Chapter:	00				
Title:	Summary for Policymakers (SPM)				
(Sub)Section:	All				
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	CAs:				
Remarks:	Second Order Draft				
Version:	01				
File name:	SRREN-Draft2-SPM.doc				
Date:	15-Jul-10 13:57	Time-zone:	CET	Template Version:	13

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Summary for Policy Makers

CONTENTS

1. Introduction

The Working Group III Special Report on Renewable Energy Sources and Climate Change Mitigation focuses on new literature on the scientific, technological, environmental, economic and social aspects of the contribution of renewable energy (RE) sources to the mitigation of climate change, supplementing and expanding on information and analysis that was presented in the 2007 IPCC 4th Assessment Report (AR4).

This Special Report provides a technology and systems level analysis based on the technical literature to support the thesis that RE can contribute significantly within a broad portfolio of mitigation options to the goals outlined in the AR4 for limiting global mean temperature increases and stabilizing the concentration of greenhouse gases (GHGs) in the atmosphere.

1) The RE resource is widely available, and a sufficient RE technology base already exists to enable significant implementation of a low-carbon and sustainable energy economy.

2) Financial barriers exist for many RE systems to compete directly with incumbent energy systems in the short-term, but continually improving technologies, efficient use improvements, policies and cost reductions from increased experience can aid the transition to a new sustainable energy system.

3) Regulatory barriers inadvertently discourage the use of RE in many cases, but countries that have eliminated them and established supportive policies have seen RE provide a rapidly growing share of energy services.

4) Low-carbon energy systems and efficient end-use can be powerful tools to expand the cost-effective access to energy services that can meet the energy needs and improve the quality of life of the poor.

RE, in its many forms, has the potential to mitigate GHG emissions, enhance energy security, provide modern and affordable energy services to those currently without, and aid sustainable development. To put RE technologies and energy practices into an economically affordable, environmentally sustainable and social acceptable use will require:

- continued attention to the economic playing-field where new innovations compete;
- regional assessments of RE resources;
- strong research and development efforts to further develop RE technologies;
- development of policy tools that can bring low-carbon energy systems into practice; and
- vigilance to the opportunities, policy tools and institutional environments available for RE to achieve its potential to address sustainable development goals for diverse communities and societies.

The following summary is organised into seven sections after this introduction:

- Drivers for a low-carbon economy
- Solutions
- Mitigation potentials
- Renewable energy technologies
- Integration of RE into current and future energy supply systems
- Policies and instruments for advancing RE deployment
- Knowledge gaps

References to the corresponding chapter sections are indicated in each paragraph in square brackets. An explanation of terms, acronyms and chemical symbols used in this SPM can be found in the glossary to the main report.

2. Drivers for a Low-Carbon Economy

2.1 Climate Change

The IPCC's 2007 AR4 concluded that there is a 90 percent likelihood that global warming is happening and that most of it is caused by human actions. AR4 [Working Group I] projected that, by the end of this century, global annual average temperature will have risen by between 1.1° and 6.4° C depending on assumptions of future socio-economic trends. [1.1.1]

Climate change is a major consequence of the more fundamental problem of unsustainable development. The AR4 concluded that human livelihoods, from small communities to major urban complexes to regional economies, are fundamentally impacted by climate change and a cycle of unsustainable development. It went on to conclude that the impacts of climate change are initially being felt among the poor in both developed and developing nations, in many cases already with significant negative impacts.

Over 80% of primary energy[1] comes from fossil fuels, which produce the heat trapping GHGs carbon dioxide as the products of combustion and methane as an inadvertent product of drilling, mining and transporting those fuels. When measured by their comparative global warming potentials, these gases account for the majority of global warming since the start of the industrial revolution.

***Carbon emissions continue to rise worldwide with CO_2 concentrations exceeding 390 ppm in 2010.* [1.1.1]**

In order to meet targets for limiting global temperature increases, GHG emissions will need to begin declining in the coming decade. Many governments, and the Copenhagen Accord now advocate that to avoid the most dangerous impacts of climate change it will be necessary to hold temperature rises to less than 2° C below preindustrial values with small island developing states and other less developed countries advocating limiting the temperature increase to below 1.5ºC. The AR4 indicated that to achieve this goal will require global GHG emissions to be at least 50% lower in 2050 than in 2000, and to begin declining by 2020.

2.2 Sustainable, Secure Energy Services

Access to energy services is central to human health and welfare, as well as a fundamental input for economic development. "Secure energy services" refers to the assured access to energy resources necessary to provide essential energy services, and this varies markedly for those at the subsistence level in developing countries, and those living in an energy intensive economy. For the former, it involves gathering fuel wood, dung or crop waste, or the reliability of intermittent electricity supply. For the later, it may depend upon the reliability of imports or the capacity of infrastructure to meet high demand.

Sustainable energy services require the ongoing delivery of energy resources over time that are economically affordable, environmentally sustainable (low pollution and carbon dioxide emissions) and socially acceptable. In order for an energy source to be sustainable requires first that it be able to continue producing energy over time with low carbon dioxide emissions and with comparatively

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[1] Primary energy refers to the energy embodied in natural resources that has not undergone any anthropogenic conversion [SRREN Glossary].

low other environmental impacts. It must also be economically sustainable in terms of using scarce resources in the best possible way according to criteria of human-well being. Finally, to be sustainable, the technology must be socially sustainable in terms of providing livelihoods and maintaining social and political acceptance.

The systems perspective on energy development and deployment links global and local decision-making to short- and long-term societal needs. The Millennium Development Goals (MDG) provide a list of challenges and objectives where governments, multinational agencies, and civil society can exercise choices and focus attention on energy services that can address poverty, reduce hunger, increase access to safe drinking water, allow domestic lighting and electricity to enable education at home, increase security, and increase gender and social equity. Quantitative measures of energy access, sustainability, and social impact will be needed to chart progress and challenges in implementing clean energy solutions that meet development and sustainability goals [1.1.6].

3. Solutions

Economic and development goals may be pursued in conjunction with climate protection goals and related targets for GHG emission reductions, particularly by means of investment in low-carbon energy-related infrastructure *[10.1]*. To address some of the bottlenecks that have historically been barriers to their development, developing countries will need to invest in infrastructure that they currently lack, also in terms of energy infrastructure. A window of opportunity exists particularly in fast-growing developing countries planning to make large investments in new energy-related infrastructure. Developed countries need to renew their energy-related infrastructures as well. Due to the long life-cycle of infrastructure (e.g. power plants, roads and buildings), medium- and long-term climate protection goals need to be taken into account in near-term investment decisions to avoid lock-in situations [10.1].

To maintain both a sustainable economy that is capable of providing essential goods and services to the citizens of both developed and developing countries, and to maintain a supportive global climate system requires a major shift in how energy is supplied and utilized. [11.7].

There are various means for lowering GHG emissions from energy sources, while still providing energy services. [1.1.4, 10.1] The following mitigation options related to energy supply are available [10.1]:

- Shift to zero carbon primary energy sources[2], including RE technologies (See Box SPM 1).
- Shift from coal, petroleum or natural gas to solid, liquid or gaseous biomass energy that is produced and used in a low carbon-emitting manner utilizing new crops and management strategies.
- Utilize combined heat and power (CHP) technologies for thermal production of electric power from both fossil fuels and RE sources.
- Shift to lower carbon-emitting fuels such as from coal to natural gas or to uranium.
- Utilize carbon dioxide capture and storage (CCS) technology to prevent carbon from fossil fuel combustion from entering the atmosphere. CCS also has the potential to remove CO_2 from the atmosphere when biomass is utilized.

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[2] GHG emissions may occur during manufacturing processes. Therefore, ‘zero-carbon primary energy source’ does not necessarily refer to the entire life-cycle of a particular technology.

The main mitigation options related to energy demand are as follows [10.1]:

- Provide the same energy service with less energy. Increase the energy efficiencies of buildings, lighting, industrial and agricultural processes, transportation and the delivery of energy services at the point of end-use.
- Change consumer behaviours to use fewer carbon and energy-intensive products and services.

In addition to the energy-related methods for mitigating climate change, additional potentials exist in the agriculture, forestry and waste sectors [10.1].

Renewable energy technologies are diverse, and have the ability to serve a wide range of energy service needs. Though all RE technologies rely on resources that can be naturally replenished, the specific characteristics of these technologies and their potential use are varied (Box SPM 1). Electrical, thermal, transport, and mechanical energy service needs can be met with RE.

Renewable energy technologies can be near-zero carbon emitters if managed appropriately. The life-cycle GHG emissions of most RE technologies are low. Though the direct GHG emissions of RE technologies are often zero, GHGs are emitted in the materials supply, manufacture, and installation of these technologies. Additionally, the variable output of some RE technologies can affect the operational efficiency of fossil-fuel power plants that are also on the grid, yielding some increase in GHG emissions from those plants. The literature suggests that, in most cases, these impacts are small, and that the net life-cycle GHG emissions of RE technologies are low compared to fossil-fuel energy supply; moreover, in the case RE technologies with variable output profiles, the use of storage and/or the coupling of diverse RE technologies into a hybrid system may reduce any impacts that do exist. [2.5, 3.6, 4.5, 5.6, 6.4, 7.6]

Concerns are sometimes expressed about the net GHG emissions of bioenergy and hydropower. Bioenergy has a significant GHG mitigation potential, provided that the resources are developed sustainably and that appropriate bioenergy systems are utilized. Perennial cropping systems and biomass residues and wastes, in particular, are able to deliver GHG reductions of 80-90% compared to the fossil energy baseline. The GHG impacts of bioenergy are conditional, however, and can be either positive or very low or even negative depending on the situation; negative impacts can, for example, occur when carbon stocks are lost due to undesired land use changes. For hydropower, research shows that life-cycle GHG emissions are typically very low, but that methane and carbon dioxide emissions may occur for certain reservoirs in tropical environments. Research is needed to obtain more-reliable estimates of net GHG emissions in these instances. [2.5, 5.6]

Box SPM.1. Renewable Energy Resources and Technologies

Bioenergy is a renewable source of fuel that may be used in a wide variety of energy applications, while biomass also continues to be the world's major source of food, fodder, and fibre. Biomass sources include forest, agricultural, and livestock residues, short-rotation forest plantations, dedicated energy crops, the organic component of municipal solid waste (MSW), and other organic waste streams. Part of these are used as feedstocks which, through a variety of chemical and physical processes, produce energy carriers in the form of solid (chips, pellets, briquettes, logs), liquid (methanol, ethanol, butanol, biodiesel), and gaseous (synthesis gas, biogas, hydrogen) fuels. The production of energy from these carriers can be used in thermal, electric, transport, construction, and chemical applications, and can take place in a centralized or decentralized fashion. [2.1, 2.3, 2.6]

Direct solar energy technologies harness the energy produced by the solar radiation of the sun to meet electricity, thermal, and in some cases transportation demands. Solar technologies range from comparatively simple devices for lighting and heating to highly sophisticated devices for electricity production; many of the technologies are modular in nature, allowing their use in both centralized and decentralized energy systems. Though solar energy relies on naturally variable energy flows, creating inherent variability in energy output, thermal energy can be stored over short periods at comparatively low cost, allowing some technologies (e.g., concentrating solar thermal power) to offer controllable output. Even when integrated storage is not available, the temporal profile of solar energy output sometimes correlates relatively well with energy demands. [3.1, 3.3, 3.7]

Geothermal energy relies on the accessible thermal energy generated and stored in the Earth's interior, either onshore or offshore. Geothermal heat is extracted using wells that access the hot fluids contained in hydrothermal reservoirs or by artificially introduced fluids in Enhanced Geothermal Systems (EGS). Once at the surface, these hot fluids can be used to generate electricity, or can be used more-directly for applications that require thermal energy. When used to generate electricity, geothermal power plants typically offer constant (base-load) output with an average worldwide capacity factor of 71% in 2008 and with newer installations capable of achieving capacity factors above 90%. [4.1, 4.3, 4.4]

Hydropower harnesses the energy of moving water from higher to lower elevations, primarily to generate electricity. Hydropower projects vary widely in type and size, creating a continuum from small-scale (a few kW) run-of-river projects to large-scale (over 10 million kW) dam projects with a reservoir that provides the possibility of controllable output. This variety gives hydropower the ability to meet large centralized urban needs as well as decentralized rural needs, and the controllable output of many hydropower facilities can be used to meet peak electricity demands and help balance electricity systems that have large amounts of variable RE generation. Hydropower facilities are often multi-use facilities, meeting the needs of water management as well as energy supply. [5.1, 5.5, 5.10]

Ocean energy derives from the potential, kinetic, heat, chemical, and biomass energy of seawater, which can be transformed to serve electricity, thermal, transport, and potable water needs. A wide range of technologies can be used for this purpose, e.g., barrages for tidal rise and fall, submarine turbines for tidal and ocean currents, heat exchange technologies for ocean thermal energy conversion (OTEC), and new technologies for osmotic power. Some of these technologies have short-term (e.g., waves) and medium-term (e.g., swells, tidal and ocean currents) variable output profiles, while others may be capable of constant or even controllable operation (e.g., OTEC and salinity gradient). [6.2, 6.3, 6.4]

Wind energy relies on the kinetic energy of moving air masses and can be used in many ways, but the primary application of relevance to climate change mitigation is to produce electricity from large wind turbines located on- or off-shore. Because wind energy relies on the kinetic energy of moving air masses, wind electricity is both variable and, to some degree, unpredictable. Actual experience and detailed studies have concluded that there are no insurmountable technical barriers to integrating wind energy into power systems, though such integration becomes increasingly costly at higher levels of wind electricity penetration as more-active management is required. [7.1, 7.3, 7.5]

Table SPM 1 Overview of RE Technologies and Applications [1.2.3]

Renewable Energy Source	Select Renewable Energy Technologies	Energy Sector (Electricity, Thermal, Transport, Mechanical)	Technology Maturity[1]				Primary Distribution Method[2]	
			R & D	Demo & Pilot Proj	Early-Stage Com'l	Later-Stage Com'l	Centralized	Decentralized
Bioenergy	Non-Commercial Use of Fuelwood/Charcoal	Thermal				X		X
	Cookstoves (Primitive and Advanced)	Thermal				X		X
	Domestic Heating Systems (pellet based)	Thermal				X		X
	Small- and Large-Scale Boilers	Thermal				X	X	X
	Digestion	Electricity/Thermal				X	X	X
	Combined Heat and Power (CHP)	Electricity/Thermal				X	X	X
	Co-firing in Fossil-Fuel Power Plant	Electricity				X	X	
	Combustion-based Power Plant	Electricity				X	X	X
	Gasification-based Power Plant	Electricity			X		X	X
	Sugar-Cane Ethanol Production	Transport				X	X	
	Corn Ethanol Production	Transport				X	X	
	Wheat Ethanol Production	Transport				X	X	
	Rapeseed Biodiesel Production	Transport				X	X	
	Palm Oil Biodiesel Production	Transport				X	X	
	Soy Biodiesel Production	Transport				X	X	
	Jathropha Biodiesel Production	Transport				X	X	
	Lignocellulose Ethanol Production	Transport			X		X	
	Lignocelluose Synfuel Production	Transport			X		X	
	Algae Fuel Production	Transport	X				X	
Direct Solar	Photovoltaic (PV)	Electricity				X	X	X
	Concentrating PV (CPV)	Electricity		X			X	
	Concentrating Solar Thermal (CSP)	Electricity			X		X	
	Low Temperature Solar Thermal	Thermal				X		X
	Solar Cooling	Thermal		X				X
	Passive Solar Architecture	Thermal				X		X
	Solar Cooking	Thermal			X			X
	Solar Fuels	Transport	X				X	X
Geothermal	Hydrothermal, Condensing Flash	Electricity				X	X	
	Hydrothermal, Binary Cycle	Electricity				X	X	
	Engineered Geothermal Systems (EGS)	Electricity		X			X	
	Submarine Geothermal	Electricity	X				X	
	Direct Use Applications	Thermal				X		X
	Geothermal Heat Pumps (GHP)	Thermal				X		X
Hydropower	Run-of-River	Electricity/Mechanical				X	X	X
	Reservoirs	Electricity				X	X	
	Pumped Storage	Electricity				X	X	
	Hydrokinetic Turbines	Electricity/Mechanical		X			X	X
Ocean Energy	Swell/Wave	Electricity		X			X	
	Tidal Rise and Fall	Electricity				X	X	
	Tidal Currents	Electricity		X			X	
	Ocean Currents	Electricity		X			X	
	Ocean Thermal Energy Conversion	Electricity/Thermal		X			X	
	Osmotic Power	Electricity		X			X	
	Marine Biomass Farming	Transport	X				X	
Wind Energy	On-shore, Large Turbines	Electricity				X	X	
	Off-shore, Large Turbines	Electricity			X		X	
	Distributed, Small Turbines	Electricity				X		X
	Turbines for Water Pumping / Other Mechanical	Mechanical				X		X
	Wind Kites and Sails	Transport		X				X
	Higher-Altitude Wind Generators	Electricity	X				X	

Notes: 1. The highest level of maturity within each technology category is identified in the table; less mature technologies exist within some technology categories.
2. Centralized refers to energy supply that is distributed to end users through a network; decentralized refers to energy supply that is created onsite. Categorization is based on 'primary' distribution method, recognizing that virtually all technologies can, in some circumstances, be used in both a centralized and decentralised fashion.

At present, the total shares of consumer energy supplied by RE systems remains low. (See Table SPM 2). The percentages of RE in local primary energy supplies can vary substantially by region. In 2007, RE sources in sum accounted for less than 13% of the total global primary energy supply, but many forms of RE are growing rapidly.

Table SPM 2 Primary energy supply of different sources in 2007.

Primary energy source	**EJ**	**%**
Fossil fuels	411.09	85.33
Nuclear	9.81	2.04
Renewables	60.49	12.55
Bioenergy	48	9.96
Solar	0.40	0.08
Geothermal	0.39	0.08
Hydro	11.08	2.30
Ocean	0.00	0.00
Wind	0.62	0.13
Other	0.39	0.08
Total	481.78	100.00

Notes: Data for this table originates from the IEA and has in some cases been updated with IPCC SRREN values. Values have been converted to reflect the direct equivalent method for calculating primary energy that is used throughout the SRREN.

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. 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 SPM 1.

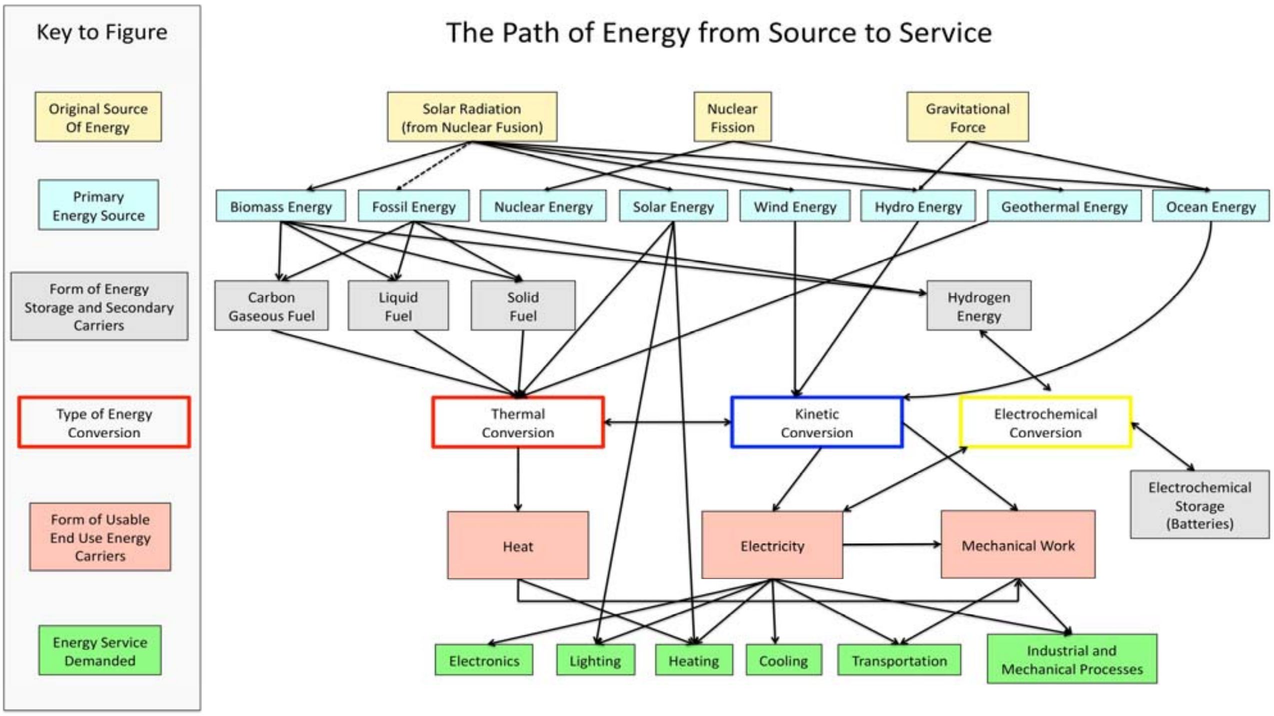

Figure SPM 1 The Path from Source to Service. The energy services delivered to the users can be provided with differing amounts of end use energy. This in turn can be provided with more or less primary energy and with differing emissions of carbon dioxide and other environmental impacts.

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. See Figure SPM 2. 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. However, the role of RE within the overall portfolio of mitigation options requires not only an assessment of technical feasibility about also a systemic perspective which takes into account all relevant information determining economic affordability, environmental sustainability and social acceptability. [1.3.1.1]

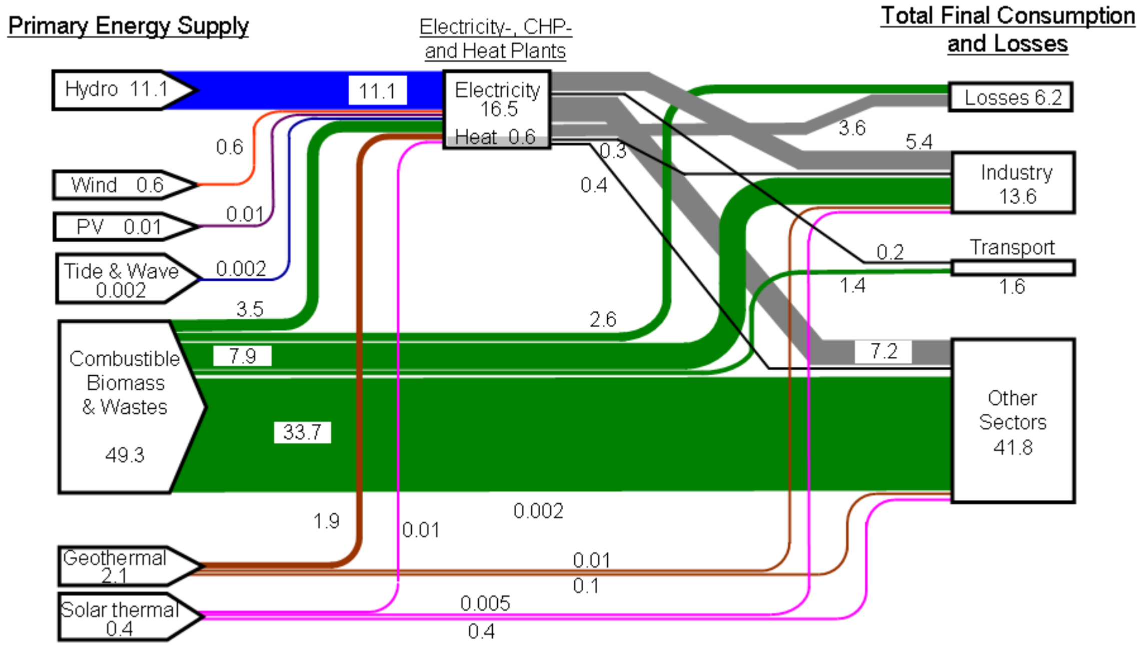

Figure SPM 2. Global energy flows (EJ in 2007) from primary renewable energy through carriers to end-uses and losses drawn with IEA data. Other sectors include agriculture, commercial and residential buildings, public services and non-specified other sectors.

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 that may create local pollutants. See Figure SPM 3. 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].

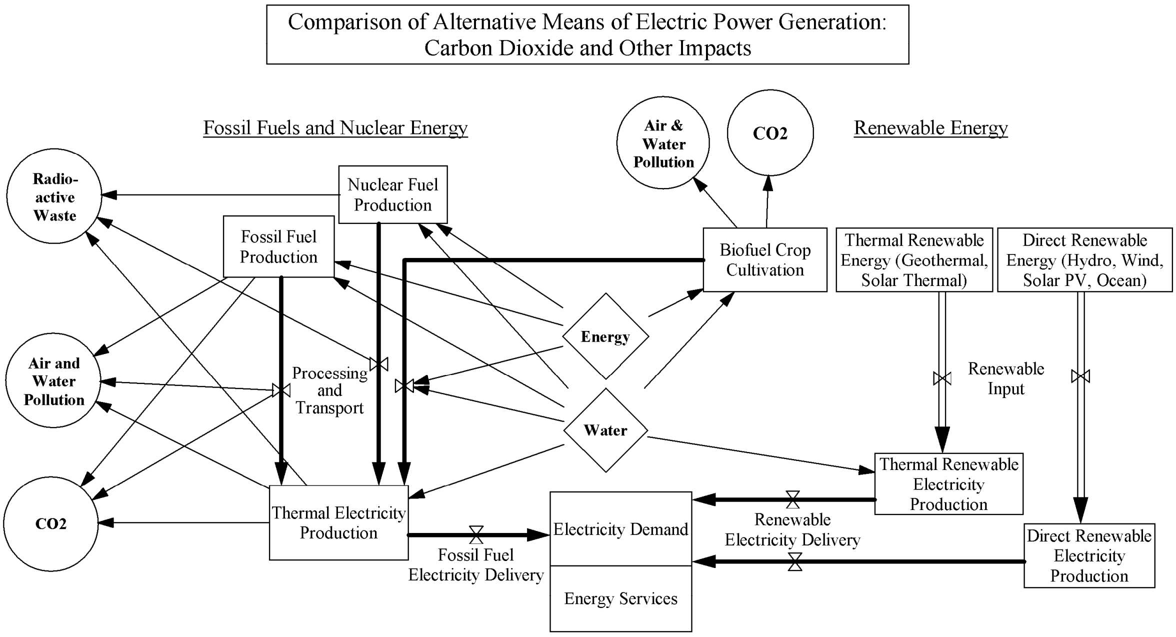

Figure SPM 3. Comparison of co-benefits, water use and CO_2 emissions associated with primary energy sources for electricity production. Not included are land impacts from surface mining of coal, land clearance for bioenergy and hydro reservoirs or methane leakage from coal natural gas and petroleum production and use or damage from oil spills and coal ash storage [1.1.6].

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. Details of the most significant environmental social and impact topics, both positive and negative, are shown in Table SPM 3.

Table SPM 3. Environmental and Social Benefits (+) and Concerns (-) Associated with Renewable and Conventional Energy Sources [9]

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	In many cases 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 atmospheric emissions	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		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, habitat and ecosystem modifications	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	-	nuisances from 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;	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

There are options to mitigate the adverse impacts of RE technologies, making them sustainable [9]. The methods for mitigating environmental and social impacts of RE sources reflect the diversity of the technologies themselves. For example, synergies with better natural resource management practices (e.g. soil carbon enhancement and restoration, water retention functions), improvements in agricultural management and the introduction of strong sustainability frameworks help to mitigate the negative impacts of bioenergy. For solar energy, dry cooling technology can be used to limit water needs for CSP power plants, and aggressive recycling of PV modules can limit concerns about electronic waste; land usage concerns can be minimized by relying on otherwise-unused land, already-disturbed land, or by integrating solar energy with buildings. For hydropower, fish migration can be restored in many cases by constructing fish ladders or elevators, and hydropower projects can provide an opportunity for the protection and creation of high-value ecosystems. Close involvement of affected human populations in the project planning process can help reduce social concerns. Ocean energy developments may benefit to some degree from earlier experience with other forms of RE (e.g., being proactive in monitoring and early mitigation of potential effects), and integrated marine spatial planning is being introduced to address competition and environmental effects. Appropriate planning and siting of wind power plants can help minimize the impact of wind energy development on local communities and the environment, and engaging local residents in consultation during the planning stage is often an essential aspect of the development process. Nonetheless, some impacts will remain, and efforts to better understand the nature and magnitude of these remaining impacts, together with efforts to minimize and mitigate those impacts, will therefore need to be pursued in concert with increasing wind energy deployment. [2.2, 2.5, 2.8, 3.6, 4.5 5.6, 6.5, 7.6]

Assessing, minimizing, and mitigating these varied impacts for all RE sources are common elements of the planning, siting, and permitting processes that occur at the national and local levels.

The output of some RE technologies is variable (dependent, for example, on natural energy flows), whereas other technologies are able to offer controllable output.(See Box SPM 1) Some RE systems are variable, from seasonal to hours and minutes. Short term wind, solar and wave power variations can be managed by better forecasting, flexible grids and inter-connections. For autonomous systems such as mini-grids and individual buildings, energy storage is an option but usually costly [1.2.2, 8.2.1] Integrating several types of RE into a hybrid system can, with suitable controls, provide controllable electric power. [8.2.1]

RE can be deployed at the point of use (decentralized) in rural and urban environments, and can be employed within large (centralized) energy networks. RE electricity generation, produced from large hydropower plants, large wind farms, geothermal, concentrating solar power or PV systems has similar transmission and distribution requirements as any other large fossil fuel or nuclear power plant but may be more remote based on the RE resource availability.

Building integrated PV and other forms of distributed energy systems require construction of minimal transmission and distribution infrastructure, when integrated into the grid, and are highly suitable for urban settings. Distributed RE technologies are also suitable for remote rural locations and islands where conventional energy infrastructure is not viable because of low energy demands and high investment costs. Mass produced RE technologies can be readily scaled to meet changing demand as they are modular and installed soon after delivery to a construction site, thereby giving a relatively fast rate of project development. [1.2.1]

RE and energy efficiency work synergistically to lower the energy required to provide each end use energy service by lowering power density demands to match those of RE supply. A disadvantage of many forms of RE is their low power density. Following the idea of suitable “system solutions”, this can best be addressed by lowering the energy requirements needed for the energy services desired. Optimising the interaction amongst energy carriers and energy efficiency options expands the opportunities for the efficient integration of RE into the energy system.

4. Mitigation Potentials

The potential role of RE in addressing climate change depends on various aspects including the rate, magnitude and location of RE project deployment [10.2]. Deployment of low-carbon energy technologies are based on energy policy choices, mitigation goals, and the fundamental drivers of energy demand including population growth, economic growth, and evolution and emergence of end-use technologies that convert energy into useful services. Deployment of RE in different regions of the globe over time depends on how strongly mitigation targets are pursued in different countries and the particular manner in which each country takes action on climate mitigation and other energy-related issues such as energy security. RE deployment rates depend on competition with other low-carbon energy technologies such as nuclear and CCS.

Published scenarios, following significantly different core assumptions, indicate a broad range of future RE deployments *[10.2]*. Meeting long-term climate goals requires a reduction in energy-related GHG emissions and those from other anthropogenic sources including deforestation, agriculture, industrial processes and wastes. As the stringency of a long-term climate goal increases, CO_2 emissions tend to decrease, and low-carbon energy makes up part of the gap. Uncertainty in the magnitude of the energy system, reflected by the wide variation in projected primary energy consumption among scenarios, means there is a large variation in low-carbon energy required to meet any long-term goal. There is also variation in projected RE deployment being only one of several low-carbon options. The projected levels of RE deployment out to 2050 are dramatically higher than those of today in the vast majority of the scenarios reaching between 200 and 400 EJ/yr compared to about 62 EJ/yr in 2007 (Figure SPM 4).

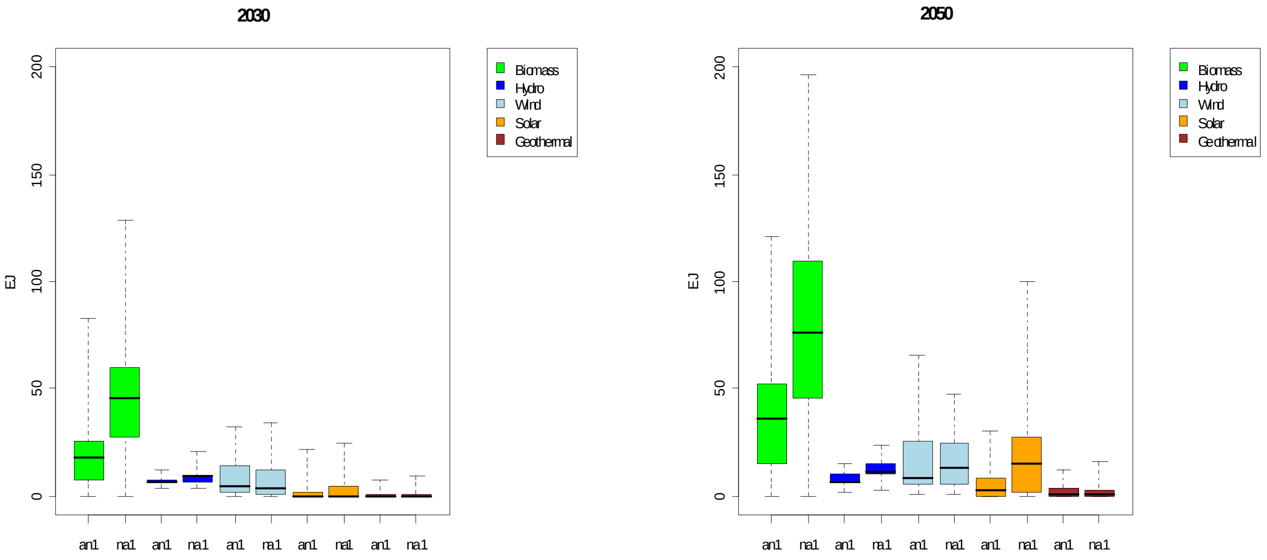

Figure SPM 4: Renewable primary energy consumption by source in Annex I and Non-Annex I countries in the mid- to long-term scenarios by 2030 and 2050. Thick black lines depict the median; coloured box the inter-quartile range (25th-75th percentile); dotted lines the total range across all reviewed scenarios.

Within the context of total RE deployment, there is great variation in the deployment characteristics of individual technologies [10.2]. Based on the scenarios in the available literature, bioenergy is shown to have a higher potential deployment over the coming 40 years than any other RE technology. By 2050, wind and solar are shown to increase more than hydro and geothermal power, while increases in ocean energy are uncertain due to unknown technology developments.

The time-scale for deployment varies across different RE technologies due to differing assumptions about technological maturity. Hydro, wind and biomass show a significant deployment being the most mature of the technologies with solar progressing after 2030 assuming continued successful technology innovations. In reality, deployment of RE technologies is the result of a complex mixture of driving forces (e.g. climate protection, security of energy supply), barrier and energy policies. In the various scenarios, because of the assumptions on technological maturity, some RE technologies (e.g. wind, hydro, direct use of bioenergy) are mostly shown to deploy independent of ambitious climate targets, whereas other RE technologies (e.g. solar, geothermal, commercial biomass) are shown to deploy mostly as the result of the underlying mitigation targets.

The distribution of RE deployment across world regions is highly dependent on the policy structure *[10.2]*. 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 these regions continuing to represent an increasingly large share of total global energy demand, assuming that RE supplies are large enough to support this growth. All other things being equal, and in consideration of environmental and climate related constraints, higher energy demands will require greater deployment of RE sources, highlighting that RE for climate mitigation is an issue for both Annex I and non-Annex I countries as discussed in the UNFCCC context.

Under real world conditions regional distribution of RE deployment depends on the country specific frame conditions [10.2]. In a real-world context, the distribution of RE deployments in the near-term would be skewed toward those countries taking the most proactive actions. Scenarios considering a delayed accession (no early action on climate) in specific countries show, that in those countries from a near to midterm perspective the relative deployments of RE are lower. The effect of delay on RE deployments is ambiguous in the period the countries have begun mitigation. In some cases, deployments are larger in the long-term and in some cases they are lower. This ambiguity is in part because the countries may need to quickly ramp up mitigation efforts by 2050 if action has been delayed but the same long-term climate target is to be met as the case with immediate action.

The competition with other options for reducing carbon emissions affects the deployment of RE technologies *[10.2]*. Nuclear energy, fossil energy with CCS, and RE produce GHG reductions as do more efficient end-use technologies or a reduction in end-use demand. All other things being equal, RE deployment will be lower if other options are more competitive. A review of individual models shows that higher deployment of competing low-carbon supply technologies leads to lower RE deployment (Figure SPM 5).

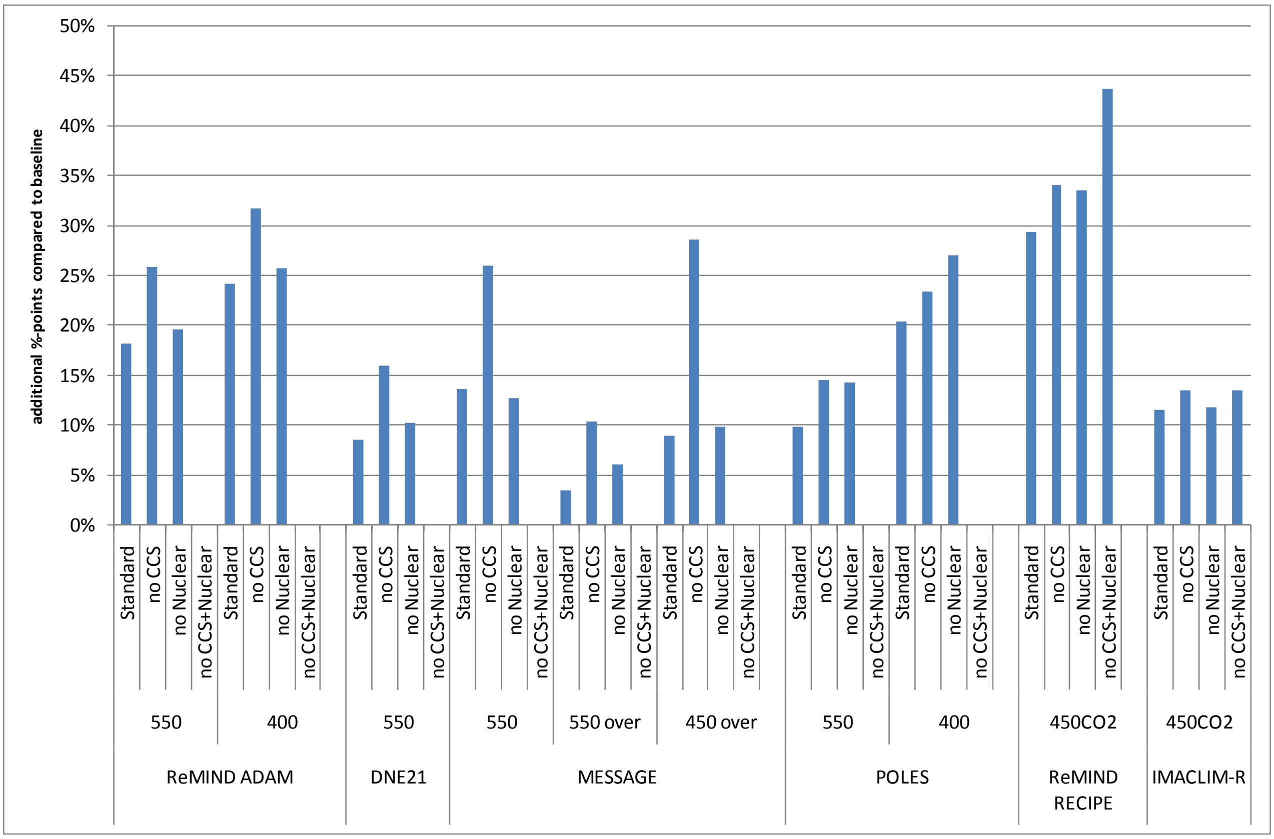

Figure SPM 5: Increase in the global share of RE by 2050 in 1st- and 2nd-best mitigation scenarios compared to the respective baseline scenarios. The exact definition of “no CCS”, “no Nuclear” and “no CCS+Nuclear” varies across models; the magnitude of the increase shows a large spread, mostly because the deployment in the respective baselines differs significantly between the models.

Variations in assessments of RE deployment across scenarios can be attributed to the assumptions made of future competing options, characteristics of RE technologies, fundamental drivers of energy systems(economic growth, population growth, energy intensity, and energy end use improvements) [10.2]. Other aspects (e.g. system integration constraints) may also play a role in determining the future role of RE [8]. As a result, the presence or absence of large-scale deployment of CCS and/or nuclear power are not the only or most critical determinants of future RE deployment.

A regional breakdown for the scope of future RE deployment shows growing shares in every world region and deployment rates significantly lower than their technological limits *[10.3]*. The regional and global energy scenarios found in the literature show a wide range of RE shares in the future. Figure SPM 6 illustrates that aspect for two selected scenarios, one representing a more or less Business as Usual pathway (IEA WEO 2008) and another scenario which follows an optimistic application path for RE assuming that the current dynamic in the sector can be maintained. Even without having reached their full technological development limits, technical potentials are not the limiting factors for the expansion of RE.

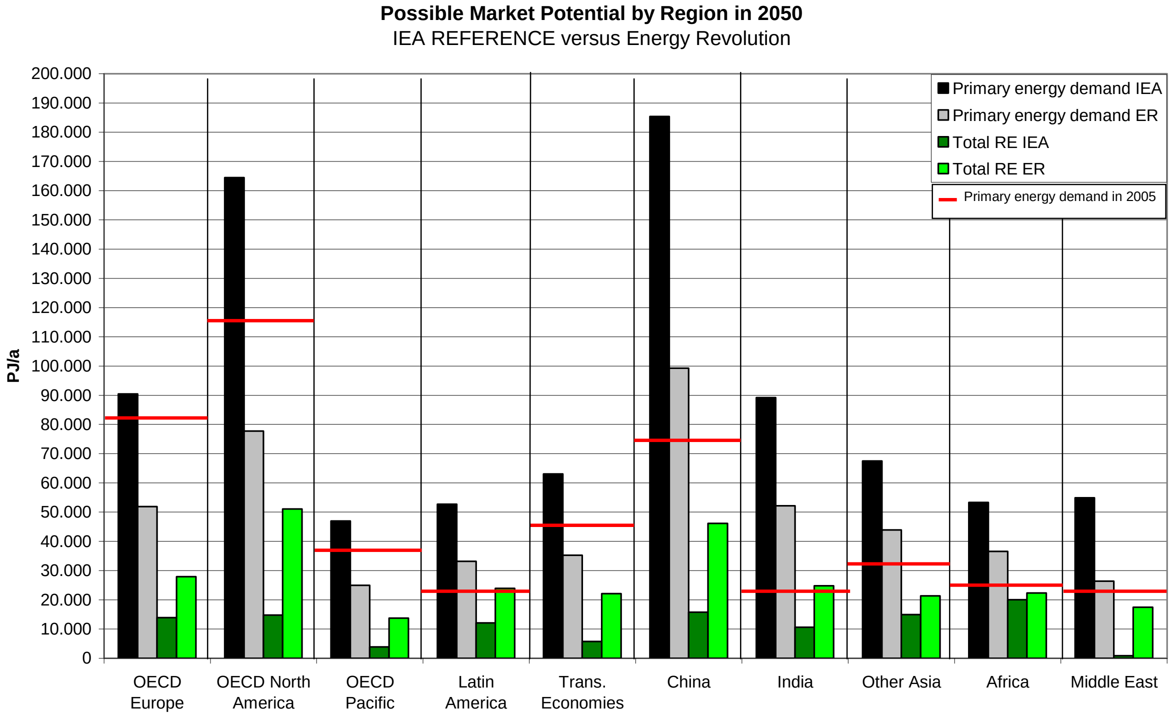

Figure SPM 6. Regional breakdown from possible RE market potential in 2050 for selected scenarios.

5. Renewable Energy Technologies

The technical and market development status of renewable energy varies by source and technology. Many of the RE technologies are technically mature and have already been or are being deployed at a significant scale, while others are in an earlier phase of technical maturity and commercial deployment (Table SPM 1).

Bioenergy: Bioenergy technologies have varying maturities, with some (e.g. domestic pellet based heating systems, small and large scale boilers) at later stage commercial development, others (e.g. gasification-based power plants) at early-stage commercial development, and still others (e.g. algue fuel production) at stages of R&D. Many bioenergy technologies have experienced decades if not centuries of practical application. Of the RE sources, biomass contributes most substantially toward global primary energy demand (10%, or 48 EJ/y, in 2007), representing 3% of primary energy in industrialised countries and 22% in developing countries. The majority of this biomass use (37 EJ/y) is non-commercial: charcoal, wood, and manure used for cooking and space heating, generally by the poorest part of the population in developing countries. Modern bioenergy uses (for industry, power generation, or transport fuels) are growing: in 2008, modern bioenergy contributed approximately 1 EJ (1.4%) of the world's total electricity generation and 2 EJ of heat (mainly via combustion of lignocellulosic materials, such as forest residues). In 2008, 2 GW of biomass electricity capacity was added for a cumulative total of 58 GW by the end of that year. Biofuels production has expanded rapidly since the end of the 1990s, mainly ethanol produced from sugar cane, corn, and cereals, and contributed about 1.5% (1.5 EJ) of transport fuel use worldwide in 2008. [2.1, 2.4, 2.8]

Direct solar energy: Solar technologies have varying maturities, ranging from early-stage R&D (e.g., solar fuels) to later-stage commercial (PV, low temperature solar thermal, and passive solar architecture). The use of solar thermal for hot water has been growing quickly, especially in China

(19 GW_{th} of additions worldwide in 2008, for a cumulative total of 145 GW_{th}, of which more than 70% was in China), while deployment of PV (more than 7 GW of additions in 2009, for a cumulative total of roughly 22 GW) has been strongly motivated by government policy in Europe, the United States, and Japan. Cumulative CSP installations by the end of 2009 were roughly 700 MW, with more than 1,500 MW of additional capacity under construction [3.4].

Geothermal energy: Hydrothermal power plants[3] and thermal applications of geothermal energy rely primarily on mature technologies, whereas EGS projects are in the demonstration and pilot phase; offshore submarine geothermal energy is in the research and development stage. Building on more than a century of commercial experience, by the end of 2009 geothermal power plants totalled almost 11 GW and were located in 24 countries, with six countries using geothermal energy to provide 10% or more of their electricity needs. Direct-use thermal applications of geothermal energy totalled 50 GW_{th} by the end of 2009, while the use of geothermal heat pumps in new and retrofit building applications accounted for 17 GW_{th} by the end of 2009. [4.3, 4.4]

Hydropower: Of the RE technologies used for electricity production, hydropower is the most mature, and leads in installed electricity capacity and production: hydropower additions in 2008 totalled roughly 35 GW, for a cumulative 945 GW by the end of that year and accounting for 16% of the world's total electricity generation. The market drivers for hydropower development include not only energy needs, but also the desire for flexibility in power systems as well as water management systems. In 2006, 43% of hydropower installations were in OECD countries (with most concentrated in Europe, the USA and Canada) and 57% in non-OECD countries (with most in China, Brazil and Russia). Recent growth in hydropower has centred on emerging markets such as China, India, and Brazil, where significant potential remains untapped; in South East Asia, trans-boundary projects have also been developed [5.2, 5.4]

Ocean energy: With the exception of tidal barrages, most ocean technologies are at the demonstration and pilot project (wave, tidal/ocean current, OTEC, and osmotic power) or research and development (marine biomass) stages. Tidal barrages have been in operation since 1966, though current worldwide capacity remains comparatively small with 264.4 MW installed. Several additional projects are under consideration in China, the Republic of Korea, Russia and the United Kingdom that, if implemented, would account for an added capacity of 21.9 GW. Most international R&D is currently focused on wave and tidal current technologies. In total, fewer than 300 MW of ocean energy facilities were operational by the end of 2009. [6.4, 6.6, 6.7]

Wind energy: Modern wind turbines have evolved from small, simple machines to large, highly sophisticated devices, driven in part by more than three decades of basic and applied R&D. As a result, on-shore wind energy technology is already being deployed at a rapid pace in Europe (e.g., Germany, Spain), North America (U.S.), and Asia (China, India), while off-shore wind energy is also beginning to expand but is at an earlier phase of technical and commercial development. From a cumulative capacity of 14 GW by the end of 1999, the global installed wind power capacity increased to almost 160 GW by the end of 2009 (38 GW was added in 2009) and was capable of meeting 1.8% of worldwide electricity demand. From 2000-2009, roughly 11% of global net electric capacity additions came from wind power plants. [7.3, 7.4]

The global technical potential of RE sources will not limit market growth. On a worldwide basis, studies have consistently found that the technical potential for RE is more than an order of magnitude larger than global energy demand (Table SPM 4). A wide range of estimates are provided in the literature, and those estimates are not entirely comparable. Nonetheless, these studies find that the technical potential for solar energy is the highest among the RE sources, but

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[3] Hydrothermal power plants are the most common form of geothermal power plants. They use the heat energy contained in water and steam flowed from geothermal wells to generate electricity.

that substantial technical potential exists for all forms of RE. Though the technical potential for individual RE sources is not evenly distributed across the globe, all regions have substantial technical potential. Even in regions with relatively lower levels of technical potential for any individual RE source there are typically significant opportunities for increased levels of deployment. The absolute size of the global technical potential is unlikely to constrain RE development. Regional resource limitations, sustainability concerns, system integration/infrastructure constraints, economic factors, and other issues are more likely to limit the future use of RE technologies. [2.2, 2.8, 3.2, 4.2 5.2, 6.2, 6.4, 7.2, 10.3]

Table SPM 4. Global Technical Potential of Renewable Energy Sources (compare to global primary energy supply in 2007 of 482 EJ) for 2020, 2030, and 2050 [10.3, 1.2.3].

		Technical 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]	1126	1351	1689	1338	14766	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]	5156	6187	8043	248	10603	Krewitt *et al.* (2009); Chapter 3 reports total range of solar electric potential (PV and CSP) of 1440 to 50,400 EJ/y
	Geothermal	4.5	18	45	1.4	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	1000	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 *et al*. (2001)
Heat (EJ/y)	Solar	113	117	123	na	na	Krewitt *et al.* (2009)
	Geothermal	104	312	1040	3.9	12590	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 *et 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 Kewitt 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)

Climate change will have impacts on the size, geographic distribution, and variability of renewable energy technical potential. Because RE sources are, in some cases, dependent on the climate, it follows that global climate change will affect the RE resource base. Research into the possible effects of global climate change on the size, geographic distribution, and variability of RE technical potential is nascent, but the RE sources likely to be most impacted include bioenergy, hydropower, and wind energy. The technical potentials of biomass are influenced by and interact with climate change, but the mechanics and details of those impacts are still poorly understood. The overall impact of a modest temperature change is likely to be relatively small on a global basis, but strong regional differences can be expected [2.5, 2.8]. For hydropower, climate change is expected to increase overall average precipitation, but regional patterns will vary: precipitation is anticipated to increase at higher latitudes and in part of the tropics, and decrease in some sub-tropical and lower mid-latitude regions. The impact of these changes on river flows and hence on the technical potential of hydropower is subject to a high level of uncertainty: the impact is likely to be relatively small on a global basis, but significant regional changes in river flow volumes and timing are possible [5.2]. For wind energy, research to date suggests that global climate change will alter the geographic distribution of the wind energy resource, but that those effects are unlikely to be of a magnitude to greatly impact the *global* mitigation potential of wind energy [7.2]. For direct solar energy, though climate change is expected to influence the distribution and variability of cloud cover, the overall effect of these changes on the technical potential of direct solar energy is anticipated to be small [3.2]. Climate change is not expected to have significant impacts on the size or geographic distribution of geothermal and ocean energy resources [4.2, 6.1, 6.2]. However, for all of the RE technologies, climate-induced extreme weather and climate events we well as instable water regimes will need to be considered in project and technology design.

Currently, the levelized costs of energy*[4] *(LCOE) are higher for the majority of RE technologies than for fossil fuel-based energy services (See Figure SPM 7). More mature RE technologies are often competitive at current prices without financial government support. Less mature technologies can also provide competitive energy services in some cases, e.g. in regions with favourable conditions like high quality resources, a lack of energy infrastructure, and/or limited availability of alternatives. Table SPM 5 provides ranges of current LCOEs for commercially available RE technologies at varying discount rates.

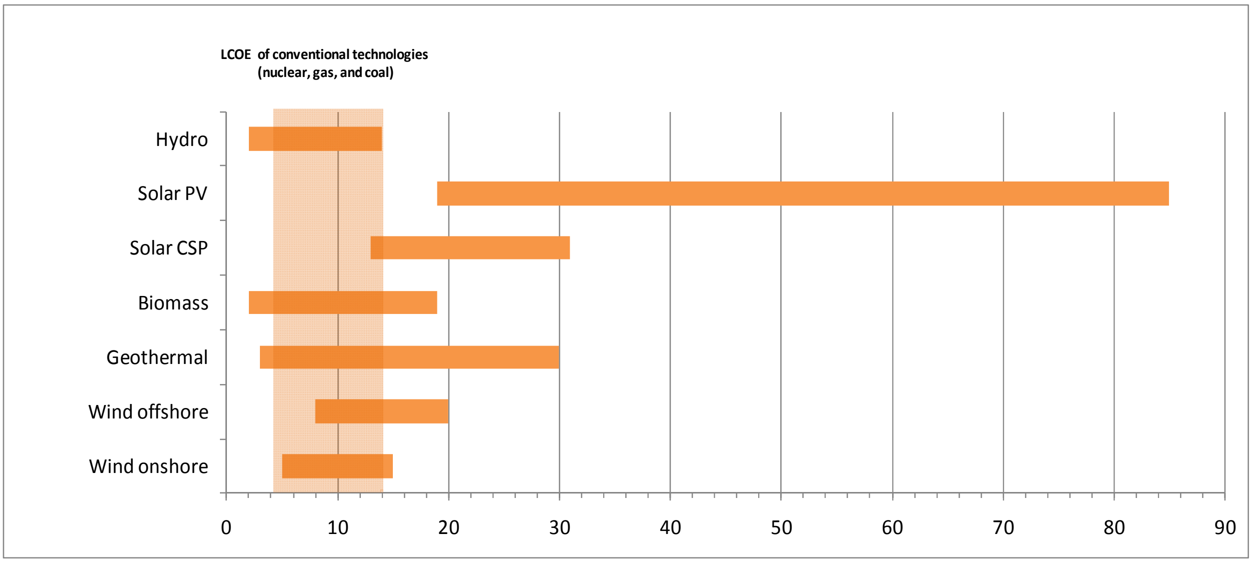

Figure SPM 7. Cost-competitiveness of selected renewable power technologies [10.5.1].

Notes: The figure is based on IEA data and updated by cost data collected for the IPCC SRREN (this report). The LCOE are given in US-cent/kWh, and have been calculated at a 10% discount rate. LCOE of conventional technologies depict the range valid for North America, Europe, and Asia Pacific. For OECD countries a future carbon price of US$ 30/t CO_2 is assumed. [Authors: This figure will be updated to clearly present which numbers originate from the IEA and which from the IPCC SRREN as are reflected in Table SPM5.]

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[4] The LCOEs of technologically identical devices can vary across the globe. They depend on the quality of the resource (which affects the capacity factor), regional investment costs including material and labour costs of construction, on the cost of financing (which affect the appropriate discount rate), and – to a lesser extent – the cost of operation and maintenance.

Table SPM 5. **Levelized Cost of Energy (2005 US$/kWh) for various RE sources**[5]**.**

Source	**RE technology**	**LCOE at 3%**		**LCOE at 7%**		**LCOE at 10%**		**Learning Rate (%)**	
		lower bound	***higher bound***	***lower bound***	***higher bound***	***lower bound***	***higher bound***	***lower bound***	***higher bound***
Direct Solar Energy	**PV, res roof**	0.20	0.50	0.31	0.69	0.40	0.85	11	26
	PV, com roof	0.17	0.46	0.26	0.64	0.34	0.79	11	26
	PV, fixed tilt	0.11	0.25	0.17	0.34	0.22	0.42	11	26
	PV, 1-axis	0.10	0.28	0.15	0.38	0.19	0.47	11	26
	CSP	0.11	0.19	0.16	0.25	0.20	0.31	5	15
Geothermal Energy	**Condensing-flash**	0.03	0.08	0.04	0.11	0.04	0.13	n.a.	n.a.
	Binary-cycle	0.03	0.11	0.04	0.14	0.05	0.17	n.a.	n.a.
Hydro	**all**	0.01	0.06	0.02	0.08	0.02	0.11	0.5%	2%
Wind Energy	**On-shore, Large**	0.04	0.09	0.05	0.13	0.06	0.15	10	17
	Off-shore, Large	0.07	0.12	0.10	0.16	0.12	0.20	n.a.	n.a.

Note: The following default assumptions were made to define the LCOE if data were unavailable:
time of construction - one year, no production during that year
O&M costs - *constant over lifetime*
production - *start after commissioning at (nameplate capacity x capacity factor)*
lifetime - *excludes years of construction*
retrofit or other major costs during regular lifetime -*assumed to be included as annuity in O&M costs, i.e., constant costs after construction*
decommissioning - *costs not included in LCOE*
Lower bound = lower bound of capital and O&M cost, higher bound of capacity factor (CF) and lifetime
Higher bound = higher bound of capital and O&M cost, lower bound of CF and lifetime

The costs of energy generated by renewable energy technologies have declined over time and are expected to decline further*. *Continued technical improvements will increase the potential for GHG reductions from renewable energy over time as costs decline. Technical advancements over the last decades have been substantial, driven by public and private R&D as well as deployment-oriented learning. Learning rates are widely used as estimates for future cost reductions[6] (See Table SPM 5). Technical advancements are expected to lead to continued cost reductions in the years ahead, resulting in greater potential for GHG reductions.

Bioenergy: Technological learning and related cost reductions have been substantial for bioenergy cropping systems, supply systems and logistics, and conversion. As a result, there are several bioenergy systems, most notably sugar-cane based ethanol production and heat and power generation from biomass residue/waste that are already deployed at a competitive prices. Depending

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[5] Some bioenergy technologies are commercially available. However, these technologies have not been included in the table due to great variations based on local conditions, biomass supply and other factors. [Authors: Efforts will be made to include comparable bioenergy costs in this table in subsequent revisions.] For a discussion of bioenergy costs see Chapter 2.
For technologies that are not yet commercially available, there are no historical reference data that allow for a balanced selection of cost-performance parameters to calculate LCOEs. Therefore, LCOEs have not been derived for technologies that are still in the pre-commercial phase, such as enhanced geothermal systems and most ocean energy technologies. Estimates of cost-performance parameters expected for projects using current technologies and current costs of input factors (projected costs) are presented and discussed in the relevant technology chapters.
[6] Learning rates may be estimated for different periods in time, different regions and for different performance measures.

on market conditions, other smaller-scale bioenergy applications can cost-effectively contribute to rural poverty reduction. Further improvements in power generation technologies, biomass supply systems, and perennial cropping are anticipated, reducing the cost of biomass electricity and heat. With respect to second-generation biofuels, recent analyses have indicated that advancements by roughly 2020 may allow these technologies to compete with oil prices of 60-70 U$/barrel. [2.7]

Direct Solar Energy: Historically, every doubling of cumulative production of PV modules has led to a reduction in module costs of 13-26% and future technical advancements are expected through reduced material use, new semiconductor materials, and improved manufacturing techniques. Further cost reductions of solar technologies in line with the known learning curves for solar PV and CSP are anticipated as the technologies mature [3.7].

Geothermal Energy: EGS cost estimates range from 75 to 175 US$/MWh for resources at 4 to 5 km depth and 200-330°C. The cost of hydrothermal power plants is anticipated to decline by about 10-15% by 2050; EGS cost reductions are expected to be more significant, at perhaps 50% by 2050, assuming a reduction in drilling costs through learning effects and success in developing stimulation technology. The capital investment for direct-use applications ranged from 1200 to 2700 US$ per installed thermal kilowatt in 2008. [4.7]

Hydropower: As a mature technology, further cost advancements for hydropower are likely to be less significant than some of the less-technically-mature RE technologies. Nonetheless, there is substantial potential[7] for improving the performance and extending the life-time of existing hydropower plants through plant refurbishment. Research is also being conducted to make hydropower projects technically feasible in a wider range of natural conditions, reduce costs, and improve environmental performance. [5.3, 5.7, 5.8]

Ocean Energy: R&D on ocean energy did not really begin until the 1970s and developments remained halting until the turn of the 21st Century, at which point R&D investment accelerated. A diverse set of technologies is under consideration, and the most cost-effective technical solutions are not yet clear; as a result, the cost of ocean energy technologies is currently higher than many of the other RE sources. Based on the current technologies and related costs[8], wave energy is forecast to have an LCOE of US$214–788/MWh, whereas tidal current energy is forecast to have an LCOE range of US$161–321/MWh. Older forecasts for OTEC plants range from US$160–200/MWh for early commercial plants, and recent forecasts for early salinity gradient plants range from US$670–1,340/MWh. As niche markets develop for these technologies (e.g., remote communities and islands), and as public and private R&D continues, costs are forecast to decline. [6.6, 6.7]

Wind Energy: Continued incremental advancements in on-shore wind energy technology are expected to yield improved design procedures, increased reliability and energy capture, reduced O&M costs, and longer turbine component life. Even greater technical advancement possibilities exist for off-shore wind energy, and fundamental research to better understand the environment in which wind turbines operate is expected to yield benefits for both on- and off-shore wind energy technology. Available literature suggests the possibility of reductions in the LCOE of on-shore wind energy of 15-35% and off-shore energy of 20-45% by 2050. [7.7, 7.8]

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[7] Over the past decade, orders received for the refurbishment of hydropower plants have been in the order of 10,000 MW/yr, or roughly 1% of existing global capacity. Refurbishment yields an estimated efficiency increase of 5%, corresponding to an increased production of 1500 GWh/year worldwide with the same amount of water. A major refurbishment will typically extend the life time of a hydropower plant by several decades.

[8] LCOEs presented here for ocean energy are not based on historical data, but forecasts. Since the underlying assumptions, including but not limited to the applied discount rates, are not transparent, these estimates are not readily comparable to LCOEs listed in the table.

Technical and market barriers will need to be addressed to achieve high levels of renewable energy deployment. RE offers significant potential for near- and long-term GHG emissions reductions, but a variety of technology-specific barriers would need to be overcome to achieve that potential (see below). In general, potential deployment levels of RE technologies may be influenced by a number of factors. Regionally, economic development and technology maturity are primary determinants: for mature technologies (e.g. hydropower) much of the available potential in OECD countries has been exhausted and the largest future expansion is expected in Non-OECD countries. Other, less mature technologies will likely initially focus on expansion in affluent regions where financing conditions and infrastructure integration are favourable. The need for cost and technological advancements varies according to the maturity of a given technology. For large-scale deployment of some technologies, integration and supply chain considerations may also be relevant. [10.2.3]

Bioenergy: Though still uncertain, competitiveness of biomass use for fuels and feedstock materials is expected to strongly improve over time, providing a push for biomass into energy markets in the longer term. A key precondition for the increased use of bioenergy is the application of well functioning sustainability frameworks and strong policies that avoid conflicts with food production, biodiversity, water and socioeconomic developments. Land-use planning, the alignment of bioenergy production with efficiency increases in agriculture and livestock management, and the use of degraded lands are especially important in this regard. Well developed logistical capacity for bioenergy markets and the facilitation of international bioenergy trade would also be important, as would further technical advancements especially for next-generation biofuels and biorefineries; analyses indicate that if R&D and near-term market support are offered, technological progress could allow for competitive 2nd generation biofuel production around 2020. [2.2, 2.7, 2.8]

Direct Solar Energy: The main barrier to the widespread use of direct solar energy is the current higher cost of certain solar technologies (PV, CSP and in some countries solar heating and cooling): further cost reduction through R&D and learning-based experience are therefore especially important. Regulatory and institutional barriers can also impede deployment, particularly for smaller, decentralized solar energy systems; to widely implement decentralised solar electricity, a different paradigm for electric system infrastructure may be needed. The deployment of passive solar technologies depends heavily on spatial planning and building codes. [3.9]

Geothermal Energy: Technical improvements, if successful, have the potential during this century to enable a two orders of magnitude increase (up to more than 1,000 GWe in 2100 from 11 GWe in 2009) in the use of geothermal energy. Achieving that result, however, will require sustained support and investment from governments and the private sector. The most important R&D challenge for geothermal is to prove that EGS can be deployed economically, sustainably, and widely; social and environmental concerns will require careful attention, including concerns about induced local seismicity for early EGS plants. Improvements in the delivery infrastructure and additional technical improvements are also important for more widespread utilization of geothermal heat in direct use applications. [4.6, 4.8]

Hydropower: The potential exists to triple the contribution of hydropower in worldwide electricity supply. As hydropower is already a mature and cost-effective RE technology, the technical and economic challenges facing such developments are limited. New hydropower projects are sometimes controversial, however, and environmental and social concerns may limit growth; benefits therefore exist in further developing sustainability assessment tools for hydropower projects. Enhanced regional and multi-party collaboration can also help in meeting energy supply and water resources management needs.[5.6, 5.9, 5.10]

Ocean Energy: Deployment of ocean energy is likely to accelerate as R&D continues and commercial maturity is achieved. In the near term, growth in tidal barrage capacity is anticipated, with tidal current and wave/swell devices moving towards commercial maturity. In addition to continued R&D investments, the deployment of ocean energy will benefit from testing centres for demonstration and pilot projects and from dedicated policies that encourage the early deployment of the technologies. [6.4]

Wind Energy: Studies suggest that the rapid recent increase in global wind power capacity is likely to continue in the near- to medium-term. By 2050, global wind electricity supply could reach or even exceed 20% of total electricity supply if ambitious efforts are made to reduce GHG emissions. Achieving this level of wind energy supply 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 the social and environmental concerns associated with wind energy deployment. [7.8]

6. Integration of RE into current and future energy supply systems

To achieve greenhouse gas stabilisation levels at around 450 ppm, high levels of RE penetration will need to be integrated into existing electricity, heating, cooling and transport energy supply systems to displace some future fossil fuel demand across all sectors (Figure SPM 8). To achieve this will require around double the present annual rate of deployment of all RE technologies.

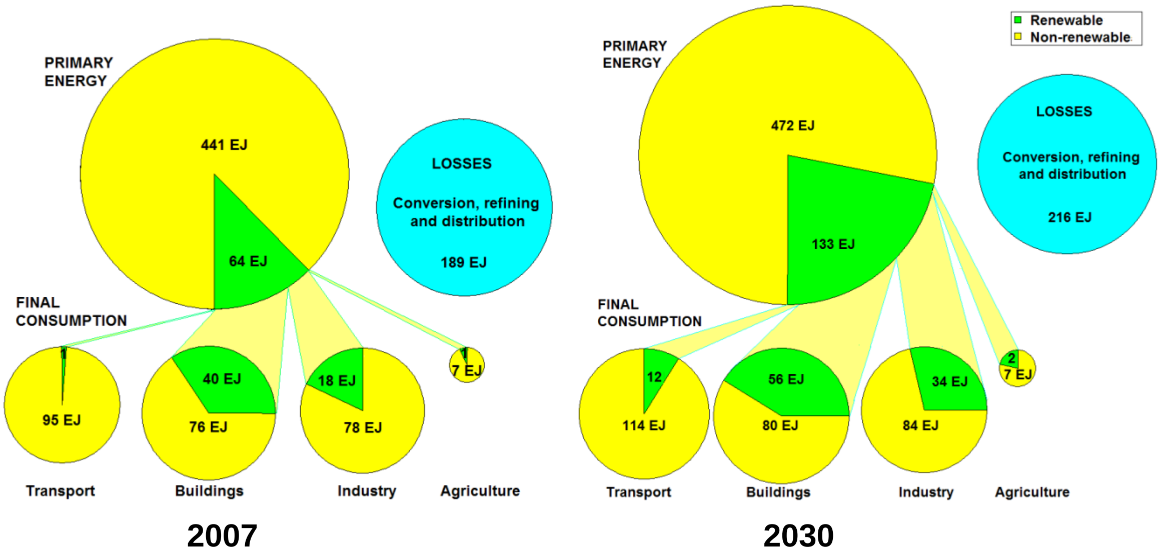

Figure SPM 8. RE shares (including traditional biomass) of primary energy and final consumption in the transport, buildings, industry and agriculture sectors in 2007 and an indication of the increasing shares needed by 2030 to meet a 450ppm scenario. [8.1]

[Authors: this figure will be updated to include WEO 2010 data and an attempt will be made to include other scenarios as reflected in SPM 3. Mitigation Potentials. It will also be amended to use the direct equivalent method for calculating primary energy. These changes are unlikely to change the RE shares as shown to any significant degree.]

Increased RE penetration through integration into existing energy systems is technically feasible in most regions, but reaching much higher levels than today could be constrained by cost, lack of infrastructure investment, societal acceptance, appropriate policy framing and lack of trained personnel as well as competition from other low-carbon technologies (including nuclear and carbon dioxide capture and storage) [8.1].

Over the long term, as related infrastructure and energy systems develop through system integration, there are few, if any, technical limits to developing a portfolio of RE technologies to meet a significant share of total energy demand in regions where suitable resources exist. A well-designed portfolio could enhance energy system reliability, security of supply, and provide improved access to energy services in both developed and developing countries. [8.1]

However, competition between RE systems to meet local and regional energy demands could reduce the future deployment potential for any single technology (for example, transport powered by either liquid biofuels, biomethane, hydrogen or electricity [8.3.1], or heating/cooling demands being met by bioenergy, solar thermal or ground source heat pumps installed in buildings competing with district heating schemes or electricity. [8.2.2]

Improved energy end-use efficiency, together with flexibility in the time of energy use in the transport, buildings, industry and agriculture sectors can facilitate greater shares of RE supply since local RE resources may then be sufficient to better meet local energy demands. [8.3]

Building-integrated RE technologies in urban or rural locations provide the potential for buildings to become net energy suppliers rather than net energy users. [8.3.2]

RE uptake can be increased in all final end-use sectors (Figure SPM 9) both directly (by utilising solar, bioenergy, and geothermal technologies integrated with new or existing buildings or into industrial processes) and indirectly (where, an increased share of RE sources can be integrated into grid-based energy carriers such as electricity, district heating, district cooling, liquid fuel blends, and biomethane and hydrogen in gas grids). [8.2.3, 8.2.4]

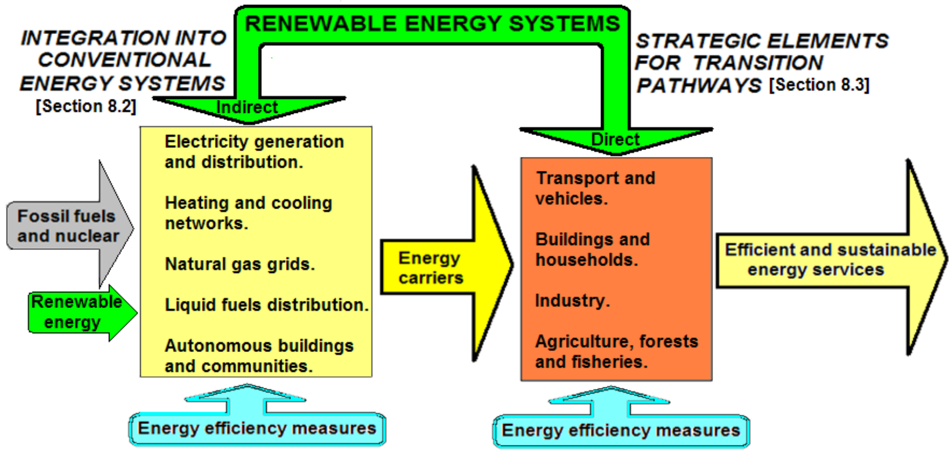

Figure SPM 9. RE sources, additional to those presently being utilised in conventional energy systems, can be utilised directly on site by end-use sectors or indirectly through enhanced integration into energy carriers.

The readily acceptable limit to the share of RE integrated into a specific energy system depends upon the existing system design (for power supply being either distributed, centralised, autonomous or inter-connected), its present operation, scale, local RE sources available, proportion of variable resources, cost-competitiveness of present technologies, social aspects, public perception and future developments. [8.2]

Electricity from RE sources are either variable (wind, ocean and solar PV) or dispatchable (reservoir hydro, bioenergy, CSP and geothermal). Experience from managing wind penetration in some countries confirms that integrating large shares (>20%) of variable sources in existing power supply systems requires designing a more flexible and intelligent grid together with a mix of generation technologies and corresponding dispatch methods (aided by short-term forecasts). The aim is to maintain a reliable system balance and secure operation at all times, therefore avoiding possible increased system operating costs.

Solutions to minimise integration costs can include investment in more transmission, stronger and inter-connected grids, improved market and system management, including the use of a wide range of existing and potential future demand response options, better RE resource forecasts that can help provide a smoothing effect, and making the system more flexible overall. Energy storage is more important to balance autonomous systems and isolated grids than it is for inter-connected grids. [8.2.1, 8.2.5]

District heating and cooling systems offer flexibility with regard to the primary energy source and can therefore use low grade RE inputs (such as geothermal heat), or heat with no or few competing uses (from industrial processes, bioenergy heat from cogeneration, or combustion of biomass derived from wastes and residues). [8.2.2]

Integrating biofuels with liquid transport fuels and injecting biomethane or hydrogen into gas distribution grids can be successfully achieved and used for a range of applications if appropriate standards can be met. [8.2.3, 8.2.4]

Additional costs of integration depend on the character of the existing system, the RE sources available, how a specific system evolves and the level of penetration. Due to the complexity of integrating RE into individual systems, it is difficult to obtain “typical” system costs and benefits in general terms from the literature. In addition, any changes in costs may not be easily attributed to a specific RE investment. [8.2]

7. Policies for advancing RE deployment

Various market failures, policy failures and barriers impede RE deployment [1.5; 11.4]. Market failures that impede RE deployment may include un-priced environmental impacts and risks, underinvestment in invention and innovation and the existence of monopoly powers in actual markets, limiting competition among suppliers or demanders, free entry and exit.

When directed to boost non-RE systems and technologies, existing policies and regulations can act as barriers to RE deployment. Government policies enacted to promote RE technologies can have negative impacts and slow the transition to a low-carbon energy economy if they are poorly formulated, inappropriate, inconsistent, or too short-term.

Barriers to RE deployment are unintentional or intentionally constructed impediments made by man. They may be categorized into the following: information and awareness barriers (e.g. a lack of consensus on the best way for a low-carbon energy transition to proceed, a lack or knowledge about best-practice for RE deployment, or a lack of knowledge about the risks of investment); socio-cultural barriers; technical and structural barriers; and economic and institutional barriers [1.4, 11.5.1]. Issues - distinct from barriers – are natural properties that impede the application of some RE sources at some place or time (e.g. flat land impeding hydropower, the inability to collect direct solar energy during dark hours) [1.4].

Comprehensive supporting policies for RE address specific barriers that hinder RE deployment; penalise negative externalities; reward positive externalities; stimulate RE innovations; and enhance international cooperation [11.5].

Targeted RE policies accelerate RE development and deployment. Public RD&D combined with deployment policies have been shown to drive down the cost of technology and sustain its deployment. Steadily increasing deployment allows for learning, drives down costs of RE technologies through economies of scale, and attracts further private investment in R&D, thereby creating virtuous cycles of technology development and market deployment.

Policy design can vary greatly and depends on the specific target or goal of the policymaker. Some policies support the deployment of one particular RE technology in a specific area. Others address all RE options in a country, region, or regional sub-grouping[9]. Policies can be weighted toward GHG emission reduction, diversification of energy sources (e.g. developed countries), or toward giving populations access to modern and clean energy sources (developing and underdeveloped countries).

The way countries design their RE policies depends on their specific circumstances. Some countries (e.g. Brazil, Germany, China, Vietnam and South Africa) have intertwined RE policies with industrial development initiatives to create niche markets and pull new RE technologies through the innovation cycle; and other countries (e.g. Nepal, Vietnam) have linked RE policies with decentralization and rural development initiatives.

Though links exist between climate and RE policy, supporting policies for RE are still necessary [11.2; 11.5] At least two broad policy approaches are required to address the major market failures of climate change: 1) carbon pricing (by carbon trading, carbon taxes, or implicitly through regulation) and 2) support for research and development and diffusion of a low-carbon technology.

Carbon pricing at levels that encourage behavioural change is necessary, but not a sufficient tool to give a low-cost transition to a low-carbon economy. There are three reasons to support RE alongside climate-change policy. First, governments have not yet implemented ‘ideal’ carbon pricing or ‘ideal’ low-carbon technology support. Second, even if governments were to implement ‘ideal’ carbon pricing and ‘ideal’ development support, there are a range of other relevant market failures (e.g. financial market failures, oligopoly and imperfect competition, etc.) that might justify additional intervention. Finally, RE yields a range of other non-market benefits (e.g. reduction in local air pollution, health benefits) relative to fossil-fuel based energy production. Without public policy to account for these benefits, RE deployment may remain low.

Successful policies are well-designed and – implemented, conveying clear and consistent signals. Successful policies take into account available RE resources, the state and changes of the technology, as well as financing needs and availability. They respond to local, political, economic, social, financial, ecological and cultural needs and conditions.

For these policies to be successful requires:

- a fair rate of return to attract investment, create strong industries, drive down costs and sustain a steadily growing market;
- the removal of economic and non-economic barriers to RE;
- a viable, predictable, clear and long-term government commitment and policy framework;
- appropriate incentives that guarantee a specific level of support varying with technology and its level of maturity;
- a combination of different types of instruments (regulatory, fiscal, etc.) to address range of barriers;
- flexibility to learn from experience, including mistakes, and to adapt policies as circumstances (technologies, market conditions, etc.) change;
- acceptance of RE on all levels as the density of RE projects increases.

Policy performance needs to be evaluated for ‘learning’ to be captured and incorporated into the designing and implementation of RE policies. Criteria of effectiveness and efficiency can establish whether policies accord with political realities, local values, administrative and other capacities for implementing the policies. Follow-up and understanding of progress and performance, successes

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[9] The Pacific Islands for example.

and failures enable learning to take place and feed iterative improvements in design and implementation.

There is more than 30 years of experience with policies targeted to overcome RE uptake and investment constraints on capacity, R&D, and infrastructure necessary for integrating RE in existing energy systems. Some have proven efficient and effective, others have not. There is substantial literature to facilitate understanding of the effectiveness, efficiency and equity aspects of policies supporting RE power generation but less so for transport, heating and cooling.

Well-designed RE policies are more likely to emerge and to function most effectively in an enabling environment[10]**.** [11.6]**.** Increasing the deployment of RE technologies depends on the coordination of policies and the components of an enabling environment (See Figure SPM 10). Governments, the private sector, research and NGO organizations help to make an environment enabling for RE by creating the education, institutional and investment capacity and mechanisms necessary to overcome barriers and stimulate technology diffusion.

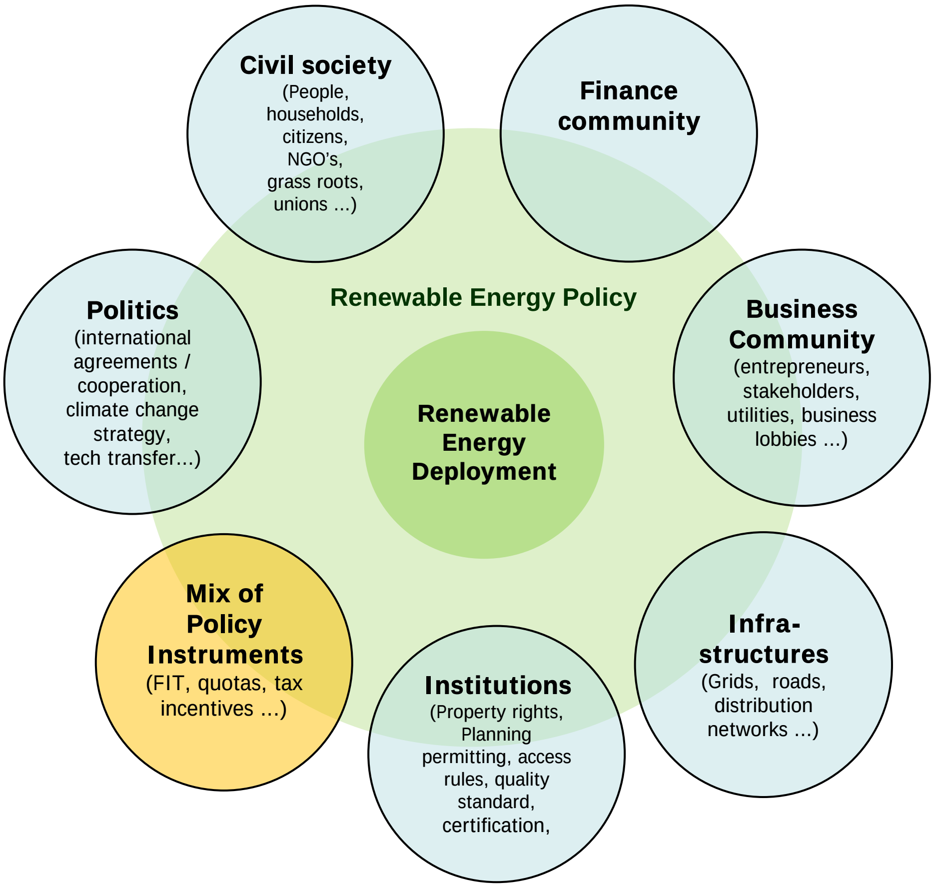

Figure SPM 10. RE technology is embedded in an enabling environment, in which RE policy instruments is one decisive dimension of many.

Accelerated deployment of RE may be facilitated by new international public and private partnerships and cooperative arrangements of multiple stakeholders. [11.2, 11.1, 11.6]. Bringing energy, environment, land planning, NGOs, experts, pressure groups and other stakeholders such as members of civil society, into a common policy network makes it easier for institutions to generate

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[10] An enabling environment is a network of institutions, social norms, infrastructure, education, technical capacities, financial and market conditions, laws, regulations and development practices that in concert provide the necessary conditions to create a rapid and sustainable increase in the role of RE sources in local, national and global systems [11.6].

institutional learning[11] thereby enabling policy making to become more comprehensive and reflexive, and enabling policy adaptation to better respond to local needs and conditions.

New suitable finance mechanisms on national and international levels, involving cooperation between the public and private sectors, work to stimulate technology transfer[12] and worldwide RE investment as well as advancing the necessary infrastructure for RE integration. The role of governments in providing not only a supportive policy environment, but also funding, fiscal policies, and the establishment of standards and regulation, is a critical element [11.6.6].

Strong political support and predictable and sustained regulatory commitment to RE deployment reduces risk for investors and often results in greater RE deployment. [11.6.2; 11.6.4; 11.2.3]. Policies that are well-designed and predictable, providing clear and long-term market signals, encourage greater levels of private investment, thereby reducing the amount of public funds required to achieve the same level of RE development and deployment.

In developed countries, governments can play a role in reducing the cost of capital and improving access to capital by mitigating the key risks, particularly non-commercial risks that cannot be directly controlled by the private sector. Given the budgetary constraints facing most developing country governments, additional funding may be necessary in those countries to underwrite the costs of low-carbon policy frameworks [11.7].

Spatial/land use planning and permitting play an important role in the sustainable deployment of most RE technologies. They provide rules and procedures to address differences in perspectives and interests that often become manifest in the process of developing a specific RE project. [11.6.5] Planning and permitting frameworks reflect historically evolved ‘ways of doing’, with huge differences between countries, such as traditions of administrative coordination between different levels of government [11.6.5.2; 11.6.5.3].

Many existing planning and permitting systems have not been tailored to RE technologies. [11.6.5.1]. Existing evidence points at the need for planning and permitting systems to become pro-active - anticipating rather than reacting to the emergence of new RE technologies – as well as place- and scale-sensitive. In order to support the deployment of RE, they should account for timely local participation, collaborative networking, co-construction of plans and should identify multiple benefits and benefit-sharing mechanisms in relation to local needs, concerns and expectations [11.6.5.4].

Social innovation[13] may be a key factor for supporting the emergence and the deployment of RE and adapting it to local contexts [11.6.1]. Technical options alone cannot successfully drive the transition from energy-intensive, mainly carbon-based societies to low energy-intensive, non-carbon-based societies. Preferences for consumption patterns depend on values, culture, lifestyles, incomes, and more non-technical attributes. Drastic reductions in carbon and energy intensities paired with adapting activities imply the active involvement of citizens. The transitions to low-carbon energy systems are systemic and evolutionary social processes. This implies important changes in societal activities, practices, and institutions with public policies driving the transformations.

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[11] Institutional learning comes about through developing knowledge or an understanding of how to undertake a successful process as a result of actively constructing and re-constructing processes of social interaction. It is a process that develops over time and incorporates learning from past mistakes.

[12] Technology transfer is the flow of technologies and know-how within and between countries resulting from a variety of arrangements and exchanges, including international trade, overseas development assistance, foreign direct investment, international exchanges and cooperation in scientific and technical training.

[13] Social innovation is the ability of people and/or institutions to change the way in which they do things.

Changes in energy using behaviours have mostly been targeted through education and information policies. Their effectiveness often depends on contextual factors, emphasizing the role of social networks as well as the consistency of RE policy frameworks in sustaining changes in individual habits [11.6].

8. Knowledge Gaps

Due to the site and technology specific nature of RE, and the complexity of energy system transitions, knowledge gaps exist primarily with regard to regional potentials of RE sources, particularly in developing countries, costs of and enabling frameworks for integration of large shares of (variable) RE into existing and future energy systems, the impacts of climate change on RE resources, the social and environmental impacts of RE (relative to other energy technologies), and policies and financial mechanisms to enhance RE development and deployment particularly in developing countries.

Specific knowledge gaps identified by this report include:

- Regional assessments of RE potentials, particularly in developing countries, including efficient tools for the identification of suitable locations and forecasting tools for optimal integration and operation [1, 7, 11]
- Potential future impacts of climate change on regional RE resources [2.2, 3.2, 4.2, 5.2, 6.2 7.2].
- Coherent sets of actual primary and secondary energy data and technical potentials [1]
- Assessment of the energy demand side in developing countries [11]
- Information on the physical characteristics of the environment in which RE technologies operate. For individual RE technologies this could help 1) reduce the cost of RE by facilitating innovative installation strategies and the introduction of less costly and more reliable technology; and 2) assess RE resource potential, as for some technologies the improvement of weather models and validation with measurements are necessary to provide accurate assessment of locations where RE generation could be attractive; this is particularly important for developing countries where measurements are sparse and computer models may provide the primary assessment of potential RE production [7].
- Improved measurement and forecasting of energy output variability of variable RE resources over time horizons ranging from milliseconds to years [7].
- Tools and information to determine RE mitigation potential and support decision making over short time horizons that explicitly address all existing policies and regulations, such as market outlooks or shorter-term national analyses (global integrated assessment models cannot provide sufficient information for short time frames, better suited to medium-long term assessments) [10].
- Information to accurately determine, in any time frame, the real mitigation potentials of RE [10].
- Adequate representation of RE potentials and contributions outside the power sector, and of distributed RE structures [1].
- Coherent sets of cost data for RE integration options [1], including comparative assessments. [8.2]
- Consistent low-carbon portfolios to determine options that create synergy, and options that are conflicting [11].

- Better understanding of the social and environmental impacts of RE technologies, relative to other energy technologies, and approaches to assess, minimize, and mitigate those impacts [7, 11].
- Reliable estimates of net GHG emissions of RE technologies, in particular of some biomass based energy technologies and large hydropower dams in the tropics [2.5, 5.6].
- A good taxonomy of (positive and negative) attributes, in particular externalities, of RE supplies [11]
- A good nomenclature of RE supplies (= sources X technologies) [11]
- Qualification of RE supplies based on the above two taxonomies on one or more sustainability indicators [11]
- Systemized information and coherent evaluations of policies and instruments to enhance access to energy services based on RE for the poor [11]
- Systematized information on financial mechanisms to develop RE in developing countries [11.2.3]
- Assignment of responsibilities for RE technology transfer and development in/to developing countries (under the UNFCCC) [9]
- Better understanding of social and institutional processes behind the development and deployment of RE technologies, including the comparison of national and local experiences with the various RE sources [11]
- Better understanding of the role of planning and permitting processes and of their articulation between the international, national and local levels [11]