at global level. (9.1)

Sustainable Development (SD) is a relatively recent concept, aiming to consider such impacts. There are several definitions of SD, but probably the most important came up in 1987, with an influential report published by the United Nations, entitled “Our Common Future” (or “The Brundtland Report”). In this publication, sustainable development is a principle to be pursued, in order to meet the needs of the present without compromising the ability of future generations to meet their own needs. The report recognized that poverty is one of the main causes of environmental degradation and that equitable economic development is a key to addressing environmental problems. (9.1)

Energy for sustainable development has three major pillars: (1) more efficient use of energy, especially at the point of end-use, (2) increased utilization of renewable energy, and (3) accelerated development and deployment of new and more efficient energy technologies. The questions of renewable and sustainable energy have their roots in two distinct issues: while renewability is a response to concerns about the depletion of primary energy sources (such as fossil fuels), sustainability is a response to environmental degradation of the planet and leaving a legacy to future generations of a reduced quality of life. Both issues now figure prominently on the political agendas of all levels of government and international relations. (9.1)

Interactions between Sustainable Development and Renewable Energy

Much of the discourses on SD have historically focused on economic and environmental dimensions of renewable energy technologies and their implementation. Social and institutional dimensions have not received the same degree of attention. With growing interest in the two-way relationship between SD and renewable energy, the latter two dimensions need to be given the same level of importance. After all, increased penetration of RE can have positive or negative local impacts on air, water, land, health and socio-economic development, and could impact attaining the Millennium Development Goals. Positive impacts include reduced air pollution, improved energy access and supply security, higher employment, enhanced lifestyles and gender equality, whereas negative ones may involve higher costs, land competition, impacts on biodiversity and displacement of people.

In most respects, consumers of energy services are focused on whether those essential services are abundant, reliable, and affordable – not on where the energy comes from. However, judging from the availability of renewable energy technologies other than large-scale hydropower, it is difficult to conceive of significant urban/industrial development based on renewable energy sources. Where current renewable energy niches in either electricity production or transportation fuels are now on the order of four to eight percent, increasing them to twenty or thirty percent is a profound challenge to scalability because of the magnitude of the needs. In addition, many renewable energy sources are based on continuous energy sources, such as water flow or plant growth, but some are based on intermittent energy sources, such as solar radiation or wind. Where the sources are intermittent, the only ways that they can meet continuing needs for energy services are either by energy storage or by using other energy sources as supplements, either of which tends to increase costs and reduce net benefits. Finally, energy costs and their affordability constitute a complex issue for renewable energy. At a local scale, in many cases renewable energy options offer a prospect of reduced energy costs. But for larger-scale energy needs for development, fossil energy sources – or intermediate sources dependent on them – are considerably less expensive at present (except for hydropower), and efforts to promote clean energy by increasing the cost of fossil energy can be a threat to development. (9.1.1)

Different forms of human settlement will each pose their own challenges in providing adequate access to energy. In rural settlements, electrification to promote development (and reduce pressures for rural to urban migration) has been a development priority for many decades. In most cases, the preferred approach has been to combine local renewable resource endowments (such as solar radiation or biomass) with institutional innovations. There have been notable early successes, such as the development of solar cells in rural villages in the Dominican Republic in the early 1980s. Often, however, rural electrification efforts have been so subsidized that they are not themselves sustainable, which can be worse for overall sustainability than not introducing those changes at all. In many urban areas in developing countries, on the other hand, the major energy access issues are (a) the lack of reliability of electricity supply and (b) air pollution associated with local industrial, transportation, and energy production, which affect rich and poor alike. But even where it is generally available, the poor often lack ready, affordable access to electricity, as urban electricity supply institutions emphasize supplies to relatively large customers who can pay. In many cases, traditional renewable energy sources such as wood or charcoal for cooking and heating and passive solar energy for food preservation are used as the only affordable options, but urban wood and charcoal consumption often poses threats to the sustainability of regional biomass energy supply capacities. (9.2.1)

One of the most attractive features of increasing the use of local renewable energy sources, especially if local populations either control or share in the control, is their contribution to energy security, as risks for external trading factors to cause sudden, disruptive supply shortages or price increases are reduced. (9.2.3)

Environmental and Social Impacts: Global and Regional Assessment

Renewables have consequences (positive and adverse) to environmental resources and qualities at regional and global level with implications for mitigating and adaptive capacity. Apart from hydropower, windpower and bioenergy, literature describing the impacts of other RE technologies on land, water, air, ecosystems and biodiversity, human health and built environment is limited. In the following paragraphs, some of the most crucial aspects are described. (9.3)

RE technologies have many *similar* positive environmental and social impacts that make them attractive compared to their fossil and nuclear counterparts. On the other hand, the adverse environmental and social issues that affect their deployment and limit development opportunities are more *technology-specific* and in some cases *site specific*. There are mitigative options for the adverse impacts and their implementation can improve and in many cases ensure sustainability of the technologies. Details of the most significant environmental and social impact topics, positive and negative, are shown in Table TS 9.1.

Land use and population: Renewable energy technologies offer a way to improve the use of degraded or desert lands that otherwise may have few productive uses. In addition, small RE power plant sites can coexist with minimal side effects on farming, forestry, and other land uses. RE offer decentralized options, reducing the impacts on land use from ducts and transmission lines.

There are several adverse impacts and conflicts with RE land use especially on lands that are being currently used for food crop production. In addition, there are risks such as land subsidence or soil contamination near geothermal plants, population displacement through the setting up of hydro reservoirs and competition with fishing in oceans. (9.3.1)

Air and Water: Most RE technologies have little or no direct local and global atmospheric emissions, which serves as a strong mitigation mandate. Exceptions include release of methane from hydro reservoirs and biomass burning, in crops or in poorly controlled industrial processes. Even so, such releases are less toxic compared to those from poorly controlled fossil fuel combustion or even with nuclear material accidents. Small bioenergy, solar PV, hydro and other RE plants serve as a valuable resource for local (rural) ground water extraction and supply of basic energy services to communities. Wind farms offer a way to amortize strong winds. (9.3.1)

Similar to fossil fuel sources, however, many types of RE technologies can adversely affect water sources. The need for cooling RE power plants in water-short arid areas, risk of water contamination through geothermal generation, thermal pollution, water quality degradation and health impacts from hydro reservoirs, swell/waves and tidal/ocean currents are established examples of water impacts. (9.3.1)

Ecosystem and Biodiversity: RE plants offer limited direct benefit to ecosystem and biodiversity. Shaded solar reflectors may improve micro-climate and ocean energy sources may increase biodiversity in some locations. On the other hand, loss of biodiversity and disruption of ecosystem structure is a major concern mainly for bioenergy and hydropower. Impacts due to monoculture originating from bioenergy sources, loss of biodiversity and obstacle to fish migration through hydro units, ecological modification of barrages, bird and bat fatalities due to wind farms are classic examples of such problems. Recent projects utilizing modern technologies, following adequate guidelines and providing due environmental compensation have mitigated significantly these adverse effects. (9.3.1)

Human Health: Human health can benefit through low and less toxic emissions from renewable energy sources. Steady and clean water supply from reservoirs serve as recreational and entertaining facilities, as well as for fishing and irrigation. By the same token, uncontrolled bioenergy combustion can increase indoor and outdoor air pollution, manufacturing and disposal of PV modules can generate toxic waste, hydro reservoirs can spread vector borne diseases and noise at wind farms can be a nuisance. (9.3.1)

Built Environment: Not unlike fossil and nuclear plants, RE infrastructure provides socio-economic benefits to local communities through creation of jobs and facilitation of local development. Ocean energy provides additional benefit through protection of coastal erosion. Changes in bioenergy plant landscape, induced local seismicity near geothermal plants, risks from dam bursts or wind tower breakdown, as well as changing conditions at ocean discharge sites are illustrations of concerns about the built environment. (9.3.1)

The environmental impacts associated with RE clearly vary by technology, location, availability of resources (e.g., water), the potential for human exposure, and local ecological susceptibilities. Proper assessments and comparisons of such issues typically require a life-cycle assessment (LCA) approach. Ideally, an LCA will characterize the flows of energy, resources, and pollutants across the life-cycle of an RE technology, which includes activities related to raw materials acquisition, manufacturing, transportation, installation and maintenance, operation, and decommissioning. The ecological and human impacts associated with such flows are further characterized across a range of impact metrics (e.g., global warming potential, human health damages, ecotoxicity, and land use). As such, LCA provides a framework for assessing and comparing RE technologies in an analytically-thorough and environmentally-holistic manner. (9.3.1)

Table TS 9.1: Environmental and Social Benefits (+) and Concerns (-) Associated with Renewable and Conventional Energy Sources

From/ on		Bioenergy	Direct Solar	Geothermal	Hydropower	Ocean Energy	Wind Energy	Nuclear	Fossil Fuels
Land Use and Population	+	positively intensified land uses (e.g. degraded land)	decentralized energy allowing better land use (e.g. degraded or desert)	decentralized energy allowing better land use	stored water for irrigation and other uses (fisheries, domestic use, recreation)	decentralized energy allowing better land use	decentralized electricity co-existing with farming, forestry, etc.	low land use from power plants	some fuels (LPG, kerosene) allow decentralized energy avoiding deforestation
	-	competition with food supply; threats to small landowners	land use (mostly urban) for large installations	risks of land subsidence and/or soil contamination	population displacement / impacts on cultural heritage	competition for areas (e.g., fishing and navigation)	competition for areas, landscape alterations	accidents may affect large areas; mining; decommissioning sites	land occupation and degradation (e.g. mining),
Air and Water	+	decentralized electricity for water extraction and supply; lower GHG emissions	no direct atmospheric emissions; water pumping from PV electricity	no direct atmospheric emissions	low GHG emissions in most cases; impounded water can be used for irrigation, fisheries and domestic uses	no direct atmospheric emissions	no direct emissions; improved water pumping, amortization of strong winds	no direct atmospheric emissions under normal operation	
	-	water usage for crops; fertilizers nitrate pollution; risk of fires; GHG emissions from land clearing	(limited) life cycle pollution; water for cooling CSP plants in arid areas	water usage by power plants in arid areas; risk of water contamination	risks of water quality degradation and associated health impacts; potential high methane emissions in some cases	swell/waves & tidal/ocean currents: possible effects on pollution	nuisances from noise	risks of leakages and accidents releasing toxic material	significant atmospheric emissions (GHG, other pollutants); risks of water spills, leakages, accidents, fires
Ecosystem and Biodiversity	+	possible integration between crops and with bio-corridors/ conservation units	no harm and some benefits (reflectors shade improving micro-climate)	-	-	increase of biodiversity for some constructions	-	no or little impact under normal operation	-
	-	Biodiversity loss; impacts from monoculture, burning practices and habitat land clearing and landscape diversity; invasive species; use of agrochemicals	risks from large scale projects (disruption of ecosystem structure); CSP may affect birds	water contamination effects	loss of biodiversity from inundation, new hydrological regimes; obstacle to fish migration and introduction of alien species	ecological modification from barrages	bird and bat fatalities, impacts from noise	short to long-term effects in case of contamination	loss of biodiversity from pollution and spills; change of vegetation and wildlife in mining and waste-fields
Human Health	+	lower and less toxic air pollutant emissions improving human health	virtually no pollution	cleaner air and improved public health; hot water for spa resorts	virtually no air pollution; water supply from reservoirs can contribute to improved health	virtually no pollution	virtually no pollution	virtually no pollution	-
	-	indoor pollution from traditional biomass burning; health effects from crop burning practices (e.g. sugarcane)	toxic waste from manufacturing and disposal of PV modules	some risks of contaminations	risk of spreading vector borne diseases in tropical areas; odor in isolated cases	-	nuisance effects (e.g., noise)	very significant impacts from potential accidents	effects from pollution (occupational, local, regional, global); significant impacts from potential accidents
Built Environment	+	high level of socio-economic benefits from new infrastructure (e.g. jobs, local development.)	socio-economic benefits from new infrastructure	socio-economic benefits from new infrastructure	socio-economic benefits from new infrastructure	socio-economic benefits from new infrastructure; wave power protects coast from erosion	socio-economic benefits from new infrastructure; (some) turbines attractiveness e	socio-economic benefits from new infrastructure	socio-economic benefits from new infrastructure
	-	changes in landscape, negative visual aspects		induced local seismicity (EGS hydrofracturing); impact on scenic quality and use of natural areas	existing infrastructure damage due to inundation; risks from dam bursts; impacts from induced occupation	changing conditions at discharge sites (OTEC/osmotic power); irreversibility (tidal barrages)	impacts of wind turbines on radar systems; visibility of wind turbines	changes in landscape; necessary escape routes	large mining and processing structures; risks of accidents; impacts from induced occupation

Socio-economic Impacts: Global and Regional Assessment (energy supply security)

Sustainable Development (SD) can be translated in a set of socioeconomic goals applicable to different energy sources and technologies. Some of the most relevant are: poverty reduction; water security; sanitation; food security; energy security; energy access; energy affordability; infrastructure; governance; land use and rural development. Compared to conventional fossil fuels, nuclear energy and large hydropower projects – which have overall highly concentrated and capital intensive production, transformation and distribution chains – renewables have an important role in rural development. Relatively simple systems such as solar panels, improved cookstoves or micro hydropower plants can provide the necessary lighting, heat or electricity to pump water, prepare food, refrigerate vaccines and medicines, or allow education during the night period. (9.2.1)

However, access to modern forms of energy, especially electricity for all purposes and clean fuels for cooking, heating and lighting to the billions of people without them today and in the future is a major challenge in itself. Making the joint achievement of promoting access while simultaneously making a transition to a cleaner and secure energy future is a challenging task. It requires a sustained effort that includes awareness raising, capacity building, policy changes, technology innovation and investment. The shift towards a sustainable energy economy also requires sound analysis of the options by policymakers, good decisions and the sharing of experience and knowledge of individuals and organizations involved in the many practical challenges that such a transition presents. These activities, and the resulting changes, are needed in industrial as well as developing countries (9.4).

Providing relevant and carefully targeted information to the different stakeholders including the general public in order to respond to concerns over climate change related issues, and to the private sector to leverage commercial interest and investments in RE, is found to be key and is already happening in many countries. (9.5.3)

[Authors: Table with quantitative data will be inserted once Chapter 9 Appendix table has been cross-checked with numbers from other chapters].

To create and strengthen institutional capacity, there are a variety of policy instruments, measures, and activities relevant for policy makers and governmental institutions at the national level to further this aim. The adoption of such policies may be directed towards supporting various stages in the RE promotion process from basic R&D at universities, private companies, or non–profit institutions, to demonstration, commercialization, and full deployment stage. Experiences from countries that have effectively promoted private investments in renewable energy show that national strategies, policies and targets are key elements. Most existing successful national renewable energy strategies have wider goals, such as security of energy supplies, environmental protection, climate change mitigation, renewable energy industry development, and ultimately sustainable development (enhancing energy access, alleviating poverty, addressing gender and equity issues, etc). (9.5.3)

Information, data and capacity constraints is often a barrier both for the setting of broad policy priorities and for drafting actual sector-specific legislation. The same constraints may also prevent the private industries, including finance companies, from estimating more accurately the risks of cleaner energy technology investments, and stifles more widespread adoption of cleaner energy technologies by industry esp. in many developing countries. (9.5.3)

Decision making and policy implementation has also in many countries changed from solely being the responsibility of certain government levels to increasingly involving various private sector stakeholders, NGO's, and civil society. This shift is incorporated in the inclusive concept of governance, which reflects the need to involve and give influential mandate to relevant parties in order to reach desired and successful outcomes. (9.5.3)

Overall, policies can be grouped into seven main categories i) research, development and demonstration incentives; ii) investment incentives; iii) tax measures; iv) incentive tariffs; v) voluntary programs; vi) mandatory programs or obligations; and vii) tradable certificates. The evolution of these policies since the 1970s reflects among other things, an increased market orientation or policies moving from regulation towards economic policy tools. Presently, feed-in tariffs, obligations and tradable green certificates are emerging as the main policy instruments in many developed and increasingly some developing countries. Investment incentives and various tax measures do, however, remain important mechanisms to stimulate renewable energy investment, and it remains to be seen if the current financial crisis will affect policy tools in a potential move back towards more direct government regulation. (9.5.3)

The gradual shift from regulatory approaches towards more economic and market oriented policy tools also has implications for the expertise required to develop and implement policies reflecting back on the need for new approaches on the capacity building side. This links in many developing countries with broader shift of the whole perception of RE implementation from niche applications and demonstration projects to having targets and policies at national level (Table TS 9.2). (9.5.3)

In most cases, the proprietary ownership of RE technologies is in the hands of private sector companies and not in the public domain and the diffusion of technologies also typically occurs through markets in which companies are key actors. This necessitates a need to focus on the capacity of these actors to develop, implement and deploy RE technologies in various countries, especially in firms in late-industrialising or emerging economies. (9.5.4)

Table TS 9.2 Renewable Energy Markets in Developing Countries

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

Source: Eric Martinot. et al (2002)

Capacity building and technical support by or for the public sector can usefully address issues that facilitate more rapid development and implementation of RE by private companies and can for example cover issues like data on resources and technology performance, strict testing and licensing procedures and increased investments in research and development of renewable energies. (9.4.3.3)

Implications of (Sustainable) Development Pathways for Renewable Energy

It is widely accepted that energy is linked with more or less all aspects of sustainable development. It is an engine for growth and poverty reduction, and therefore it has to be accorded high priority and this has to be reflected in policies, programs and partnerships at national and international levels. The provision of energy in a sustainable way, guaranteeing the availability of resources, security of supply, environmental, economic and social compatibility and low-risk production, is therefore pivotal to the aim of achieving sustainable development. (9.4)

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

Future scenarios of renewables for different regions, different end-user sections and different energy sources need to consider a broad spectrum of possible RETs, as well as the associated risks, the affordability and limitations of the proposed technologies. Furthermore, to achieve low stabilisation targets, not only all technology options have to be evaluated, but also all sources of CO_2 and non-CO_2 emissions have to be considered. When assessing different future scenarios for renewable energy in the context of sustainable development, questions like how are we going to deal with a conventional baseline in terms of equity, trade, security, environment, as well as the impact of subsidies, need to be addressed. What will be possible outcomes in the medium to long-term? And how will this impact on how development pathways are determined. (9.4.1)

To facilitate a global transition to renewable energy will require large investment in national, regional and local energy infrastructures in developing as well as developed countries and economies in transition. These investments will need to come from the public and the private sectors and will have to take many forms, including financial incentives from government, loans and capital investment from banks, private investors, venture capital funds and communities, as well as new innovative markets that contribute to the benefits of renewable energy and energy efficiency. (9.4.2)

While some developing countries have the opportunity to leapfrog the more polluting fossil fuel based technologies and industries and move directly to more advanced renewable energy technologies, they cannot afford to be dependent on technology transfer and foreign supply to sustain their technological progress. Instead, technology transfer needs to be coupled with capacity building. This requires finance mechanisms that are appropriate for the specific conditions within which they are applied. (9.4.2)

On the global level there is a recognized need for the international community to strengthen its commitment to the scaling up of renewable energy development and use, especially in developing countries. There is a range of international and national institutions that play an important role in building capacity and improving financing and transfer of technology know-how for renewable energies. In addition, numerous international and regional initiatives and efforts, such as WSSD, the G-8 Gleneagles Summit and the European Union energy policy, are strongly involved in the advancement of renewable energy technologies. On the national level, government institutions can stimulate technical progress and speed up the technological learning processes so that RETs will be able to compete with conventional technologies, once the environmental costs have been internalised. (9.4.8)

Gaps in Knowledge and Future Research Needs

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

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

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

Future research will need to examine the role of renewable energy and its implications on the pursuit of sustainable development goals. Several chapters in this report provide information on the implications of renewable energy sources on various SD attributes. Missing is a complete understanding of the life-cycle analysis (LCA) of the implications of the use of renewable energy and so far methods, tools and data sources are lacking sufficient quality and comparability. Future work will need to focus on this important aspect of renewable energy, which in some cases has minor or no direct GHG emissions but may have significant indirect emissions.

Mitigation Potential and Costs

Introduction

The implementation of mitigation technologies is triggered, amongst others, by cost effects or specific policy incentives (IEA 2008b). The uncertain future is reflected in the wide, and growing, range of emissions pathways across emission scenarios in the literature,(Calvin et al, 2009) as was well reflected in the most recent IPCC assessment report (IPCC, 2007).AR 4 focused on the behaviour of the overall energy system and, as such, discussion of single technologies as a matter of course had to be rather short. One of the main questions in that context is the role renewable energy sources (RE) are likely to play in the future and how they can particularly contribute to GHG-mitigation pathways.

RE, following the investigated scenarios, is expected to play an important, and increasing, role in achieving ambitious climate mitigation targets but already even without setting any climate protection goals. Although some RE technologies already belong to competitive technologies (e.g. large hydropower) and many others are becoming increasingly market competitive, there are still innovative technologies in the field of RE under the given frame conditions have a long way to go before becoming mature alternatives to non-renewable technologies.

Behind this background, this chapter discusses the mitigation potentials and related costs of RE technologies based on an assessment of the most recent scenario literature available on the subject. An in-depth analysis of selected scenarios is used to come to a technological and regional breakdown. Underlying assumptions about scenario based supply curves are also stressed as so far as given data allows costs for commercialization and deployment. A discussion about social and environmental cost and benefits closes the section.

Synthesis of Mitigation Scenarios for Different Renewable Energy Strategies

A total of 162 recent medium- to long-term scenarios from large-scale, integrated, energy-economic and integrated assessment models are reviewed to provide context for understanding the role of RE in climate mitigation. Although this set of scenarios is by no means exhaustive of recent work on mitigation scenarios, it is large enough and extensive enough to provide robust insights. The full set of scenarios covers a large range of CO_2 concentrations (350-1050 ppm atmospheric CO_2 concentration by 2100), some of which represent scenarios of aggressive action to address climate change and other of which represent no-policy, or baseline, scenarios. The full set of scenarios also covers time horizons 2050 to 2100, and all of the scenarios are global in scope.

These scenarios reflect the most recent understanding of key underlying parameters and the most up-to-date representations of the dynamics of the underlying human and Earth systems. The scenarios also include a relatively large number of “2nd-best” scenarios which cover less optimistic views on international action to deal with climate change (delayed participation) or address consequences of limited mitigation portfolios (technology failure). Although scenarios assuming idealized climate policy approaches and full technology availability (“1st-best scenarios”) have historically dominated the mitigation scenario literature, 2nd-best scenarios have received growing attention in recent years.

The statistical perspective applied gives a comprehensive overview about the full range of mitigation scenarios and tries to identify the major relevant driving forces and system interactions (e.g. competing technologies) for the resulting RE deployment in the market and the specific role of these technologies in mitigation paths. One focus is to assess the robust evolutions of RE as a whole and single technologies reflecting different sets of assumptions.

Following the scenario analysis, increasing demand for energy, and for low-carbon energy in particular, if the world chose to reduce greenhouse gas emissions, could lead to a great variation in the deployment characteristics of individual technologies (**Error! Reference source not found.** and Figure TS 10.2).

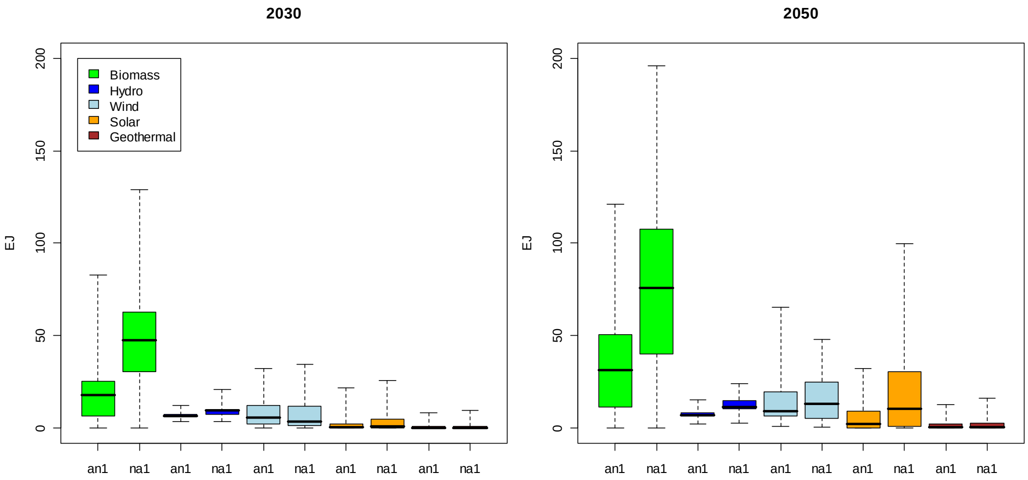


Figure TS 10.1 Renewable primary energy consumption by source in Annex I (an1) and Non-Annex I (na1) countries in the long-term scenarios by 2030 and 2050. [The thick black line corresponds to the median, the colored box corresponds to the interquartile range (25th-75th percentile) and the whiskers correspond to the total range across all reviewed scenarios.]

Several dimensions of this variation bear mention. First, the absolute scales of deployments vary considerably among technologies, representing differing assumptions about long-term potential. Bioenergy deployment is of a dramatically higher scale over the coming 40 years than any of the other RE technologies, although it should be noted that the figures include traditional biomass which contributes close to 40 EJ in the base year with a modest decline over time in most scenarios. By 2050, wind and solar constitute a second tier of deployment levels. Hydroelectric power and geothermal power deployments fall into a lower tier. The variation in these deployment levels represents assumptions by the scenario developers regarding the cost, performance, and potential of these different sources. They indicate, for example, that the consensus among scenario developers is that solar power, bioenergy, and wind power are the most likely large-scale contributors in the 2050 time frame and beyond; there is room for growth in hydroelectric power and geothermal power, but the potential for this growth is limited.

Second, the time-scale of deployment varies across different RE sources, in large part representing differing assumptions about technological maturity. Hydro, wind and biomass show a significant deployment over the coming one or two decades in absolute terms. These are the most mature of the technologies. Solar energy is deployed to a large extent beyond 2030, but at a scale that is surpassing that of the other RE sources apart from biomass, capturing the notion that there is substantial room for technological improvements over the next several decades that will make solar largely competitive and increase the capability to integrate solar power in the electricity system. Indeed, solar energy deployment by 2100 is on the same scale at bioenergy production. Direct biomass use in the end-use sectors is largely stable or even slightly declining across the scenarios. It should be noted that direct use is dominated by traditional, non-commercial fuel use in developing countries which is typically assumed to decline as economic development progresses.

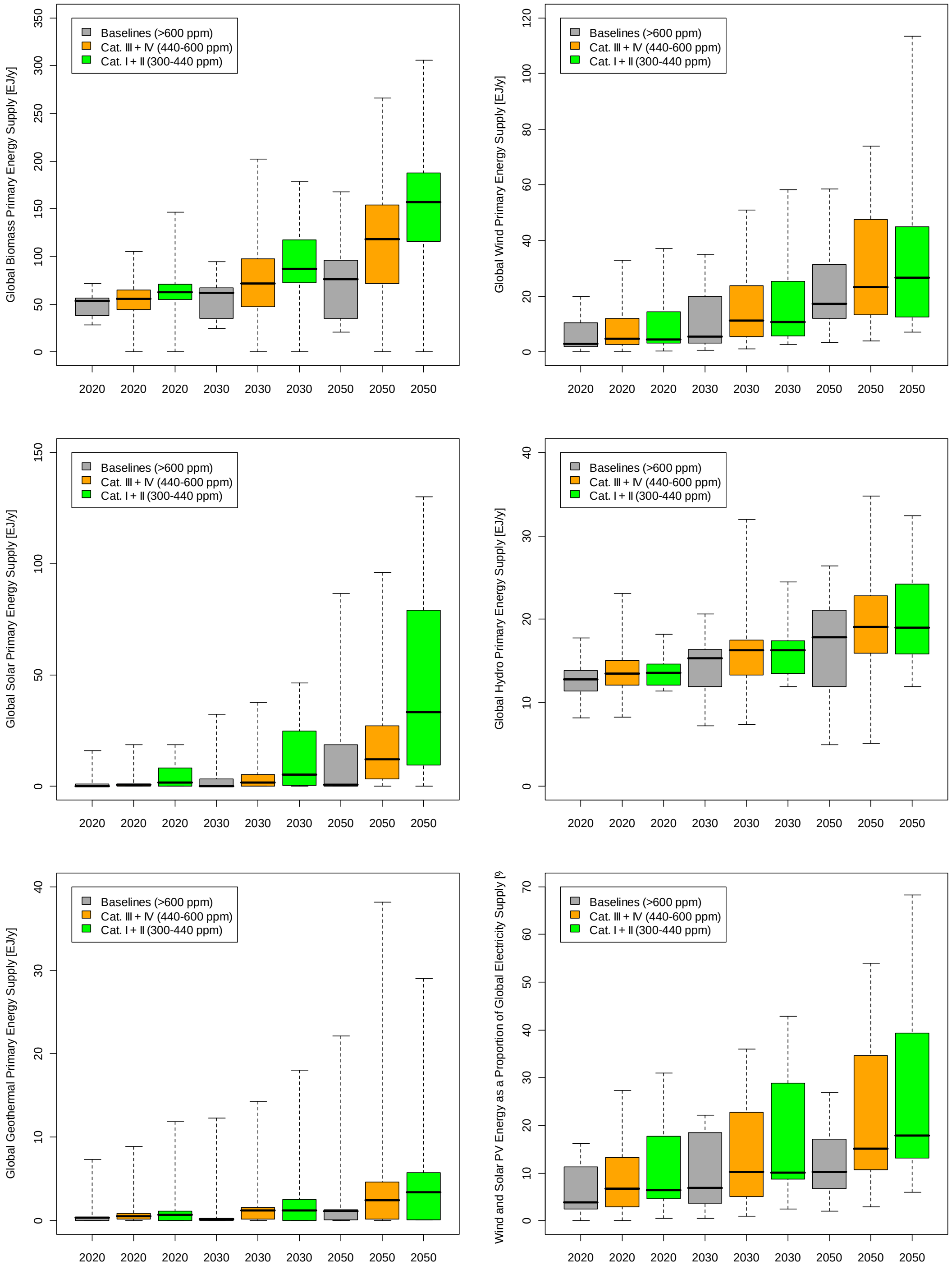


Figure TS 10.2 Global primary energy supply of biomass, wind, solar, hydro, geothermal and share of variable renewables (wind and solar PV) in global electricity generation in the long-term scenarios by 2020, 2030 and 2050, grouped by different categories of atmospheric CO2 concentration level in 2100. [The thick black line corresponds to the median, the coloured box corresponds to the interquartile range (25th-75th percentile) and the whiskers correspond to the total range across all reviewed scenarios.]

This decrease cannot be compensated by an increase in commercial direct biomass use in the majority of scenarios. In contrast, biomass that is used as a feedstock for liquids production or an input to electricity production – commercial biomass – is increasing over time, reflecting assumptions about growth in the ability to produce bioenergy from advanced feedstocks, such as cellulosic feedstocks.

Third, the deployment of some RE sources in the scenarios is driven mostly by climate policy (e.g. solar, geothermal, commercial biomass) whereas others are deployed irrespective of climate action (e.g. wind, hydro, direct use of bioenergy) (Figure TS 10.2). This is also to a large degree a reflection of assumptions regarding technology maturity. Wind and hydro are already considered largely mature technologies, so the imposition of climate policy would not provide the same increase in competitiveness as it would for emerging technologies such as solar, geothermal, and advanced bioenergy.

Finally, the distribution of RE deployments across countries is highly dependent on the nature of the policy structure. In scenarios that assume a globally efficient regime in which emissions reductions are undertaken where and when they will be most cost-effective, non-Annex 1 countries begin to take on a larger share of RE deployment toward mid-century. This is a direct result of the assumption that these regions will continue to represent an increasingly large share of total global energy demand, along with the assumption that RE supplies are large enough to support this growth. All other things being equal, higher energy demands will require greater deployment of RE sources. This is important in the sense that it highlights that RE sources in climate mitigation is both an Annex 1 and a non-Annex 1 issue.

The notion that deployment in the non-Annex 1 will become increasingly important is robust across scenarios; in the long run, meeting the stricter goals will require fully comprehensive global mitigation. At the same time, a more realistic assumption regarding the near- to mid-term is that mitigation efforts may differ substantially across regions, with some regions taking on larger commitments than others. In this real-world context, the distribution of RE deployments in the near-term would be skewed toward those countries taking the most aggressive action.

Assessment of Representative Mitigation Scenarios for Different Renewable Energy

The regional and global energy scenarios found in the literature show a wide range of RE deployment in the future, as portrayed in the previous section. In this section, a selected part of the global scenarios is reviewed, with a more detailed and near-term-focus, providing a next level of detail for exploring the role of RE in climate change mitigation. Four scenarios integrate the subgroup here reviewed, representing the whole scope of available literature, from a more or less business as usual pathway to a more optimistic deployment scenario path for RE, assuming that the current dynamic in the sector can be maintained. These four scenarios are: the ReMind, EMF 22, IEA World Energy Outlook 2009 and Energy [R]evolution scenarios. Interesting enough, even without having reached their full technological development limits, technical potentials seem not to be the limiting factor to the expansion of RE in all scenarios reviewed.

The total contribution of renewable energy sources to the world global primary energy demand is the summary of the four scenario outcomes for all sectors: power generation, heating/cooling and transport. Figures TS 10.3 and TS 10.4 provide, for the four scenarios here reviewed, summaries of both global RE development projections by technology (Figure TS 10.3), and global RE development projections by source and global renewable primary energy shares by source (Figure TS 10.4) for 2020, 2030 and 2050. Bioenergy has the highest market share all scenarios, followed by solar. This is due to the fact, that bioenergy can be used across all sectors (power, heating & cooling as well as transport), while solar can be used for power generation and heating/cooling. As the residual material potential and available land for bioenergy is limited and competition with nature conservation issues as well as food production must be avoided, the sectoral use for the available bioenergy depends on where it is used most efficiently. Cogeneration power plants use bioenergy most efficiently to a level of up to 90%.

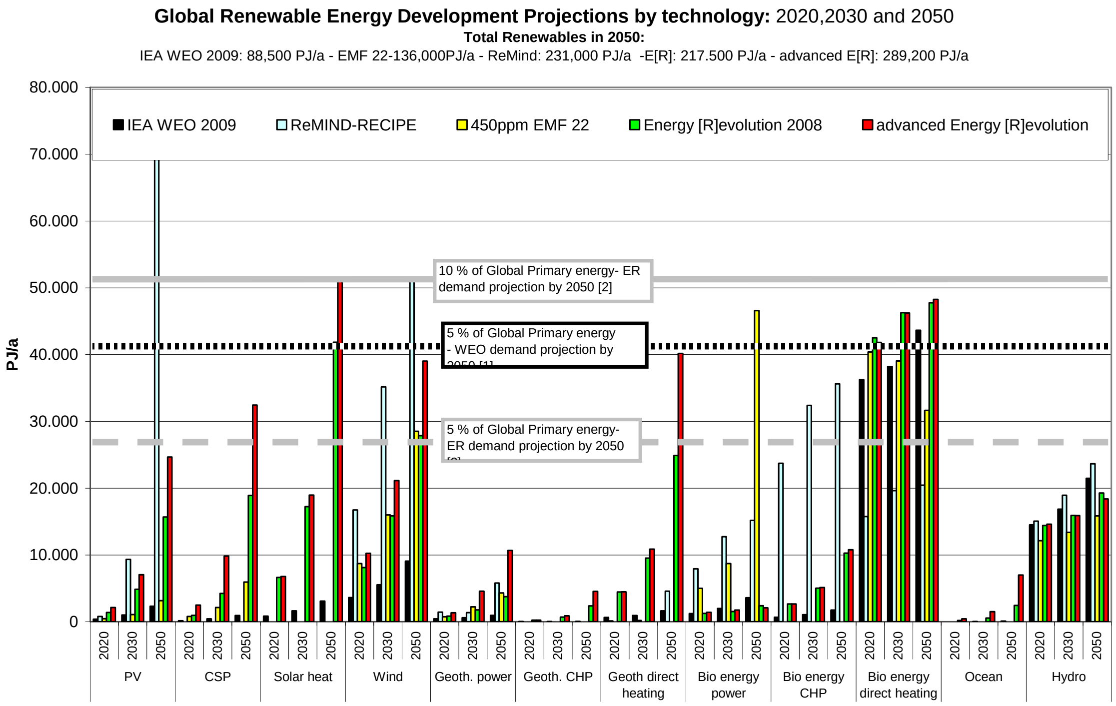


Figure TS 10.3 Global Renewable Energy Development Projections by Technology

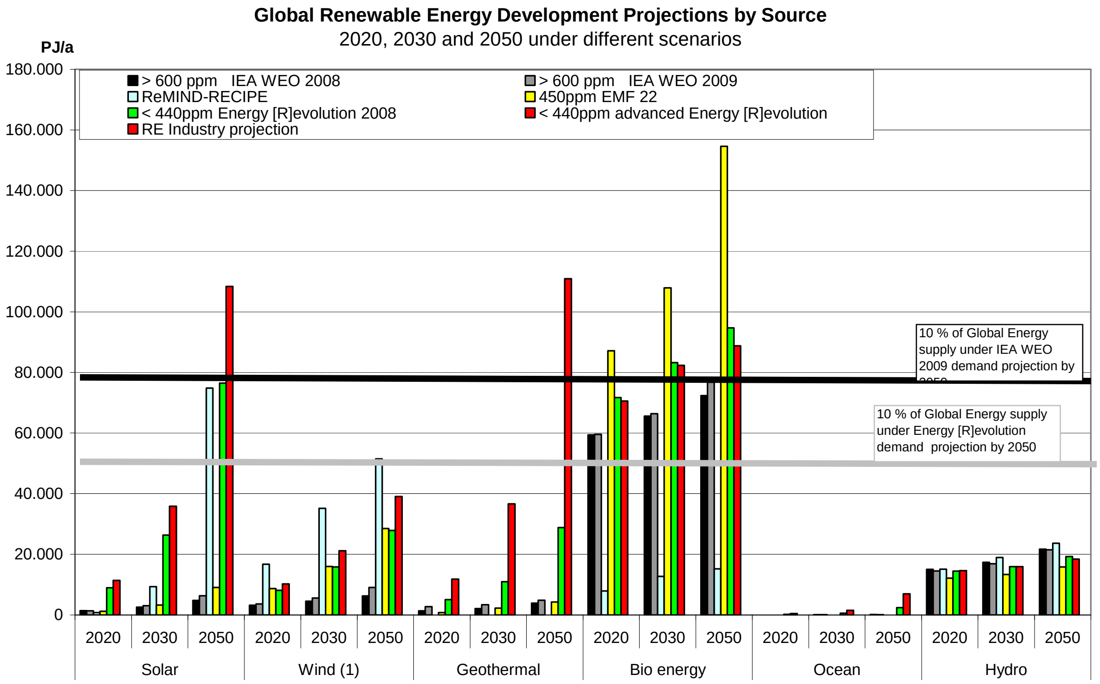


Figure TS 10.4 Global Renewable Energy Development Projections by Source and Global renewable primary energy shares by source

However solar energy can be used for heating/cooling and power generation as well, but solar technology starts from a relatively low level. In the medium case, solar energy ranks third by 2050 followed by hydro and wind energy. The relatively low primary energy share for wind and hydro is due to its exclusive use in the power sector. None of the analysed scenarios looks in to the use of wind in the transport sector, such as advanced wind drives for shipping.

The total renewable energy share by 2050 has a huge variation across all four scenarios. With only 15% by 2050 – about today´s level – the IEA WEO 2009 projects the lowest renewable energy share, while the Energy [R]evolution achieves 56% of the worlds primary energy demand. Both the ReMind and EMF 22 projection are in the range of one quarter renewable energy by 2030 and one third by 2050.

Finally, when it comes to regional scenarios, some scenarios available in the literature also show a wide range of the RE shares in the future. In order to show the different ranges of deployment rates for RE sources by sector and region, Figure TS 10.5 compares a reference scenario (>600ppm), which was developed from the German Space Agency (DLR) on the basis of the IEA World Energy Outlook 2007, with a category II (<440ppm) scenario (Energy [R]evolution 2008 DLR/EREC/GPI). While the reference scenario more or less represents the pathway of a “frozen” energy policy, the ER2008 assumes a wide range of policy measure in favour of renewable energy sources as well as a significant price setting for carbon.

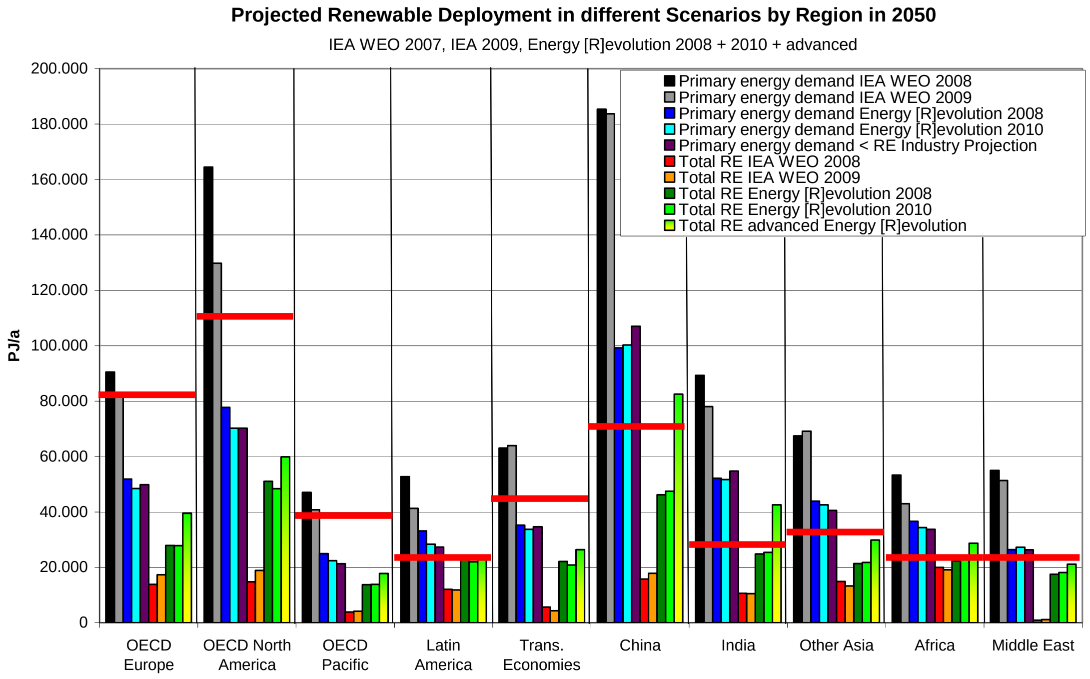


Figure TS 10.5 Regional breakdown from possible renewable energy market potential: Reference (> 600ppm) versus Category II (<440ppm) scenario

Regional Cost Curves for Mitigation with Renewables

Cost curves have already been touched upon in the previous section. While these curves illustrate, from a specific perspective, how scenarios see RE deployment and which technology when and at what cost, additionally the existing literature on regional RE sources supply curves as well as abatement cost curves as they pertain to mitigation using RE are reviewed.

The concept of supply curves of carbon abatement, energy, or conserved energy all rest on the same foundation. They are curves consisting typically of discreet steps, each step relating the marginal cost of the abatement measure/energy generation technology or measure to conserve energy to its marginal cost; and rank these steps according to their cost. As a result, a curve is obtained that can be interpreted similarly to the concept of supply curves in traditional economics.

This concept is very often used approach for mitigation strategy setting and prioritizing abatement options. One of the most important strengths of this method is, of course, that the results can be understood easily and that the outcomes of those methods give, on a first glance, a clear orientation as they rank available options in order of cost-effectiveness.

While abatement curves are very practical and can provide important strategic overviews, it is pertinent to understand that their use for direct and concrete decision-making has also some severe limitations. Most of the concerns are, amongst others, related to simplification issues; difficulties with the interpretation of negative costs; the reflecting of real actor's choice; the uncertainty factors with regard to the discount rate as a crucial assumption for the resulting cost data; the missing dynamic system perspective considering relevant interactions with the overall system behaviour; and the sometimes not very sufficient documentation status. For GHG abatement cost curves, a key input that largely influences the results is the carbon intensity, or emission factor of the country or area to which it is applied, and the uncertainty in projecting this into the future. This may lead to a situation where the option in one locality is a much more attractive mitigation measure as compared to an alternative than in another one simply as a result of the differences in emission factors. As a result, a carbon abatement curve for a future date may say more about expected policies on fossil fuels than about the actual measures analyzed by the curves, and the ranking of the individual measures is also very sensitive to the developments in carbon intensity of energy supply.

The reviews of the existing regional and national literature on RE supply or, more generally, mitigation potential related cost curves , show a very broad range of results (Table TS 10.1). In general, it is very difficult to compare data and findings from different RE supply curves, as there have been very few studies using a comprehensive and consistent approach and detail their methodology, and most studies use different assumptions (technologies reviewed, target year, discount rate, energy prices, deployment dynamics, technology learning, etc.). Therefore, country- or regional findings in need to be compared with caution, and for the same reasons findings for the same country can be very different in different studies. The weakness of many regional or technology studies is that they usually do not account for the competition for land and other resources such as capital among the various energy sources (except for probably the various plant species in the case of biomass). In studies that do take this into account, potentials seriously decline in case of exclusive land use, with solar PV suffering the worst losses both in technical and economic potential.

Regional carbon abatement cost curves related to RE deployment, on the other hand, have a different focus, goal and approach as compared to RE supply curve studies, and are broader in scope, examining RE sources within a wider portfolio of mitigation options (Table TS 10.2). One general trend can be observed based on this limited sample of studies. Abatement curve studies tend to find lower potentials for mitigation through RE sources than those focusing on RE for energy supply. Even for a same country these two approaches may find very different potentials. For instance, the Enviros (2005) study identified a 33% potential by renewable energy as a percentage of 2015 TPES in the UK (see) under the cost of 200 USD/MWh; while CBI (2007) attributed only an 0.93% carbon mitigation potential for renewables for the UK for 2020 under the cost of 200 USD/t CO_2e. The highest figure in carbon mitigation potential share by the deployment of RE sources, as demonstrated by

, is for Australia: 13.43% under 200 USD/t CO_2e by 2030 (in contrast with the much higher shares as a percentage of national TPES reported before) (data from McKinsey and Company 2008a).

One factor contributing to this general trend is that RE supply studies typically examine a broader portfolio of RE technologies, while the carbon mitigation studies reviewed focus on selected resources/technologies to keep models and calculations at reasonable complexity. For instance, remaining with the UK example, the CBI (2007) study does not take into consideration other RE sources presented by Enviros (2005) as low-cost options, such as landfill gas, sewage gas and hydropower.

Table TS 0.2 Summary of regional/national literature on renewable energy supply curves, with the potentials grouped into cost categories

Country/region		Cost ($/MWh)	Total RES (TWh/yr)	% of baseline	Discount rate (%)	Notes	Source
Central and Eastern Europe		<100	3,233	74	N/A	- Biomass only, best scenario with willow being the selected energy crop (highest yield) - Countries: BG, CZ, EST, HU, LV, LT, PL, RO, SK - Baseline data includes Slovenia, however, its share is rather low, therefore resulting distortion is not so high.	RES data: van Dam et al. (2007) Target year: 2030 Baseline data: Solinski (2005)
Czech Republic		<100	101	20	4	- Only biomass production - Best case scenario where future yields equal the level of the Netherlands	RES data: Lewandowski et al. (2006) Target year: 2030 Baseline data: IEA (2005)
Germany		<100	160	24	N/A	- Only Wind and PV are included - PV only enters above 200 USD	RES data: Scholz (2008) Baseline data: McKinsey and Company (2007)
		<200	177	27			
		<300	372	56			
Global (Biomass)		<100	97,200	N/A	10	- Study claims biomass production under this price can exceed present electricity consumption multiple times	Hoogwijk et al. (2003) Target year not specified
Global		< 100	200,000-300,000	>100	10	- Combined potential of Onshore Wind, solar PV and Biomass given land usage constrains and technology scenarios - Sources of uncertainty considered	de Vries et al. (2006), baseline: World Energy Council, 2001 and Hoogwijk, 2004.
Global	Wind	<100	42,000	133	10	- Liquid transport fuel and electricity from biomass, onshore wind, PV - Capacity calculated for the whole world, grid connections, supply-demand relationships etc. not incorporated - Global technical potential for electricity generation - High technology development scenario (A1) with stabilizing world population and fast and widespread yield improvements.	RES data: de Vries et al. (2007) Target year: 2050 Baseline data: IEA (2003)
		<80	39,000	123			
		<60	23,000	72			
		<40	2,000	6			
	Biomass	<60	59,000	187			
	PV	<100	1,850,000	5,868			
		<80	400,000	1,268			
Global		<70	21,000	600-700	10	- Technical potential for onshore wind based on wind strength and land use issues, grid availability, network operation and energy storage issues are ignored - baseline refers to 2001 world electricity consumption	Hoogwijk et al. (2004), Reference year: 2004 baseline IEA 1996
		<100	53,000				
	Former USSR	<70	2,000	160			
		<100	7,000	550			
	USA	<70	3,000	80			
		<100	13,000	350			
	East Asia	<70	0	0			
		<100	50	3			

Western Europe	<70 <100	1,000 2,000	40 80			
Country/region	**Cost ($/MWh)**	**Total RES (TWh/yr)**	**% of baseline**	**Discount rate (%)**	**Notes**	**Source**
Global	<50	121,805	N/A	10	- Biomass energy from short-rotation crops at abandoned cropland and restland - four IPCC CRES land-use scenarios for the year 2050 - land productivity improvement over time, cost reductions due to learning and capital-labour substitution - Present world electricity consumption (20 PWh/yr) may be generated at costs below $45/MWh (A1 B1 scenarios) and 50 $/MWh (A2 B2 scenarios) in 2050	Hoogwijk et al. (2009) Target year: 2050
Former USSR		23,538				
USA		9,444				
East Asia		17,666				
OECD Europe		3,194				
India	<200	450,000	12	10	- wind - Grid availability not expected to be a serious concern - baseline refers to 2005 electricity consumption	Pillai et al. (2009) Target year: 2030
	<100	140,000	6		- small hydro - Grid availability not expected to be a serious concern - baseline refers to 2005 electricity consumption	
Netherlands	<100	22	2.1	N/A	- Included: onshore and offshore wind, PV, biomass and hydro; - Interest rate is not available, however, this option is a scenario where sustainable production is calculated. Therefore they use 5% IRR assuming that there are governmental support; - Baseline is TPES forecast for 2020 by IEA;	RES data: Junginger et al. 2004 Reference year: 2020 Baseline data: IEA (2006)
	<200	23	2.2			
	<300	24	2.3			
UK	<100	815	22	7.9	- Included: "Low-cost technologies" (landfill gas, onshore wind, sewage gas, hydro); - Costs: capital, operating and financing elements; - Baseline is all electricity generated in the UK forecasted for 2015;	RES data: Enviros (2005) Baseline data: UK SSEFRA (2006)
	<200	119	33			
United States	<100	3,421	15	N/A	- Wind energy only	RES data: Milligan (2007) Baseline data: EIA (2009)
United States (WGA)	<100	177	0.77	N/A	- Only the WGA region - CSP, biomass, and geothermal; - Geothermal reaches maximum capacity under 100 $/MWh; - CSP has a large potential, but full range is between 100 and 200 $/MWh	RES data: Mehos and Kearney (2007), Overend and Milbrandt (2007), Vorum and Tester (2007) Baseline data: EIA (2009)
	<200	1,959	8.5			
	<300	1,971	8.6			
United States (AZ 2025)	<100	0.28	N/A	Biomass and PV: 7.5	- State of Arizona, United States - RES: wind, biomass, solar, hydro, geothermal Interest rates vary between energy sources	RES data: Black & Veatch Corporation (2007)
	<200	10.5	N/A			

	<300	20	N/A	7.5 Rest: 8	Interest rates vary between energy sources	

Table TS 0.3 Summary of carbon abatement cost curves literature (cells including grey literature are coloured in grey)

Country/region	Year	Cost ($/tCO2e)	Mitigation potential (million tonnes CO2)	% of baseline	Discount rate (%)	Notes	Source
Annex I	2020	<100	2,818	20	N/A	- Different abatement allocations analysed depending (equal marginal cost, per capita emission right convergence, equal percentage reduction) - CO2 equivalent emissions six Kyoto GHGs, but exclude LULUCF - Costs in 2005 USD	Elzen et al. (2009) Baseline Scenario: WEO 2009
Australia	2020	<100	74	9.5	N/A		McKinsey and Company (2008a)
Australia	2030	<100	105	13			
Australia (NSW Region)	2014	<100	8.1	1.0	N/A	- New South Wales region - Includes governmental support for RES	Abatement data: Next Energy (2004) Baseline data: McKinsey (2008a)
		<300	8.5	1.1			
China	2030	<100	1,560	11	4		McKinsey and Company (2009a)
China	2030	<50	3,484	30	N/A	- Storylines do not describe all possible development (eg. disaster scenarios, explicit new climate policies) - Main abatement (half of total) is efficiency, the rest is renewable and fuel switch from coal	Van Vuuren et al. (2003) Baseline scenario: IPCC SRES (2000) Baseline Scenario: WEO 2009

China	2030	<100	2,323	20	N/A	- Main factor influencing abatement cost is constraints on the rollout of nuclear power - Baseline seems to be underestimated as 2010 power consumption is 40% below fact.	Chen, 2005 Baseline Scenario: WEO 2009
Country/region	Year	Cost ($/tCO2e)	Mitigation potential (million tonnes CO2)	% of baseline	Discount rate (%)	Notes	Source
Czech Republic	2030	<100	9.3	6.2	N/A	- Scenario with maximum use of renewable energy sources	McKinsey and Company (2008b)
		<200	11.9	8.0			
		<300	16.6	11			
Germany	2020	<100	20	1.9	7	- Societal costs (governmental compensation not included)	McKinsey and Company (2007)
		<200	31	3.0			
		<300	34	3.2			
Global	2030	<100	6,390	9.1	4	- Scenario A (Maximum growth of renewables and nuclear) - Scenario B (50% growth of renewables and nuclear)	McKinsey and Company (2009c)
		<100	4,070	5.8			
Global	2050	<200	46,195	85	N/A	- Key sensitivities: lower potential for wind, hydro or CCS, lower uranium resources raise abatement costs by 2-5%	Syri et al. (2008). Baseline model: global ETSAP/TIAM Baseline Scenario: WEO 2009
Poland	2015	<100	50	11	6	- Only biomass - Best case scenario	Abatement data: Dornburg et al. (2007) Baseline data: EEA (2007)
		<200	55.90	12			
Switzerland	2030	<100	0.9	1.6	2,5	- Base case scenario	McKinsey and Company (2009b)
South Africa	2050	<100	83	5.2	10	- Renewable electricity to 50% scenario	Hughes et al. (2007)
Sweden	2020	<100	1.26	1.9	N/A		McKinsey and Co. (2008c)
United States	2030	<100	380	3.7	7		Creyts et al. (2007)

United Kingdom	2020	<100	4.38	0.46	N/A		CBI (2007)
		<200	8.76	0.93			

Costs of Commercialization and Deployment

This sections reviews current RE technology costs, as well as the expectations on how these costs might evolve into the future resulting in assumptions regarding the cost of commercialization and deployment.

Although some technologies are already competitive (e.g., large hydropower, combustible biomass (under favorable conditions) and larger geothermal projects (>30 MW), IEA, 2007a, page 6), many innovative technologies in this field are still on the way to becoming mature alternatives to fossil fuel technologies (IEA, 2008a). Currently and in the mid-term, the application of these technologies therefore will result in additional (private) costs compared to energy supply from conventional sources if external costs are not considered.

Most technologies applied in the field of renewable energy usage are innovative technologies. As a consequence, huge opportunities exist to improve the energetic efficiency of the technologies, and/or to decrease their production costs. Together with mass market effects, these two effects are expected to decrease the levelized energy generation cost of many renewable energy sourcing technologies substantially in the future.

As a consequence of a growing demand on the market in combination with significant R&D expenditures, many technologies applied in the field of renewable energies showed a significant cost decrease in the past (see Figure TS 10.6). This effect is called technological learning. However, the respective learning rate is not time-independent. Care must be taken if historic experience curves are extrapolated in order to predict future costs. Obviously, the cost reduction cannot go ad infinitum and there might be some unexpected steps in the curve in practice (e.g. caused by technology breakthroughs). In order to avoid implausible results, integrated assessment models that extrapolate experience cost curves in order to assess future costs therefore should constrain the cost reduction by appropriate *floor costs* (cf. Edenhofer et al., 2006).

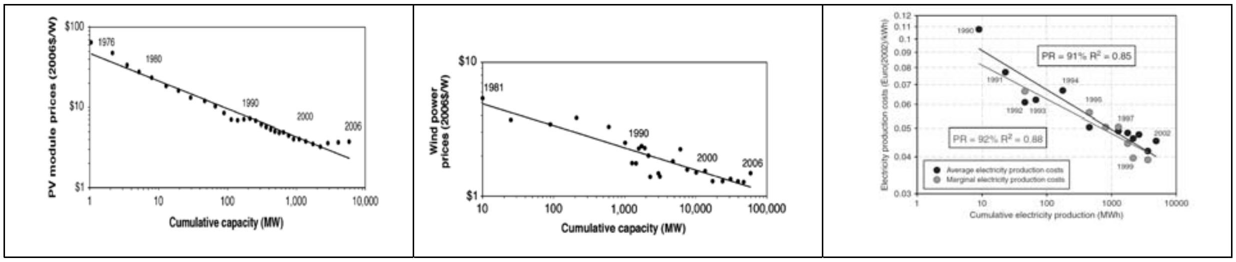


Figure TS 10.6 Illustrative learning curves for a) photovoltaic modules, b) wind turbines and c) Swedish bio-fuelled combined-heat and power plants. Source: Nemet, 2009, Junginger et al. 2006. Due to data gaps learning curves normally have to be based on product prices and not the underlying real costs. Both might differ significantly from each other and deviations can be explained by supply bottlenecks for instance or by typical effects of demand or supply driven markets.

In the beginning of the deployment phase, additional costs are expected to be positive ("expenditures"). Due to technological learning and the possibility of increasing fossil fuel prices, additional costs could be negative after some decades. A least cost approach towards a decarbonized economy therefore should not focus solely on the additional costs that are incurred until the break-even point with conventional technologies has been achieved (learning investments). After the break-even point, the innovative technologies considered are able to supply energy with costs lower than the traditional supply. As these costs savings occur then (after the break-even point) and indefinitely thereafter, their present value might be able to compensate the upfront investments (additional investment needs). Whether this is the case depends on various factors and technology.

From a macro-economic perspective significant upfront investments in innovative renewable energy technologies are often justified if these technologies are promising with respect to their renewable resource potential and their learning capability (Edenhofer et al., 2006). Unfortunately, many of the existing global energy scenarios do not calculate *technology specific* mitigation costs in a comprehensive way. Therefore, there is a severe lack of economic assessments, in general, and additional costs of technology specific mitigation paths and the avoided cost in a longer time period, in particular. The IPCC AR4 highlights the overall GDP losses of different mitigation paths (referring to given scenarios), but does not specify the resulting transition costs of specific renewable energy penetration strategies. In order to fill this gap, the present report focuses at least using illustrative examples on the cumulative and time dependent expenditures that are needed in the deployment phase in order to realize ambitious renewable energy pathways.

In the following Figure TS 10.7, deployment cost estimates indicating how much money will be spent in the sector of renewable energies once these scenarios materialize are shown for different emission mitigation scenarios discussed in Chapter 10.3. The given numbers therefore are important for investors who are interested in the expected market volume.

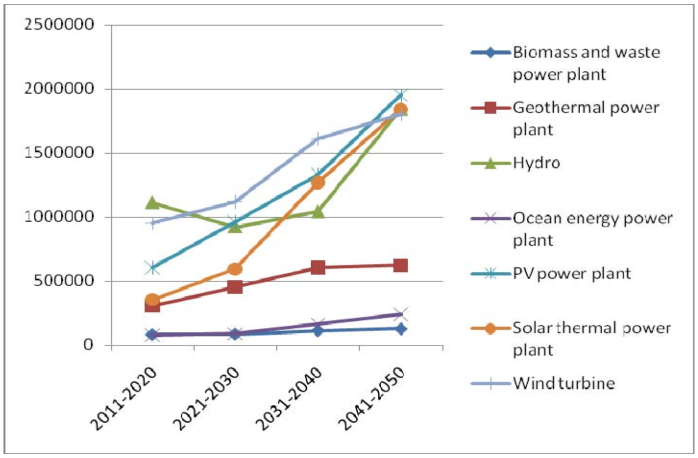


Figure TS 10.7 Illustrative global decadal investment needs (in Mio US $2005) in order to achieve ambitious climate protection goals. Source: Greenpeace, 2007. [Editorial note: In the second order draft, this diagram will be replaced by common assessment of various top-down studies discussed in Chapter 10.2. The corresponding deployment cost ranges will be depicted similar to Fig.8 of Chapter 10.2 that shows the total primary energy supply for different renewable energy sources.]

Although a few scenarios considered in Chapter 10.3 provide technology specific data on the associated (investment) needs no global scenario currently is able to deliver the fossil fuel cost that are avoided by the deployment of the various renewable energy technologies – and to attach the respective share to the considered technology which is a clear knowledge gap. Only for some regions as here (Figure TS 10.8) shown for Germany taking the so called Lead Scenario which was conducted on behalf of the German Ministry for Environment as an illustrative example the upfront investment in renewable energies have been compared with fossil fuel costs that can be avoided in the long-term.

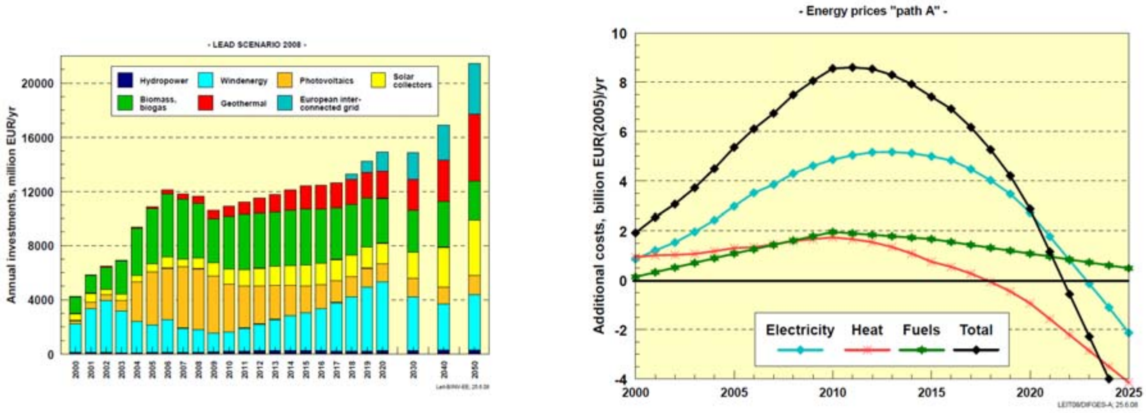


Figure TS 10.8 a) Annual investment volume for renewable installations for electricity and heat supply (including investments for local district heat networks) according to the Lead Scenario 2008. b) Additional costs of renewable energy expansion in all sectors according to the Lead Scenario 2008 (Nitsch, 2008, p. 26 and 28).

Social, Environmental Costs and Benefits

Social, environmental costs and benefits of increased deployment of RE are synthesized in relation to climate change mitigation and sustainable development. The analysis is performed by RE technology and, to a minor extent also by geographical area, as regional information is still mostly very sparse, in the context of sustainable development.

Although social and environmental external costs vary heavily amongst different energy sources and are still connected with a high uncertainty range, they should be considered if the advantages and disadvantages of future paths are being assessed. Typically, the production and use of fossil fuel cause the highest external costs dominated by the costs due to climate change impacts. Most of the time RE sources have clearly lower external costs than non-RE, even when assessed on a life-cycle basis. However, the uncertainty and variability by energy chains is considerable. Some RE production cases can cause considerable external cost relevant impacts as well.

The increase of RE in the energy system typically reduces the overall external costs of the system and can on the other hand produce external benefits. The increase of RE decreases for instance society's dependency on fluctuating prices and depleting resources of fossil fuels and it can improve the access to energy. It can also have a positive impact on trade balance and employment, e.g. in the case of energy biomass production. So far there are no holistic approaches available to translate these benefits completely into cost figure. However, also negative cost relevant effects can be emerge. According to the results of some economic model studies, a forced increase of RE can raise the price level of energy and slow slightly the growth of the economy as well, in certain situations.

Policy, Financing and Implementation

An Introduction to Policy Options

This chapter sets out the issues surrounding the policies, financing and implementation of RE. It lays out the general RE policy options that are available for rapidly increasing the uptake of RE, examines which policies have been most effective and efficient to date and why, and it looks at both RE specific policies and policies that create an "enabling environment" for RE. Issues concerning individual RE resources and/or technologies are examined in the appropriate technology chapter.

The key findings of this chapter are the following:

- Targeted RE policies accelerate RE development and deployment;
- Multiple success stories exist and it's important to learn from them;
- Economic, social, and environmental benefits are motivating Governments and individuals to adopt RE;
- Multiple barriers exist and impede the development of RE policies to support development and deployment;
- 'Technology push' coupled with 'market pull' creates virtuous cycles of technology development and market deployment;
- Successful policies are well-designed and -implemented, conveying clear and consistent signals;
- Policies that are well-designed and predictable can minimize key risks, encouraging greater levels of private investment and reducing costs;
- Well-designed policies are more likely to emerge and to function most-effectively in an enabling environment;
- The global dimension of climate change and the need for sustainable development call for new international public and private partnerships and cooperative arrangements to deploy RE;
- Structural shifts characterize the transition to economies in which low CO_2 emitting renewable technologies meets the energy service needs of people in both developed and developing countries;
- Better coordinated and deliberate actions accelerate the necessary energy transition for effectively mitigating climate change.

The number of countries with RE policies in place has risen significantly, particularly since the early to mid-2000s.

This trend toward more RE policies in a growing number of countries has played an important role in advancing RE and increasing investment in the RE sector. RE policies have a critical role to play in the transition to an energy future based on low-CO_2 RE. Although there are limited examples of countries that have come to rely primarily on RE without supportive policies (such as Iceland and Norway with geothermal and hydropower, both of which generate more than 80% of their electricity with hydropower, in most cases targeted policies are required to advance RE technology development and use.

The Importance of Tailored Policies and an Enabling Environment

To date, in almost every country that has experienced significant installation of RE capacity, production, and investment in manufacturing and capacity, there have been policies to promote RE. There is now clear evidence of success, on the local, regional and national levels, demonstrating that the right policies have a substantial impact on the uptake of RE and enhanced access to clean energy. A limited number of communities and regions have made quite rapid transitions to or toward 100 percent RE

At the same time, the IEA has found that only a limited number of countries have implemented policies that have effectively accelerated the diffusion of RE technologies in recent years. Simply enacting support mechanisms for RE is not enough.

Tailored policies are required to overcome the numerous barriers to RE that currently limit uptake in investment, in private R&D funding, and in infrastructure investments. Accelerating the take-up of RE requires a combination of policies but also a long-term commitment to renewable advancement, policy design suited to a country's characteristics and needs, and other enabling factors.

Policies are most effective if targeted to reflect the state of the technology and available RE resources, and to respond to local political, economic, social and cultural needs and conditions. Moreover, policies that are clear, long-term, stable and well-designed, and that provide consistent signals generally result in high rates of innovation, policy compliance, and the evolution of efficient solutions. When these factors are brought together, a policy can be said to be well-designed and -tailored.

Policy and regulation, and their design, play a crucial role in improving the economics of RE, and as such can be central to attracting private capital to RE technologies and projects, and influencing longer-term investment flows.

Well-designed policies are more likely to emerge, and to lead to successful implementation, in an enabling environment, described later.

Finally, achieving a sustainable energy system, one in which low-CO_2 RE meets the energy service needs of people around the world, will require a structural shift to a more integrated energy service approach that takes advantage of synergies between RE and energy efficiency. The RE growth seen to date must be accelerated on a global scale for RE to play a major role in mitigating climate change. This is true not only for those RE technologies which have already seen successes related to manufacture and implementation, but also for other RE uses such as renewable heating and cooling, which thus far has experienced limited growth and limited policy support despite its enormous potential.

Political and Financial Trends in Support of RE

The number of RE policies—specific RE policy mechanisms enacted and implemented by governments—and the number of countries with RE policies, is increasing rapidly around the globe. The focus of RE policies is shifting from a concentration almost entirely on electricity to include the heating/cooling and transportation sectors as well. These trends are matched by increasing success in the development of a range of RE technologies and their manufacture and implementation (See Chapters 2-7), as well as by a rapid increase in annual investment in RE and a diversification of financing institutions. This section describes recent and current trends in RE policies and in public and private finance and investment.

Table TS 11.1 lists and defines a range of mechanisms currently used specifically to promote RE, and notes which types of policies have been applied to RE in each of the three end-use sectors of electricity, heating and cooling, and transportation.

1 **Table TS 11.1** Existing RE Policy Mechanisms, Definitions and Use by Sector

		End-use Sector		
Policy	**Definition**	**Electricity**	**Heating/ Cooling**	**Transport**
REGULATORY				
Access Related				
Net metering	Allows a two-way flow of electricity between the electricity distribution grid and customers with their own generation. The meter flows backwards when power is fed into the grid.	X		
Priority Access to network	Provides RE supplies with unhindered access to established energy networks.	X	X	
Priority Dispatch	Ensures that RE supplies are integrated into energy systems before supplies from other sources.	X	X	
Quota Driven				
Renewable Portfolio Standard/ Renewable Obligations or Mandates	Obligates designated parties (generators, suppliers, consumers) to meet minimum RE targets, generally expressed as percentages of total supplies or as an amount of RE capacity. Includes mandates for blending biofuels into total transportation fuel in percent or specific quantity. Also RE heating purchase mandates and/or building codes requiring installation of RE heat or power technologies.	X	X	X
Tendering/ Bidding	Public authorities organize tenders for given quota of RE supplies or supply capacities, and remunerate winning bids at prices mostly above standard market levels.	X		
Tradable Certificates	Provide a tool for trading and meeting RE obligations among consumers and/or producers. Mandated RE supplies quota are expressed in numbers of tradable certificates which allow parties to meet RE obligations in a flexible way (buying shortfalls or selling surplus).	X	X	

Price Driven				
Feed-in tariff (FIT)	Guarantees RE supplies with priority access and dispatch, and sets a fixed price per unit delivered during a specified number of years.	X	X	X
Premium payment	Guarantees RE supplies an additional payment on top of their energy market price or end-use value.	X	X	
Quality Driven				
Green energy purchasing	Regulates the option of voluntary RE purchases by consumers, beyond existing RE obligations.	X	X	
Green labeling	Government-sponsored labeling (there are also some private sector labels) that guarantees that energy products meet certain sustainability criteria to facilitate voluntary green energy purchasing. Some governments require labeling on consumer bills, with full disclosure of the energy mix (or share of RE).	X	X	X
Guarantee of origin (GO)	A (electronic) document providing proof that a given quantity of energy was produced from renewable sources. Important for RE trade across jurisdictions and for green labeling of energy sold to end-users.	X		
FISCAL				
Accelerated depreciation	Allows for reduction in income tax burden in first years of operation of renewable energy equipment. Generally applies to commercial entities.	X	X	X
Investment grants, subsidies or rebates	One-time direct payments from the government to a private party to cover a percentage of the capital cost of an investment in exchange for implementing a practice the government wishes to encourage.	X	X	X
Energy production payments	Direct payment from the government per unit of renewable energy produced.	X	X	

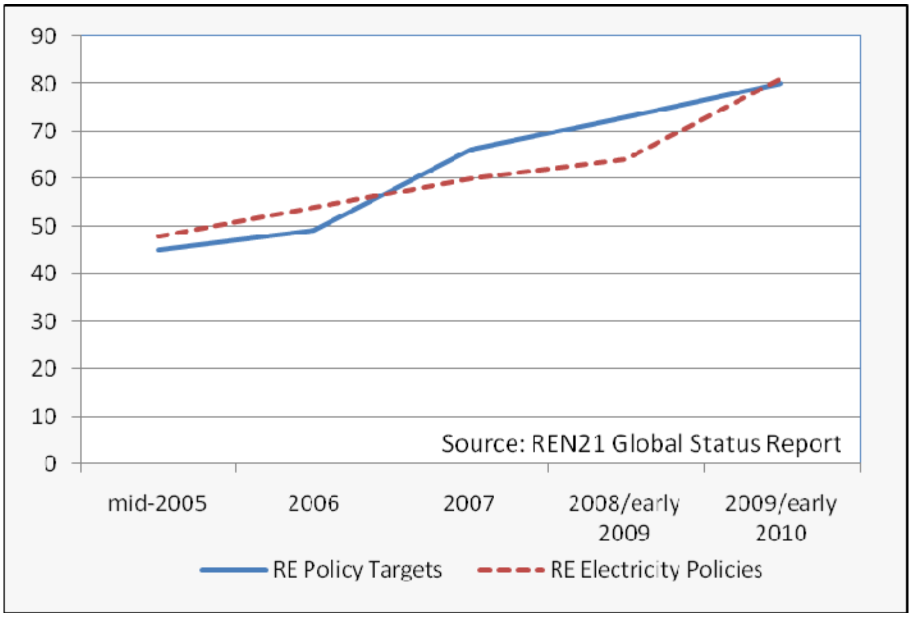
Production/ investment tax credits	Provides the investor or owner of qualifying property with an annual income tax credit based on the amount of money invested in that facility or the amount of electricity that it generates during the relevant year. Allows investments in RE to be fully or partially deducted from tax obligations or income.	X	X	X
Reductions in sales, VAT, energy or other taxes	Reduction in taxes applicable to the purchase (or production) of renewable energy or technologies.	X	X	X
PUBLIC FINANCE				
Grants	Grants and rebates that help reduce system capital costs associated with preparation, purchase or construction of renewable energy equipment or related infrastructure. In some cases grants are used to create concessional financing instruments (e.g., allowing banks to offer low interest loans for RE systems).	X	X	X
Equity investments	Financing provided in return for an ownership interest in an RE company or project. Usually delivered as a government managed fund that directly invests equity in projects and companies, or as a funder of privately managed funds (*fund of funds*).	X	X	X
Loans	Financing provided to an RE company or project in return for a debt (i.e., repayment) obligation. Provided by development banks or investment authorities usually on concessional terms (eg lower interest rates or with lower security requirements).	X	X	X
Guarantees	Risk sharing mechanism aimed at mobilizing domestic lending from commercial banks for RE companies and projects that have high perceived credit (i.e., repayment) risk. Typically guarantees are partial, that is they cover a portion of the outstanding loan principal with 50%-80% being common.	X	X	X
OTHER				
Public Procurement	Public entities preferentially purchase renewable energy and RE equipment.	X	X	X

Trends in RE Policies

While several factors are driving rapid growth in RE markets, government policies have played a crucial role in accelerating the deployment of RE technologies to date.

Until the early 1990s, few countries had enacted policies to promote RE. Since then, and particularly since the early- to mid-2000s, policies have begun to emerge in an increasing number of countries at the national, provincial/state, regional, and municipal levels. Initially, most policies adopted were in developed countries, but an increasing number of developing countries have enacted policy frameworks to promote RE since the late 1990s and early 2000s.

According to the Renewable Energy Network for the 21st Century (REN21)[5], the only source that currently tracks RE policies annually on a global basis, the number of countries with some kind of national RE target and/or RE deployment policy in place almost doubled from an estimated 55 in early 2005 to more than 100 in early 2010. At least 80 countries had adopted policy targets for RE by early 2010, up from 45 (43 at the national level and two additional countries with state/provincial level policies) in mid-2005. (See Figure TS 11.1) Many of these countries aimed to generate a specific share of their electricity from RE sources by a specific date (with most target years between 2010 and 2020), while many (with some overlap) had targets for share of primary or final energy from RE. There were also a large number of countries with specific RE capacity targets by early 2010. In addition, many existing policies and targets have been strengthened over time and several countries have more than one RE-specific policy in place.



Source: REN21 Global Status Report

Figure TS 11.1 Number of Countries with RE Targets or Electricity Policies, 2005-early 20106 [To be updated.]

RE policies are directed to all end-use sectors – electricity, heating and cooling, transportation. However, most RE had focused on the electricity sector. At least 81 countries had adopted some

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[5] REN21 is a global policy network that is open to a range of stakeholders and connects governments, international institutions, non-governmental organisations, industry associations, and other partnerships and initiatives. Its goal is to advance policy development for the rapid expansion of RE in developed and developing and economies.

[6] Note that all numbers are minimum estimates. Not all national renewable energy targets are legally binding. Overall RE targets and electricity promotion policies are national policies or targets, with the exception of the United States and Canada, which cover state and provincial targets but not national. 2006 statistic for number of countries with RE promotion policies is not available, so figure shows the average of 2005 and 2007 data.

sort of policy to promote RE power generation by early 2010, up from an estimated 64 in early 2009, and at least 48 in mid-2005. (Figure 11.1) These included regulations such as feed-in tariffs (FITs), quotas, net metering, and building standards; fiscal policies including investment subsidies and tax credits; and government financing such as low-interest loans. Of those countries with RE electricity policies, approximately half were developing countries from every region of the world.

Despite the increasing number of countries, states and municipalities with RE policies, the vast majority of capacity or generation for most non-hydropower RE technologies is still in a relatively small number of countries. By early 2010, five countries—the United States, Germany, Spain, China and India—accounted for more than 85% of global wind energy capacity. Three countries—Germany, Spain and Japan—represented approximately 82% percent of the world's solar photovoltaic (PV) capacity, while a handful of countries led in the production and use of biofuels.

Financing Trends

In response to the increasingly supportive policy environment, the overall RE sector globally has seen a significant rise in the level of investment since 2004-2005 These global figures are aggregated for all types of finance, with the possible exception of public R&D. Figure TS 11.2 shows that $117 billion of new financial investment went into the RE sector in 2008, up from 15.5 billion USD$_{2005}$ in 2004[7].

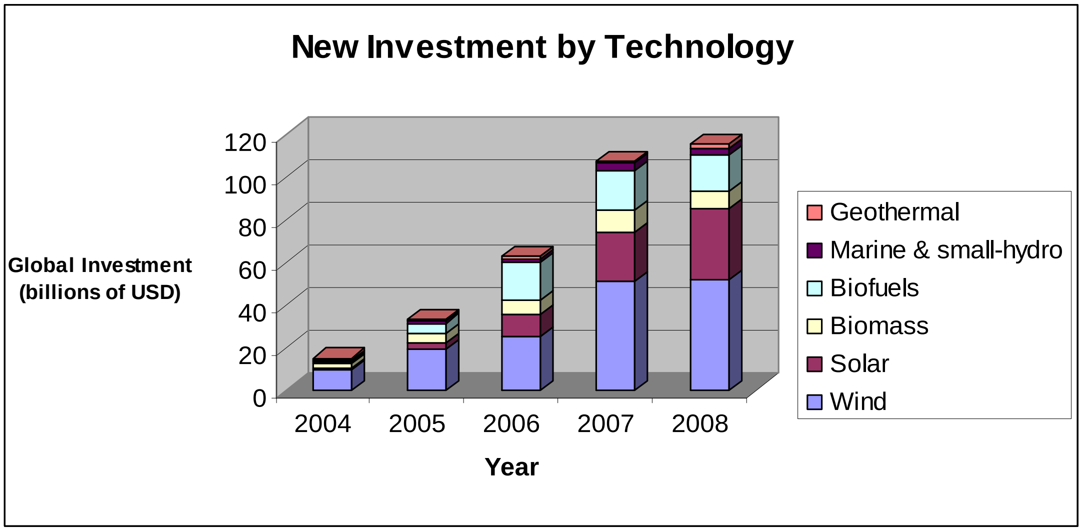

Figure TS 11.2 Global Investment in RE, 2004 – 2008 [TSU: reference missing]

Financing has been increasing along the continuum into the five areas of i) R&D; ii) technology development and commercialization; iii) equipment manufacture and sales; iv) project construction; and v) the refinancing and sale of companies, largely through mergers and acquisitions. The trends in financing along the continuum represent successive steps in the innovation process and provide indicators of the RE sector's current and expected growth

Financing Technology R&D

Figures collected by the International Energy Agency are a good guide to public RE R&D spending in OECD countries up till the middle of this decade. (IEA, 2008b) provides supplementary information on spending by large non-OECD economies, while data for spending on some forms of

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[7] Derived by stripping out the energy efficiency investment figures from United Nations Environment Programme and New Energy Finance (2009): Global Trends in Sustainable Energy Investment 2009: Analysis of Trends and Issues in the Financing of Renewable Energy and Energy Efficiency, Paris. (Will update with 2009 data.)

RE technology in non-IEA European countries is provided in (Wiesenthal, Leduc et al., 2009). The IEA data suggest the heyday of public funding in RE R&D occurred three decades ago. Spending on renewables peaked at 2.03 billion USD_{2005} in 1981. As oil prices dropped, spending fell by over two thirds, hitting a low in 1989. It has crept up since then, to about 727 M USD_{2005} a year in 2006.

The relationship between spending on RE R&D and movements in the oil price illustrate the significant role that the 'security of supply' consideration has on government decisions to fund research into alternative sources of energy. By this logic, governments would choose to focus their attention on technologies that have greatest potential to harness natural resources that are present on their territories. Indeed, this is argued by (International Energy Agency (IEA), 2008), noting that New Zealand and Turkey have spent 55 percent and 38 percent, respectively, of their RE R&D budgets on developing geothermal energy. Non-IEA countries also justify focusing on a particular energy resource by pointing to its relative local abundance, like solar energy in India and Singapore. But there are important exceptions to the rule. Germany, for instance, spends more on photovoltaic R&D than any other country in Europe, but does so with a view to growing a competitive export industry.

Photovoltaics and bioenergy are each now the beneficiaries of a third of all government R&D on RE. The proportion spent on wind has remained stable since 1974 and declined for geothermal, concentrating solar and solar for heating and cooling applications. Ocean energy and other RE technologies have also received support but at a much lower level. An overview of the kind of research being funded around the world in these areas can be found in (European Commission, 2006).

It is perhaps most instructive to look at R&D spending patterns in recent years when policy support for renewables has been growing quickly. Spending on wind, bioenergy, PV and concentrating solar thermal power averaged 536 M USD annually in the EU Member States over the 2002-2006 period, compared to 226 M USD_{2005} in the United States and 95.7 M USD_{2005} in Japan during the same years. The International Energy Agency notes that averaging figures over this period hides some steep increases in spending, which have occurred in UK, France, Hungary and China. By 2006 Chinese spending on solar and wind R&D was up in the 37 and 42 M USD_{2005} range, roughly equivalent to that of Spain.

Financing technology development and commercialization

While governments fund most of the basic R&D and large corporations fund applied or 'lab-bench' R&D, venture capitalists begin to play a role once technologies are ready to move from the lab-bench to the early market deployment phase. According to Moore and Wüstenhagen, venture capitalists have initially been slow to pick up on the emerging opportunities in the energy technology sector, with Renewable Energies accounting for only 1-3 percent of venture capital investment in most countries in the early 2000s. However since 2002 venture capital investment in RE technology firms has increased markedly. Venture capital into RE companies grew from $188 million USD_{2005} to $3.81 billion USD_{2005}[8], representing a compound annual growth rate of 60%. This growth trend in technology investment now appears to be a leading indicator that the finance community expects continued significant growth in the RE sector. Downturns such as that experienced in 2008/2009 may slow or reverse the trend in the short term, but in the longer term an increasing engagement of financial investors is foreseen in RE technology development.

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[8] Derived by stripping out energy efficiency investment from venture capital figures in United Nations Environment Programme and New Energy Finance (2009): Global Trends in Sustainable Energy Investment 2009: Analysis of Trends and Issues in the Financing of Renewable Energy and Energy Efficiency, Paris.

Drivers and Barriers to RE Implementation

Deployment of RE has been driven in great part by government policies, and policies for the deployment of RE are, in turn, driven by several environmental, economic, social and security goals. Drivers are factors that are pushing for the deployment of RE policy (for example climate change and the need to reduce fossil fuel emissions from the energy sector). Drivers are not necessarily objective but reflect the perception of policy makers about RE. Drivers can also take the form of opportunities which, for example, lead a country to invest in RE with the explicit goal of developing a new domestic or export industry. Certain benefits of RE, like for instance reduced emissions, improved health and more jobs may also drive promotion policies. The distinctions among these factors are necessarily close and overlapping. In this section we use the term "driver" to describe drivers in its narrower sense as well as opportunities and benefits. Examples from selected countries are included hear for illustrative reasons.[9]

The relative importance of the drivers, opportunities or benefits varies from country to country and may vary over time, as changing circumstances affect economies, attitudes and public perceptions. RE technologies offer governments the potential to realize multiple policy goals, sometimes simultaneously, that <u>cannot</u> be obtained to the same extent or quality through the development and use of conventional energies.

Key drivers for policies to advance RE are:

- Mitigating climate change
- Enhancing access to energy
- Improving security of energy supply and use
- Decreasing environmental impacts of energy supply
- Decreasing health impacts associated with energy production and use and, a key issue which is both a driver and an opportunity: fostering economic development and job creation..

Barriers to RE Implementation

A barrier may be defined as 'any obstacle to developing and deploying a RE potential that can be overcome or attenuated by a policy, programme or measure'. Barriers are factors, or attributes of factors, that operate in between the actual development and deployment of RE and the, often much higher, potential of RE supply. Policies address the failures and barriers which cause this gap between actual deployment and potential.Chapter 1 offers an overview of barriers to RE development and implementation and it categorises them as barriers as: information and awareness; socio-cultural; technical and structural; economic and institutional and this section follows the same categories. Barriers to putting a RE policy in place related to

A Lack of Information and Awareness includes a limited consensus on how the transitions of the various energy systems in the world would best proceed. This means that many policy-makers lack the required knowledge to, and experience of, pro-actively integrating RE supplies with other low-carbon options (like energy efficiency); Furthermore, RE technological development is uncertain, dynamic, systemic, and cumulative. Staying informed about the best technical options for local conditions requires time and links to the practitioner and scientific communities.

Socio-Cultural Changing energy behaviour is not a simple, nor a mechanical process. While prices, information, education and technological availabilities contribute to changing people's ways of producing and consuming energy, energy behaviours are not dictated by context variables in a mechanical way. This is especially the case for what is called "active" behaviour – the fact of

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[9] For a comprehensive review of features of RE compared to other energy carriers refer to Chapter 9.

actually changing “ways of doing” with energy, such as adopting a distributed RE technology or switching to a RE electricity supply – as opposed to “passive” behaviours – the fact of subscribing to a campaigning NGO, or supporting a policy to increase the share of RE in the supply mix. This translates into a slow build-up of support for RE, followed by pressure to have RE policies; and then a complex active-passive interaction with the outcomes of those policies.

- Behaviour relates in a complex way to individual values, attitudes, personal norms, social norms and current ways of living. This makes it sometimes difficult to find ways of sustaining a shift from “passive” to “active” behaviours.
- There often remains a gulf between the high levels of “passive” support for RE found in opinion polls and the lesser extent of active support for distributed generation and renewable energy.

Technical and Structural Energy use and supply is a complex, global technical-socio-economic activity. Most energy systems worldwide are still fossil fuel based. The existing energy system exerts a strong momentum for its own continuation, which Locks-in and Locks-out new technologies and ways of doing things.

Economic Discourse and action in the energy world is still based on the concept of “cheap fossil fuels” and “affordable nuclear risks”. The external costs and risks of non-sustainable options continue to be insufficiently recognized, identified , quantified and incorporated. This means that energy markets continue to favour fossil fuels and nuclear power more than they should.

Institutional The building blocks, or enabling environment, of a successful RE policy may not be in place, and it may not be clear to policy-makers of all levels, whether international through to local, what institutions are required to get a policy going. In addition, RE project developers face a number of administrative barriers. There can be many authorities involved in deploying RE and a lack of co-ordination between them. A different acceptance of RE benefits between national and local authorities or disagreements on spatial planning rules for accommodating RE installations may lead to a long process for obtaining the necessary permits.

RE Financing barriers

In terms of scale, capacity, energy resource characteristics, points of sale for output, status of technology, and a number of other factors, RE technologies are usually markedly different from conventional energy systems. The differences are not lost on financiers, as financing a RE plant is different from financing conventional fossil-fuelled power plants and requires new thinking, new risk-management approaches, and new forms of capital.

To become more effective at placing capital in RE markets, financiers must travel up a learning or experience curve. Market failures impede this learning process and create barriers to entry into the market. To operate effectively, markets rely on timely, appropriate, and truthful information. In perfect markets this information is assumed to be available, but the reality is that energy markets are far from perfect, particularly those like the RE market in technological and structural transition. As a result of insufficient information, underlying project risk tends to be overrated and transaction costs can increase.

Compounding this lack of information are the issues of financial structure and scale. RE projects typically have higher capital costs and lower operational costs than conventional fossil-fuel technologies. The external financing requirement is therefore high and must be amortised over the life of the project. This makes exposure to risk a long-term challenge.

Since RE projects are typically smaller, the transaction costs are disproportionately high compared with those of conventional infrastructure projects. Any investment requires initial feasibility and due-diligence work and the costs for this work do not vary significantly with project size. As a result, pre-investment costs, including legal and engineering fees, consultants, and permitting costs have a proportionately higher impact on the transaction costs of RE projects. These costs apply as well to the CDM where, according to Willis and Wilder, the transaction costs of developing smaller scale RE projects as CDM projects may be prohibitively high compared to the volume of CERs expected to be generated. Furthermore, the generally smaller nature of RE projects results in lower gross returns, even though the rate of return may be well within market standards of what is considered an attractive investment.

Developers of RE projects are often under-financed and have limited track records. Financiers therefore perceive them as being high risk and are reluctant to provide non- recourse project finance. Lenders wish to see experienced construction contractors, suppliers with proven equipment, and experienced operators. Additional development costs imposed by financiers on under-capitalised developers during due diligence can significantly jeopardise a project.

Laying out the Policy Options

Chapter 11 has set out policies in Table TS 11.1 as regulatory, fiscal, public finance (including R&D) and other mechanisms, such as Government (or any other) procurement.

- The regulatory policies are described as access based (meaning they are either related to payment for RE once it has accessed the distribution grid, beyond self-generation; or related to rules of connection access to a grid or rules for taking RE generation before other sorts of generation); Quota driven (such as obligations or mandates; Tendering/Bidding, Mandating, Tradable Green Certificates (TGC)); Price driven (Feed-in tariffs, premium or bonus payments); and Quality driven (such as green energy purchasing, green labeling and guarantees of origin).
- The Fiscal policies related to accelerated depreciation, investment grants, subsidies and rebates, energy production payments, production or investment tax credits; reductions in taxes (for example sales tax, VAT and so on)
- Public finance policies relate to grants; equity investments, loans and guarantees; and
- Other policies include public procurement.

Those policies can also be differentiated between those which provide technology push support, which tend to occur at the start of their development, and demand pull policies, which are implemented as the technology becomes nearer competitiveness. An appropriate balance between technology push and demand pull policies for any given technology can lead to a virtuous cycle of reducing costs, increasing investment and increasing demand and deployment (Figure TS 11.3). Technology push policies can improve technologies and reduce their costs, attracting investment which can, along with demand pull policies, help introduce them to the market cycle and lead to greater deployment. The demand pull also helps to reduce their costs which in turns makes them more attractive in the market, which increases deployment which allows technology learning to occur, thereby improving the technology. In this virtuous cycle, investors have confidence in the technology, as a result of the earlier R&D, and capital becomes easier to access, leading new companies to enter the market and to increased competition for market shares through additional R&D investment for technological improvement. Designing a series of policies which together enables this virtuous cycle will lead to effective and efficient technology development and deployment.

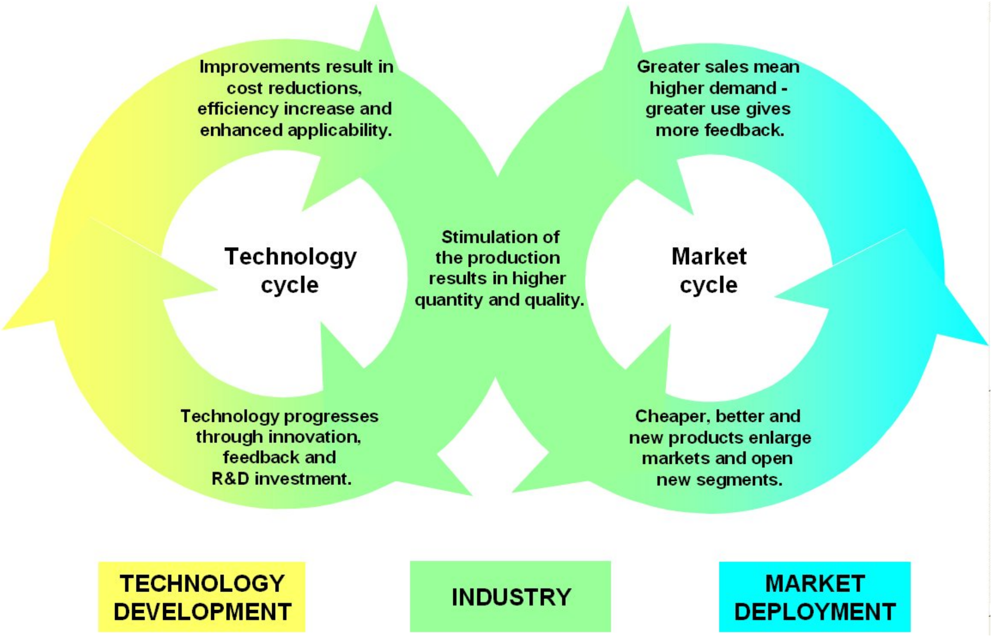

Figure TS 11.3 The mutually-reinforcing "virtuous cycle" of technology development and market deployment drives technology costs down.

Policies for Different Targets

RE policies can provide support from the R&D technology area through to payments for installed or available production capacity (heat or power), or generated electricity or produced heat (kWh). Both capacity and generation supplies can be qualified by RE source (type, location, flow or stock character, variability, density), by technology (type, vintage, maturity, scale of the projects), by ownership (households, co-operatives, independent companies, electric utilities), and other attributes that are in some way measurable which allows the amount of support to be made contingent upon it. RE may be weighed by additional qualifiers such as time and reliability of delivery (availability) and other metrics related to RE's integration into networks.

The link between policy and finance

Policies, and their design, play an important role in improving the economics of renewable energy systems, and as such can be central to attracting private finance and influencing longer-term investment flows. Private sector investment decisions are underpinned by an assessment of risk and return. A policy framework to induce investment will need to be designed to reduce risks and enable attractive returns, and be stable over a timeframe relevant to the investment. To be fully effective, or 'investment grade', policy needs to cover all of the factors (see Box TS11.1) relevant to a particular investment or project.

Box TS 11.1 Investment Grade Policies

General features of investment grade policies include:

- Clearly set objectives: financiers may want to anticipate a policy review or change should progress not be on track. Policy design to achieve the objective may also differ: for example achieving a simple volume increase of renewable energy and seeking a diversity of renewable technologies within the energy mix are likely to require different incentive design.

- Stability across project-relevant time horizon: project finance may cover a 15 year period or greater. The legal or mandatory nature of goals and support mechanisms can foster greater confidence in policy and regulatory stability, together with a clear enforcement or penalty regime.
- Simplicity: complex market systems can increase risk and uncertainty, compared to more straightforward ones.

For a specific project, relevant policy areas include:

- Planning or licensing approval: clarity over average timeframe to move through the planning process and costs involved are directly relevant. Financiers will want to know if experience indicates a long planning period with a track record of objections, or multiple approvals from different agencies, that could delay project start-up (and revenue generation), this could prove unattractive
- Support mechanisms/incentives : a crucial part of making returns attractive; the design of mechanisms including feed-in tariffs will be important, with one international bank describing the design features as ‘transparency, longevity and certainty’ review provisions will also be closely scrutinised.
- Policy coherence across any relevant national or international supply chain, e.g. policies that might impact access to biomass feedstock; sustainability, water etc.
- Grid or infrastructure availability, access and costs: projects are unlikely to get financed if there is uncertainty over the availability of underlying infrastructure e.g. for offshore grid for offshore wind projects. The ability to sign a long-term power purchase agreement from a creditworthy off-taker may also be a key part of the financing equation. Infrastructure has implications for sequencing of planning and policy, as well as anticipating new regulatory needs.

A regional policy perspective, beyond national boundaries, may be increasingly relevant for larger scale penetration of renewable energy, with respect to anticipating medium-term rising levels of interconnection, particularly electricity, which could have implications for energy trading, energy pricing and so on.

Policies for Tech. Development

The costs of the transition to a low carbon economy are so large, that Governments are aiming to leverage their funding as far as possible with private collaboration and investment across the technology development spectrum.

Policy measures in the RD&D sphere are becoming more collaborative and innovative as they seek new means of tapping into potential financiers, investors and innovators

The amount of funding is not the only important factor – achieving an appropriate balance between R&D and deployment funding can accelerate ‘learning’ as can supporting efforts for ‘bricolage’ (or the steady progression of small scale learning which sum up to large scale innovation) rather than ‘breakthrough’ (ie focusing on large scale innovation)

Specific policies in support of renewable energy are required from the early stages of technology development through to when they become commercially mature. An important Government role is to fill in the ‘gaps’ in this continuum where support for technology development is lacking, while at the same time encouraging input (ie financial /in-kind support) from other sectors where possible.

Developing Country Off-grid and Rural Issues

Many of the issues related to RE development are the same for developed and developing countries. There are several challenges for investors in RE in developing countries – just as there are in developed countries – and these are discussed in more detail in 11.5.4, 11.5.5 and 11.5.6. There have been several reviews of the importance of RE policies for developing countries, for example from the World Bank; their successes and difficulties. These reviews reinforce the central role that national policy plays. There is no ‘one size fits all’. The overall policy environment needs to provide enough confidence for investors.

RE policy for off-grid and rural issues – given the specific differences of requirements in developing countries from developed countries are very important. Access to energy is of paramount importance as it increases living standards of rural populations, providing essential goods and services. RE enhances access to reliable, affordable clean energy to meet basic needs, especially through small scale decentralized systems renewable, and it allows for industries, production and transport to leapfrog and avoid dependence on fossil fuels.

There are some success stories, for example in Nepal by 2009, more than 200,000 rural families were using domestic biogas technology for cooking. By early 2009, in India, a cumulative total of 4250 villages and 1160 hamlets had been electrified using RE. Contrary to that Nepal has managed to install more than 150, 000 domestic biogas plants from *ad-hoc* support mechanisms before a national rural (renewable) energy policy promulgated in 2006. In Bangladesh to more than 100,000 solar home systems were promoted before a national level renewable energy policy was promulgated in 2008.

For many low income developing countries, simply channelling a subsidy to rural areas is not enough. This is due to immature markets and a lack of capacity, and a weak and fragmented supply chain Developing countries have multiple tasks of development, so more integrated renewable policies emphasising on energy access, rural and regional development, betterment of health and education sector and promoting better environment, employment and industrial sector development should be promulgated

Policies for Deployment – Electricity

Feed-in Tariff (FIT)

The most prevalent national policy for promoting renewable electricity is the FIT, also known as Feed Laws, Standard Offer Contracts, Minimum Price Payments, Renewable Energy Payments, and Advanced Renewable Tariffs, and is an over-arching term for price driven support. FITs can be divided between those where the Government sets a fixed price which is independent of electricity market prices and those that are linked to electricity market prices but paid a fixed premium price, also set by the Government. All FITs have different impacts on investor certainty and payment, ratepayer payments, the speed of deployment, and transparency and complexity of the system.

Like all mechanisms, their success comes down to details but the most successful FIT designs have included most or all of the following elements:

- Priority dispatch and access
- Establish tariffs based on cost of generation and differentiated by technology type and project size;
- Ensure regular adjustment of tariffs, with incremental adjustments built into law, to reflect changes in technologies and the marketplace
- Provide tariffs for all potential generators, including utilities

- Guarantee tariffs for long enough time period to ensure adequate rate of return
- Ensure that costs are integrated into the rate base and shared equally across country or region
- Provide clear connection standards and procedures to allocate costs for transmission and distribution
- Streamline administrative and application processes.

Quota Obligations

After FITs, the most common policy mechanism in use is a quota obligation, also known as Renewable Portfolio or Electricity Standards (RPS or RES) in the United States and India, Renewables Obligations (RO) in the United Kingdom, Mandatory Renewable Energy Target in Australia. By the end of 2008, quotas were in place in at least 9 countries at the national level and by at least 40 states or provinces, including more than half of U.S. states.

Under quota systems, governments typically mandate a minimum share of capacity or generation to come from renewable sources. Any additional costs of RE are generally bourne by electricity consumers. With the most common form of quota system, generators comply with the quota by installing capacity which an actor purchases. In the case, of the UK this is the electricity supplier who is responsible for all contractual arrangments. Elsewhere, for example Texas, renewable electricity may by bought through a bidding process. .

As with FITs, the success or failure of quota mechanisms comes down to the details. The most successful mechanisms have included most if not all of the following elements, particularly those that minimize risk:

- System should apply to large segment of the market
- Include specific purchase obligations and end-dates; and not allow time gaps between one quota and the next
- Establish adequate penalties for non-compliance, and provide adequate enforcement
- Provide long-term targets, of at least 10 years
- Establish minimum certificate prices
- Liquid market to ensure that certificates are tradable

Policies for Deployment – Heating and Cooling

Heating and cooling processes account for 40-50 percent of global energy demand with consequent implications for emissions from fossil fuels. Historically, renewable energy policy has tended to have a greater focus on renewable electricity, with increasing activity in support of biofuels for transportation over the last decade. However, renewable energy sources of heat (RES-H) have gained support in recent years as awareness of their potential has been increasingly recognized. Many nations have some form of district heating. As well as heat delivery infrastructure this tends to imply some pricing and regulatory oversight. Waste heat from fossil fuel and nuclear generation is commonly used in systems across Eastern Europe, former soviet states and Scandinavia. RE for cooling (RES-C) has even fewer mechanisms of support than RE for Heating. As a result, experience of what works and what doesn't is far less than that for RE electricity or fuels.

Bonus Mechanisms and Quotas

The bonus (or tariff) mechanism and the quota or renewable portfolio standard (RPS) are the two key variations in providing support to RES-H. The bonus mechanism (roughly, the equivalent to the RES-E FIT) has been characterised as a "purchase/remuneration obligation with fixed reimbursement rates". It legislates a fixed payment for each unit of heat generated, with potential for setting different levels of payment according to technology. Payments can be capped either for a fixed period, or for a fixed output, and can be designed to vary with technology and building size to complement energy conservation efforts. Digression may be applied to reduce the level of the bonus payment annually to allow the capture of cost reductions for the public purse. Digression has been cited as 'best practice' in the consultation document for the adoption of a renewable heating tariff in the UK, based on experience with RES-E tariffs in Europe.

Currently, no RES-H/C centred quota mechanism has been applied in practice nor are any planned. Efforts to legislate a RES-H quota mechanism in the UK in 2005 were unsuccessful and the UK has now adopted legislation for a RES-H bonus mechanism with a projected April 2011 adoption largely on the grounds of the greater projected cost associated in a comparison of quota ad tariff mechanisms. Germany also favoured a bonus mechanism for RES-H, but finally adopted mandatory installation of RES-H in new buildings.

Other regulated policies are Mandating Connection Technologies, 'Use' Obligation and Standards and Building Regulations

Policies for Deployment – Transportation

A range of policies have been implemented to support the deployment of biofuels in countries and regions around the world. Robust biofuels industries exist only in countries where government supports have enabled them to compete in markets dominated by fossil fuels. An example of this is Brazil. There are many countries where basic regulations for the production, sale, and use of biofuels do not yet exist. Some countries, like Mexico and India, have implemented national biofuels strategies in recent years. The most widely used policies include volumetric targets or blending mandates, tax incentives or penalties, preferential government purchasing, and local business incentives for biofuel companies.

Renewable Fuel Mandates and Targets

National targets are key drivers in the development and growth of most modern biofuels industries. Blend mandates have been enacted or are under consideration in at least 27 countries and 40 countries have some form of biofuels promotion legislation. Among the G8 +5 Countries, Russia is the only one that has not created a transport biofuel target. Voluntary blending targets have been common in a number of countries. However blending mandates enforceable via legal mechanisms are becoming increasingly utilized and with greater effect.

Governments do not need to provide direct funding for blending mandates since the costs are paid by the industry and consumers. Mandates have been quite effective in stimulating biofuels production, but they are very blunt instruments and should be used in concert with other policies, such as sustainability requirements, in order to prevent unintended consequences.

Sustainability Standards

Although environmental quality is regulated in most countries, comprehensive sustainability laws for biofuels are in place only in Europe where individual government efforts (especially in the Netherlands, the United Kingdom, and Germany) led to an EU-wide mandatory sustainability requirements for biofuels that was put into law in 2009. These include biodiversity, climate, land use and other safeguards.

Taxes

Taxes are one of the most widely used and most powerful policy support instruments for biofuels because they change the cost competitiveness of biofuels compared to fossil fuel substitutes in the marketplace. In recent years, the European countries and several of the other G8 +5 countries have begun gradually abolishing tax breaks for biofuels, and are moving to obligatory blending.

Other Direct Government Support for Biofuels

Most countries that are encouraging biofuels development are using some form or forms of direct loan or grant supports, generally paid for directly by Government.

Indirect Policy

Policies, other than those that are focused on renewable energy, can also be supportive for renewable transport fuels. These can be agricultural policies (discussed further in Chapter 2); storage policies (discussed further in Chapter 8); and on non-RE specific transport policies (for example, urban transport policies, also discussed in Chapter 8); and low carbon fuel standards.

Infrastructure Policies

Alternative fuels, including electricity, hydrogen and biofuels all require new infrastructures and capital investment to supply transport users with propellants. The dynamics underlying competition between fuels are crucial. Conventional fuels and power trains represent sunk investments, and with experience and economics of scale they have developed down their respective technological learning curves for 100 years; alternative fuels and technologies are naturally disadvantaged. Hence, policies addressing infrastructure investments are needed to overcome fossile fuel dependence. The degree of these investments, however, varies among alternative fuels.

Enabling Environment and Regional Issues

Energy systems are complex. They are made up of interrelated components. The process of developing and deploying new energy technologies follows systemic innovation “pathways”: innovation most often occurs in concert with several other associated or overlapping innovations. This pathway has been described as a succession of phases from R&D to full market deployment, but these phases are not linear.

The scale of technology development is conditioned by an “enabling environment”, which interlinks with RE policies (i.e. enables targeted RE policies to be more effective and efficient). The enabling environment includes institutions, regulations, the business and finance communities, civil society, material infrastructures for accessing RE resources and markets, and international agreements for facing the challenge of climate change or developing technology transfer (Figure TS 11.4).

> The Enabling Environment is defined as:
>
> “A network of institutions, social norms, infrastructure, education, technical capacities, financial and market conditions, laws, regulations and development practices that in concert provide favorable conditions to create a rapid and sustainable increase in the role of renewable energies in local, national and global energy systems”

Policies can be successful on their own in certain context. For instance, British Columbia and Norway provide examples of countries or jurisdiction with large endowments of renewable energy resource, that RE policies have brought on the way to high penetration of renewable energies (see Box 11.7).

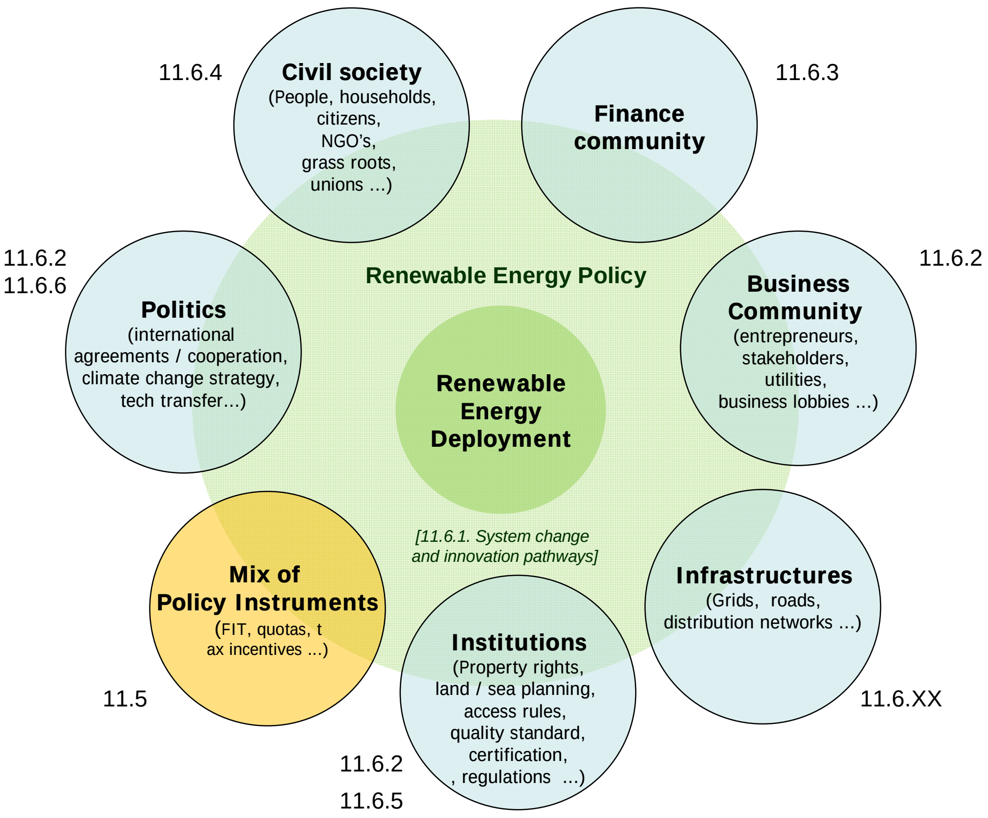

Figure TS 11.4 RE technology is embedded in an enabling environment, RE policy is one decisive dimension of this environment, but not the only one [TSU: reference?]

However, as renewable energy deployment increases, the enabling environment – whether gaining planning permission, gaining access to financing or to the grid – can make renewable energy deployment easier. On the whole, the barriers set out in various parts of the SSREN Report relate to one or several aspects of an enabling environment. If that enabling environment is in place then its related barriers should be overcome or reduced.

So, while RE policies can start very simply, with a mix of the various policy instruments discussed in section 11.5, successful experiences also suggest that developing such an enabling environment contributes to the emergence of well-designed policies and to their success, which in turn contributes to an increasing flow of private investment.

An enabling environment is therefore characterised by the readiness of society and stakeholders, including decision-makers to create an environment in which RE development and deployment can prosper. The intertwined requirements to increase the rate of deployment needed is a systemic and evolutionary process.The coordination among policies and the sub-components of the enabling environment – whether technological, social, cultural, institutional, legal, economic, financial– is essential

A Structural Shift

Transitions from one energy source to another have characterized human development. A shift from the current energy system to one that includes a high proportion of RE also implies a number of structural changes.

Movements from one energy source to another have occurred as each new source of energy provided a new and desired service which displaced and augmented the services available from the previous ‘standard’ energy source. The timescales of these energy transitions and their linked infrastructure replacements or developments varied by countries but occurred over several decades. A transition to a low carbon economy using low carbon emitting RE is different from past transitions because the time period available is restricted, and relatively short compared to the timescales of previous transitions. Further RE is trying to integrate into a system (including policies, regulations and infrastructure) that was built to suit fossil fuels (which have a number of continuing useful qualities such as energy density and portability) and nuclear power. While RE provides different benefits, services are similar. Because of this movement towards the transition has to be deliberate.

A few towns, local authorities, or communities have moved considerably toward sourcing 100% of their energy from RE (see Case Study 11.17). The key lesson of whether, and how, these city’s and communities were able to do this ultimately depended on the *spatial, environmental, social and economic capacities to implement RE* – and this would only be possible if the concerns of the three main actors – state, market and civil society - are addressed together. This is the practical representation of the arguments for structural change set out in 11.7.2 – an alignment has to occur between the State; the social mindset and institutions.

Key Choices and Implications

This section has illuminated the key requirements and choices that policy makers face and which have significant implications for society. Governments are required to orchestrate the deliberate move from fossil fuels to RE use. As is argued in the IEA’s Deploying Renewables (2008), success in delivery occurs where countries have got rid of non-economic barriers and where policies are in place at the required level to reduce risk to enable sufficient financing and investment. In addition, this section has set out that

- RE Policies, the enabling environment and more structural shfts are all on a continuum towards a transition to an energy system with more and more RE.
- A ‘breakthrough’ or a ‘bricolage’ policy approach to technology develeopment and system change is a key choice
- Another key choice is the the policy priority of whether to support a technology optimistic pathway ; a behaviour optimistic pathway or one that combines both
- the degree to which policies are devolved down from national to local governments, and open to individual choice
- the degree to which the State, the market and civil society are brought together to address, and create, sufficient spatial, environmental, social and economic capacities to enable a move to a low carbon economy

The choices will affect the actors described above so that societal activities, practices, institutions and norms can be expected to change. Thus, choice of policies is central to the success of policies.