INTERGOVERNMENTAL PANEL ON climate change

Summary for Policymakers

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Summary for Policy Makers

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1. Introduction

The Working Group III Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) presents an assessment of the literature on the scientific, technological, environmental, economic and social aspects of the contribution of six renewable energy (RE) sources to the mitigation of climate change. It is intended to provide policy relevant information to governments, intergovernmental processes and other interested parties. This Summary for Policymakers provides an overview of the SRREN, summarizing the essential findings.

The SRREN consists of 11 chapters. Chapter 1 sets the context for RE and climate change; Chapters 2 through 7 provide information on six RE technologies, and Chapters 8 through 11 address integrative issues (see Figure SPM.1).

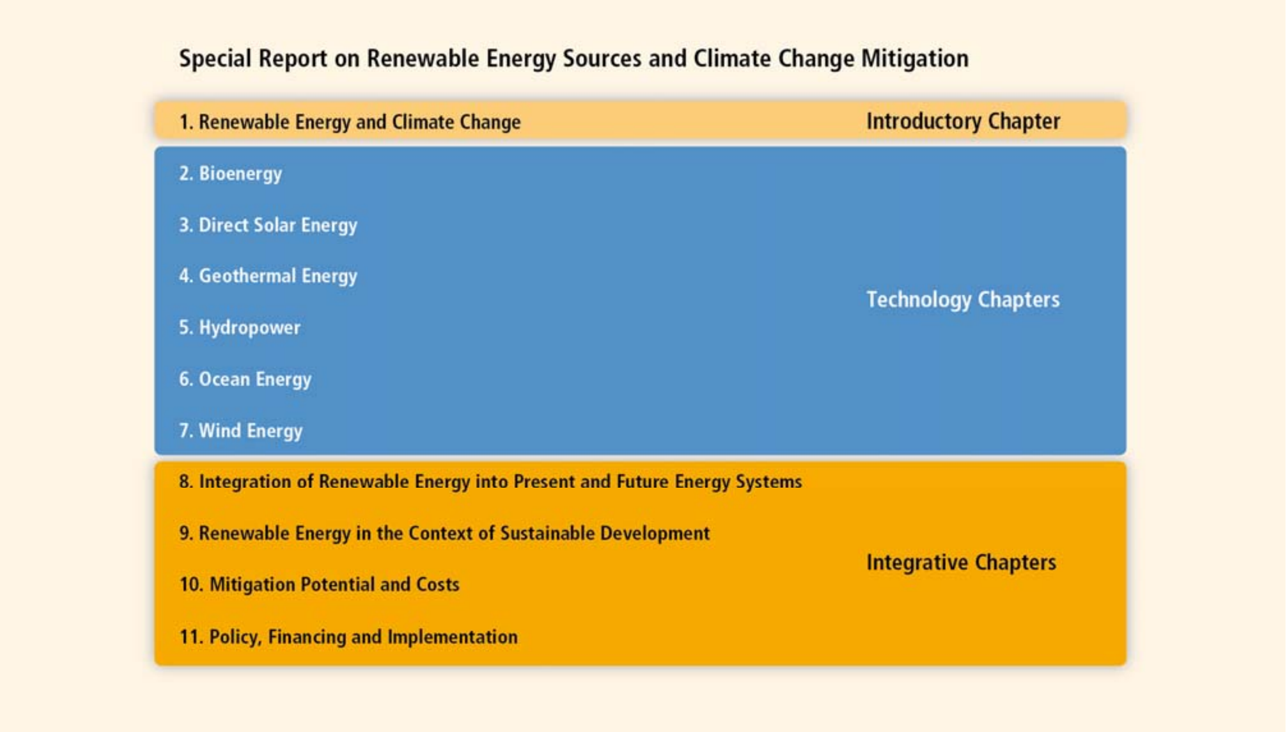

Figure SPM.1 | Structure of the SRREN [Figure 1.1, 1.1.2]

References to chapters and sections are indicated with corresponding chapter and section numbers in square brackets. An explanation of terms, acronyms and chemical symbols used in this SPM can be found in the glossary of the SRREN (Annex I). Conventions and methodologies for determining costs, primary energy and other topics of analysis can be found in Annex II and Annex III. This report communicates uncertainty where relevant.[1]

2. Renewable energy and climate change

Demand for energy and associated services, to meet social and economic development and improve human welfare and health, is increasing. All societies require energy services to meet basic human needs (e.g., lighting, cooking, space comfort, mobility and communication) and to serve productive processes. [1.1.1, 9.3.2] Since approximately 1850, global use of fossil fuels (coal, oil and gas) has increased to dominate energy supply, leading to a rapid growth in carbon dioxide (CO_2) emissions (Figure 1.6).

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[1] This report communicates uncertainty, for example, by showing the results of sensitivity analyses and by quantitatively presenting ranges in cost numbers as well as ranges in the scenario results. This report does not apply formal IPCC uncertainty terminology because at the time of the approval of this report, IPCC uncertainty guidance was in the process of being revised.

GHG emissions resulting from the provision of energy services have contributed significantly to the historic increase in atmospheric GHG concentrations. The IPCC Fourth Assessment Report (AR4) concluded that "Most of the observed increase in global average temperature since the mid-20th century is very likely[2] due to the observed increase in anthropogenic greenhouse gas (GHG) concentrations."

Recent data confirms that consumption of fossil fuels accounts for the majority of global anthropogenic GHG emissions[3]. Emissions continue to grow and CO_2 concentrations had increased to over 390 ppm, or 39% above preindustrial levels, by the end of 2010. [1.1.1, 1.1.3]

There are multiple options for lowering GHG emissions from the energy system while still satisfying the global demand for energy services. [1.1.3, 10.1] Some of these possible options, such as energy conservation and efficiency, fossil fuel switch, RE, nuclear and CCS were assessed in the AR4. A comprehensive evaluation of any portfolio of mitigation options would involve an evaluation of their respective mitigation potential as well as all associated risks, costs and their contribution to sustainable development. [1.1.6]. This report will concentrate on the role that the deployment of RE technologies can play within such a portfolio of mitigation options

As well as having a large potential to mitigate climate change, RE can provide wider benefits. RE may, if implemented properly, contribute to social and economic development, energy access, a secure energy supply, and reducing negative impacts on the environment and health [9.2, 9.3].

Under most conditions increasing the share of RE in the energy mix will require policies to stimulate changes in the energy system. Deployment of RE technologies has increased rapidly in recent years, and their share is projected to increase substantially under most ambitious mitigation scenarios [1.1.5, 10.2]. Additional policies would be required to attract the necessary increases in investment in technologies and infrastructure [11.4.3, 11.5, 11.6.1, 11.7.5].

3. Renewable energy technologies and markets

RE comprises a heterogeneous class of technologies (Box SPM.1). Various types of RE can supply electricity, thermal energy and mechanical energy, as well as produce fuels that are able to satisfy multiple energy service needs [1.2]. Some RE technologies can be deployed at the point of use (decentralized) in rural and urban environments, whereas others are primarily deployed within large (centralized) energy networks [1.2, 8.2, 8.3, 9.3.2]. Though a growing number of RE technologies are technically mature and are being deployed at significant scale, others are in an earlier phase of technical maturity and commercial deployment or fill specialized niche markets [1.2]. The energy output of RE technologies can be (i) variable and - to some degree - unpredictable over differing time scales (from minutes to years), (ii) variable but predictable, (iii) constant, or (iv) controllable [8.2, 8.3].

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[2] According to the formal uncertainty language used in the AR4, the term 'very likely' refers to a > 90% assessed probability of occurrence.

[3] The contributions of individual anthropogenic GHGs to total emissions in 2004, reported in AR4, expressed as $CO_{2\text{-eq}}$ were: CO_2 from fossil fuels (56.6%), CO_2 from deforestation, decay of biomass etc. (17.3%), CO_2 from other (2.8%), CH_4 (14.3%), N_2O (7.9%) and F-gases (1.1%) [Figure 1.1b, AR4, WG III, Chapter 1. For further information on sectoral emissions, including forestry, see also Figure 1.3b and associated footnotes.]

Box SPM.1 | Renewable energy sources and technologies considered in this report

Bioenergy can be produced from a variety of biomass feedstocks, including forest, agricultural and livestock residues; short-rotation forest plantations; energy crops; the organic component of municipal solid waste; and other organic waste streams. Through a variety of processes, these feedstocks can be directly used to produce electricity or heat, or can be used to create gaseous, liquid, or solid fuels. The range of bioenergy technologies is broad and the technical maturity varies substantially. Some examples of commercially available technologies include small- and large-scale boilers, domestic pellet-based heating systems, and ethanol production from sugar and starch. Advanced biomass integrated gasification combined-cycle power plants and lignocellulose-based transport fuels are examples of technologies that are at a pre-commercial stage, while liquid biofuel production from algae and some other biological conversion approaches are at the research and development (R&D) phase. Bioenergy technologies have applications in centralized and decentralized settings, with the traditional use of biomass in developing countries being the most widespread current application.[4] Bioenergy typically offers constant or controllable output. Bioenergy projects usually depend on local and regional fuel supply availability, but recent developments show that solid biomass and liquid biofuels are increasingly traded internationally. [1.2, 2.1, 2.3, 2.6, 8.2, 8.3]

Direct solar energy technologies harness the energy of solar irradiance to produce electricity using photovoltaics (PV) and concentrating solar power (CSP), to produce thermal energy (heating or cooling, either through passive or active means), to meet direct lighting needs and, potentially, to produce fuels that might be used for transport and other purposes. The technology maturity of solar applications ranges from R&D (e.g., fuels produced from solar energy), to relatively mature (e.g., CSP), to mature (e.g. passive and active solar heating, and wafer-based silicon PV). Many but not all of the technologies are modular in nature, allowing their use in both centralized and decentralized energy systems. Solar energy is variable and, to some degree, unpredictable, though the temporal profile of solar energy output in some circumstances correlates relatively well with energy demands. Thermal energy storage offers the option to improve output control for some technologies such as CSP and direct solar heating. [1.2, 3.1, 3.3, 3.5, 3.7, 8.2, 8.3]

Geothermal energy utilizes the accessible thermal energy from the Earth's interior. Heat is extracted from geothermal reservoirs using wells or other means. Reservoirs that are naturally sufficiently hot and permeable are called hydrothermal reservoirs, whereas reservoirs that are sufficiently hot but that are improved with hydraulic stimulation are called enhanced geothermal systems (EGS). Once at the surface, fluids of various temperatures can be used to generate electricity or can be used more directly for applications that require thermal energy, including district heating or the use of lower-temperature heat from shallow wells for geothermal heat pumps used in heating or cooling applications. Hydrothermal power plants and thermal applications of geothermal energy are mature technologies, whereas EGS projects are in the demonstration and pilot phase while also undergoing R&D. When used to generate electricity, geothermal power plants typically offer constant output. [1.2, 4.1, 4.3, 8.2, 8.3]

Hydropower harnesses the energy of water moving from higher to lower elevations, primarily to generate electricity. Hydropower projects encompass dam projects with reservoirs, run-of-river and in-stream projects and cover a continuum in project scale. This variety gives hydropower the ability to meet large centralized urban needs as well as decentralized rural needs. Hydropower technologies are mature. Hydropower projects exploit a resource that varies temporally. However, the controllable output provided by hydropower facilities that have reservoirs can be used to meet peak electricity demands and help to balance electricity systems that have large amounts of variable RE

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[4] Traditional biomass is defined by the International Energy Agency (IEA) as biomass consumption in the residential sector in developing countries and refers to the often-unsustainable use of wood, charcoal, agricultural residues, and animal dung for cooking and heating. All other biomass use is defined as modern [Annex I].

generation. The operation of hydropower reservoirs often reflects their multiple uses, for example, drinking water, irrigation, flood and drought control, and navigation, as well as energy supply. [1.2, 5.1, 5.3, 5.5, 5.10, 8.2]

Ocean energy derives from the potential, kinetic, thermal and chemical energy of seawater, which can be transformed to provide electricity, thermal energy, or potable water. A wide range of technologies are possible, such as barrages for tidal range, submarine turbines for tidal and ocean currents, heat exchangers for ocean thermal energy conversion, and a variety of devices to harness the energy of waves and salinity gradients. Ocean technologies, with the exception of tidal barrages, are at the demonstration and pilot project phases and many require additional R&D. Some of the technologies have variable energy output profiles with differing levels of predictability (e.g., wave, tidal range and current), while others may be capable of near-constant or even controllable operation (e.g., ocean thermal and salinity gradient). [1.2, 6.1, 6.2, 6.3, 6.4, 6.6, 8.2]

Wind energy harnesses the kinetic energy of moving air. The primary application of relevance to climate change mitigation is to produce electricity from large wind turbines located on land (onshore) or in sea- or freshwater (offshore). Onshore wind energy technologies are already being manufactured and deployed on a large scale. Offshore wind energy technologies have greater potential for continued technical advancement. Wind electricity is both variable and, to some degree, unpredictable, but experience and detailed studies from many regions have shown that the integration of wind energy generally poses no insurmountable technical barriers. [1.2, 7.1, 7.3, 7.5, 7.7, 8.2]

On a global basis, it is estimated that RE accounted for 12.9% of the total 492 Exajoules (EJ)[5] of primary energy supply in 2008 (Box SPM.2) (Figure SPM.2). The largest RE contributor was biomass (10.2%), with the majority (roughly 60%) being traditional biomass used in cooking and heating applications in developing countries but with rapidly increasing use of modern biomass as well.[6] Hydropower represented 2.3%, whereas other RE sources accounted for 0.4%. [1.1.5] In 2008, RE contributed approximately 19% of global electricity supply (16% hydropower, 3% other RE) and biofuels contributed 2% of global road transport fuel supply. Traditional biomass (17%), modern biomass (8%), solar thermal and geothermal energy (2%) together fuelled 27% of the total global demand for heat. The contribution of RE to primary energy supply varies substantially by country and region [1.1.5, 1.3.1, 8.1].

Box SPM.2 | Accounting for primary energy in the SRREN.

There is no single, unambiguous accounting method for calculating primary energy from non-combustible energy sources such as non-combustible RE sources and nuclear energy. The SRREN adopts the 'direct equivalent' method for accounting for primary energy supply. In this method, fossil fuels and bioenergy are accounted for based on their heating value while non-combustible energy sources, including nuclear energy and all non-combustible RE, are accounted for based on the secondary energy that they produce. This may lead to an understatement of the contribution of non-combustible RE and nuclear compared to bioenergy and fossil fuels by a factor of roughly 1.2 up to 3. The selection of the accounting method also impacts the relative shares of different individual energy sources. Comparisons in the data and figures presented in the SRREN between fossil fuels and bioenergy on the one hand, and non-combustible RE and nuclear energy on the other, reflect this accounting method. [1.1, Annex II.4]

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[5] 1 Exajoule = 10^18 joules = 23.88 Mtoe.

[6] In addition to this there is biomass use estimated to amount to 20 to 40% not reported in official databases, such as dung, unaccounted production of charcoal, illegal logging, fuelwood gathering, and agricultural residue use [2.1, 2.5].

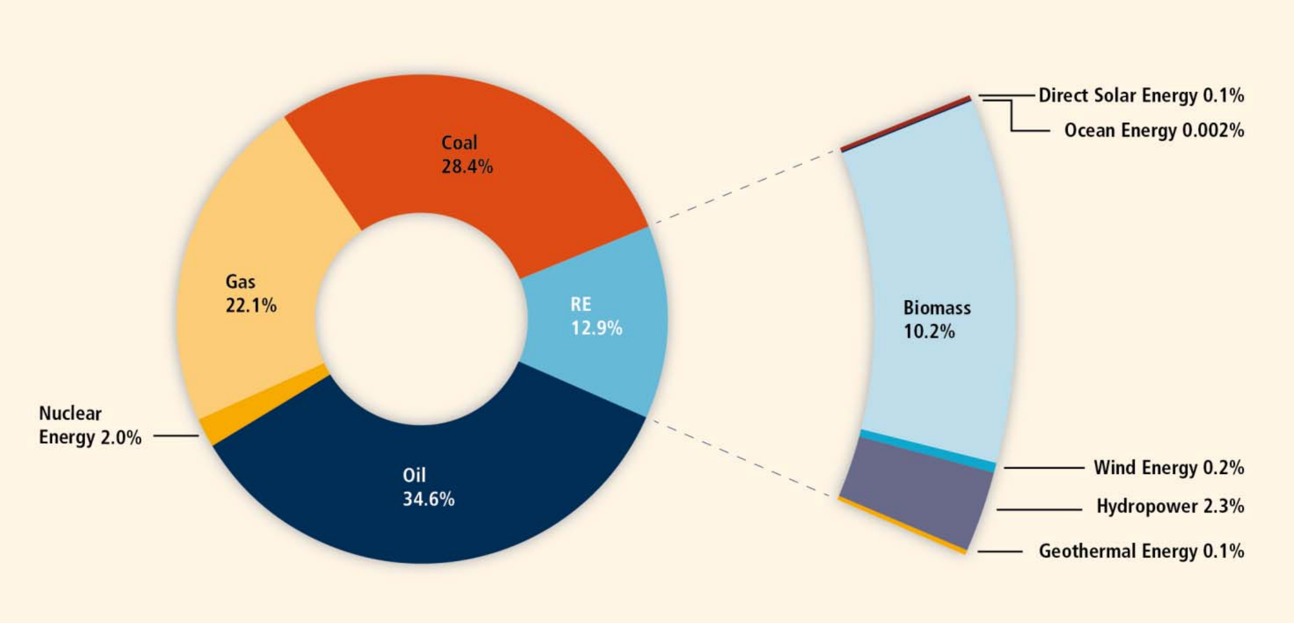

Figure SPM.2 | Shares of energy sources in total global primary energy supply in 2008 (492 EJ) Modern biomass contributes 38% of the total biomass share. [Figure 1.10, 1.1.5]. Notes: Underlying data for figure has been converted to the 'direct equivalent' method of accounting for primary energy supply [Box SPM.2, 1.1.9, Annex II].

Deployment of RE has been increasing rapidly in recent years (Figure SPM.3). Various types of government policies, the declining cost of many RE technologies, changes in the prices of fossil fuels, an increase of energy demand and other factors have encouraged the continuing increase in the use of RE [1.1.5, 9.3, 10.5, 11.2, 11.3]. Despite global financial challenges, RE capacity continued to grow rapidly in 2009 compared to the cumulative installed capacity from the previous year, including: wind power (32% increase, 38 Gigawatts (GW) added), hydropower (3%, 31 GW added), grid-connected photovoltaics (53%, 7.5 GW added), geothermal power (4%, 0.4 GW added), and solar hot water/heating (21%, 31 GW_{th} added). Biofuels accounted for 2% of global road transport fuel demand in 2008 and nearly 3% in 2009. The annual production of ethanol increased to 1.6 EJ (76 billion litres) by the end of 2009 and biodiesel to 0.6 EJ (17 billion litres) [1.1.5, 2.4, 3.4, 4.4, 5.4, 7.4].

Of the approximate 300 GW of new electricity generating capacity added globally over the two-year period from 2008 to 2009, 140 GW came from RE additions. Collectively, developing countries host 53% of global RE electricity generation capacity [1.1.5]. At the end of 2009, the use of RE in hot water/heating markets included modern biomass (270 GWthermal), solar (180 GWthermal), and geothermal (60 GWthermal). The use of decentralized RE (excluding traditional biomass) in meeting rural energy needs at the household or village level has also increased, including hydropower stations, various modern biomass options, PV, wind or hybrid systems that combine multiple technologies. [1.1.5, 2.4, 3.4, 4.4, 5.4]

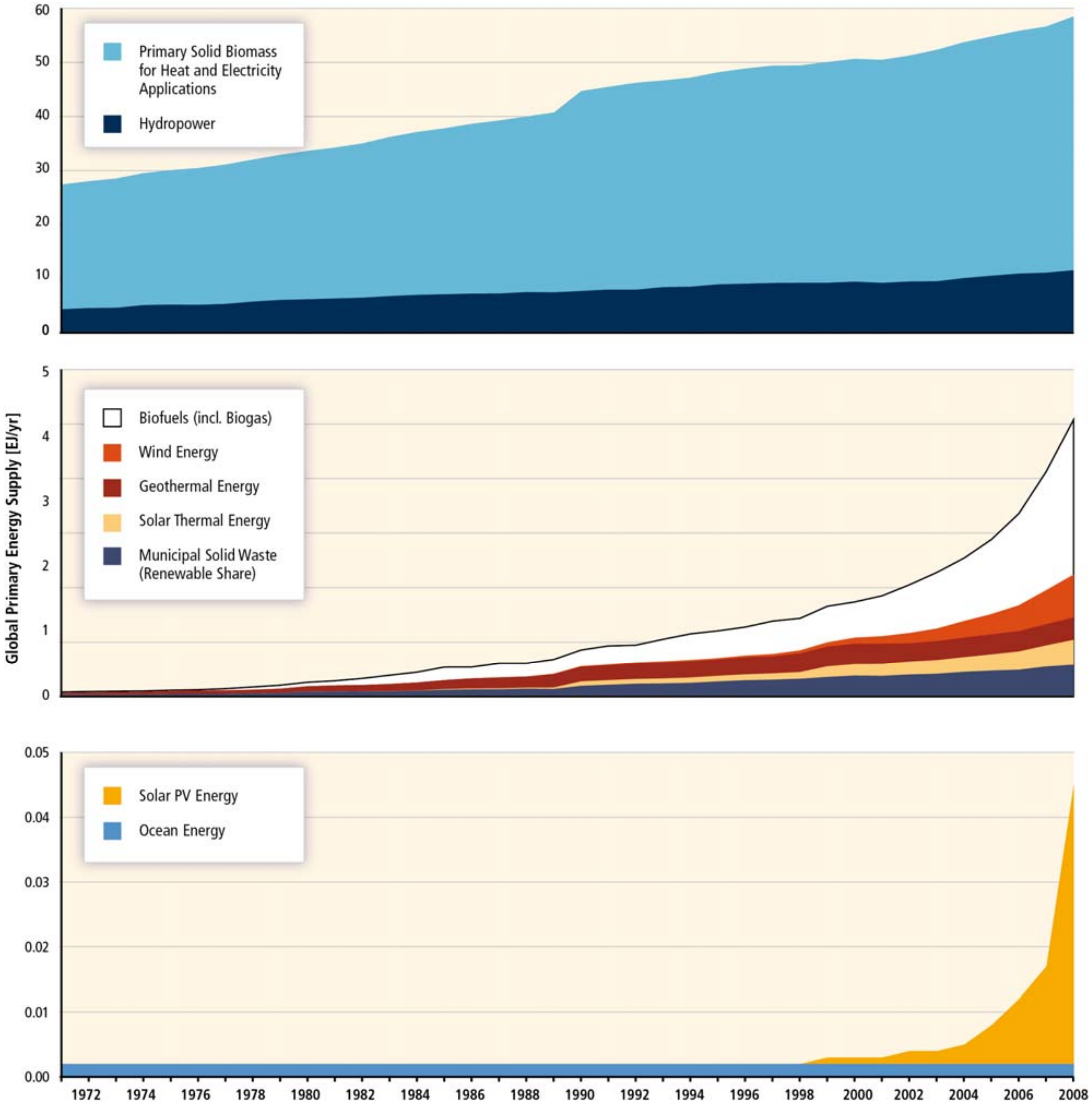

Figure SPM.3 | Historical development of global primary energy supply from renewable energy from 1971 to 2008 [Figure 1.12, 1.1.5].
Notes: Technologies are referenced to separate vertical units for display purposes only. Underlying data for figure has been converted to the ‘direct equivalent’ method of accounting for primary energy supply [Footnote 1, 1.1.9, Annex II], except that the energy content of biofuels is reported in secondary energy terms (the primary biomass used to produce the biofuel would be higher due to conversion losses [2.3, 2.4]).

The global technical potential[7] of RE sources will not limit continued growth in the use of RE. A wide range of estimates are provided in the literature, but studies have consistently found that the total global technical potential for RE is substantially higher than global energy demand (Figure SPM.4) [1.2.2, 10.3, Annex II]. The technical potential for solar energy is the highest among the RE

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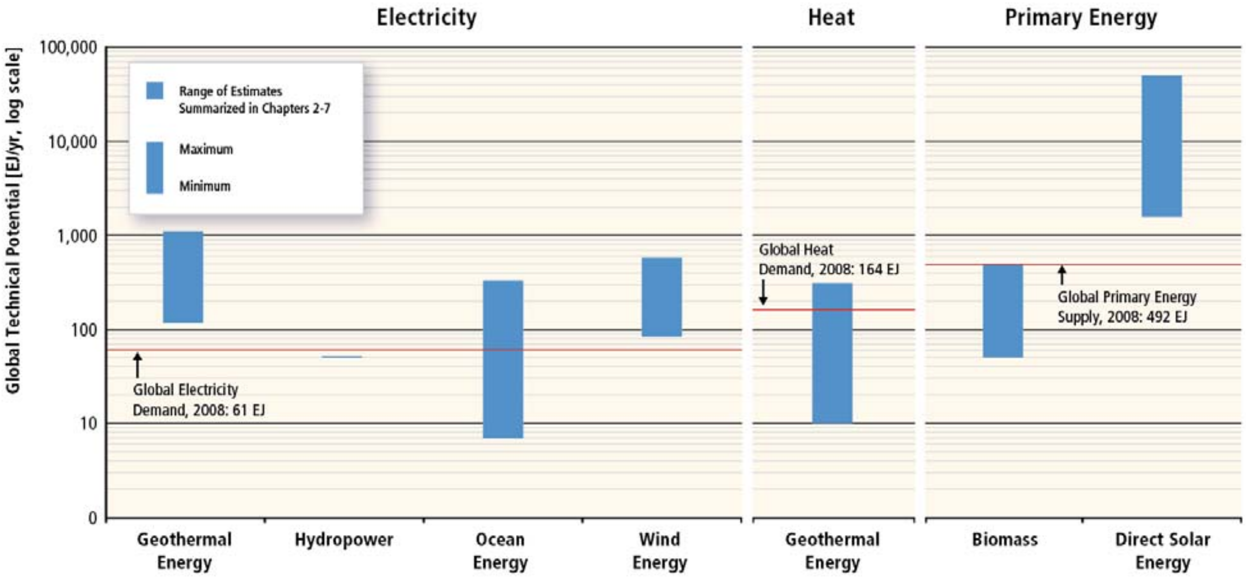
[7] Definitions of technical potential often vary by study. “Technical potential” is used in the SRREN as: The amount of RE output obtainable by full implementation of demonstrated technologies or practices. No explicit reference to costs, barriers or policies is made. Technical potentials reported in the literature and assessed in the SRREN, however, may have taken into account practical constraints and when explicitly stated they are generally indicated in the underlying report. [Annex I]

sources, but substantial technical potential exists for all six RE sources. Even in regions with relatively low levels of technical potential for any individual RE source, there are typically significant opportunities for increased deployment compared to current levels [1.2.2, 2.2, 2.8, 3.2, 4.2, 5.2, 6.2, 6.4, 7.2, 8.2, 8.3, 10.3]. In the longer term and at higher deployment levels, however, technical potentials indicate a limit to the contribution of some individual RE technologies. Factors such as sustainability concerns [9.3], public acceptance [9.5], system integration and infrastructure constraints [8.2], or economic factors [10.3] may also limit deployment of renewable energy technologies.



Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Figure SPM.4 | Ranges of global technical potentials of renewable energy sources derive from studies presented in Chapters 2 through 7. Biomass and solar are shown as primary energy due to their multiple uses; note that the figure is presented in logarithmic scale due to the wide range of assessed data [Figure 1.17, 1.2.3].
Notes: Technical potentials reported here represent total worldwide potentials for annual renewable energy supply and do not deduct any potential that is already being utilized. Note that RE electricity sources could also be used for heating applications, whereas biomass and solar resources are reported only in primary energy terms but could be used to meet various energy service needs. Ranges are based on various methods and apply to different future years; consequently, the resulting ranges are not strictly comparable across technologies. For the data behind Figure SPM.4 and additional notes that apply, see Chapter 1 Annex, Table A.1.1 (as well as the underlying chapters).

Climate change will have impacts on the size and geographic distribution of the technical potential for RE sources, but research into the magnitude of these possible effects is nascent. Because RE sources are, in many cases, dependent on the climate, global climate change will affect the RE resource base, though the precise nature and magnitude of these impacts is uncertain. The future technical potential for bioenergy could be influenced by climate change through impacts on biomass production such as altered soil conditions, precipitation, crop productivity and other factors. The overall impact of a global mean temperature change of below 2°C on the technical potential of bioenergy is expected to be relatively small on a global basis. However, considerable regional differences could be expected and uncertainties are larger and more difficult to assess compared to other RE options due to the large number of feedback mechanisms involved [2.2, 2.6]. For solar energy, though climate change is expected to influence the distribution and variability of cloud cover, the impact of these changes on overall technical potential is expected to be small [3.2]. For hydropower the overall impacts on the global potential is expected to be slightly positive. However, results also indicate the possibility of substantial variations across regions and even within countries [5.2]. Research to date suggests that climate change is not expected to greatly impact the global technical potential for wind energy development but changes in the regional distribution of the wind energy resource may be expected [7.2]. Climate change is not anticipated to have significant impacts on the size or geographic distribution of geothermal or ocean energy resources [4.2, 6.2].

The levelized cost of energy[8] for many RE technologies is currently higher than existing energy prices, though in various settings RE is already economically competitive. Ranges of recent levelized costs of energy for selected commercially available RE technologies are wide, depending on a number of factors including, but not limited to, technology characteristics, regional variations in cost and performance, and differing discount rates (Figure SPM.5) [1.3.2, 2.3, 2.7, 3.8, 4.8, 5.8, 6.7, 7.8, 10.5, Annex III]. Some RE technologies are broadly competitive with existing market energy prices. Many of the other RE technologies can provide competitive energy services in certain circumstances, for example, in regions with favourable resource conditions or that lack the infrastructure for other low-cost energy supplies. In most regions of the world, policy measures are still required to ensure rapid deployment of many RE sources. [2.3, 2.7, 3.8, 4.7, 5.8, 6.7, 7.8, 10.5]

Monetizing the external costs of energy supply would improve the relative competitiveness of RE. The same applies if market prices increase due to other reasons (Figure SPM.5) [10.6]. The levelized cost of energy for a technology is not the sole determinant of its value or economic competitiveness. The attractiveness of a specific energy supply option depends also on broader economic as well as environmental and social aspects, and the contribution that the technology provides to meeting specific energy services (e.g., peak electricity demands) or imposes in the form of ancillary costs on the energy system (e.g., the costs of integration) [8.2, 9.3, 10.6].

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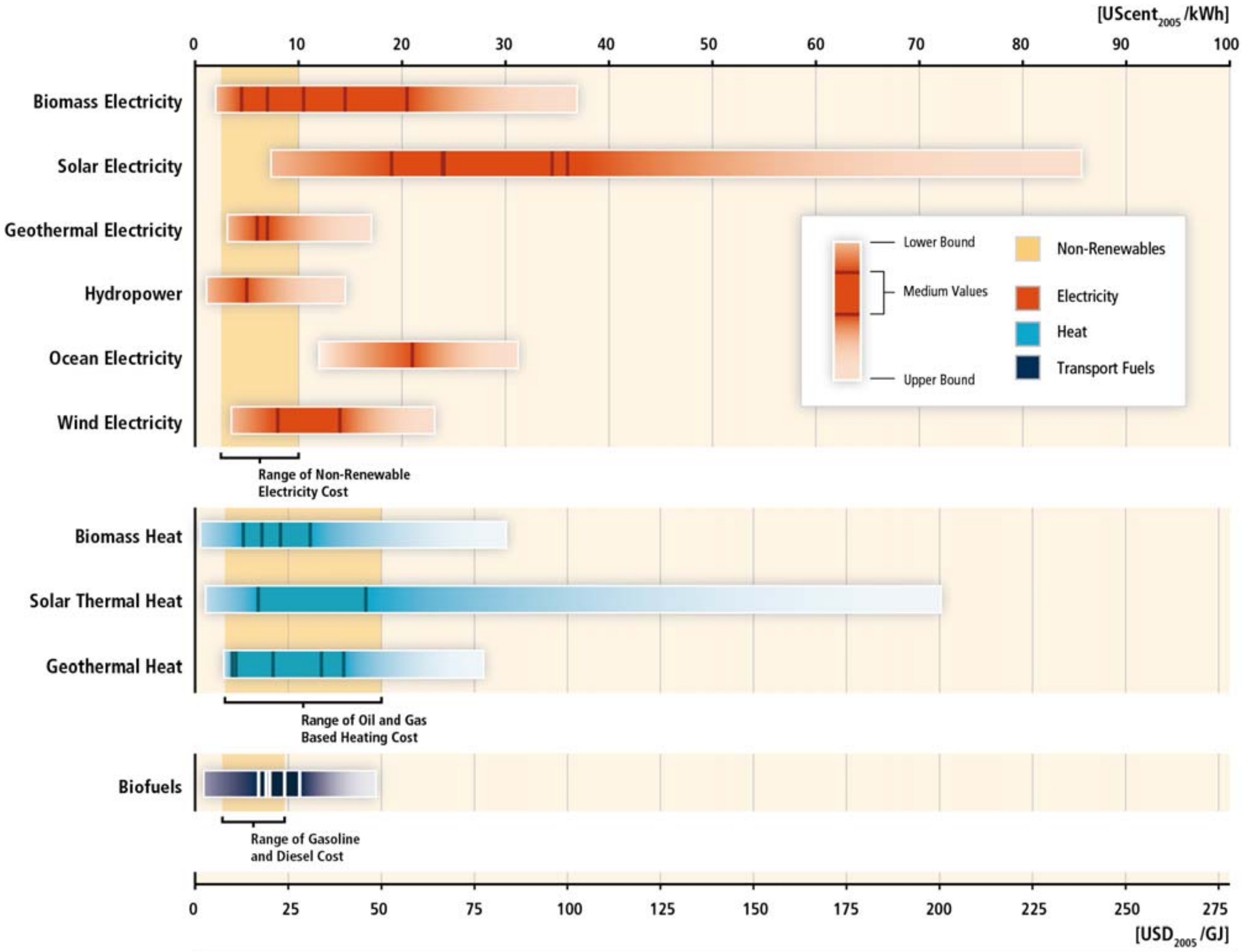
[8] The levelized cost of energy represents the cost of an energy generating system over its lifetime; it is calculated as the per-unit price at which energy must be generated from a specific source over its lifetime to break even. It usually includes all private costs that accrue upstream in the value chain, but does not include the downstream cost of delivery to the final customer; the cost of integration; or external environmental or other costs. Subsidies and tax credits are also not included.



Notes: Medium values are shown for the following subcategories, sorted in the order as they appear in the respective ranges (from left to right):

Electricity

Biomass:
1. Cofiring
2. Small scale combined heat and power, CHP (Gasification internal combustion engine)
3. Direct dedicated stoker & CHP
4. Small scale CHP (steam turbine)
5. Small scale CHP (organic Rankine cycle)

Solar Electricity:
1. Concentrating solar power
2. Utility-scale PV (1-axis and fixed tilt)
3. Commercial rooftop PV
4. Residential rooftop PV

Geothermal Electricity:
1. Condensing flash plant
2. Binary cycle plant

Hydropower:
1. All types

Ocean Electricity:
1. Tidal barrage

Wind Electricity:
1. Onshore
2. Offshore

Heat

Biomass Heat:
1. Municipal solid waste based CHP
2. Anaerobic digestion based CHP
3. Steam turbine CHP
4. Domestic pellet heating system

Solar Thermal Heat:
1. Domestic hot water systems in China
2. Water and space heating

Geothermal Heat:
1. Greenhouses
2. Uncovered aquaculture ponds
3. District heating
4. Geothermal heat pumps
5. Geothermal building heating

Transport Fuels

Biofuels:
1. Corn ethanol
2. Soy biodiesel
3. Wheat ethanol
4. Sugarcane ethanol
5. Palm oil biodiesel

The lower range of the levelized cost of energy for each RE technology is based on a combination of the most favourable input-values, whereas the upper range is based on a combination of the least favourable input values. Reference ranges in the figure background for non-renewable electricity options are indicative of the levelized cost of centralized non-renewable electricity generation. Reference ranges for heat are indicative of recent costs for oil and gas based heat supply options. Reference ranges for transport fuels are based on recent crude oil spot prices of USD 40 to 130/barrel and corresponding diesel and gasoline costs, excluding taxes.

Figure SPM.5| Range in recent levelized cost of energy for selected commercially available RE technologies in comparison to recent non-renewable energy costs. Technology subcategories and discount rates were aggregated for this figure. For related figures with less or no such aggregation, see [1.3.2, 10.5, Annex III].

The cost of most RE technologies has declined and additional expected technical advances would result in further cost reductions. Significant advances in RE technologies and associated long-term cost reductions have been demonstrated over the last decades, though periods of rising prices have sometimes been experienced (due to, for example, increasing demand for RE in excess of available supply)(Figure SPM.6). The contribution of different drivers (e.g., R&D, economies of scale, deployment-oriented learning, and increased market competition among RE suppliers) is not always understood in detail [2.7, 3.8, 7.8, 10.5]. Further cost reductions are expected, resulting in greater potential deployment and consequent climate change mitigation. Examples of important areas of potential technological advancement include: new and improved feedstock production and supply systems, biofuels produced via new processes (also called next-generation or advanced biofuels, e.g., lignocellulosic) and advanced biorefining [2.6]; advanced PV and CSP technologies and manufacturing processes [3.7]; enhanced geothermal systems (EGS) [4.6]; multiple emerging ocean technologies [6.6]; and foundation and turbine designs for offshore wind energy [7.7]. Further cost reductions for hydropower are expected to be less significant than some of the other RE technologies, but R&D opportunities exist to make hydropower projects technically feasible in a wider range of locations and improve the technical performance of new and existing projects [5.3, 5.7, 5.8].

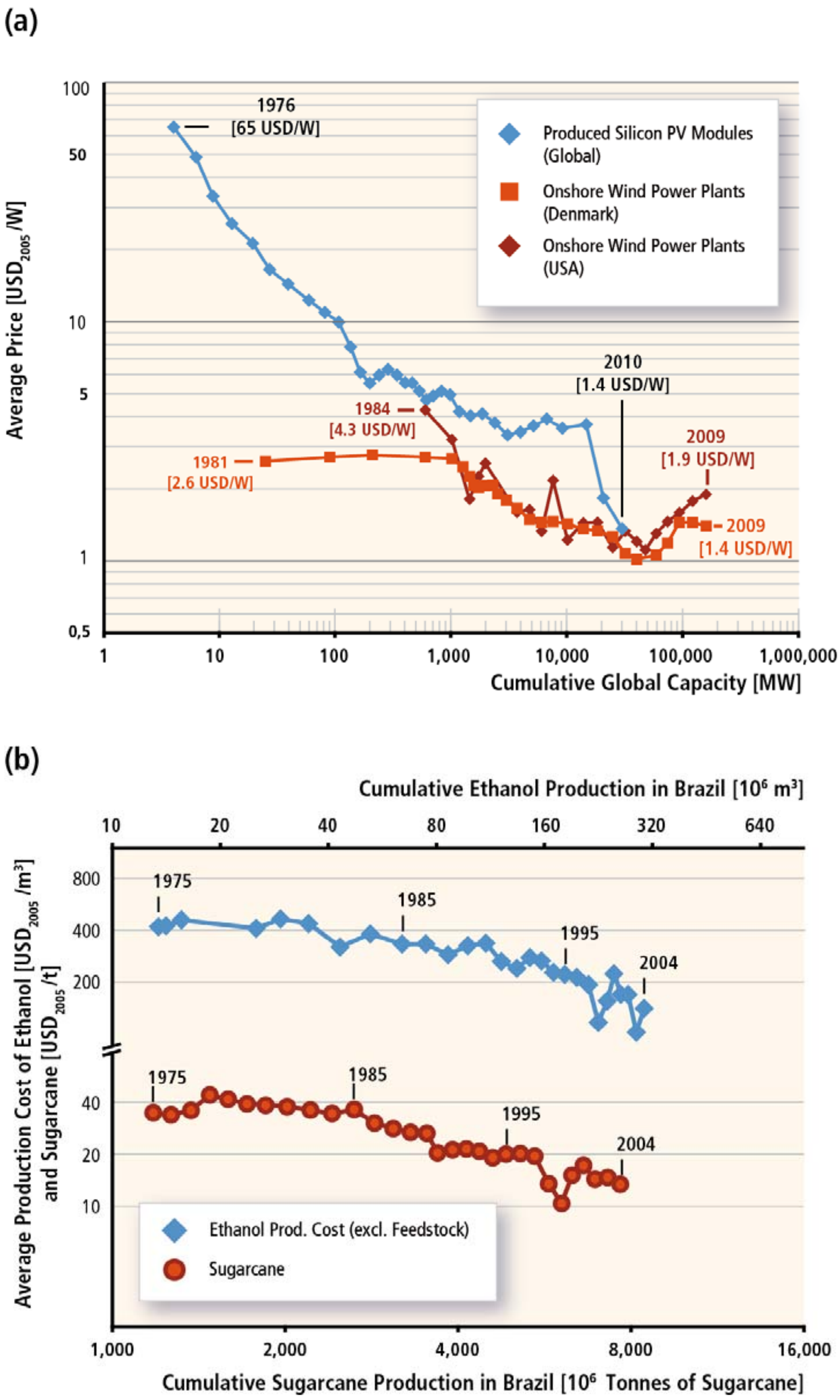


Figure SPM.6 | Selected experience curves in logarithmic scale for (a) the price of silicon PV modules and onshore wind power plants per unit of capacity; and (b) the cost of sugarcane-based ethanol production [data from Figure 3.17, 3.8.3, Figure 7.20, 7.8.2, Figure 2.21, 2.7.2].

Notes: Depending on the setting, cost reductions may occur at various geographic scales. The country-level examples provided here derive from the published literature. No global dataset of wind power plant prices or costs is readily available. Reductions in the cost or price of a technology per unit of capacity understate reductions in the levelized cost of energy of that technology when performance improvements occur [7.8.4, 10.5].

A variety of technology-specific challenges (in addition to cost) may need to be addressed to enable RE to significantly upscale its contribution to reducing GHG emissions. For the increased and sustainable use of bioenergy, proper design, implementation and monitoring of sustainability frameworks can minimize negative impacts and maximize benefits with regard to social, economic and environmental issues. [SPM.3, 2.2, 2.5, 2.8] For solar energy, regulatory and institutional barriers can impede deployment, as can integration and transmission issues [3.9]. For geothermal energy, an important challenge would be to prove that enhanced geothermal systems (EGS) can be deployed economically, sustainably and widely [4.5, 4.6, 4.7, 4.8]. New hydropower projects can have ecological and social impacts that are very site specific, and increased deployment may require improved sustainability assessment tools, and regional and multi-party collaborations to address energy and water needs [5.6, 5.9, 5.10]. The deployment of ocean energy could benefit from testing centres for demonstration projects, and from dedicated policies and regulations that encourage early deployment [6.4]. For wind energy, technical and institutional solutions to transmission constraints and operational integration concerns may be especially important, as might public acceptance issues relating primarily to landscape impacts [7.5, 7.6, 7.9].

4. Integration into present and future energy systems

Various RE resources are already being successfully integrated into energy supply systems [8.2] and into end-use sectors [8.3] (Figure SPM.7).

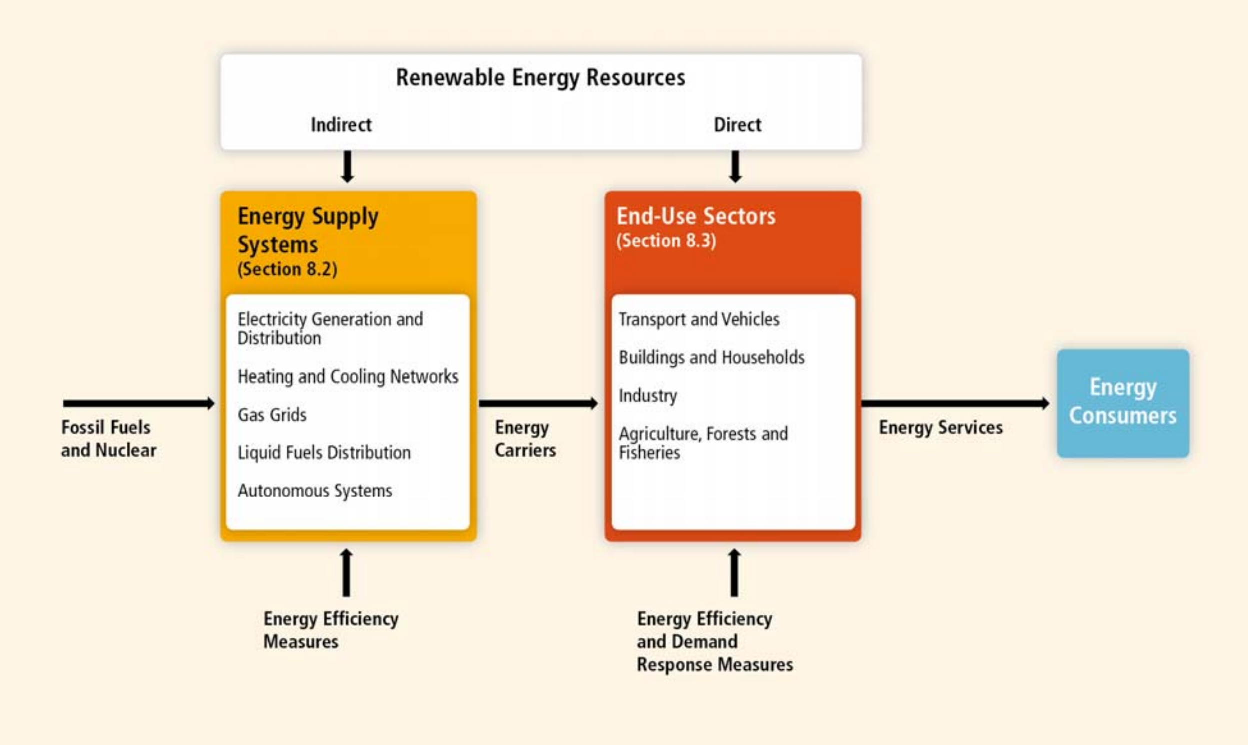


Figure SPM.7 | Pathways for RE integration to provide energy services, either into energy supply systems or on-site for use by the end-use sectors. [Figure 8.1, 8.1]

[Note: Figure will be amended to remove ‘indirect’ and ‘direct’ in the box titled ‘Renewable Energy Resources’]

The characteristics of different RE sources can influence the scale of the integration challenge. Some RE resources are widely distributed geographically. Others, such as large scale hydropower, can be more centralized but have integration options constrained by geographic location. Some RE resources are variable with limited predictability. Some have lower physical energy densities and different technical specifications from fossil fuels. Such characteristics can constrain ease of integration and invoke additional system costs particularly when reaching higher shares of RE. [8.2]

Integrating RE into most existing energy supply systems and end-use sectors at an accelerated rate -- leading to higher shares of RE -- is technologically feasible, though will result in a number of additional challenges. Increased shares of RE are expected within an overall portfolio of low GHG emission technologies [10.3, Tables 10.4-10.6]. Whether for electricity, heating, cooling, gaseous fuels or liquid fuels, including integration directly into end-use sectors, the RE integration challenges are contextual and site specific and include the adjustment of existing energy supply systems [8.2, 8.3].

The costs and challenges of integrating increasing shares of RE into an existing energy supply system depend on the current share of RE, the availability and characteristics of RE resources, the system characteristics, and how the system evolves and develops in the future.

- RE can be integrated into all types of *electricity* systems from large inter-connected continental-scale grids [8.2.1] down to small stand-alone systems and individual buildings [8.2.5]. Relevant system characteristics include the generation mix and its flexibility, network infrastructure, energy market designs and institutional rules, demand location, demand profiles, and control and communication capability. Wind, solar PV energy and CSP without storage can be more difficult to integrate than dispatchable[9] hydropower, bioenergy, CSP with storage and geothermal energy.

  As the penetration of variable RE sources increases, maintaining system reliability may become more challenging and costly. Having a portfolio of RE technologies is one solution to reduce the risks and costs of RE integration. Other solutions include the development of complementary flexible generation and the more flexible operation of existing schemes; improved short term forecasting, system operation and planning tools; electricity demand that can respond in relation to supply availability; energy storage technologies (including storage-based hydropower); and modified institutional arrangements. Additional electricity network transmission (including inter-connections between systems) and/or distribution infrastructure may need to be strengthened and extended, partly because of the geographical distribution and fixed remote locations of many RE resources. [8.2.1]

- *District heating systems* can use low-temperature thermal RE inputs such as solar and geothermal heat, or biomass, including sources with few competing uses such as refuse-derived fuels. *District cooling* can make use of cold natural waterways [8.2.2]. Thermal storage capability and flexible cogeneration can overcome supply and demand variability challenges as well as provide demand response for electricity systems.

- In *gas distribution grids*, injecting biomethane, or in the future, RE-derived hydrogen and synthetic natural gas, can be achieved for a range of applications but successful integration requires that appropriate gas quality standards are met and pipelines upgraded where necessary [8.2.3].

- *Liquid fuel systems* can integrate biofuels for transport applications or for cooking and heating applications. Pure (100%) biofuels, or more usually those blended with petroleum-based fuels usually need to meet technical standards consistent with vehicle engine fuel specifications. [8.2.4, 8.3.1]

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[9] Electricity plants that can schedule power generation as and when required are classed as dispatchable [8.2.1.1, Annex I]. Variable RE technologies are partially dispatchable (i.e. only when the RE resource is available). CSP plants are classified as dispatchable when heat is stored for use at night or during periods of low sunshine.

There are multiple pathways for increasing the shares of RE across all end-use sectors. The ease of integration varies depending on region, characteristics specific to the sector and the technology.

- For *transport*, liquid and gaseous biofuels are already and are expected to continue to be integrated into the fuel supply systems of a growing number of countries. Integration options may include decentralized on-site or centralized production of RE hydrogen for fuel cell vehicles and RE electricity for rail and electric vehicles [8.2.1, 8.2.3] depending on infrastructure and vehicle technology developments [8.3.1]. Future demand for electric vehicles could also enhance flexible electricity generation systems.
- In the *building* sector, RE technologies can be integrated into both new and existing structures to produce electricity, heating and cooling. Supply of surplus energy may be possible, particularly for energy efficient building designs [8.3.2]. In developing countries, the integration of RE supply systems is feasible for even modest dwellings [8.3.2, 9.3.2].
- Agriculture as well as food and fibre process *industries* often use biomass to meet direct heat and power demands on-site. They can also be net exporters of surplus fuels, heat, and electricity to adjacent supply systems [8.3.3, 8.3.4]. Increasing the integration of RE for use by industries is an option in several sub-sectors, for example through electro-thermal technologies or, in the longer term, by using RE hydrogen [8.3.3].

The costs associated with RE integration, whether for electricity, heating, cooling, gaseous or liquid fuels, are contextual, site-specific and generally difficult to determine. They may include additional costs for network infrastructure investment, system operation and losses, and other adjustments to the existing energy supply systems as needed. The available literature on integration costs is sparse and estimates are often lacking or vary widely.

In order to accommodate high RE shares, energy systems will need to evolve and be adapted [8.2, 8.3]. Long-term integration efforts could include investment in enabling infrastructure; modification of institutional and governance frameworks; attention to social aspects, markets and planning; and capacity building in anticipation of RE growth [8.2, 8.3]. Furthermore, integration of less mature technologies, including biofuels produced through new processes (also called advanced biofuels or next-generation biofuels), fuels generated from solar energy, solar cooling, ocean energy technologies, fuel cells and electric vehicles, will require continuing investments in research, development and demonstration (RD&D), capacity building and other supporting measures [2.6, 3.7, 11.5, 11.6, 11.7].

RE could shape future energy supply and end-use systems, in particular for electricity which is expected to attain higher shares of RE earlier than either the heat or transport fuel sectors at the global level [10.3]. Parallel developments in electric vehicles [8.3.1], increased heating and cooling using electricity (including heat pumps) [8.2.2, 8.3.2, 8.3.3], flexible demand response services (including the use of smart meters) [8.2.1], energy storage and other technologies could be associated with this trend.

As infrastructure and energy systems develop, in spite of the complexities, there are few, if any, fundamental technological limits to integrating a portfolio of RE technologies to meet a majority share of total energy demand in locations where suitable RE resources exist or can be supplied. However, the actual rate of integration and the resulting shares of RE will be influenced by factors, such as costs, policies, environmental issues and social aspects. [8.2, 8.3, 9.3, 9.4, 10.2, 10.5]

5. Renewable energy and sustainable development

Historically, economic development has been strongly correlated with increasing energy use and growth of GHG emissions and RE can help decouple that correlation, contributing to sustainable development (SD). Though the exact contribution of RE to SD has to be evaluated in a country specific context, RE offers the opportunity to contribute to social and economic development, energy access, secure energy supply, climate change mitigation, and the reduction of negative environmental and health impacts. [9.2] Providing access to modern energy services would support the achievement of the Millennium Development Goals. [9.2.2, 9.3.2]

- ***RE can contribute to social and economic development.*** Under favorable conditions, cost savings in comparison to non-RE use exist, in particular in remote and in poor rural areas lacking centralized energy access. [9.3.1, 9.3.2.] Costs associated with energy imports can often be reduced through the deployment of domestic RE technologies that are already competitive. [9.3.3] RE can have a positive impact on job creation although the studies available differ with respect to the magnitude of net employment. [9.3.1]
- ***RE can help accelerate access to energy, particularly for the 1.4 billion people without access to electricity and the additional 1.3 billion using traditional biomass.*** Basic levels of access to modern energy services can provide significant benefits to a community or household. In many developing countries, decentralized grids based on RE and the inclusion of RE in centralized energy grids have expanded and improved energy access. In addition, non-electrical RE technologies also offer opportunities for modernization of energy services, for example using solar energy for water heating and crop drying, biofuels for transportation, biogas and modern biomass for heating, cooling, cooking and lighting, and wind for water pumping. [9.3.2, 8.1] The number of people without access to modern energy services is expected to remain unchanged unless relevant domestic policies are implemented, which may be supported or complemented by international assistance as appropriate. [9.3.2, 9.4.2]
- ***RE options can contribute to a more secure energy supply, although specific challenges to integration must be considered.*** RE deployment might reduce vulnerability to supply disruption and market volatility if competition is increased and energy sources are diversified. [9.3.3, 9.4.3] Scenario studies indicate that concerns regarding secure energy supply, could continue in the future without technological improvements within the transport sector. [2.8, 9.4.1.1, 9.4.3.1, 10.3] The variable output profiles of some RE technologies often necessitate technical and institutional measures appropriate to local conditions to assure energy supply reliability. [8.2, 9.3.3]
- ***In addition to reduced GHG emissions, RE technologies can provide other important environmental benefits. Maximizing these benefits depends on the specific technology, management, and site characteristics associated with each RE project.***
    - ***Lifecycle assessments (LCA) for electricity generation indicate that GHG emissions from RE technologies are, in general, significantly lower than those associated with fossil fuel options, and in a range of conditions, less than fossil fuels employing CCS.*** The median values for all RE are ranging from 4 to 46 g CO_2 eq/kWh while those for fossil fuels range from 469 to 1001g CO_2-eq/kWh (excluding land use change emissions) (Figure SPM 8).
    - ***Most current bioenergy systems, including liquid biofuels, result in GHG emission reductions, and most biofuels produced through new processes (also called advanced biofuels or next generation biofuels) could provide higher GHG mitigation. The GHG balance may be affected by land use changes and corresponding emissions and removals.*** Bioenergy can lead to avoided GHG

emissions from residues and wastes in landfill disposals and co-products; the combination of bioenergy with CCS may provide for further reductions (see Figure SPM 8). The GHG implications related to land management and land use changes in carbon stocks have considerable uncertainties. [2.2, 2.5, 9.3.4.1]

- ***The sustainability of bioenergy, in particular in terms of life cycle GHG emissions, is influenced by land and biomass resource management practices.*** Changes in land and forest use or management that, according to a considerable number of studies, could be brought about *directly* or *indirectly* by biomass production for use as fuels, power or heat, can decrease or increase terrestrial carbon stocks. The same studies also show that indirect changes in terrestrial carbon stocks have considerable uncertainties, are not directly observable, are complex to model and difficult to attribute to a single cause. Proper governance of land use, zoning, and choice of biomass production systems are key considerations for policy makers. [2.4.5, 2.5.1, 9.3.4, 9.4.4]. Policies are in place that aim to ensure that the benefits from bioenergy, such as rural development, overall improvement of agricultural management and the contribution to climate change mitigation, are realized; their effectiveness has not been assessed. [2.2, 2.5, 2.8]

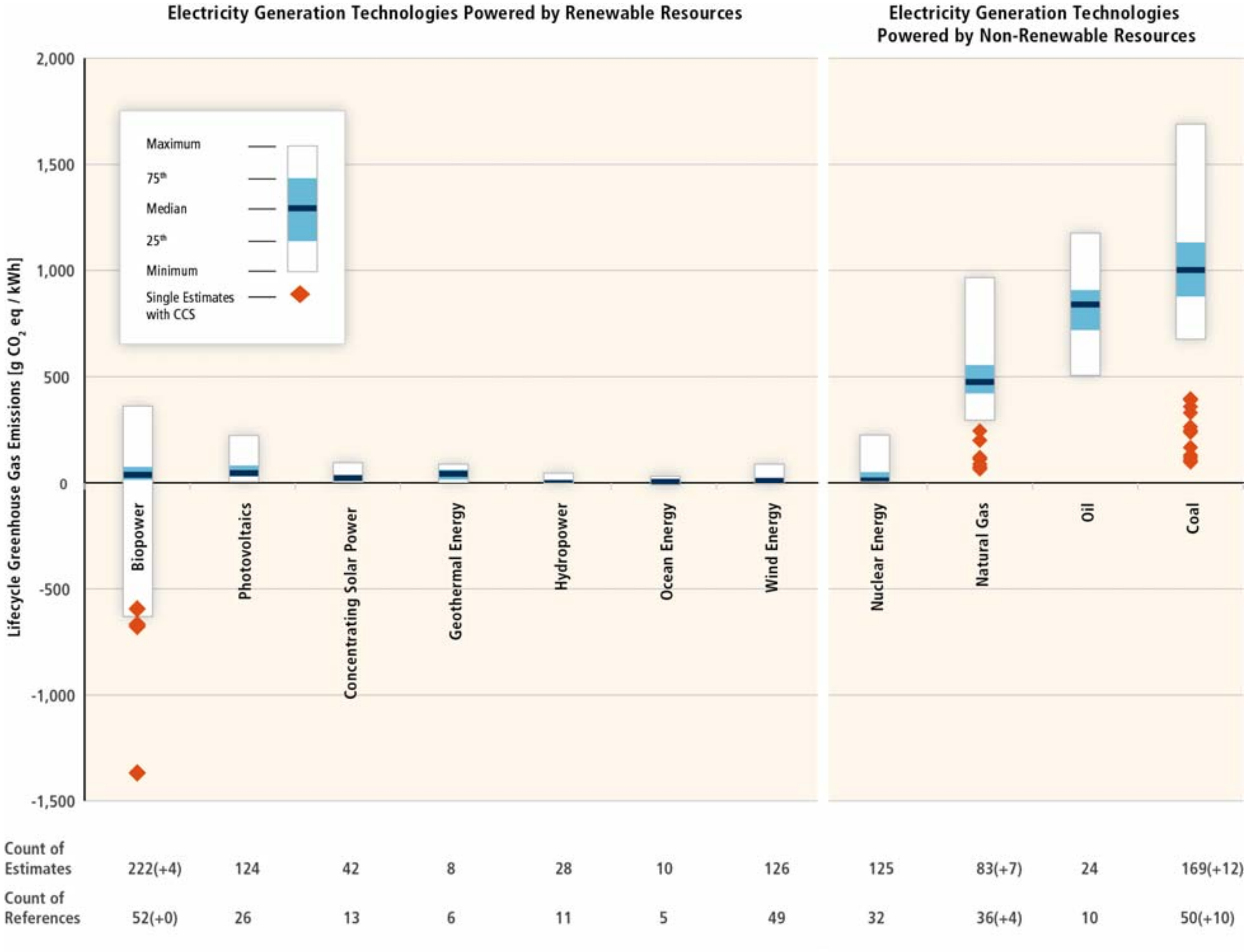

Figure SPM.8. | Estimates of lifecycle GHG emissions (g CO2-eq / kWh) for broad categories of electricity generation technologies, plus some technologies integrated with CCS. Land-use related net changes in carbon stocks (mainly applicable to biopower and hydropower from reservoirs) and land management impacts are excluded; negative estimates[10] for biopower are based on

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[10] 'Negative estimates' within the terminology of life-cycle assessments presented in the SRREN refer to avoided emissions. Unlike the case of bioenergy combined with CCS, avoided emissions do not remove GHGs from the atmosphere.

assumptions about avoided emissions from residues and wastes in landfill disposals and co-products. References and methods for review are reported in Annex II. The number of estimates is greater than the number of references because many studies considered multiple scenarios. Numbers reported in parentheses pertain to additional references and estimates that evaluated technologies with CCS. Distributional information relates to estimates currently available in LCA literature, not necessarily to underlying theoretical or practical extrema, or the true central tendency when considering all deployment conditions. [Figure 9.8, 9.3.4.1]

- ***RE technologies, in particular non-combustion based options, can offer benefits with respect to air pollution and related health concerns*** [9.3.4.3, 9.4.4.1]. Improving traditional biomass use can significantly reduce local and indoor air pollution (alongside GHG emissions, deforestation and forest degradation) and lower associated health impacts, particularly for women and children in developing countries [2.5.4, 9.3.4.4].
- ***Water availability could influence choice of RE technology.*** Conventional water cooled thermal power plants may be especially vulnerable to conditions of water scarcity and climate change. In areas where water scarcity is already a concern, non-thermal RE technologies or thermal RE technologies using dry-cooling can provide energy services without additional stress on water resources. Hydropower and some bioenergy are dependent on water availability, and can either increase competition or mitigate water scarcity. Many impacts can be mitigated by siting considerations and integrated planning. [2.5.5.1, 5.10, 9.3.4.4]
- ***Site specific conditions will determine the degree to which RE technologies impact biodiversity.*** RE specific impacts on biodiversity may be positive or negative. [2.5, 3.6, 4.5, 5.6, 6.5, , 9.3.4.6]
- ***Renewable energy technologies have low fatality rates.*** Accident risks of RE technologies are not negligible, but their often decentralized structure strongly limits the potential for disastrous consequences in terms of fatalities. However, dams associated with some hydropower projects may create a specific risk depending on site specific factors. [9.3.4.7]

6. Mitigation potentials and costs

A significant increase in the deployment of RE by 2030, 2050 and beyond is indicated in the majority of the 164 scenarios reviewed in this Special Report[11]. In 2008, total RE production was roughly 64 EJ/yr (12.9% of total primary energy supply) with more than 30 EJ/yr of this being traditional biomass. More than 50% of the scenarios project levels of RE deployment in 2050 of more than 173 EJ/yr reaching up to over 400 EJ/yr in some cases (Figure SPM.9). Given that traditional biomass use decreases in most scenarios, a corresponding increase in the production level of RE (excluding traditional biomass) anywhere from roughly three-fold to more than ten-fold is projected. The global primary energy supply share of RE differs substantially among the scenarios. More than half of the scenarios show a contribution from RE in excess of a 17% share of primary energy supply in 2030 rising to more than 27% in 2050. The scenarios with the highest RE shares reach approximately 43% in 2030 and 77% in 2050. [10.2, 10.3]

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[11] For this purpose a review of 164 global scenarios from 16 different large-scale integrated models was conducted. Although the set of scenarios allows for a meaningful assessment of uncertainty, the reviewed 164 scenarios do not represent a fully random sample suitable for rigorous statistical analysis and do not represent always the full RE portfolio (e.g., so far ocean energy is only considered in a few scenarios) [10.2.2]. For more specific analysis, a subset of four illustrative scenarios from the set of 164 was used. They represent a span from a baseline scenario without specific mitigation target to three scenarios representing different CO_2 stabilization levels. [10.3]

RE can be expected to expand even under baseline scenarios. Most baseline scenarios show RE deployments significantly above the 2008 level of 64 EJ/yr and up to 120 EJ/yr by 2030. By 2050 many baseline scenarios reach RE deployment levels of more than 100 EJ/yr and in some cases up to about 250 EJ/yr (Figure SPM.9). These baseline deployment levels result from a range of assumptions, including, for example, continued demand growth for energy services throughout the century, the ability of RE to contribute to increased energy access and the limited long-term availability of fossil resources. Other assumptions (e.g., improved costs and performance of RE technologies) render RE technologies increasingly economically competitive in many applications even in the absence of climate policy. [10.2]

RE deployment significantly increases in scenarios with low GHG stabilization concentrations. Low GHG stabilization scenarios lead on average to higher RE deployment compared to the baseline. However, for any given long-term GHG concentration goal, the scenarios exhibit a wide range of RE deployment levels (Figure SPM.9). In scenarios that stabilize the atmospheric CO_2 concentrations at a level of less than 440 ppm, the median RE deployment level in 2050 is 248 EJ/yr (139 in 2030), with the highest levels reaching 428 EJ/yr by 2050 (252 in 2030). [10.2]

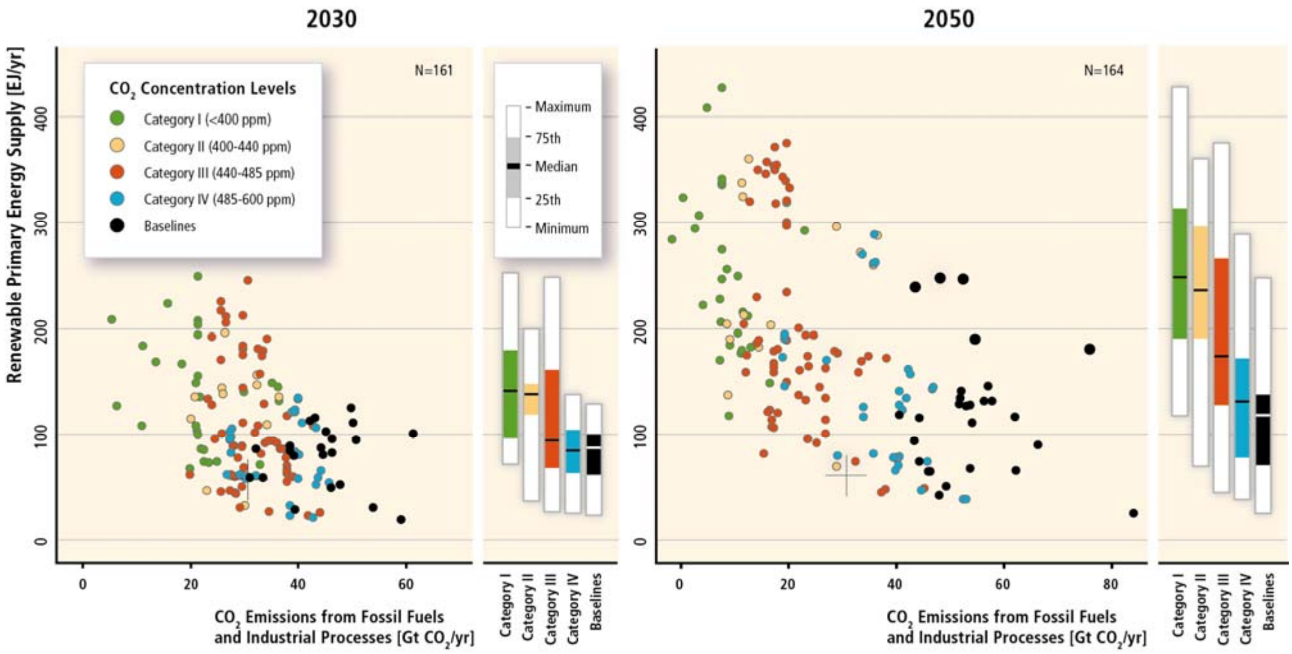

Figure SPM.9 | Global RE primary energy supply (direct equivalent) from 164 long-term scenarios versus fossil and industrial CO_2 emissions in 2030 and 2050. Colour coding is based on categories of atmospheric CO_2 concentration stabilization levels which are defined consistently with those in AR4. The panels to the right of the scatterplots show the deployment levels of RE in each of the atmospheric CO_2 concentration categories. The thick black line corresponds to the median, the coloured box corresponds to the inter-quartile range (25th to 75th percentile) and the ends of the white surrounding bars correspond to the total range across all reviewed scenarios. The grey crossed lines show the relationship in 2007.

Note that categories V and above are not included and category IV is extended to 600ppm from 570ppm, because all stabilization scenarios lie below 600ppm CO_2 in 2100 and because the lowest baselines scenarios reach concentration levels of slightly more than 600ppm by 2100. [Figure 10.2, 10.2.2.2]

Notes: For data reporting reasons only 161 scenarios are included in the 2030 results shown here, as opposed to the full set of 164 scenarios. RE deployment levels below those of today are a result of model output and differences in the reporting of traditional biomass. For details on the use of the 'direct equivalent' method of accounting primary energy supply and the implied care needed in the interpretation of scenario results see Box SPM.2.

Many combinations of low-carbon energy supply options and energy efficiency improvements can contribute to given low GHG concentration levels, with RE becoming the dominant low-carbon energy supply option by 2050 in the majority of scenarios. This wide range of results originates in assumptions about factors such as developments in RE technologies (including bioenergy with CCS) and their associated resource bases and costs; the comparative attractiveness of other mitigation options (e.g., end-use energy efficiency, nuclear energy, fossil energy with CCS); patterns of consumption and production; fundamental drivers of energy services demand (including future population and economic growth); the ability to integrate variable RE sources into power grids; fossil fuel resources; specific policy approaches to mitigation; and emissions trajectories towards long-term concentration levels. [10.2]

The scenario review in this Special Report indicates that RE has a large potential to mitigate GHG emissions. Four illustrative scenarios span a range of global cumulative CO_2 savings between 2010 and 2050 from about 220 to 560 Gt CO_2 compared to about 1530 Gt cumulative fossil and industrial CO_2 emissions in the IEA World Energy Outlook 2009 Reference scenario during the same period. The precise attribution of mitigation potentials to RE depends on the role scenarios attribute to specific mitigation technologies, on complex system behaviours and, in particular, on the energy sources that RE displaces. Therefore, attribution of precise mitigation potentials to RE should be viewed with appropriate caution. [10.2, 10.3, 10.4]

Scenarios generally indicate that growth in RE will be widespread around the world. Although the precise distribution of RE deployment among regions varies substantially across scenarios, the scenarios are largely consistent in indicating widespread growth in RE deployment around the globe. In addition, the total RE deployment is higher over the long term in the group of non-Annex I countries[12] than in the group of Annex I countries in most scenarios (Figure SPM.10). [10.2, 10.3]

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[12] The terms “Annex I” and “non-Annex I” are categories of countries that derive from the United Nations Framework Convention on Climate Change (UNFCCC).

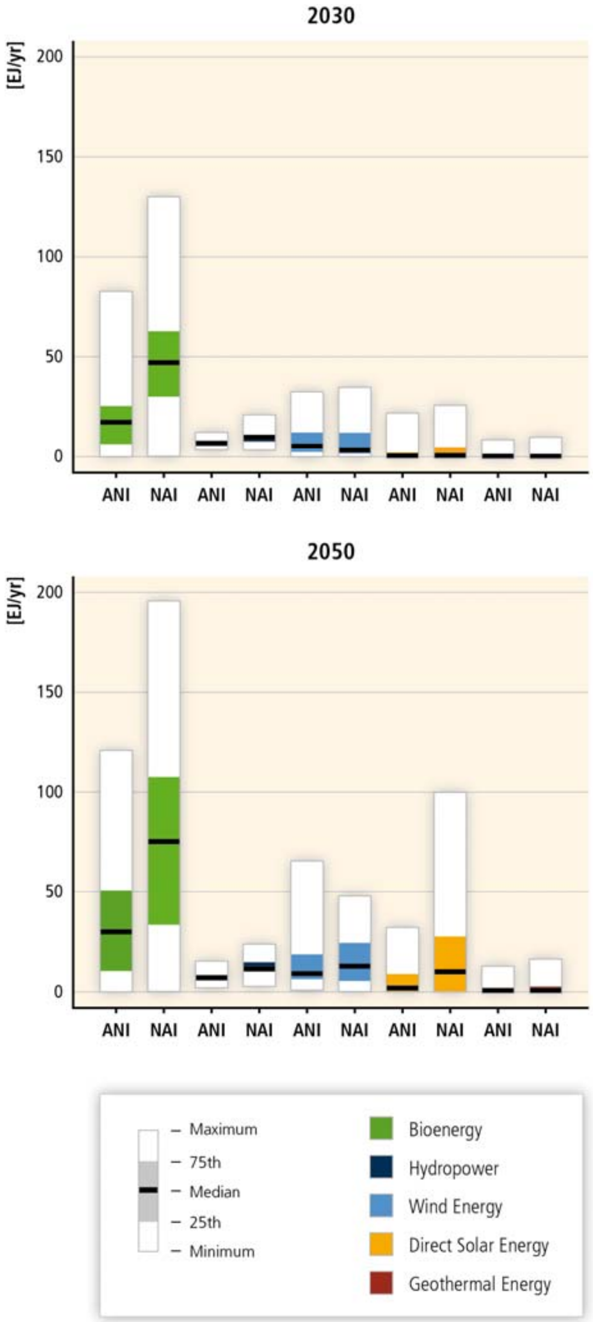
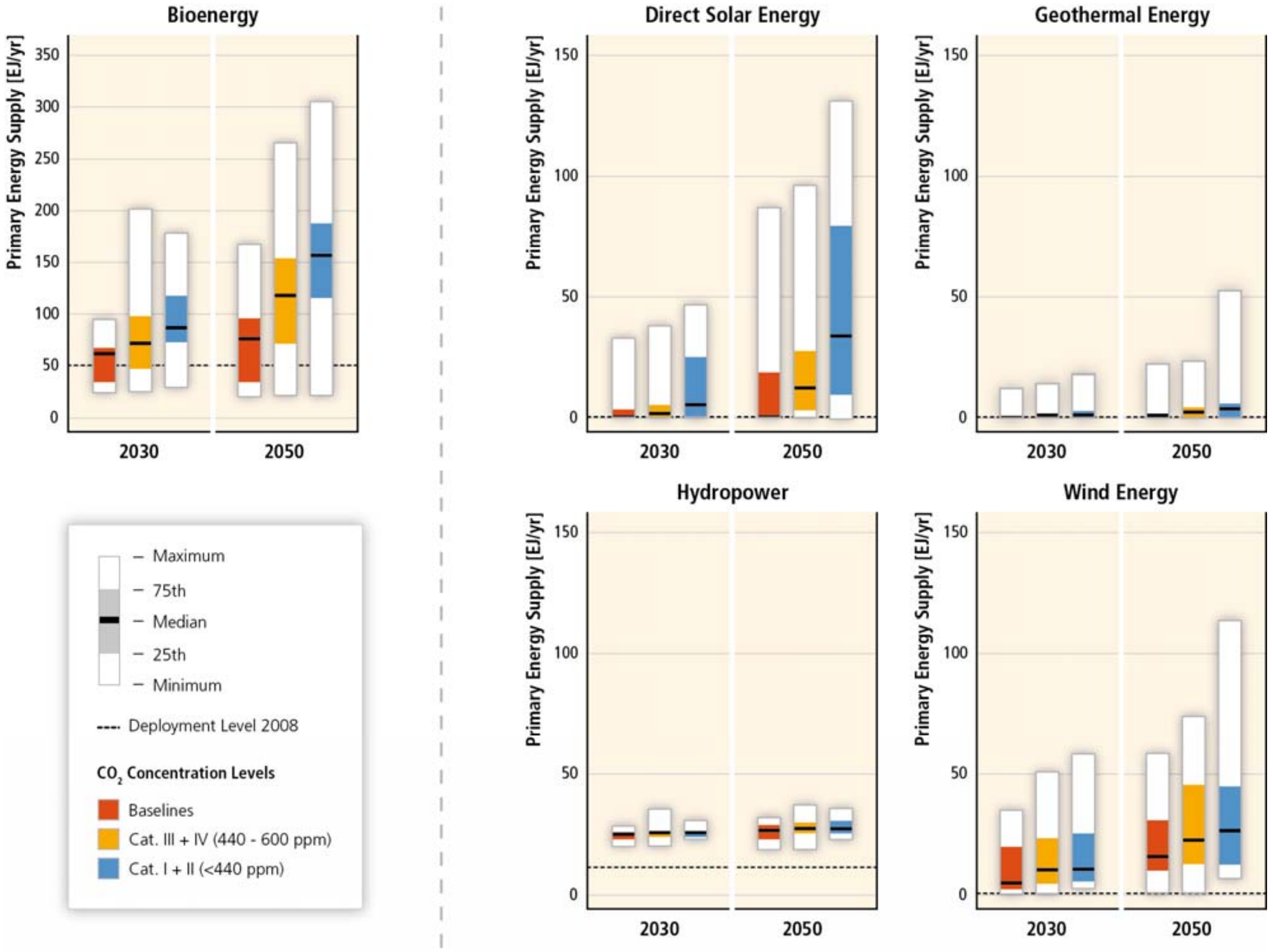


Figure SPM.10. | Global RE primary energy supply (direct equivalent) by source in the group of Annex I (AI) and the group of Non-Annex I (NAI) countries in 164 long-term scenarios by 2030 and 2050. The thick black line corresponds to the median, the coloured box corresponds to the interquartile range (25th to 75th percentile) and the ends of the white surrounding bars correspond to the total range across all reviewed scenarios. [Figure 10.8, 10.2.2.5]

Notes: For details on the use of the 'direct equivalent' method of accounting primary energy supply and the implied care needed in the interpretation of scenario results see Box SPM.2. More specifically, the ranges of secondary energy provided from bioenergy, wind energy and direct solar energy can be considered of comparable magnitude in their higher penetration scenarios in 2050. Ocean energy is not presented here as only very few scenarios consider this RE technology.

Scenarios do not indicate an obvious single dominant RE technology at a global level; in addition, the global overall technical potentials do not constrain the future contribution of RE. Although the contribution of RE technologies varies across scenarios, modern biomass, wind and direct solar commonly make up the largest contributions of RE technologies to the energy system by 2050 (Figure SPM.11). All scenarios assessed confirm that technical potentials will not be the limiting factors for the expansion of RE at a global scale. Despite significant technological and regional differences, in four illustrative scenarios less than 2.5% of the global available technical RE potential is used. [10.2, 10.3]



Bioenergy Supply is Accounted for Prior to Conversion

Primary Energy Supply is Accounted for Based on Secondary Energy Produced

Figure SPM.11. | Global primary energy supply (direct equivalent) of bioenergy, wind, direct solar, hydro, and geothermal energy in 164 long-term scenarios in 2030 and 2050, and grouped by different categories of atmospheric CO_2 concentration level which are defined consistently with those in AR4. The thick black line corresponds to the median, the coloured box corresponds to the inter-quartile range (25th to 75th percentile) and the ends of the white surrounding bars correspond to the total range across all reviewed scenarios. [Excerpt from Figure 10.9, 10.2.2.5]

Notes: For details on the use of the 'direct equivalent' method of accounting primary energy supply and the implied care needed in the interpretation of scenario results see Box SPM.2. More specifically, the ranges of secondary energy provided from bioenergy, wind energy and direct solar energy can be considered of comparable magnitude in their higher penetration scenarios in 2050. Ocean energy is not presented here as only very few scenarios consider this RE technology. Note that categories V and above are not included and category IV is extended to 600ppm from 570ppm, because all stabilization scenarios lie below 600ppm CO_2 in 2100 and because the lowest baselines scenarios reach concentration levels of slightly more than 600ppm by 2100.

Individual studies indicate that if RE deployment is limited, mitigation costs increase and low GHG stabilization concentrations may not be achieved. A number of studies have pursued scenario sensitivities that assume constraints on the deployment of individual mitigation options, including RE as well as nuclear and fossil energy with CCS. There is little agreement on the precise magnitude of the cost increase. [10.2]

A transition to a low-GHG economy with higher shares of RE would imply increasing investments in technologies and infrastructure. The four illustrative scenarios analyzed in detail in this Special Report estimate global cumulative RE investments (in the power generation sector only) ranging from USD_{2005} 1,360 to 5,100 billion for the decade 2011 to 2020, and from USD_{2005} 1,490 to 7,180 billion for the decade 2021 to 2030. The lower values refer to the IEA World Energy Outlook 2009 Reference Scenario and the higher ones to a scenario that seeks to stabilize atmospheric CO_2 (only) concentration at 450 ppm. The annual averages of these investment needs are all smaller than 1% of the world GDP. Beyond differences in the design of the models used to investigate these scenarios, the range can be explained mainly by differences in GHG concentrations assessed and constraints imposed on the set of admissible mitigation technologies. Increasing the installed capacity of RE power plants will reduce the amount of fossil and nuclear fuels that otherwise would be needed in order to meet a given electricity demand. In addition to investment, operation and maintenance (O&M) and (where applicable) feedstock costs related to RE power plants, any assessment of the overall economic burden that is associated with their application therefore will have to consider avoided fuel and substituted investment costs as well. Even without taking the avoided costs into account, the lower range of the RE power investments discussed above is lower than the respective investments reported for 2009. The higher values of the annual averages of the RE power sector investment approximately correspond to a fivefold increase of the current global investments in this field. [10.5, 11.2.2]

7. Policy, implementation and financing

An increasing number and variety of RE policies - motivated by many factors - have driven escalated growth of RE technologies in recent years [1.4, 11.2, 11.5, 11.6]. Government policies play a crucial role in accelerating the deployment of RE technologies. Energy access and social and economic development have been the primary drivers in most developing countries whereas secure energy supply and environmental concerns have been most important in developed countries [9.3, 11.3]. The focus of policies is broadening from a concentration primarily on RE electricity to include RE heating and cooling and transportation [11.2, 11.5].

RE specific policies for research, development and demonstration and deployment help to level the playing field for RE. Policies include regulations such as feed-in-tariffs, quotas, priority grid access, building mandates, biofuel blending requirements, and bioenergy sustainability criteria. [2.4.5.2, 2.ES, TS.2.8.1] Other policy categories are fiscal incentives such as tax policies and direct government payments such as rebates and grants; and public finance mechanisms such as loans and guarantees. Wider policies aimed at reducing GHG emissions such as carbon pricing mechanisms may also support RE.

Policies can be sector specific and can be implemented on the local, state/provincial, national and in some cases regional level and can be complemented by bilateral, regional and international cooperation. [11.5]

Policies have promoted an increase in RE capacity installations by helping to overcome various barriers. [1.4, 11.1, 11.4, 11.5, 11.6]. Barriers to RE deployment include:

- institutional and policy barriers related to existing industry, infrastructure and regulation of the energy system;
- market failures, including non-internalized environmental and health costs, where applicable.
- lack of general information and access to data relevant to the deployment of RE and lack of technical and knowledge capacity; and
- barriers related to societal and personal values and affecting the perception and acceptance of RE technologies. [1.4, 9.5.1, 9.5.2.1]

Public resesarch and development (R&D) investments in RE technologies are most effective when complemented by other policy instruments, particularly deployment policies that simultaneously enhance demand for new technologies. Together, R&D and deployment policies create a positive feedback cycle, inducing private sector investment. Enacting deployment policies early in the development of a given technology can accelerate learning by inducing private R&D, which in turn further reduces costs and provides additional incentives for using the technology. [11.5.2]

Some policies have been shown to be effective and efficient in rapidly increasing RE deployment. However, there is no one-size-fits-all policy. Experience shows that different policies or combinations of policies can be more effective and efficient depending on factors such as the level of technological maturity, affordable capital, ease of integration into the existing system and the local and national RE resource base.

- Several studies have concluded that some feed in tariffs have been effective and efficient at promoting RE electricity, mainly due to the combination of long term fixed price or premium payments, network connections, and guaranteed purchase of all RE electricity generated. Quota policies can be effective and efficient if designed to reduce risk; e.g. with long term contracts.
- An increasing number of governments are adopting fiscal incentives for RE heating and cooling. Obligations to use RE heat are gaining attention for their potential to encourage growth independent of public financial support.
- In the transportation sector, RE fuel mandates or blending requirements are key drivers in the development of most modern biofuel industries. Other policies include direct government payments or tax reductions. Policies have influenced the development of an international biofuel trade.

The flexibility to adjust as technologies, markets and other factors evolve is important. The details of design and implementation are critical in determining the effectiveness and efficiency of a policy. [11.5]. Policy frameworks that are transparent and sustained can reduce investment risks and facilitate deployment of RE and the evolution of low-cost applications. [11.5, 11.6]

'Enabling' policies support RE development and deployment*.* A favourable, or enabling, environment for RE can be created by addressing the possible interactions of a given policy with other RE policies as well as with energy and non-energy policies (e.g., those targeting agriculture, transportation, water management and urban planning); by easing the ability of RE developers to obtain finance and to successfully site a project; by removing barriers for access to networks and markets for RE installations and output; by increasing education and awareness through dedicated communication and dialogue initiatives; and by enabling technology transfer. In turn, the existence of an 'enabling' environment can increase the efficiency and effectiveness of policies to promote RE. [9.5.1.1, 11.6]

Two separate market failures create the rationale for the additional support of innovative RE technologies that have high potential for technological development, even if an emission market (or GHG pricing policy in general) exists. The first market failure refers to the external cost of GHG emissions. The second market failure is in the field of innovation: if firms underestimate the future benefits of investments into learning RE technologies or if they cannot appropriate these benefits, they will invest less than is optimal from a macroeconomic perspective. In addition to GHG pricing policies, RE specific policies may be appropriate from an economic point of view if the related opportunities for technological development are to be addressed (or if other goals beyond climate mitigation are pursued). Potentially adverse consequences such as lock-in, carbon leakage and rebound effects should be taken into account in the design of a portfolio of policies. [11.1.1, 11.5.7.3]

The literature indicates that long-term objectives for RE and flexibility to learn from experience would be critical to achieve cost-effective and high penetrations of RE. This would require systematic development of policy frameworks that reduce risks and enable attractive returns which provide stability over a timeframe relevant to the investment. An appropriate and reliable mix of policy instruments, including energy efficiency policies, is even more important where energy infrastructure is still developing and energy demand is expected to increase in the future. [11.5, 11.6, 11.7]

8. Advancing knowledge about renewable energy

Enhanced scientific and engineering knowledge should lead to performance improvements and cost reductions of RE technologies. Additional knowledge related to RE and its role in GHG emissions reductions remains to be gained in a number of broad areas including [for details, see Table 1.1]:

- Future cost and timing of RE deployment;
- Realizable technical potential for RE at all geographical scales;
- Technical and institutional challenges and costs of integrating diverse RE technologies into energy systems and markets;
- Comprehensive assessments of socio-economic and environmental aspects of RE and other energy technologies;
- Opportunities for meeting the needs of developing countries with sustainable RE services; and
- Policy, institutional and financial mechanisms to enable cost-effective deployment of RE in a wide variety of contexts.

Knowledge about RE and its climate change mitigation potential continues to advance. The existing scientific knowledge is significant and can facilitate the decision-making process [1.1.8].