RENEWABLES GLOBAL FUTURES REPORT

Online Supplement

SCENARIO PROFILES REPORT

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REN21 Renewable Energy Policy Network for the 21st Century

Institute for Sustainable Energy Policies

DISCLAIMER

The scenario profiles provided in this supplementary report are intended to provide the reader with a broad overview of a number of selected scenarios that were used in the *Renewables Global Futures Report.* However, the information contained in these scenario profiles is not warranted to be accurate relative to the original sources. The reader desiring to use specific items of data from scenarios is advised to consult the original sources. Only scenario data employed in the main text of the *Futures Report* have been double-checked for accuracy with the original sources.

LIST OF SCENARIOS PROFILED
(See Bibliography for Full Reference Citations)

GLOBAL

AFRICA

CHINA, INDIA, AND ASIA

EUROPE

LATIN AMERICA

UNITED STATES

1. *World Energy Outlook 2012* (International Energy Agency (IEA), 2012)

Scenario Description

The World Energy Outlook (WEO) develops three main scenarios; the “Current Policies Scenario,” the “New Policies Scenario” (NPS), and the “450 parts per million of carbon-dioxide equivalent (ppm CO2-eq) Scenario,” and the “Efficient World Scenario.” The NPS, which is the central case, details the impact of existing policy commitments and the implementation of those recently announced, on the key energy demand, supply, trade, investment and emissions trends in the period up to 2035. In this scenario, fossil fuel subsidies are assumed to be phased out by 2020 in all net energy importing countries and more gradually in exporting ones that have announced plans to do so. Apart from this important assumption, other primary assumptions include population growth to 8.6 billion by 2035, and an average rate of economic growth in real terms of 3.5% per year through 2035. By 2035, the NPS also predicts that the price of crude oil import will reach $125/barrel (in year 2011 dollars), that the price of coal will reach $115/tonne, and that carbon prices will range from $30 to $45/tonne.

The WEO 2012 makes use of the World Energy Model that replicates the dynamics of energy markets using historical data on economic and energy variables to generate projections.

Key Projections/Results

In the NPS, global primary energy demand will increase by 35% between 2010 and 2035. Approximately 90% of that increase will come from non-OECD countries as the share of OECD countries in world energy demand fall to about 35% in 2035 (a decline of roughly 10 percentages points compared to 2010).

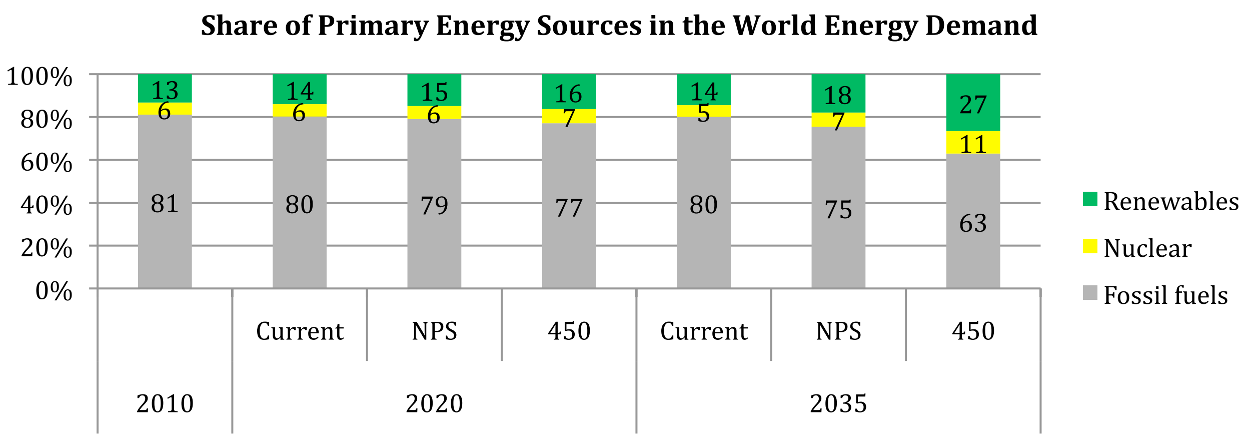


Figure A-1

In the NPS, the share of fossil fuels will decrease from 81% in 2010 to 75% in 2035 (Figure A-1). Oil, coal, and gas will thus remain the predominant sources of energy. However, renewable energy sources will continue to grow; from 13% of the global primary energy demand to 18% at the end of the outlook period. The share of nuclear will remain constant around 6-7%.

In the NPS, electricity demand will increase by more than 70%, with over 9,300 GW of installed capacity needed by 2035. Although the share of fossil fuels in electricity generation decreases; approximately less than 10 percentage points compared to 2010, fossil fuels will still provide 57% of the electricity supply in 2035 (Figure A-2). Electricity generated from renewables will almost triple, and the share of renewables in the world electricity mix will increase from 20% to 31%. Hydro energy provides and will continue to provide the largest share of renewables. The nuclear share will remain constant at around 12-13%.

Among all renewables, wind power will play a growing role; the wind power share in the electricity mix will increase to 7.3% in 2035, up from 1.6% in 2010. The contribution of biomass and solar PV technologies in power generation will also increase, but to a lesser extent.

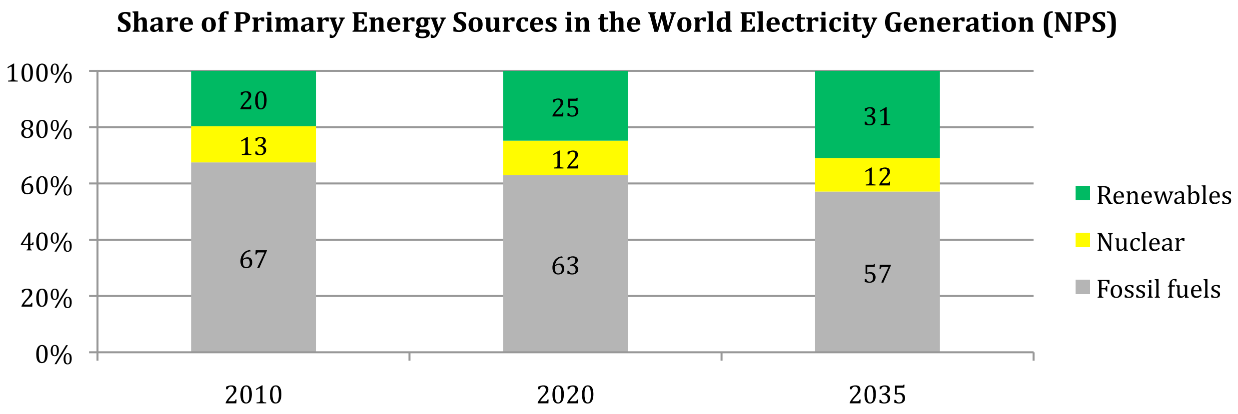


Figure A-2

In the NPS, in terms of renewables installed capacity, the growth of wind power means that the dominance of hydropower will decline. By the end of the outlook period, these two technologies combined will account for almost three-quarters of the total renewables installed capacity. Beyond hydro and wind, solar PV capacity will exceed biomass capacity by 2015, and solar PV will grow by more than 15-fold to reach over 600 GW by 2035. The growth rate of CSP will be significant, but its deployment in terms of capacity will be less significant than for solar PV. Geothermal and ocean remain relatively small.

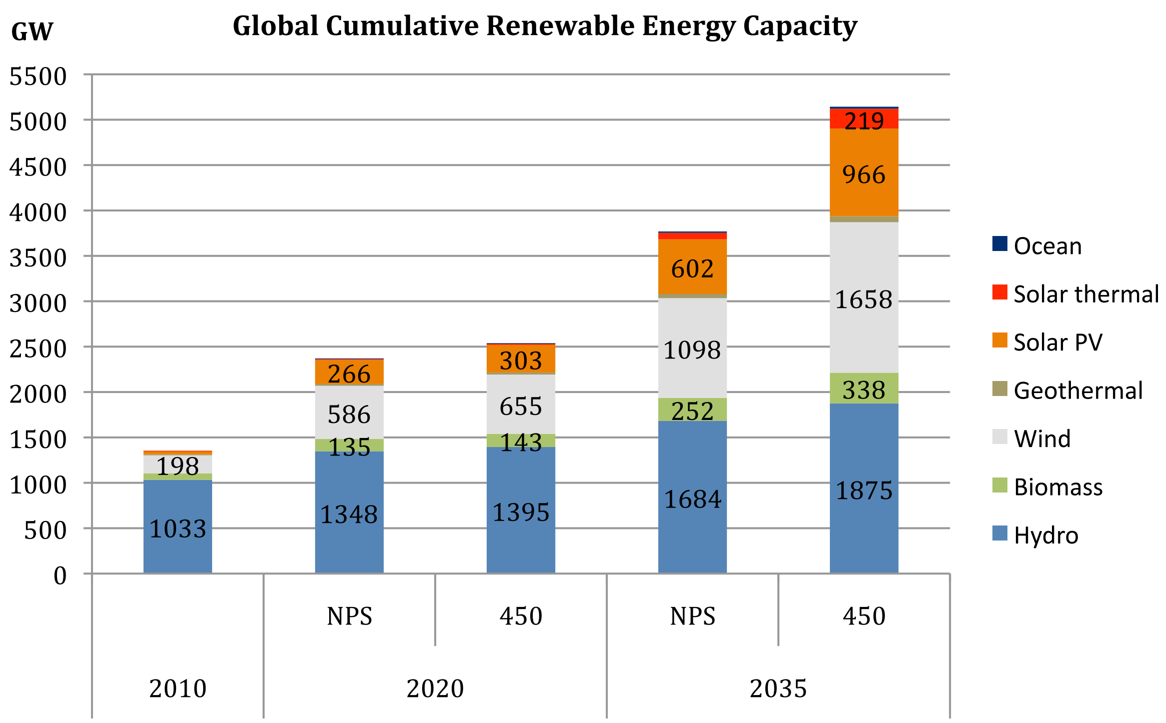


Figure A-3

In the NPS, renewables (essentially biofuels) will represent 6% of the transport sector uses by 2035. The United States and Brazil will remain the largest producers of biofuels.

In the NPS, renewables will represent 14% of the heat demand by the end of the outlook period. Solar and geothermal heat are expected to grow significantly.

2. *Energy Technology Perspectives 2012, Pathways to a Clean Energy System* (International Energy Agency (IEA), 2012)

Scenario Description

The Energy Technology Perspectives (ETP) report is a guide for decision makers on energy trends and what needs to be done to build a clean, secure and competitive energy future. It demonstrates how technologies can make a decisive difference in limiting climate change and enhancing energy security. For instance, it notably shows how energy systems will become more complex, why flexible electricity systems are increasingly important, and how a system with smarter grids, energy storage and flexible generation can work.

In the framework of this analysis the report presents detailed scenarios and strategies to 2050. It starts from the target of limiting average global temperature increase to 2°C. Then it develops three possible energy futures, the boundaries of which are set by total energy-related CO2 emissions:

- The 6°C Scenario (6DS), an extension of current trends that assumes no new policy action is taken to address climate change and energy security concerns what results in an average global temperature rise of at least 6°C in the long term (consistent with the IEA World Energy Outlook *Current Policy Scenario*);

- The 4°C Scenario (4DS), which represents a concerted effort to move away from current trends and technologies, with the goal of reducing both energy demand and emissions vis-a-vis the 6DS (consistent with the IEA WEO *New Policy Scenario*);

- The 2°C Scenario (2DS), which describes a vision of a sustainable energy system consistent with an emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2°C (consistent with the IEA WEO *450 Scenario*). The 2DS scenario reflects a concerted effort to reduce overall consumption and replace fossil fuels with a mix of renewable and nuclear energy sources, and dramatic improvements in terms of energy efficiency.

Among the main assumptions incorporated: global gross domestic product (GDP) increases by 3.3% per year on average through 2050, global population is projected to reach 9.3 billion people by 2050, and the price of crude oil by 2050 will be $87/barrel in the 2DS scenario and $149/barrel in the 6DS scenario.

Key Projections/Results

Total primary energy supply (TPES) will grow in all scenarios. In the 2DS, TPES increases by approximately 37% from 2009 to 2050. This is significantly lower than the 85% rise in the 6DS. In the OECD, TPES is projected to stay almost constant in the 2DS, and increase only moderately in the 6DS. In the non-OECD countries, even in the 2DS TPES is projected to rise by about 70% in 2050 compared to 2009.

The share of renewables in the world energy mix will be 41% in the 2DS, 24% in the 4DS and 15% in the 6DS in 2050, compared to 13% in 2009 (Figure B-1).

In all scenarios, fossil fuels remain a significant part of the global energy system for decades. Even though global oil use falls, it will remain particularly significant in transport and as a feedstock in industry. Natural gas will remain a significant fuel in all sectors through 2050.

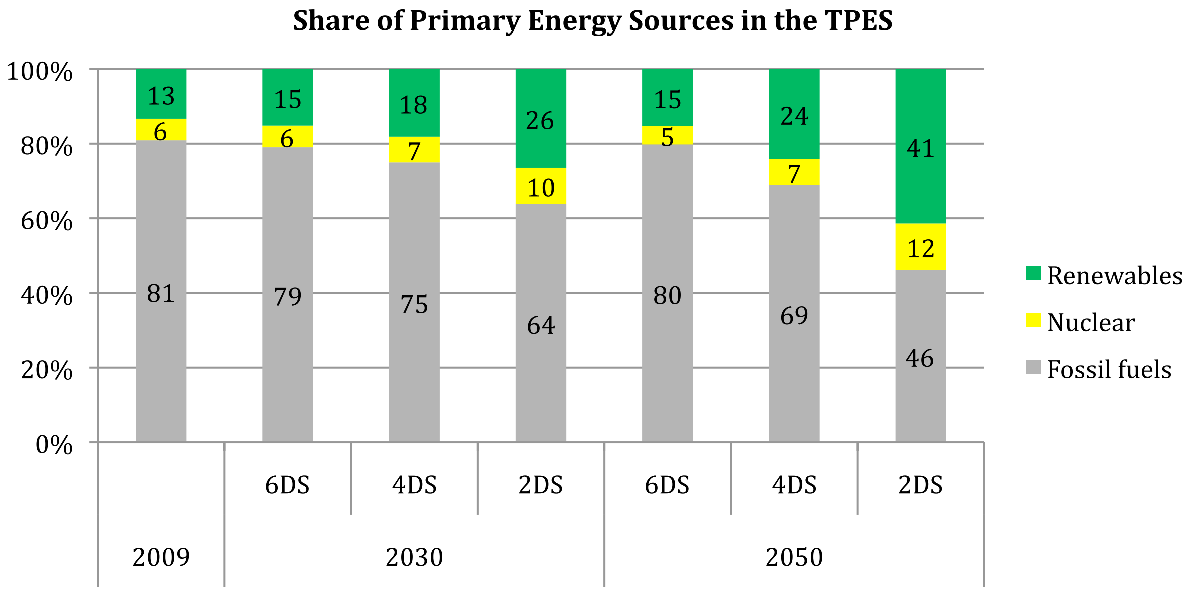


Figure B-1

In the 2DS, electricity generated from renewables will increase by more than 6-fold in absolute terms. The share of renewables in the world electricity mix will increase to 57% by 2050 (Figure B-2). Hydro will represent 17% of the total electricity generated, wind 15% (two-thirds onshore, and one-third offshore), CSP 8%, biomass 7%, solar PV 6%, geothermal 2%, and ocean 1%.

In the 4DS and the 6DS, the share of renewables in the world electricity mix by 2050 is respectively 36% and 24% (compared to 19% in 2009).

Low-carbon electricity generation is already competitive in many markets and will take an increasing share of generation in the coming years, integrating a much higher share of variable generation, such as wind power and solar PV.

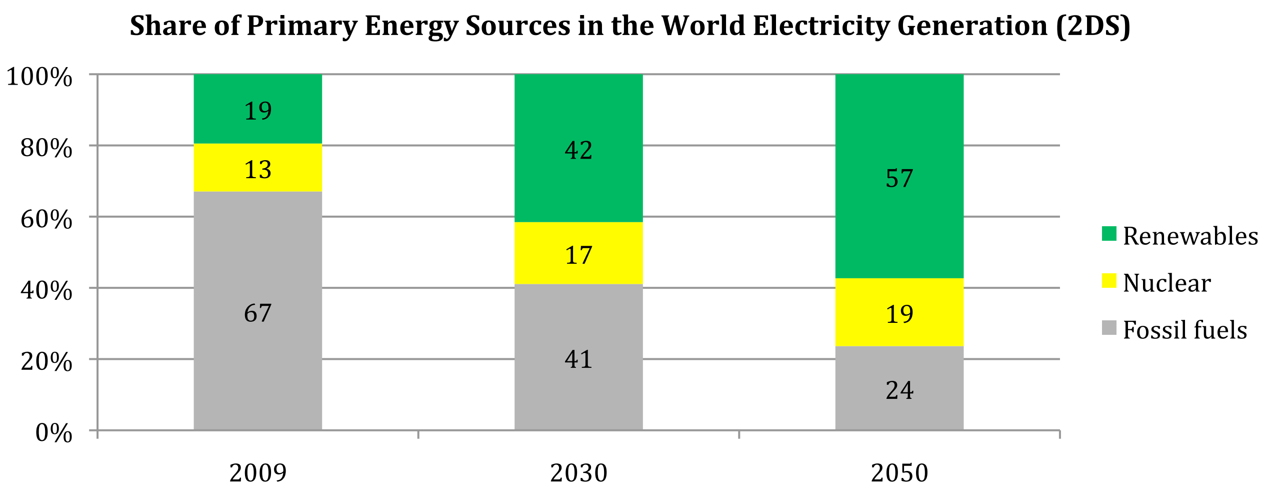


Figure B-2

By 2050, the share of electricity as a fraction of total final consumption will rise from 17% in 2009 to 26% in the 2DS, and 23% in the 4DS.

Cumulative investments of around $7.7 trillion in power generation are required in the 2DS, in addition to the $18 trillion investment in the 6DS, between 2012 and 2050.

The average cost of generating electricity will rise by 40% to 50% in all scenarios through 2050.

In the 2DS, in terms of installed capacity, hydropower will remain the most significant renewable energy source until 2035-2040. During this period it will be overtaken by wind power. By the end of the outlook period there will be almost 2,350 GW of wind power capacity in the world (Figure B-3), of which about 600 GW will be offshore. By 2050, with over 2,000 GW of installed capacity solar PV will also overtake hydropower to become the second most important renewable energy source. The growth of solar PV will mainly occur after 2030 with almost a tripling of the considered technology capacity between 2030 and 2050. The growth of solar thermal and ocean technologies will be significant after 2040 with an increase of respectively 475 GW and 155 GW installed capacity during the last decade of the outlook period. Biomass and geothermal capacities will respectively increase by 11–fold and 12–fold between 2009 and 2050. By 2050, with approximately 8,150 GW of installed capacity renewable energy sources will account for over two-thirds of global power capacity, compared to 25% in 2009.

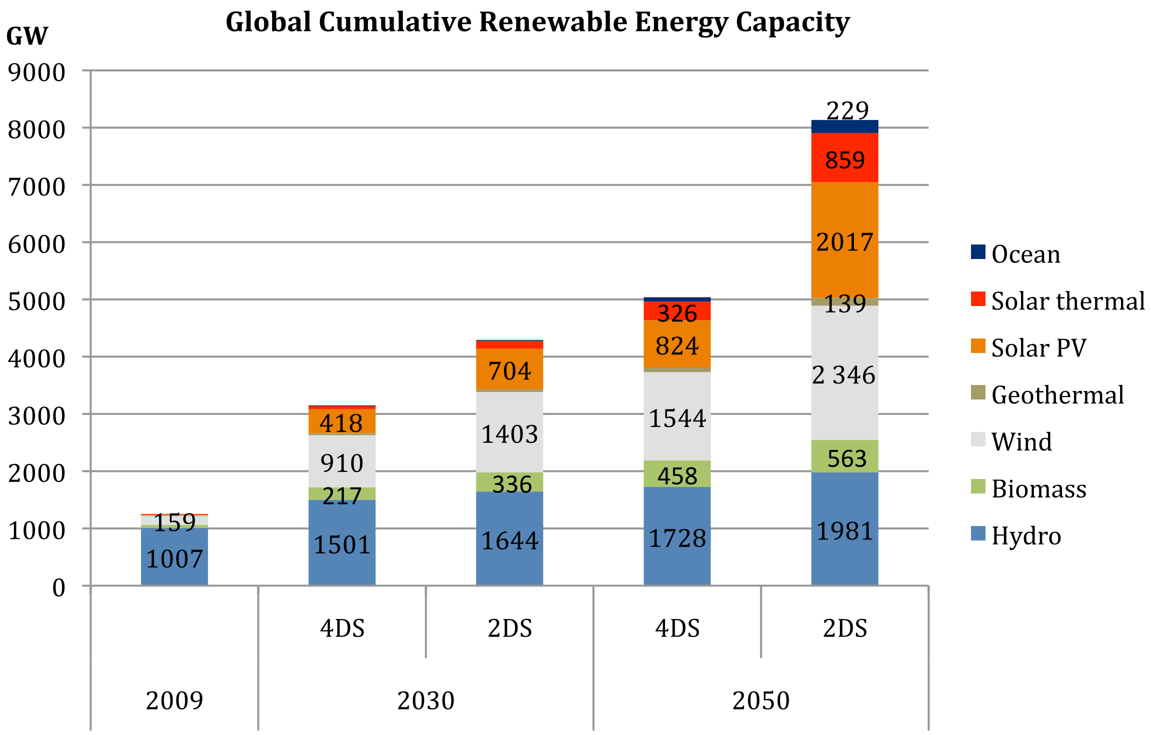


Figure B-3

For the transportation sector:

- In the 6DS scenario, transport remains based almost exclusively on fossil fuels. There is little penetration of plug-in electric vehicles and other alternative technologies and fuels.

- In the 4DS scenario, penetration of alternative-fuel vehicle technologies (plug-in hybrid electric, and battery electric vehicles) is slow. The only new alternative technology that gains significant market share is gasoline hybrid vehicles, reaching some 25% of sales in 2050.

- In the 2DS scenario, oil is partially replaced by a portfolio of three alternative fuels: electricity, hydrogen and biofuels. After 2030, the increased share of electric and plug-in hybrid electric vehicles becomes increasingly important for cars and light-duty trucks, reaching 50% of vehicle sales in 2050. The use of biofuels will increase to approximately 240 billion liters (gasoline equivalent) by 2020. Achieving this figure largely depends on the development of advanced biofuels.

Concerning the buildings energy consumption and the industrial one; the 2DS projects an increasing use of biomass and waste, and of electricity.

Concerning the district heating and cooling; biomass and a mix of other renewable energy sources will represent almost three-quarters of primary energy consumption in the 2DS in 2050.

The cost of creating low-carbon energy systems in the shorter term will be outweighed by the potential fuel savings enjoyed by future generations; a sustainable energy system will require $140 trillion in investments to 2050, but will generate undiscounted net savings of more than $60 trillion.

3. *Energy [R]evolution: A Sustainable World Energy Outlook* (Greenpeace, Global Wind Energy Council (GWEC), and European Renewable Energy Council (EREC), 2012)

Scenario Description

The study uses a bottom-up, technology-driven approach to illustrate the possibility of 100% renewable power by 2050. Two scenarios are produced: a Reference one and an Energy Advanced [R]evolution one.

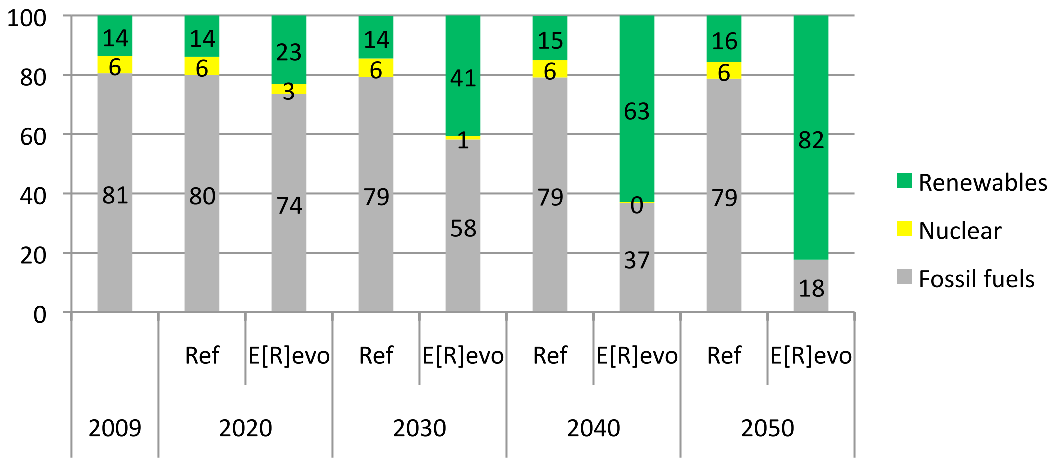
The Energy Advanced [R]evolution scenario ("E[R]evolution") looks at the potential of reducing energy demand through energy efficiency and providing electricity through decentralized renewable energy sources. It explores the use of smart grids to connect these decentralized systems and assumes that hybrid/electric cars will be predominant in 2050 and that nuclear energy will be phased out by 2050.

Other main assumptions for 2050 include a population of nearly 9.3 billion, average economic growth of 3.1%, a decline in energy intensity (final energy demand per unit of GDP) of almost 70%, an average crude oil cost of US$152 a barrel, a coal price of US$206 per tonne, and a carbon price of US$75 per tonne.

Key Projections/Results

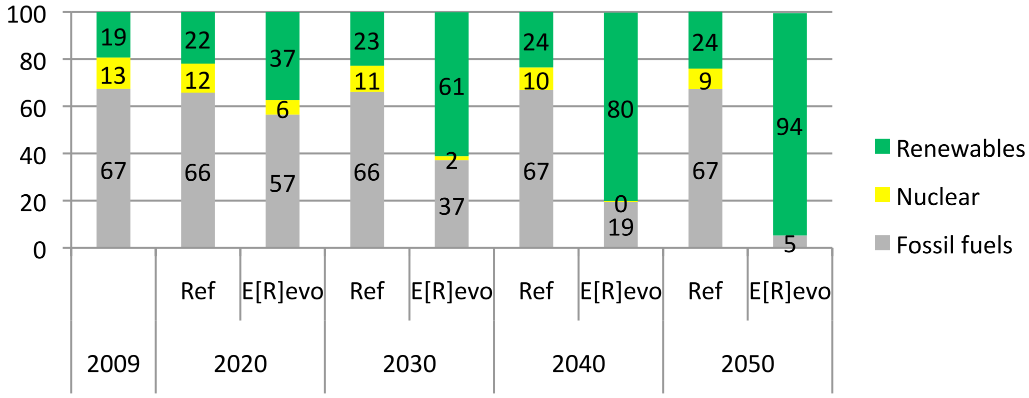
Under the E[R]evolution scenario, world primary energy demand will decrease to 481,050 petajoules (PJ) in 2050 as a result of energy efficiency measures, the phaseout of nuclear, and reduced dependence on fossil fuels. Meanwhile, the share of renewable energy will increase considerably, accounting for 82% of world primary energy demand in 2050. (See Figure B-1.)

Figure B-1. Share of Primary Energy Sources in World Energy Demand



Nearly 95% of the world's electricity will come from renewable energy sources in 2050, reflecting the fact that a renewables-based future is possible. (See Figure B-2.) Wind, solar PV, and geothermal will represent some 60% of electricity generation, and approximately 91% of heat energy will come from renewables.

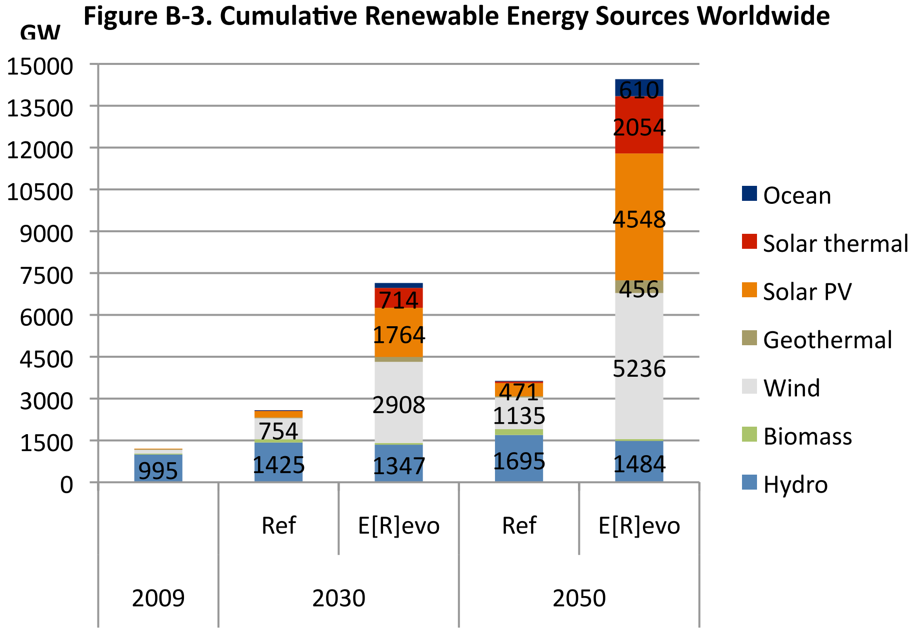
Figure B-2. Share of Primary Energy Sources in World Electricity Generation



Due in large part to the growth of offshore wind (to 892 GW in 2050), wind will become the leading renewable energy source, followed by solar PV and solar thermal. (See Figure B-3.) Ocean energy will also expand significantly, surpassing geothermal and biomass in installed capacity.

In the Reference scenario, hydropower will remain the main renewable energy source, followed by onshore wind and solar PV. Other sources will have only marginal contributions.

Figure B-3. Cumulative Renewable Energy Sources Worldwide



Pathways to Implementation

To achieve the goal of 100% renewable power by 2050, several policy measures are crucial. These include the phaseout of fossil fuel subsidies and the gradual phaseout of nuclear energy. A cap-and-trade emission trading scheme is equally important, as well as adequate reforms in the electricity market that allow for greater renewable energy use.

4. *The Energy Report: 100% Renewable Energy by 2050* (World Wide Fund for Nature (WWF) and Ecofys, 2011)

Scenario Description

The study investigates possible pathways to achieving 100% renewable energy, shaped by two fundamental questions: what is the minimum amount of energy needed to deliver various functions, and how can this be supplied in a sustainable way?

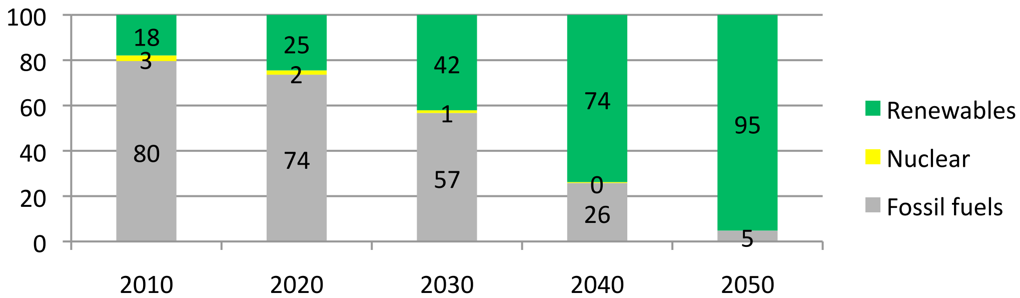
The key pathways outlined are energy efficiency, electrification, and bioenergy. Although this energy transformation requires a high investment cost, the later stages of the transition will bring a cost advantage, primarily through savings. The strategy for achieving this vision involves reducing energy demand, supplying energy through renewables, and satisfying the remaining demand via traditional energy sources provided in a clean way.

The model assumes that energy demand is the product of (a) the volume of activity requiring energy, and (b) energy intensity. Activity depends on economic and population growth, whereas intensity is dependent on the fastest rollout of the most efficient technologies. Estimates of supply look at the supply potential for each energy carrier: electricity, fuel, and heat.

Key Projections/Results

The scenario projects that by 2050, 95% of world final energy consumption will be met by renewable energy sources, with the rest being supplied by fossil fuels and a gradual phaseout of nuclear. (See Figure C-1.) Final energy consumption will peak in 2020 and then decrease to 261.4 exajoules (EJ) in 2050, down from 327.7 EJ in 2010.

Figure C-1. Share of Primary Energy Sources in World Final Energy Consumption



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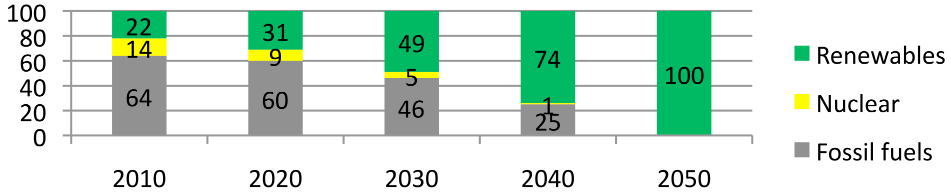
This transition to renewable energy is possible through significant changes in the energy mix in four distinct sectors: buildings, industry, electricity, and transport.

In the building sector, actions are taken in the existing stock and also with new buildings. In existing stock, a retrofitting program by 2050 is key to reducing heating needs by 60%. Heating and hot water needs will be met by solar thermal systems and heat pumps, while cooling will be provided by local renewable solutions. New buildings will be near-zero-energy by 2030, with residual heat demand met by passive solar, solar thermal installations, and heat pumps. Buildings will also be all-electric. Although there will be a decrease in heating demand, a rise in electricity demand is inevitable. These changes will contribute to buildings being powered by 100% renewables in 2050, compared to a 60% dependence on fossil fuels in 2010.

In industry, the share of renewables will increase from 8% in 2010 to 79% in 2050, while demand will decrease considerably to its 2000 level.

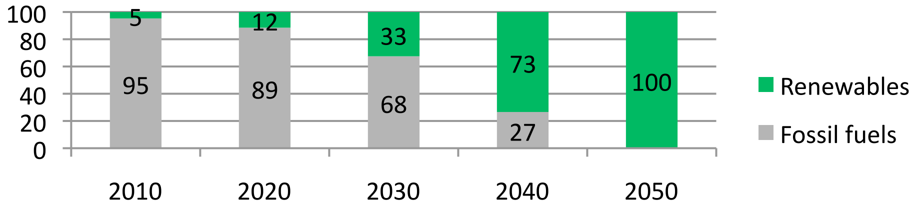
Electrification in various sectors will increase the demand for power to 127 EJ annually in 2050, double the 2010 figure. Renewables will account for a projected 100% of electricity consumption in 2050, compared to just over 20% in 2010. (See Figure C-2.) Offshore wind energy will increase by 30% and onshore wind by 20% annually through 2050. Solar technologies that will play an important role are PV, solar thermal (CSP), CSH (concentrating solar high-temperature heat, used primarily in industry), and solar thermal low-temperature heat for buildings. PV will grow annually by 25–30% (including building-integrated PV and large-area PV installations), and CSP will grow by 20%.

Figure C-2. Share of Primary Energy Sources in World Electricity Generation



In the transport sector, there will be a modal shift from fuel to electricity; electric cars and electric rail systems will be more prominent, with more-efficient technologies. The basic assumptions for electrification of transport are a shift to plug-in hybrid and electric cars, energy efficient heavy vehicles, and shipping fuel from hydrogen produced from renewable energy. Electric vehicle batteries will be mainly lithium Ion. Electrification will enable the transport sector to be 100% powered by renewables. (See Figure C-3.)

Figure C-3. Share of Primary Energy Sources in World Transport



5. *Global Energy Assessment: Toward a Sustainable Future* (GEA, 2012)

Scenario Description

The report examines major global challenges and their linkages to energy; the technologies and resources available for providing adequate, modern, and affordable forms of energy; the plausible structure of future energy systems most suited to addressing the century's challenges; and the policies, measures, institutions, and capacities needed to realize sustainable energy futures.

The report develops 60 alternative pathways through which energy systems could be transformed to simultaneously address critical social and environmental goals: stabilizing global climate change to 2°C above pre-industrial levels (to be achieved in the 21st century), enhancing energy security through diversification of the energy supply (particularly by reducing dependence on imported oil), eliminating household and ambient air pollution, and attaining universal access to modern energy services by 2030.

The pathways are grouped into three different approaches for achieving these goals: "GEA-Supply," "GEA-Mix," and "GEA-Efficiency." GEA-Supply depicts futures with radical developments such as hydrogen or carbon capture and storage, GEA-Mix relies more on today's advanced infrastructure such as biofuels, and GEA-Efficiency relies more on today's advanced options such as efficiency and renewables. The three approaches were developed using two integrated assessment modeling frameworks: MESSAGE and IMAGE.

The main assumptions include: global per capita GDP increases by 2% a year on average through 2050; global population reaches 9 billion people by 2050; and today's advanced technologies, many of which are not commercially viable under current market conditions, will be improved through vigorous R&D and deployment to achieve cost reductions and better technical performance through economies of scale and through learning by using and by doing.

Key Projections/Results

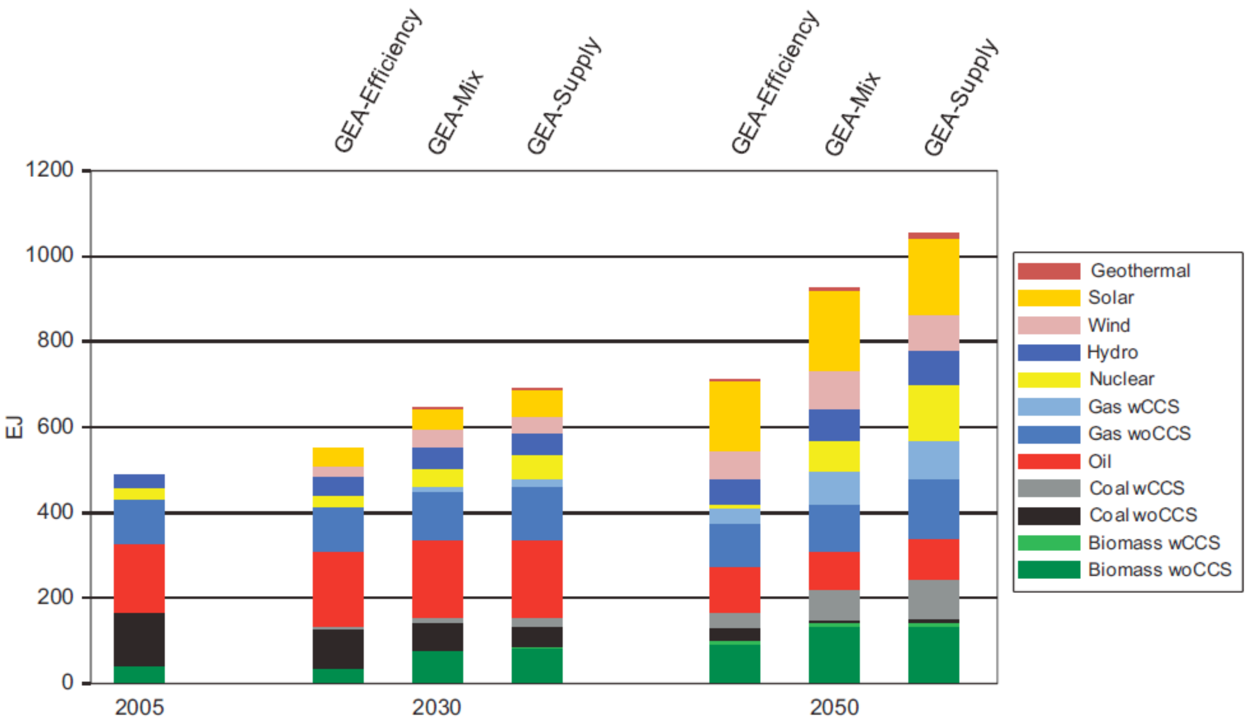
According to the report, 41 of the 60 alternative pathways satisfy all of the GEA goals simultaneously. Thus, the analysis demonstrates that a sustainable future is possible and that there are many energy portfolio options and many ways to transform energy systems. The single most important area of action is efficiency improvement in all sectors.

Renewable energy plays an important role in all of the transition pathways. Strong growth in renewables is not only expected, but it begins immediately, expanding to 165–650 EJ of primary energy by 2050. The share of renewables (biomass, hydro, wind, solar, and geothermal) in global primary energy will increase from the current 17% to between 30% and 75% (and in some regions more than 90%) by 2050.

In GEA-Efficiency, renewables will represent approximately 75% of primary energy by 2050, when primary energy demand is expected to reach 700 EJ (up from 490 EJ in 2005), and 90% by the end of the century. In GEA-Supply, renewables will contribute about half of primary energy by 2050, when primary energy demand is expected to reach 1,050 EJ.

Figure D-1 shows the composition of global primary energy supply in 2005, 2030, and 2050 across pathway groups under an unrestricted supply portfolio and "Conventional Transportation" setup. It reveals that even in a not particularly ambitious scenario, biomass and wind power will grow significantly in all pathway groups by 2050, and solar will not only be the leading renewable energy source, but also one of the two leading energy sources (along with natural gas) by mid-century.

Figure D-1



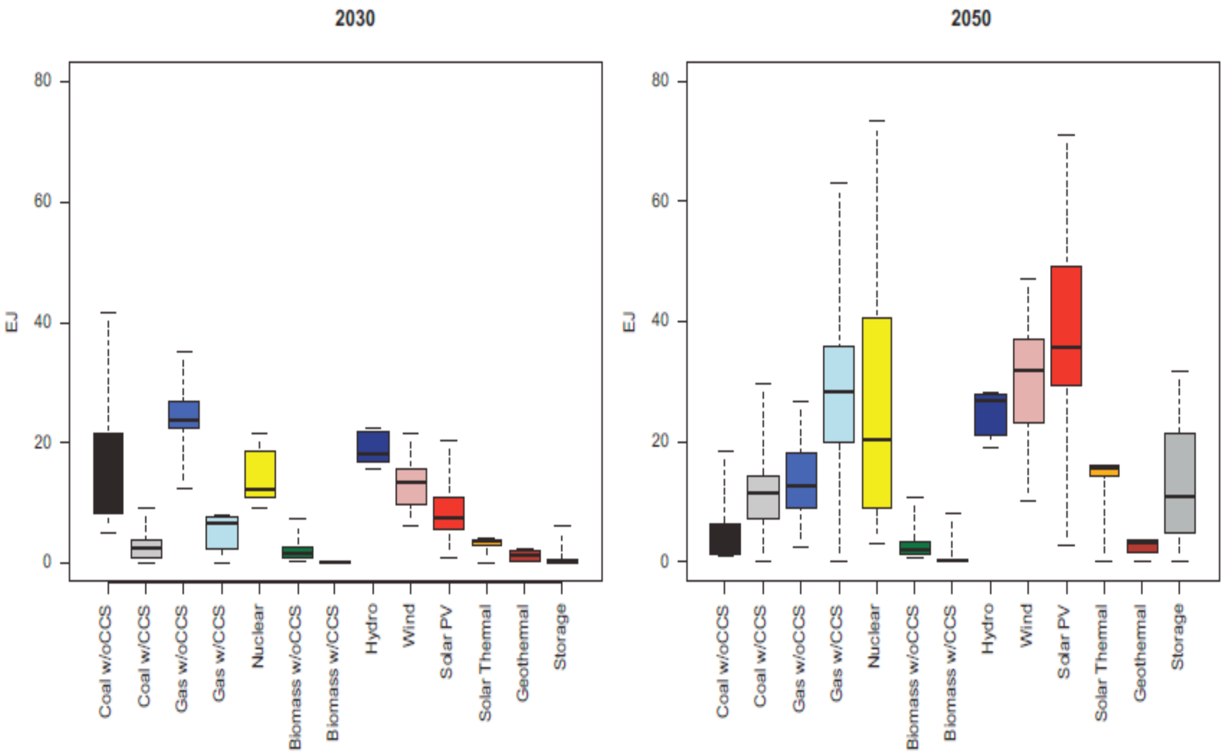
Several of the GEA pathways explore limitations of various renewable energy options. Yet even under these constraints, relatively mature technologies such as hydropower and onshore wind power experience strong growth to 2030 and 2050, with limited variation among pathway groups. Solar PV and solar thermal (CSP) are more variable and show stronger deployment after 2030, although by 2020 the average deployment shows a multifold increase compared with today's levels. Biomass and geothermal electricity generation show much lower deployment levels on average compared with these other renewable technologies.

In the power sector, the share of renewables will grow depending on the requirements for energy storage technologies, especially in those pathways with very high deployment of intermittent sources (wind, solar PV, and to a lesser extent CSP). This trend will be more pronounced in the medium and long terms, when renewables become increasingly dominant sources of energy supply.

Storage will be supplemented with demand-side management and/or smart grids, although these requirements will depend on the availability of negative carbon options (BioCCS and carbon sinks). If such negative emissions technologies do not become available on large scale, more rapid early action, including larger contributions of wind and solar PV, will be needed. The same will be true if nuclear power is excluded, with the slack again taken up by intermittent renewable sources. This shift will be technically feasible since both wind and solar PV power are already cost competitive in some markets and are projected to become more so in many markets in the next 5–10 years without any public subsidy.

Figure D-2 illustrates the electricity supply from different generation technologies in 2030 and 2050, under the GEA pathways. The boxes represent interquartile (25th to 75th percentile) ranges, and the horizontal lines within boxes represent medians across all feasible GEA pathways from MESSAGE and IMAGE. Error bars indicate the full range across all feasible pathways. The Figure indicates that solar PV and wind will be the two main sources of renewable power by 2050.

Figure D-2



In the transport sector, the report explores three different pathways, all of which assume a phaseout of conventional oil shortly after 2050. In GEA-Efficiency, electricity and biofuels dominate, while In GEA-Mix, natural gas and fossil/biofuel liquids are also used. In GEA-Supply, hydrogen plays a large role. The analysis concludes that many varied combinations of energy carriers would be able to fuel the transport sector. (See Figure D-3.)

Figure D-3

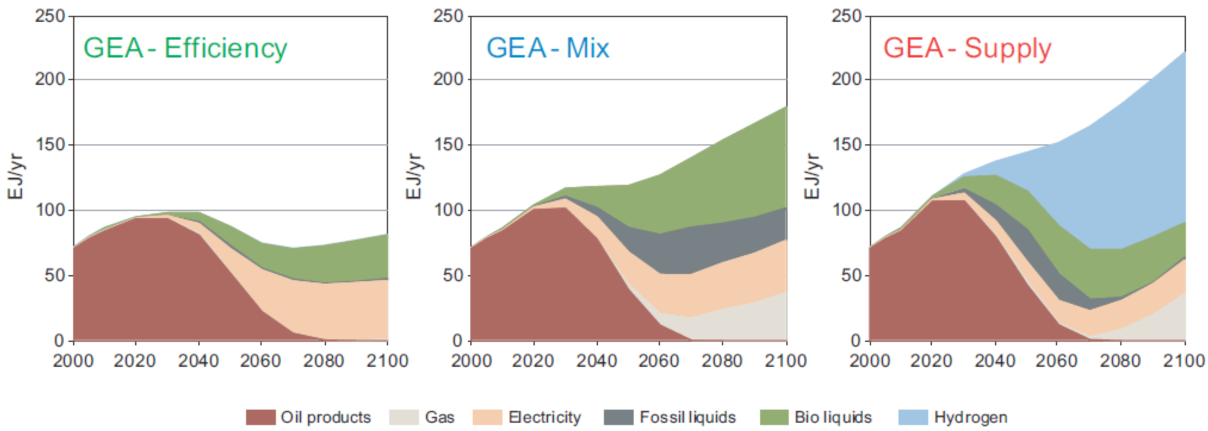
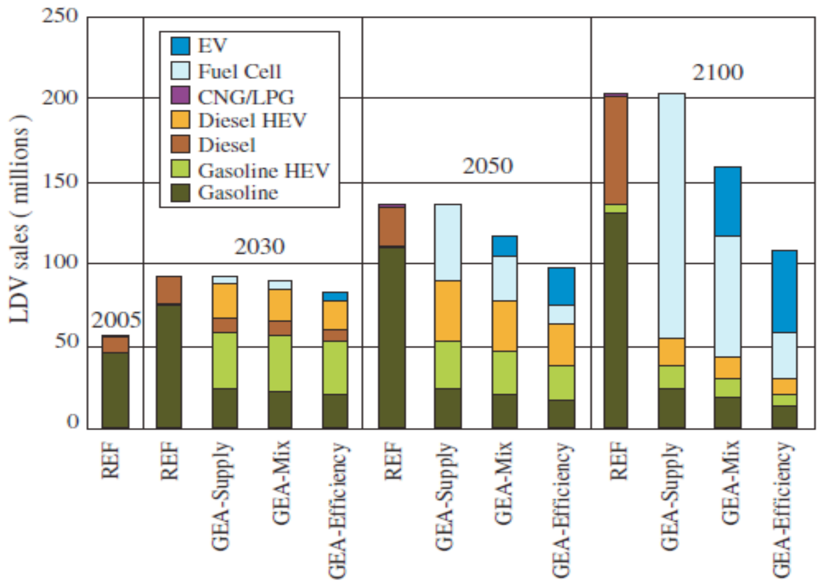


Figure D-4 shows worldwide sales of light-duty vehicles (LDVs) by vehicle type, under the three pathways. The results indicate that the future of fuel cell and electric LDVs is relatively promising in the long term.

Figure D-4



The GEA distinguishes two sets of assumptions about the transition in the transport sector, "Advanced Transportation" and "Conventional Transportation." Advanced Transportation is characterized by a transition to electricity or hydrogen, or both, as leading transportation fuels in the medium to long term. By 2050, these two fuels would deliver between 20% and more than 60% of the sector's final energy (depending strongly on overall transportation demand). In the Conventional Transportation scenario, current modes of operation continue to rely largely on liquid fuels and, in some regions, on gasoline.

In the industrial sector, the GEA-Efficiency pathway illustrates that a switch to 25% renewable energy throughout the manufacturing industry is achievable.

In the heating and cooling sector, the analysis demonstrates that a roughly 46% reduction of global final energy use for heating and cooling is possible by 2050 (compared with 2005), through full use of today's best practices in design, construction, and building operation technology and know-how. An investment of US$15 trillion is needed to realize this pathway. Increased heat demand could be met in part by solar (mainly for water heating and passive-solar building designs), geothermal (from direct heating and ground-source heat pumps), and modern biomass (including from crop and forest residues, landfill gas, biogas, and combined heat and power).

The analysis indicates that investment in global energy systems needs to increase to some US$1.7–2.2 trillion annually by 2050, with about US$300–550 billion of this required for demand-side efficiency, compared to today's roughly US$1 trillion annually in supply-side investments and $300 billion in demand-side investments in energy components. These investments correspond to about 2% of world GDP in 2005, and would be about 2–3% by 2050.

Of supply-side options, the largest increase in investment needs is for renewable power, ranging from US$160 billion annually in pathways that have restricted renewables penetration to US$800 billion annually in pathways without carbon capture and storage and nuclear power—up from US$160 billion in 2010.

Another investment priority is building electricity transmission and distribution systems with sufficient operation and capacity reserves to increase reliability, as well as power storage to allow the integration of intermittent renewables. Global average electricity grid investment (including storage) by 2050 is expected to increase to US$310–$500 billion annually across the GEA pathways, up from US$260 billion in 2010.

6. *BP Energy Outlook 2030* (BP, 2012)

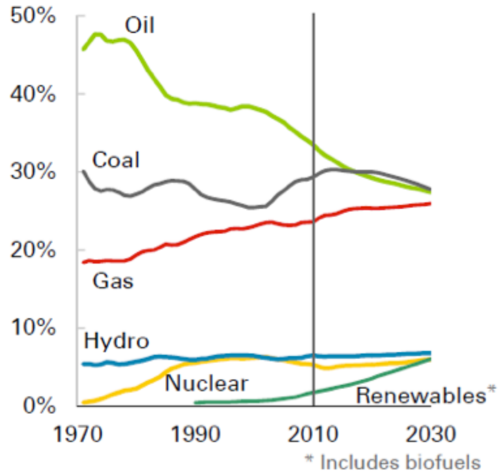
Scenario Description

The report is neither an extrapolation nor an attempt to model policy targets. It is instead a reflection of judgment, where assumptions regarding policy, technology, and the economy are shaped by internal and external consultations. The outlook encompasses two sets of data: a base case and a policy case that assesses the impact of possible policy changes. In the base case, population and income growth are assumed to be the major driving force of energy demand, whereas in the policy case, some stringent policy measures are adopted to cut the CO_2 emissions of developed countries and to reduce the energy intensity of developing countries.

Key Projections/Results

According to the report, world primary energy consumption will grow by almost 40% in the next two decades, with 96% of this growth coming from non-OECD countries, mainly China and India. Fossil fuels will meet approximately 80% of world primary energy consumption, while the share of modern renewables (including biofuels) will be only about 6% in 2030. (See Figure E-1.)

Figure E-1. Shares of World Primary Energy



Although the three main fossil fuels (coal, oil, and natural gas) appear to represent about 27% each of world energy consumption, this trend is the result of declining oil use and rising natural gas use. Renewable energy will grow by about 8% annually during 2010–2030. By 2030, renewables (excluding hydro) will supply 11% of world electricity. Oil will represent 87% of the world transport fuel, with biofuels comprising only 7%.

7. *The Outlook for Energy: A View to 2040* (ExxonMobil, 2012)

Scenario Description

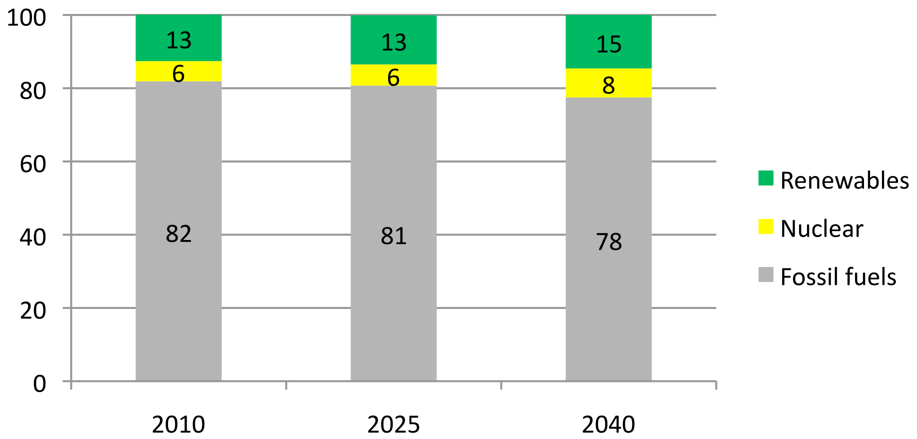
The report offers ExxonMobil's vision for future energy trends. It seeks to answer the following questions: what types of energy will the world use, and how much? How will patterns of demand and sources of supply evolve in different countries? And how will new technologies affect the energy mix and overall energy efficiency?

The outlook assumes that population and economic growth will be the most important drivers of energy demand. World population will grow more than 25% between 2010 and 2040, to nearly 9 billion people by the end of the outlook period, and GDP will grow at an average rate of 2.9%.

Key Projections/Results

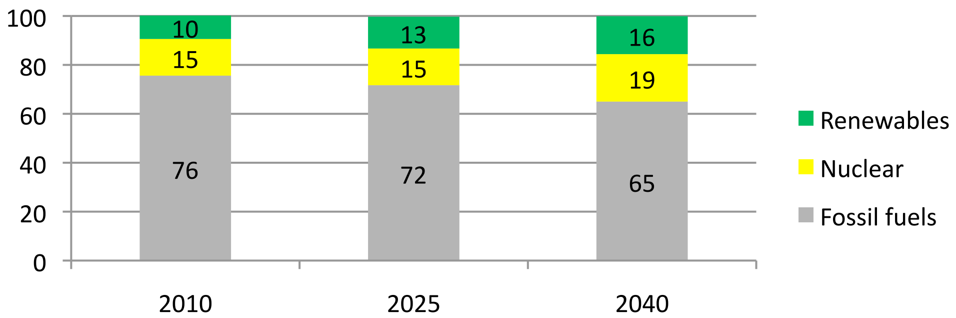
According to the report, global energy demand will increase by about 30% between 2010 and 2040. Electricity generation will remain the single biggest driver of demand, accounting for more than 40 percent of global energy consumption by 2040, followed by industry and transport. Energy intensity will decrease by almost 45%. The share of fossil fuels in world energy demand will remain very high, at nearly 78%, and the renewables share will increase slowly to nearly 15%. (See Figure F-1.)

Figure F-1. Share of Primary Energy Sources in World Energy Demand



By 2040, 35% of the world's electricity will be generated from renewables and nuclear, while the rest will be provided by traditional fossil fuel sources, with a shift from coal to natural gas. (See Figure F-2.)

Figure F-2. Share of Primary Energy Sources in World Electricity Generation



8. *International Energy Outlook 2011* (U.S. Department of Energy, Energy Information Administration (US DOE EIA), 2011)

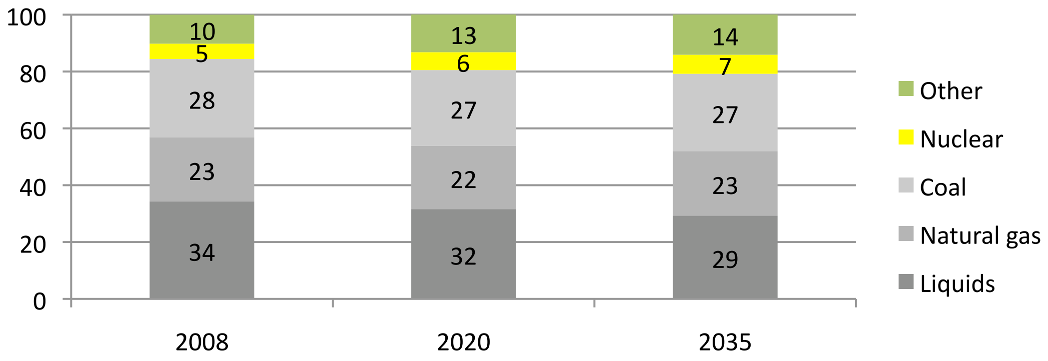
Scenario Description

The report is the U.S. EIA's outlook assessment of energy markets, focused mainly on marketed energy. Projections are generated from the EIA's World Energy Projection Plus (WEPS+) model, which is based on assumptions about population growth, economic growth, energy intensity, and historical energy market data. It does not reflect the potential impact of proposed legislation, regulations, or measures. The main assumptions are that world GDP will grow 3.4% annually on average from 2008 to 2035; energy intensity will decline by just under 40% from the 2008 level, and that the price of oil is US$125 per barrel in 2035.

Key Projections/Results

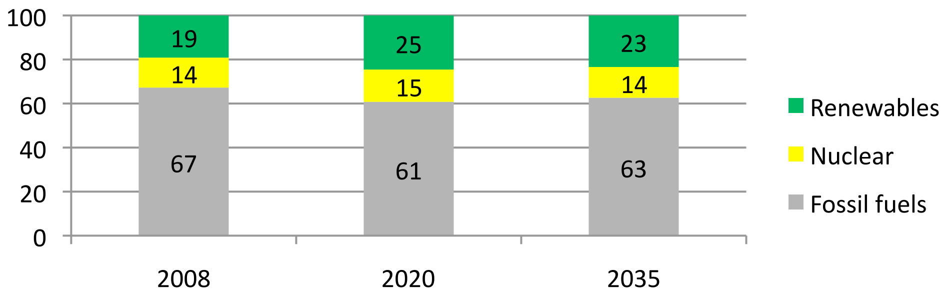
Under the scenario, world total energy consumption will increase by 53% from 2008 to 2035, with the share of liquids in energy consumption falling from approximately 34% in 2008 to 29% in 2035 as oil prices increase. (See Figure G-1.) The use of liquids will increase in the transportation sector, however, rising by about 46% during 2008–2035; by 2035, the sector will consume almost 60% of liquids. Natural gas use will increase by almost 53%, most of it for use in industrial processes and electricity generation.

Figure G-1. Share of Primary Energy Sources in World Total Energy Consumption



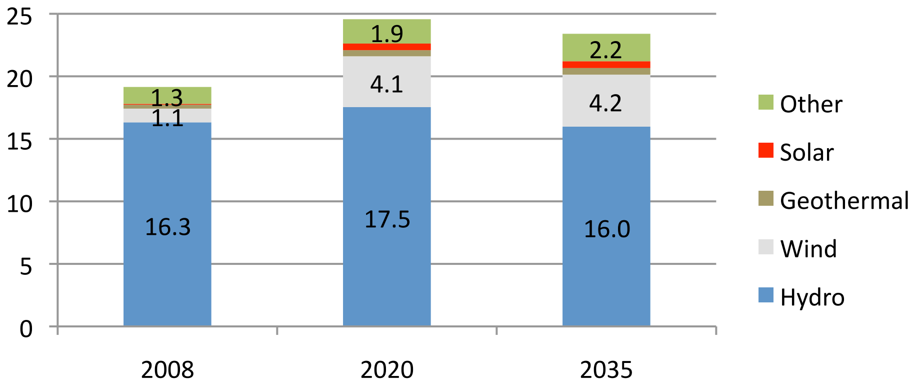
Electricity generation will increase by nearly 84%. Generation from renewable sources will rise 3.1% annually on average, reaching a share of approximately 23% by 2035. (See Figure G-2.)

Figure G-2. Share of Primary Energy Sources in World Electricity Generation



More than 82% of the increase in electricity generation from renewables will come from wind and hydro. (See Figure G-3.)

Figure G-3. Share of Renewables in World Electricity Generation



Coal-based generation will grow by 1.9% annually on average from 2008 to 2035, and coal's share in electricity generation will decrease slightly from about 40% to 37%. Natural gas generation will grow by 2.6%, while nuclear will grow by 2.4%. In the electricity sector, most renewables except hydro will not be able to compete with fossil fuels, particularly coal and natural gas, due primarily to high construction costs. The intermittent nature of wind and solar also hinders the economic competitiveness of these resources, although the use of energy storage will help greatly to curb this problem.

9. *Global Wind Energy Outlook* (Global Wind Energy Council (GWEC), 2010)

Scenario Description

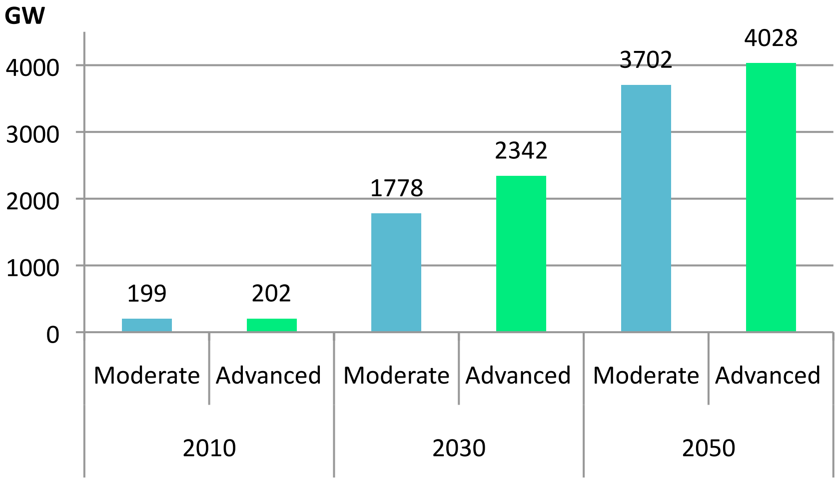
The study examines the future potential of wind power up to 2050 and is based on three distinct scenarios: the Reference scenario, the Moderate scenario, and the Advanced scenario. The Reference scenario adopts the assumptions of the IEA *World Energy Outlook*, with restrained progress in renewable energy and wind power. The Moderate scenario assumes that current renewables and CO_2 targets will be met, and the Advanced scenario explores the implications of achieving an ambitious plan to unleash the full potential of the wind industry.

Electricity demand is based on the IEA's (WEO 2009) projected increase from 15,000 terawatt-hours (TWh) in 2005 to 29,000 TWh in 2030.

Key Projections/Results

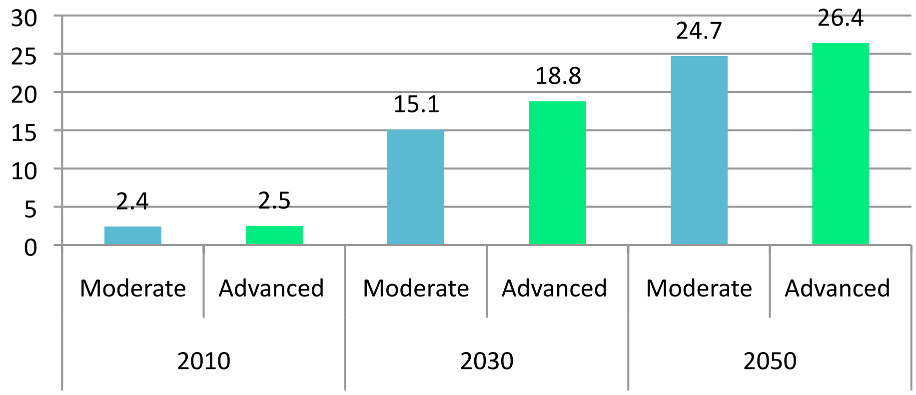
The Moderate scenario sees an annual increase in global wind power of 63 GW per year by 2030, with a total capacity of 1,800 GW by 2030. In the Advanced scenario, the annual wind market will be 120 GW per year by 2020 and 185 GW by 2030, with a total installed capacity of 2,300 GW by 2030. (See Figure H-1.)

FIgure H-1. Cumulative Installed Wind Power Capacity



The share of wind energy in global electricity generation will also increase considerably, from only 2.5% in 2010 to some 25–26% in 2050. (See Figure H-2.)

Figure H-2. Share of Wind Power in World Electricity Generation



10. *Africa Energy Outlook 2040* (SOFRECO, 2011)

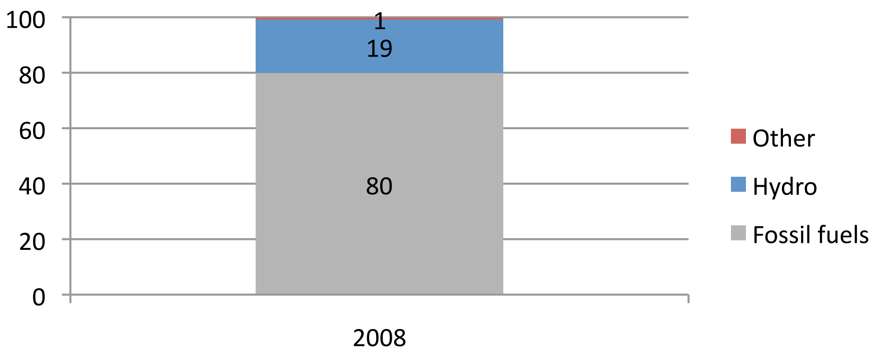
Scenario Description

The report provides information about the current state of energy in Africa, as well as future trends in the continent's primary energy demand and electricity sector development by 2040. It explores the potential of renewable energy (hydro, geothermal, wind, and solar), although, except for hydropower, it does not provide figures assessing the contribution of renewables to Africa's future energy mix.

Africa is currently home to abundant, but unevenly distributed, resources of oil (Libya, Nigeria, Algeria, and Angola), natural gas (Libya, Nigeria, Algeria, and Egypt), coal (South Africa), and hydro (mainly East and Central Africa). These resources are underexploited, and demand is underserved because of Africa's low capacity to mobilize financing for investment, especially from private sources, because of the high political risk and low creditworthiness of countries and utilities.

Africa currently has only 125 GW of installed electricity capacity, 20% of which is hydro. (See Figure I-1.) Power plants are generally small (250 MW on average, 166 MW for hydro), reflecting the fragmented nature of African power systems and the national autonomy of power systems. The continent's transmission system covers only 90,000 kilometers, and it lacks unified or standardized specifications (at least 15 levels of transmission line voltages exist, ranging from 110 kilovolts to 700 kV). Pipelines for natural gas and petroleum products are limited as well. Overall, the continent lacks infrastructure and regional interconnections.

Figure I-1. Share of Primary Energy Sources in Africa, Installed Capacity (plants > 50 MW)



The report's main assumptions include: average GDP growth of 6.2% per year for Africa, differentiated by country; access to electricity of over 60% in all countries by 2030; energy efficiency gains of 20% over the coming 20 years; and fuel prices based on a future oil price of US$820 per tonne (US$113 per barrel), in 2000 prices. To meet rising energy demand, investments of US$43.6 billion annually will be needed in the energy sector, 42.3 of this in the power sector.

Key Projections/Results

Under this scenario, demand for primary energy (excluding biomass) in Africa will increase by 8.9% annually. The role of coal will decrease alongside the development of natural gas for power and industry and liquid petroleum products for transport and power. Nuclear power will experience the most significant growth during the outlook period, with projects in South Africa and later in Egypt. (See Figures I-2 and I-3.)

Figure I-2.

Consumption fossil and hydro primary energy of Africa (in million TOE)

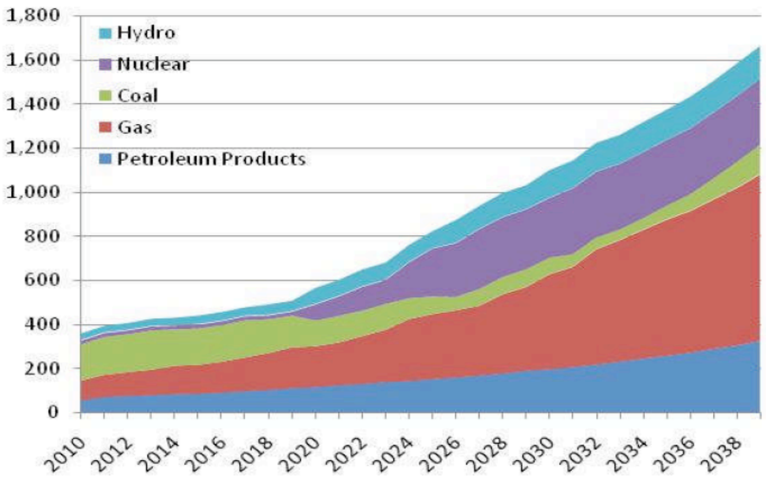


Figure I-3.

Annual Growth of Primary Energy consumption (%)

Primary Energy	Annual Growth Rate %
Petroleum products	6.5%
Gas	8.6%
Coal	2.7%
Nuclear	18.5%
Hydro	5.8%
Total	8.9%

Electricity demand will increase by 5.7% annually on average during 2011–2040, rising 5.4-fold to 3,188 TWh by 2040. Generation capacity demand will increase by 6.2%, a 6-fold increase to 694 GW by 2040.

Africa's hydropower resources are large but will be insufficient to meet long-term demand, based on currently identified hydro sites. After 2030, the continent will continue to depend on fossil fuels, particularly natural gas, and will rely increasingly on nuclear unless renewable energy sources become more competitive than at present. The outlook considers renewables to be commercially unviable without substantial subsidies, and focuses only on their potential, without concrete implementation in the future. It notes:

- Only a small fraction of the continent's hydro potential has been developed so far, with an installed capacity of 22 GW in 2008 compared with a conservatively estimated economic potential that is more than seven times current annual hydro generation. For instance, the Inga site on the Congo River has an estimated potential of between 39 GW and 44 GW, but only 1,774 MW are used.

- Africa's geothermal energy potential is concentrated mostly in eastern Africa. The Rift Valley could represent an untapped potential ranging from 2.5 GW to 14 GW of electric power. Today, less than 200 MW of this potential has been developed for electricity generation, mainly in Kenya (167 MW of installed capacity in 2010).

- Africa's wind energy potential is substantial and uniformly distributed. Best prospects for the development of wind power are located near special topographical funneling features close to coastal locations, mountain ranges, and other natural channels in the northern and southern regions of the continent. The three main African countries that have developed wind energy are Egypt, Morocco, and Tunisia, which together supply around 95% of the 563 MW of installed capacity. Egypt has set a target for wind to make up 12% of its total energy by 2020, with wind farms adding 7.2 GW to the grid. South Africa is planning to develop its wind energy potential through independent producers and to add 400 MW to the grid by 2015.

- The distribution of solar resources across the continent is fairly uniform, with more than 80% of Africa's landscape receiving almost 2,000 kilowatt-hours (kWh) per square meter per year. This gives solar power the potential to bring energy to most locations in Africa without the need for expensive large-scale grid infrastructure.

- Solar thermal (CSP) generating potential for 17 countries in Africa varies from a low of 7 TWh annually in Eritrea to a high of 40,500 TWh annually in Libya; the main potential is in Libya, Egypt, the Kalahari Desert, and some in Algeria.

- Solar PV electricity generation potential varies from a low of 33 TWh annually in Gambia to a high of 8,700 TWh annually in Sudan, with the main potential in Algeria, Sudan, and the Democratic Republic of the Congo.

The main project being considered for developing the solar energy potential of the Sahara is the Desertec project, based on CSP technology. The solar power would be supplied to regional markets in Africa and exported to Europe. The project is on a massive scale and envisages up to US$400 billion in investment over the period 2020–2050.

11. *Prospects for the African Power Sector, Scenarios and Strategies for Africa Project* (International Renewable Energy Agency (IRENA), 2012)

Scenario Description

The report aims to provide early insights for Africa's power sector. It focuses on the period to 2030, with an outlook to 2050 to examine long-term issues that have an impact on investment decisions in the near future. The report develops two scenarios: a Reference one and a Renewable one. The Reference scenario is a continuation of existing economic, demographic, and energy sector trends, taking into account only existing policies. Universal electricity access is not achieved, and access hits only 43% in 2030.

The Renewable scenario examines the impact of policies in Africa to actively promote the transition to a renewable-based electricity system to meet rising power demand, boost economic development, and improve electricity access. It assumes concerted government action in the area of efficiency standards and programs, as well as renewable deployment policies and regulation. Specifically, more ambitious energy efficiency policies are implemented that improve energy efficiency by 20–30% in 2050 compared to the Reference scenario. The scenario assumes a CO_2 price of US$25 per tonne, and that universal electricity access is achieved by 2030.

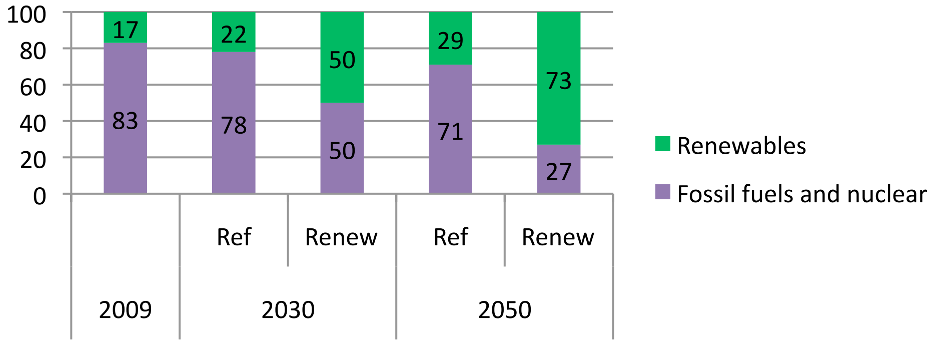
The main assumptions of the analysis are that Africa's population will increase from 1 billion currently to 2–3 billion by 2050 and that 62% of the continent's population will be urban by 2050 (up 23 percentage points from 2008). This has consequences for a successful renewable power strategy, as over the period to 2050 the emphasis will shift from off-grid solutions to large-scale, grid-based systems with significant daytime peak demands. The analysis assumes that Africa's annual GDP growth rate will be 5.8% from 2008 to 2015, 5.0% from 2015 to 2030, and 4.3% from 2030 to 2050. Fossil fuel prices in 2050 will reach US$140 a barrel for oil, US$120 a tonne for coal, and between US$9–$14 per GJ for natural gas.

The analysis relies on two new power pool models that were developed by the International Atomic Energy Agency (IAEA) and updated by the International Renewable Energy Agency (IRENA) to have a refined representation of renewables, as well as a third model developed by IRENA that complements the two IAEA ones. In this third model, the electricity supply from the two power pool models is incorporated into a five-region model for Africa to model electricity supply and demand in each region. This integrated, regional model is then used to develop electricity scenarios on a continental level.

Key Projections/Results

In the Reference scenario, fossil fuels will still dominate the African electricity mix, accounting for around 70% of the continent's power generation in 2050. (See Figure J-1.) There will be a notable shift from coal to natural gas because electricity demand in southern Africa grows at a much slower rate than in other African regions, and coal-based power generation is concentrated in South Africa. The renewables share will increase from 17% in 2009 to approximately 30% in 2050 thanks to large hydro deployment and the development of wind power. Nuclear will play a marginal role.

Figure J-1. Share of Primary Energy Sources in African Electicity Generation

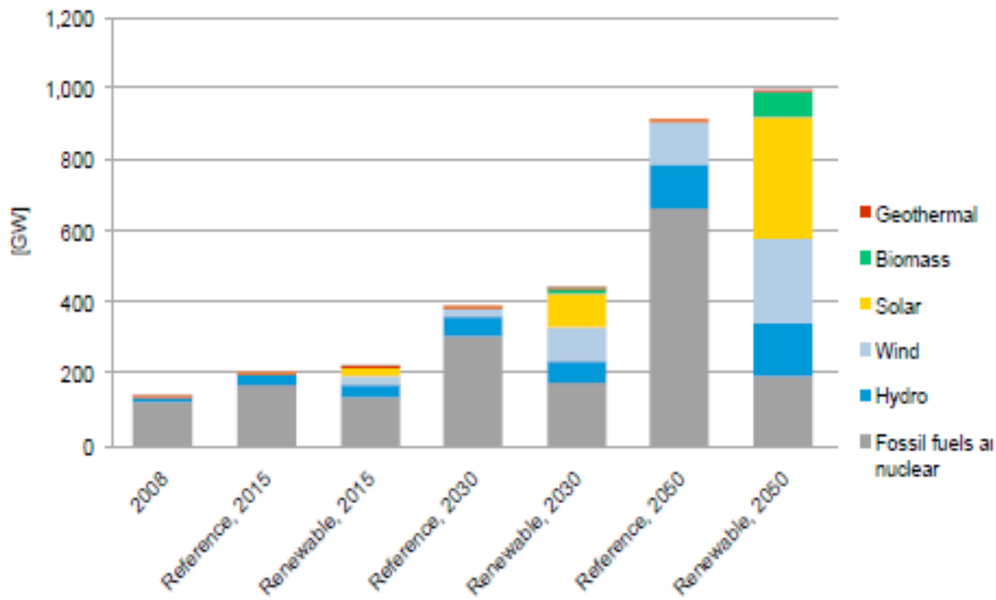


In the Renewable scenario, electricity generation will increase from 620 TWh in 2008 to 3,146 TWh in 2050, 15% lower than in the Reference scenario. Renewables will generate half of Africa's electricity in 2030 and almost 75% in 2050. The share of solar PV will grow from virtually none in 2008 to 8% in 2030 and 14% in 2050. Solar thermal (CSP) will grow to 6% of total generation in 2030 and 10% in 2050; wind will reach 14% in 2030 and 17% in 2050; and biomass technologies will reach 4% in 2030 and 10% in 2050. Hydro's share will be relatively stable at 17% in 2030 and 21% in 2050. Fossil fuel-based generation will fall to 50% in 2030 and 23% by 2050, and nuclear will play a minor future role.

In the Reference scenario, around 410 GW of total installed capacity will be in operation in 2030, while in the Renewable scenario this figure will reach 442 GW. This gap will widen as the share of renewables increases. By 2050, around 80 GW more capacity will be installed in the Renewables scenario than in the Reference one. (See Figure J-2.)

Figure J-2.

INSTALLED ELECTRICITY GENERATION CAPACITY BY FUEL IN THE REFERENCE AND RENEWABLE SCENARIOS, 2008 TO 2050



Africa had 147 GW of power generation capacity as of January 2011; this included 27.8 GW of renewable energy capacity, 25.9 GW of which was hydro.

By 2030, in the Renewable scenario, there will be approximately 280 GW of renewables installed capacity in Africa, with 95 GW of this wind, 90–100 GW solar, and the rest primarily hydro. Then, between 2030 and 2050, there will be a dramatic transformation of the electricity sector. All growth in capacity will be based on renewable technologies, thanks to cost reductions that increase their competitiveness. By 2050, onshore wind, solar PV, and CSP will play a key role. Africa will have about 810 GW of renewables installed capacity, of which approximately 240 GW will be wind and 325 GW solar. The rest will mainly be hydro and biomass, with geothermal still playing a marginal role.

Investments from 2008 to 2050 will reach US$7,765 billion in the Reference scenario and US$6,708 billion in the Renewable one.

The report identifies several issues and policy areas that require attention if the Renewable scenario is to become a reality, including:

- developing clear and stable policy frameworks that enable the private sector to invest with confidence;
- exploring opportunities for local manufacturing as a means to reduce capital costs, create local employment opportunities, and improve trade balances;
- including renewables in economic development strategies, developing long-term energy sector scenarios and strategies, and developing business/entrepreneurship models for renewables and their productive use;
- assessing the specific technology needs in Africa at the national level, and designing strategies and roadmaps to tailor renewable technologies to local conditions and accelerate their deployment;
- enhancing the mapping of renewable energy potentials (notably small hydro, biomass, and onshore wind) and making the information publicly available; and
- cooperating in the development of a continental electricity grid of sufficient capacity to connect remote renewable resources, improving security of supply, and managing higher shares of variable renewables in the electricity mix.

12. *Wind of Change: East Asia's Sustainable Energy Future* (World Bank and AusAid, 2010)

Scenario Description

The report looks at the energy prospects of China and five major East Asian countries: Indonesia, Malaysia, the Philippines, Thailand, and Vietnam (the "EAP5"). It assumes that economic growth in China will be 6.8% by 2030, while that of the other five countries will be 5%, 5%, 4.2%, 4.4%, and 6%, respectively. Oil prices are projected at US$85 a barrel, gas prices at $13.2/mmBTU, and coal at US$85 per tonne in 2030.

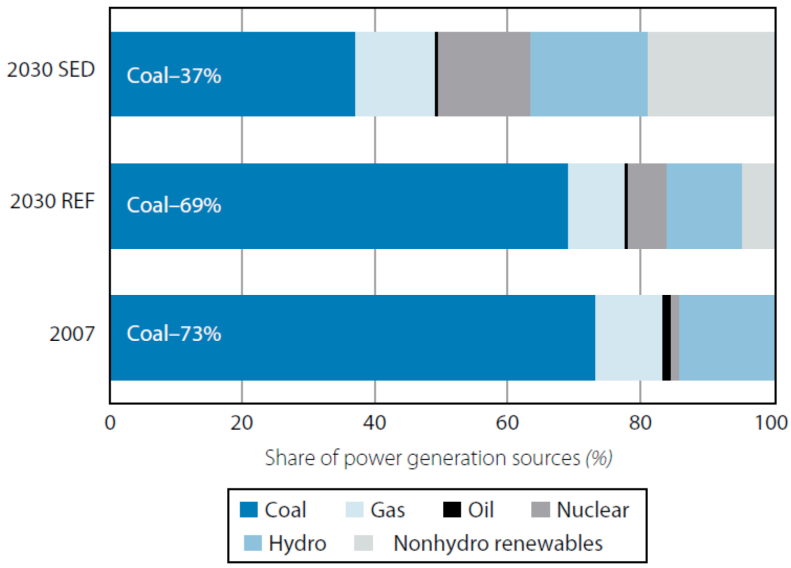
The report discusses two scenarios. The Reference scenario assumes that energy use in East Asia will double by 2030, and reflects a continuation of current governmental policies, plans, and targets. The Sustainable Energy Development (SED) scenario reflects environmental friendly policies and the use of low-carbon technologies (excluding carbon capture and storage).

Key Projections/Results

According to the analysis, by 2030, the share of coal use will increase by 60% in China but only 21% in the EAP5. Gas and oil will grow more rapidly than coal in China, but in the EAP5 coal will show the fastest growth, meaning that coal will remain the region's main energy source in 2035. The electricity supply will be multiplied by three by 2030, reaching a total installed capacity of 2,300 GW. Generation from renewable sources will increase 50% during 2010–2030, due mainly to hydropower use. Nuclear power will increase by 12%, largely because of demand in China.

In the SED scenario, which considers decreasing the carbon footprint of those countries and ensuring energy security, renewable energy sources will meet approximately 40% of the power demand by 2030, with the share of coal declining from about 73% to 37%. (See Figure K-1.)

Figure K-1.



13. *Energy Outlook for Asia and the Pacific* (Asia-Pacific Economic Cooperation (APEC) and Asian Development Bank, 2009)

Scenario Description

The report projects the energy demand and supply of the regional members of the Asian Development Bank (ADB) up to 2030. The only scenario considered is a business-as-usual scenario.

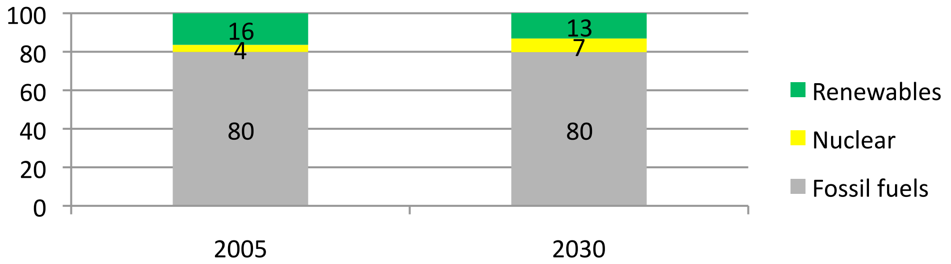
Assumptions for 2030 are: 3.5% average annual growth in the GDP of Asia and the Pacific between 2005 and 2030; population increase of approximately 24%, from 3.7 billion to nearly 4.6 billion; and energy sector investments of about US$7.0–$9.7 trillion (in constant 2006 prices), 60% of which are dedicated to electricity generation, transmission, and distribution. The crude oil price is from the IEA (WEO 2008) and is assumed to reach US$122 per barrel in 2030. Improvements in energy efficiency are also considered.

The study applies an econometric approach to forecast energy demand, and uses the Institute of Energy Economics of Japan (IEEJ) model in the majority of the country analyses. It estimates demand equations econometrically using historical data, and projects future values using explanatory variables.

Key Projections/Results

In the scenario, primary energy demand in Asia and the Pacific is projected to increase from just over 4 billion tons of oil equivalent (toe) in 2005 to 7.2 billion toe in 2030 (an increase of nearly 80%), growing at a rate of 2.4% annually. Fossil fuels will still largely dominate the Asia and the Pacific energy mix, with a near 80% share of total primary energy demand. (See Figure L-1.)

Figure L-1. Share of Primary Energy Sources in Asia-Pacific Energy Demand



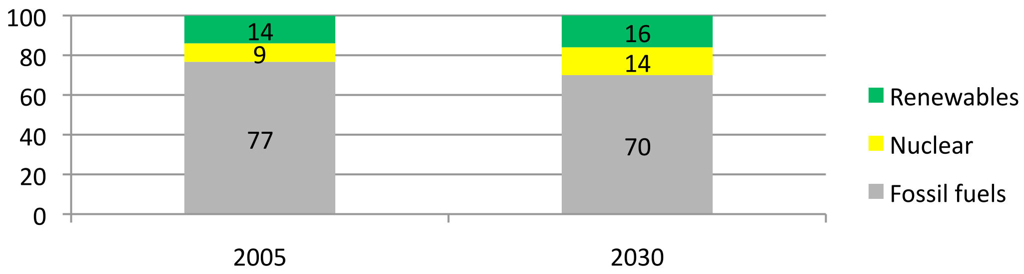
Coal will maintain the highest share of total primary energy demand in 2030, at 38.3%, followed by oil at 27% (driven by motorization and the development of road transport infrastructure). Natural gas will grow the fastest among fossil fuels, at 3.6% per year, achieving at 14.5% share of total primary energy demand in 2030. Nuclear's share will be 7.1%, showing the fastest annual growth at 5.1% annually and reflecting the expected expansion of installed capacity in China.

Renewable energy sources (hydro excluded), used mainly for heat and power, will represent 11.2% of total primary energy demand, with biomass still providing an important contribution. Wind, solar, and geothermal will increase at a faster rate than biomass, but because of their low cost-competitiveness and the fact that they still are not considered close to becoming mature technologies, their annual growth rate will be only 1.3%. Compared to other renewables, hydro will increase at a relatively rapid rate of 3.0% per year through 2030, but its share will reach only 2% of total primary energy demand.

Total electricity generation in Asia and the Pacific is projected to increase from 6,068 TWh in 2005 to 14,016 TWh in 2030—an increase of nearly 131%—with average annual growth of 3.4%. Almost three-quarters of this will come from China (45.5%), India (17.2%), and Japan (9.4%).

The electricity generation mix still will be dominated largely by fossil fuels in 2030, with 70% of electricity coming from coal, oil, and natural gas. However, this share will decrease by 7.1 points compared to 2005, mainly in favor of nuclear and new renewables. (See Figure L-2.)

Figure L-2. Share of Primary Energy Sources in Asia-Pacific Electricity Generation



Despite a 4.5-point decrease, coal-fired generation will account for the highest share of total generation in 2030, at 52%. Oil's share will decrease from 6.4% in 2005 to 2% in 2030, becoming marginal, and natural gas use will increase from 13.8% to 16%. Nuclear will see the greatest growth, from 9.3% to 14%. Renewable energy will account for 16% of generation in 2030 (up 2.1 percentage points), with a slight decrease of hydro from 12.8% in 2005 to 11.9% in 2030, and a three-point increase of other renewables, which will achieve a 4.1% share in 2030.

14. *China's Energy and Carbon Emissions Outlook to 2050* (Lawrence Berkeley National Laboratory, 2011)

Scenario Description

The report explores possible pathways for Chinese carbon emissions to 2050, using a comprehensive range of energy consumption projections for different economic sectors.

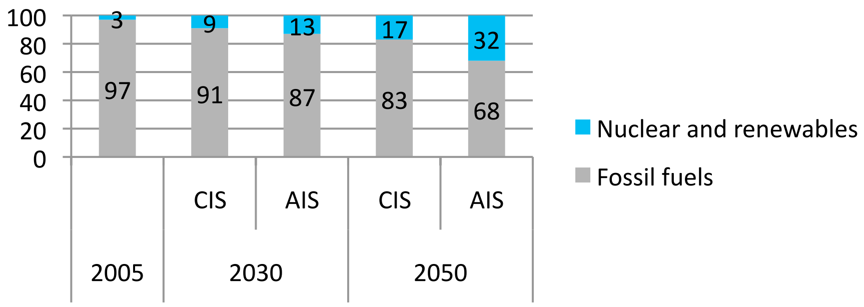
It presents two scenarios: the baseline "Continued Improvement Scenario" (CIS) and the alternative "Accelerated Improvement Scenario" (AIS), which shows advanced energy efficiency. The scenarios are designed to assess the impact of actions already taken by the Chinese government (planned or proposed), as well as actions that may not yet have been considered, in order to evaluate China's potential to control energy demand growth and mitigate CO_2 emissions. The CIS uses efficiency improvements that are consistent with trends in "market-based" improvement, achieving levels common in industrialized countries, whereas the AIS assumes a more aggressive trajectory toward current best practice and implementation of important alternative energy technologies.

The main assumptions are: GDP growth rates of 7.7% during 2010–2020, 5.9% during 2020–2030, and 3.4% during 2030–2050, and a Chinese population of 1.4 billion in 2050. The analysis considers improvements in the energy efficiency of appliances, buildings, heating and cooling systems, lighting, and internal combustion engines, as well as increasing electrification of rail transport and use of electric vehicles. It assumes a decline in energy intensity of between 76.5% and nearly 80% by 2050, from the 2005 level.

Key Projections/Results

Under the scenario, China's primary energy consumption will grow from the current 2,250 million tons of coal equivalent (Mtce) to a projected 5,481 Mtce under the CIS and 4,558 Mtce under the AIS in 2050. Fossil fuels will still dominate the energy mix, but under both scenarios the share of coal will decline significantly, from about 75% in 2005 to 47% (CIS) and 30% (AIS) by 2050. (See Figure M-1.)

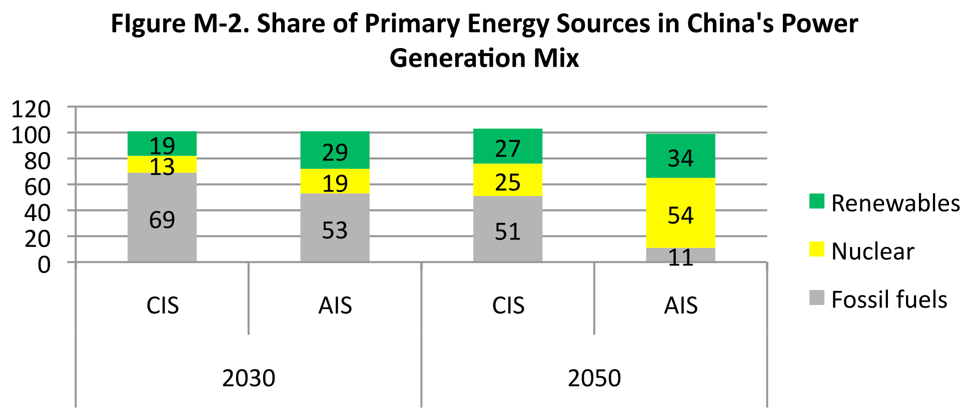
Figure M-1. Share of Primary Energy Sources in China's Total Energy Use



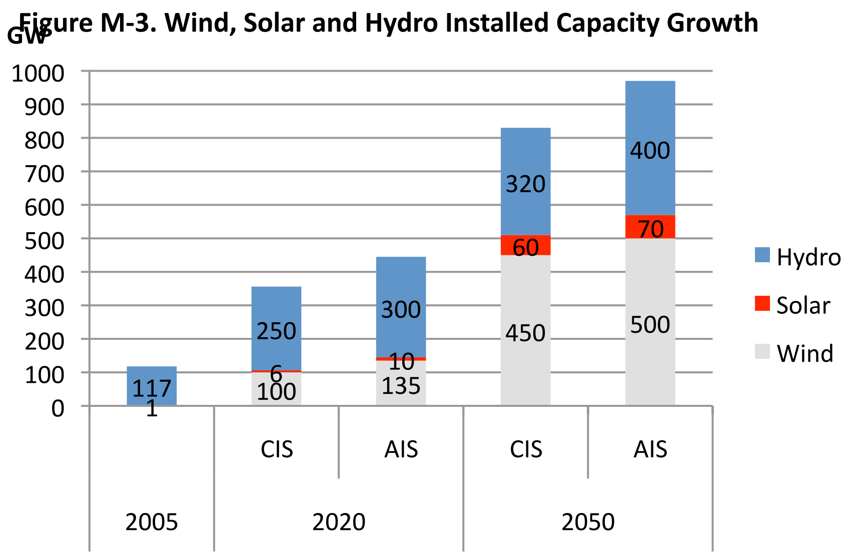
Petroleum use will grow both in absolute terms and in its share of overall energy consumption, driven by China's burgeoning transport sector. Urban private car ownership is expected to increase to over 356 million vehicles by 2050, with the share of electric vehicles being 30% in CIS and 70% in AIS. In general, demand for CO_2 emission-free technologies, renewable energy, and nuclear will grow significantly.

Total electricity demand by 2050 will reach 9,100 TWh in the CIS and 7,764 TWh in the AIS. Electricity demand in the commercial building sector will increase, offsetting the decreasing demand in industry. Under the CIS, the commercial sector will be responsible for nearly one-third of all electricity demand, whereas under the AIS, the transport sector accounts for a growing share of demand because of more aggressive rail and road electrification.

The share of coal, and fossil fuels overall, in power generation will decrease, but the extent of this reduction differs significantly between the two scenarios. (See Figure M-2.) In the CIS, coal decreases but remains the major energy source for electricity generation; in the AIS, coal is replaced by nuclear, which becomes China's main energy source, and by renewables, the share of which increases significantly. Interestingly, the share of renewables could range between 27% and 34%, while the share of nuclear could range between 25% and 54%, making nuclear appear to be the main alternative in coal substitution.



In the CIS, the installed capacity of wind, solar, and biomass power grows from 2.3 GW in 2005 to 535 GW in 2050, and nuclear grows from 7 GW to 300 GW. In the AIS, the installed capacity of wind, solar, and biomass power reaches 608 GW in 2050, and nuclear 550 GW. In both scenarios, growth rates for wind and solar exceed an annual average of 14%. (See Figure M-3.)



15. *Potential Secure, Low Carbon Growth Pathways for the Chinese Economy* (China Energy Research Institute, 2011)

Scenario Description

The purpose of the study is to explore China's options for low-carbon pathways in the context of aggressive, near-term emissions reductions in other countries, as well as to explore some of the technological leaps that China could take to achieve low-carbon development and avoid the high-carbon pathways of other industrialized economies.

Three scenarios are developed: a "Baseline" scenario, which reflects existing policies and measures, including current Chinese government efforts to increase efficiency and control emissions; a "Low Carbon" scenario, which assumes that China will make an effort to achieve a relatively low-carbon future by making CO_2 emissions control a domestic environmental target and by implementing domestic policies such as economic structural reform away from energy-intensive industries; and an "Enhanced Low Carbon" scenario, which assumes that by partaking in global efforts to achieve emissions reductions, China will undertake greater efforts on emissions control. In this third scenario, zero-emission vehicles, low-emission buildings, renewable energy sources, and nuclear power would reach their maximum potential. Decentralized power would be widespread, and some coal-fired power plants would employ carbon capture and storage.

The main assumptions are: average GDP growth rate of 6.4% annually between 2005 and 2050; a Chinese population of 1.46 billion in 2050; an urbanization rate of 79% by 2050; and 40% higher energy efficiency than present.

Key Projections/Results

According to the analysis, China's primary energy demand will increase from approximately 2,100 Mtce in 2005 to about 6,500 Mtce under the Baseline scenario, 5,300 Mtce under the Low Carbon scenario, and 5,100 under the Enhanced Low Carbon scenario, by 2050.

All scenarios assume the wide deployment of onshore wind generation. The Low Carbon and Enhanced Low Carbon scenarios assume large-scale construction of offshore wind generation as well. The cost of solar energy in 2050 is 0.39 yuan/kWh In the Baseline scenario, but more than 30% lower in the two other scenarios, at 0.37 yuan/kWh.

To achieve low-carbon development, by 2050 China will need to have 400–500 GW of new capacity each for wind, hydro, and nuclear, and 300–400 GW for solar.

16. *China Wind Power Outlook 2011* (Greenpeace, 2011)

Scenario Description

The study analyses the development of China's wind power sector in 2010, the development of China's PV power sector, and other renewable energy trends discussed in the government's 12th Five-Year Plan (2011–2015).

Key Projections/Results

In 2010, Mainland China added almost 19 GW of newly installed wind power capacity, maintaining its lead in the global growth ranking. By the end of 2010, China overtook the United States to become the world leader in installed wind capacity, at 44.7 GW, and this figure is expected to reach 100–150 GW by the end of 2015. China will continue to lead in wind generation for the next five years, thanks to improvements in the economics of wind power, the gradual resolution of issues related to connecting wind power to the grid, and strong government policy support.

China's total installed capacity of offshore wind farms grew about 150 MW by the end of 2010. It is expected expand to 5 GW by 2015 and about 30 GW by 2020, according to current targets.

In 2010, China's PV module output rose to 10 GW, accounting for 45% of world production and maintaining the country's lead as the top producer for four straight years. By 2010, China's installed PV capacity reached 0.9 GW, ranking it among the top 10 nations in the world. Chinese output of silicon-based thin-film panels remained low, however, as the industry is still not mature. Problems facing Chinese PV include: insufficient investment in research and development; blind expansion; backward production capacity; redundant production; lack of a sustainable, clean development concept; lack of support for domestic market development; lack of long-term development goals; and a high cost of electricity production.

China's 12th Five-Year Plan of Renewable Energy Development adopts different strategies and tasks for each energy resource. By 2015, for example, annual wind generation will reach 190 TWh, and solar installed capacity will reach 5–10 GW. In a discussion paper on the Plan, the National Energy Administration suggests that by 2015, China's solar installed capacity will reach 10 GW, of which 5 GW would be from grid-connected, mid-sized power plants in the desert, 3 GW from grid-connected plants in urban and rural areas, and 2 GW from off-grid and distributed PV. By then, China will be the world's biggest PV market.

By about 2020, wind power and solar power will replace hydropower as the key pillars of China's renewable energy sector.

17. "A Study of the Role Played by Renewable Energies in China's Sustainable Energy Supply" (Zhang Xiliang, Wang Ruoshui, Huo Molin, and Eric Martinot, 2010)

Scenario Description

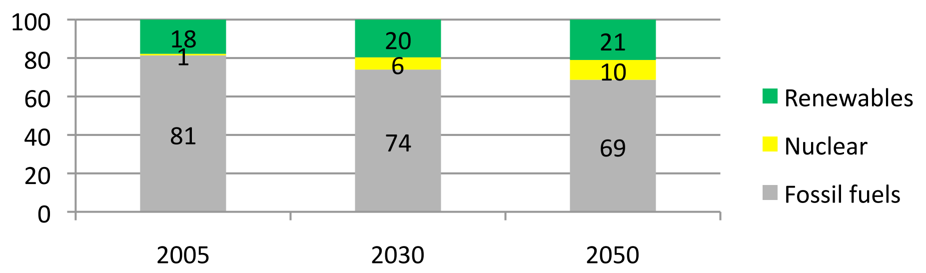
The study provides an overview of renewable energy development in China (including recent related legislation), detailing the current status of renewables and the role they play in the national energy supply. It then examines the national indicative targets for renewables and presents a long-term scenario of the role of renewable energy in China's energy transition to 2050. Finally, it discusses the main risks involved in the country's renewables development and proposes some policy measures for risk management.

The scenario assumes that implementation of China's Renewable Energy Law and of the Medium and Long Term Plan for Renewable Energy Development will create an enabling environment for the development of renewable energy sources.

Key Projections/Results

According to the analysis, China's energy demand will reach 5.4 billion tce in 2050, up from 2.3 billion tce in 2005, reflecting a more than 130% increase in the country's total primary energy supply in under half a century. In 2050, China's energy mix will still be dominated largely by fossil fuels, mainly coal and oil. (See Figure N-1.)

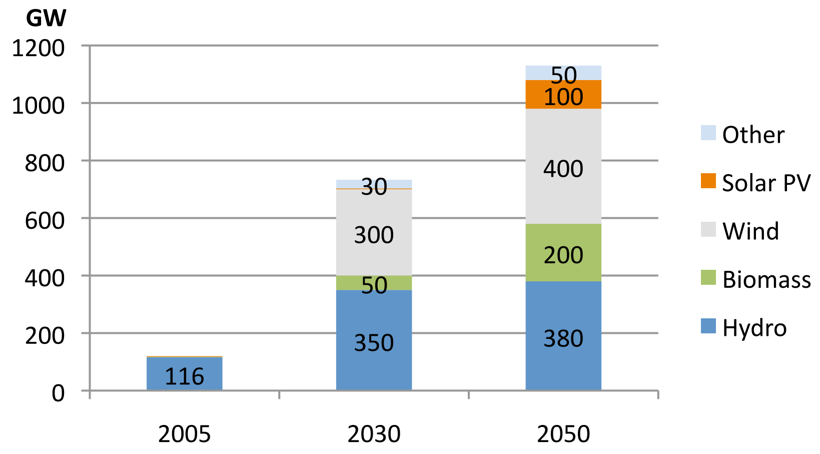
Figure N-1. Share of Primary Energy Sources in China's Energy Demand



Renewable energy will contribute approximately 21% of China's total primary energy supply in 2050 (up 3.2 percentage points from 2005). The share of traditional biomass will decline from 10.7% in 2005 to 0% in 2050 and will be replaced completely by modern biomass. The contribution from new renewables (modern biomass, solar, and wind) will grow from 0.9% in 2005 to 14.4% in 2050. The share of hydro will increase slightly to 6.6% (up 0.4 points). Most of the renewable energy supply is in the form of electricity. Nuclear growth also will be significant.

China's installed power generation capacity will grow from 511 GW in 2005 to 2,620 GW in 2050. Renewables will account for nearly 48% of this growth. In 2005, the total installed renewable power capacity was almost 120 GW, accounting for 23.4% of the country's total. In 2050, these figures will reach 1,130 GW and 43.1%, respectively. (See Figure N-2.) Wind power will lead this growth, expanding from 1.27 GW of installed capacity in 2005 to 400 GW in 2050. Biomass and solar PV will also develop significantly.

Figure N-2. Cumulative Renewable Energy Sources in China



To increase the penetration of renewables in the future, the report recommends improving implementation of China's feed-in tariff, expediting the formulation of fiscal and taxation measures, and increasing public R&D and information support.

18. *Indian Wind Energy Outlook* (Global Wind Energy Council (GWEC), World Institute of Sustainable Energy (WISE), and Indian Wind Turbine Manufacturing Association (IWTMA), 2011)

Scenario Description

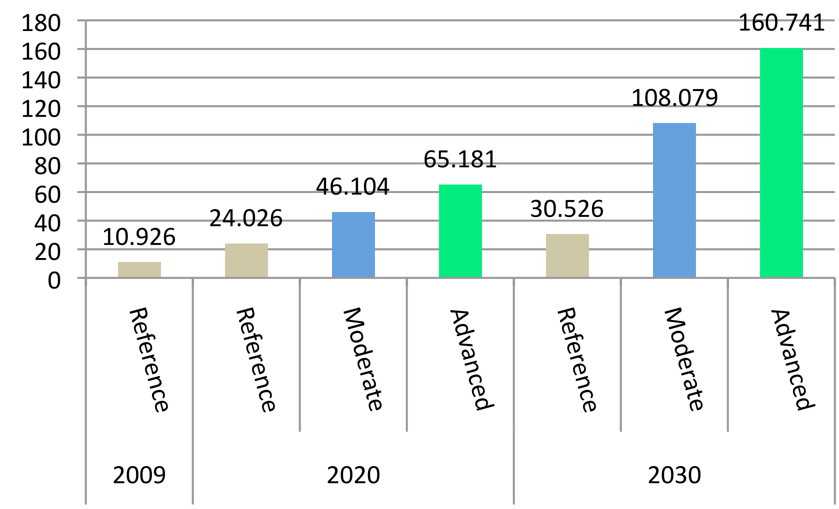
The study looks at the prospects for wind energy in India to 2030 and elaborates three scenarios, a "Reference" one based on IEA WEO 2009 projections (taking into account only existing policies and measures), a "Moderate" one (taking into account all policy and measures to support renewable energy and protect the environment enacted or in planning stages), and an "Advanced" one (assuming the best use of India's potential with more appropriate policies). It assumes (as per the IEA WEO 2009 projections) that by 2030, Indian energy demand will be 1,299 Mtoe and electricity demand will be 2,700 TWh.

India has 170 GW of installed power generation capacity, of which 10.9% is renewable energy (excluding large hydro), particularly wind (13 GW). The country, with over 1 billion people, consumes 645 TWh of electricity annually. India's National Action Plan on Climate Change sets a target of 15% renewables in India's energy mix by 2020.

Key Projections/ Results

In the Reference scenario, investments in wind power in India would drop to about $910 million by 2030. In the Moderate scenario, the country would invest about $9 billion in wind annually by 2020, representing a quadrupling of the 2009 figure. In the Advanced scenario, annual investment would reach $10.4 billion by 2020. Depending on the investment level, the projected installed wind power capacity would vary. (See Figure 0-1.)

Figure 0-1. Cumulative Wind Power Capacity in India



19. *Energy [R]evolution: A Sustainable India Energy Outlook* (Greenpeace and European Renewable Energy Council (EREC), 2008)

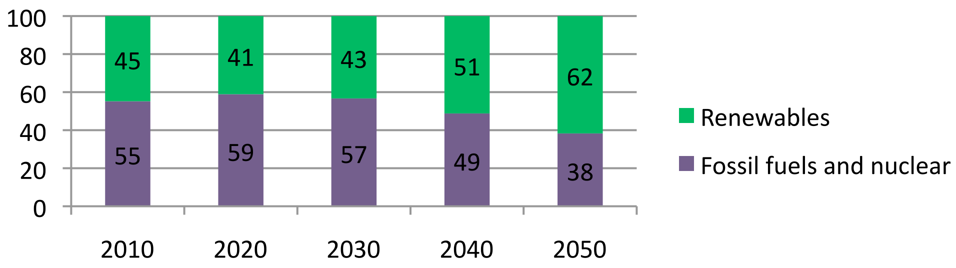
Scenario Description

The report examines the possibility of a renewable energy future in India given the national context and the country's renewables potential. Two scenarios are developed: a "Reference" one that reflects the current state of matters, and the "[R]evolution" one, which exploits the potential of renewable energy in India with the phaseout of nuclear energy and the adoption of energy efficiency measures.

Key Projections/Results

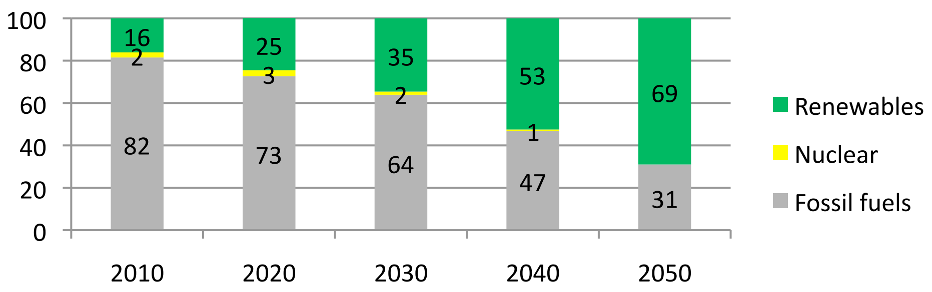
According to the analysis, India's primary energy demand will increase by more than 230% to reach 62,577 PJ annually in 2050. In the [R]evolution scenario, the share of renewable energy in final energy demand will increase to nearly 62% by 2050. (See Figure P-1.) About 70% of demand in the heat and cooling sector and 29% of that in the transport sector will be met by renewables.

Figure P-1. Share of Primary Energy Sources in India's Final Energy Demand



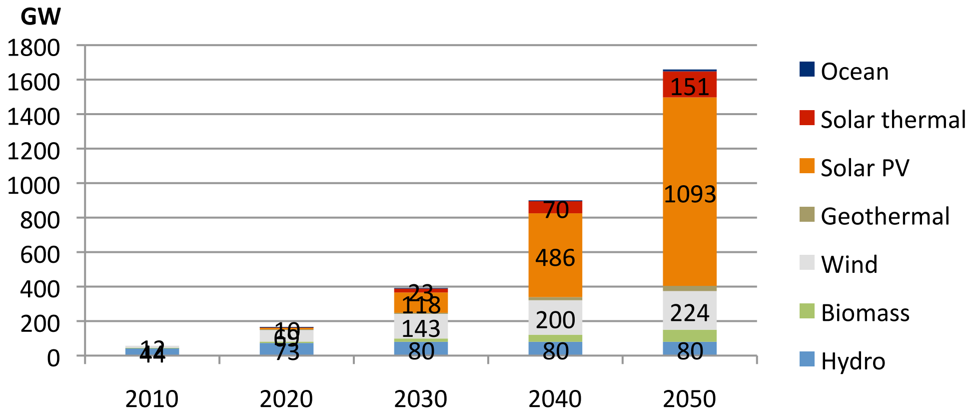
By 2050, in the [R]evolution scenario, approximately 69% of India's electricity generation will come from renewables (this figure includes combined heat and power production). (See Figure P-2.)

Figure P-2. Share of Primary Energy Sources in India's Electricity Generation



In the [R]evolution scenario, solar PV, wind, and solar thermal will account for just under 55% of electricity generation in 2050. Solar PV will become by far the most prominent renewable energy source, representing 27% of electricity generation and 66% of the renewables installed capacity in 2050. (See Figure P-3.)

Figure P-3. Cumulative Renewable Energy Sources Capacity in India



20. "Energy Scenario and Vision 2020 in India" (P. Garg, 2012)

Scenario Description

The report examines the current energy situation in India, the present contribution of all energy sources, the potential of renewables, and their total share in the energy mix by 2022 based on existing policy targets. It assumes an average GDP growth rate of 8–9% annually over the outlook period and beyond.

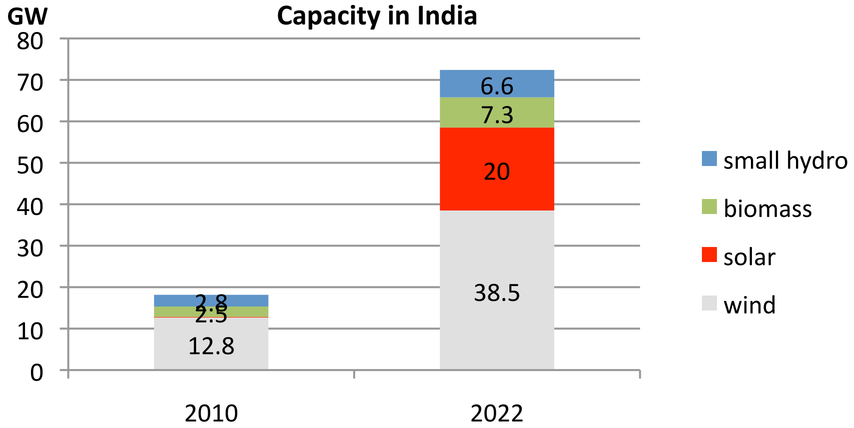
Key Projections/Results

At the assumed GDP growth rate, India will require a total primary energy supply of some 1,192 Mtoe by 2021–22 and 2,043 Mtoe by 2031–32, up from only 616 Mtoe at present. Electricity consumption is expected to rise to some 2,280 billion kWh by 2021–22 and 4,500 billion kWh by 2031–32, up from 645 billion kWh at present. Meeting these needs will be a great challenge, and shortages may occur because of an inadequate transmission and distribution network.

Coal currently supplies 55% of India's energy needs and will remain the most important domestic energy source due to the low exploitation cost and to the country's huge reserves (estimated at 246 billion tonnes, of which 92 billion tonnes are proven). Oil's future share will depend on oil price fluctuations as well as the development of India's transport sector. Natural gas prices will be key to India's future use of gas. And nuclear will increase dramatically, from 4.78 GW of installed capacity in 2010 to 64 GW by 2032.

Hydro potential is significant, but its contribution to India's energy mix is likely to remain small. The need to mitigate the environmental and social impacts of storage schemes often delays hydro development, causing huge cost overruns. Overall, India aims to supply around 15.9% of its total energy needs from renewables by 2022. Wind and solar will supply the bulk of this increase, accounting for more than 80% of renewables installed capacity by 2022. (See Figure Q-1.)

Figure Q-1. Cumulative Renewable Energy Sources Installed Capacity in India



With regard to the potential of new renewable energy sources in India, the report notes that:

- Wind power is the fastest growing renewable, and its development is financed almost entirely by private sector investments, thanks to the provision of accelerated depreciation of 80%. India has a potential of around 48.5 GW.

- The Jawaharlal Nehru National Solar Mission, launched in 2010, targets 20 GW of grid-connected solar power (based on solar thermal systems and solar PV technologies) and 2 GW of off-grid capacity (including 20 million solar lighting systems and 20 million square meters of solar thermal collector area by 2022). Solar technology appears to have the greatest potential for off-grid energy production.

- The current potential for biomass power generation from surplus agricultural and agro-industrial residues is estimated at 17 GW. With efficient cogeneration plants in new sugar mills and modernization of existing ones, the potential of surplus power generation through bagasse cogeneration in sugar mills is estimated at 5 GW.

- The estimated potential for power generation from small hydro plants is about 15 GW from 5,718 identified sites. So far, over 760 small hydro projects with 2,803 MW of combined capacity have been set up around the country, and 285 projects totaling about 940 MW are in various stages of implementation. At present, a capacity addition of about 300 MW per year is being achieved.

21. "India's Renewable Scenario" (Madhavan Nampoothiri, 2012)

Scenario Description

The report provides information on the current state and potentials of renewable energy in India. It also describes major energy policies supporting the development of renewables technologies.

Key Projections/Results

According to the analysis, India will need over 300 GW of energy installation by 2017, up from some 191 GW of power generation capacity today. Almost half of this (48%) is coal based, 20% is hydro, and 10% is other renewables. Nuclear's share is marginal, at 2%.

As of February 2011, India had 18.45 GW of renewables installed capacity (excluding hydro), with an estimated total potential (excluding solar) of about 89 GW.

Regarding the current status and potential of various renewables in India, the report notes:

- Wind leads the renewable energy sector with a cumulative installed capacity of 13,065 MW. India's potential for onshore wind power is estimated at 48.5–70 GW.

- Solar development will be driven mainly by the Jawaharlal Nehru National Solar Mission, which targets an installed capacity of 20 GW of grid-connected solar power by 2022, up from about 18 MW at the end of 2010. As more components are manufactured in India, the price of solar PV modules is expected to drop significantly, enabling more solar power installations nationwide.

- The unpredictable availability of feedstock will be the key challenge to biomass power development, as many of the biomass producers are backward integrating to energy crop farming, especially into bamboo farming.

- India's small hydro potential is estimated to be 15 GW.

Two major energy policies promoting the development of renewable energy In India are the JNNSM and the trading of Renewable Energy Certificates (RECs). Under the latter mechanism, distribution companies are mandated to purchase a percentage of their power from renewables. In the event that they cannot fulfill their obligation, they can compensate by purchasing RECs sold by renewable energy producers. The trading of RECs is expected to make returns on investments in renewable technologies more attractive and to eventually make the sector more market driven and less policy driven.

22. *Pure Power: Wind Energy Targets for 2020 and 2030* (European Wind Energy Association (EWEA), 2011)

Scenario Description

The study examines the future of wind power in Europe from 2010 to 2050, under the assumption that 100% of the electricity generated in 2050 will come from renewables. The starting point of the study is that 34% of electricity in the European Union comes from renewables, reflecting the EU's existing target. The report focuses on how to make the transition from 34% to 100% renewables, and the role that wind power will play in this shift. To ensure the continued buoyancy of the wind sector and this path toward green electricity, the EWEA insists that EU renewables legislation is needed now for the period after 2020.

The EWEA provides two scenarios for each national market in 2020: a "baseline" scenario and a "high" scenario. The baseline scenario is based on EWEA's traditionally conservative approach to setting targets for wind energy. The "high" scenario acknowledges that wind power, as the most affordable of the renewable electricity technologies in most EU Member States, could meet a higher share than either the 14% of electricity demand by 2020 indicated by the National Renewable Energy Action Plans or the 14.2% assumed by the European Commission in its PRIMES model. But this would happen only if EU policy certainty beyond 2020 is achieved before 2014, if additional R&D efforts are made, and if the necessary infrastructure investments and power market reforms are undertaken.

Key Projections/Results

According to the analysis, by 2020 the EU will install 230 GW of wind capacity, including 40 GW of offshore wind, to represent 22.9% of EU total installed electricity generating capacity. This will involve annual wind capacity installations of 24.8 GW, of which 17.8 GW, or 72%, is onshore and 6.9 GW, or 28%, is offshore. These facilities will produce 581 TWh of power (433 TWh onshore and 148 TWh offshore), meeting from 15.7% to 16.5% of EU electricity needs depending on total demand.

The share of renewables in EU electricity consumption will reach 34% by 2020. This will represent annual investments of €26.6 billion (€16.2 billion onshore and €10.4 billion offshore) and a total investment for 2011–2020 of €192 billion.

By 2030, the EU will install 400 GW of wind capacity, including 150 GW of offshore, to represent 36% of EU total installed electricity generating capacity. This will involve annual wind capacity installations of 23.7 GW, of which 10 GW, or 42%, is onshore and 13.7 GW, or 58%, is offshore. These facilities will produce 1,153 TWh of power (591 TWh onshore and 562 TWh offshore), meeting approximately 28.5% of EU electricity needs depending on total demand.

The share of renewables in electricity consumption will reach 55% by 2030. This will represent annual investments of €25.3 billion (€8.2 billion onshore and €17.1 billion offshore) and a total investment for 2021–2030 of €257 billion.

By 2050, the EU will install 735 GW of wind capacity, including 460 GW of offshore. These facilities will produce 2,512 TWh of power (699 TWh onshore and 1,813 TWh offshore), meeting approximately 50% of EU electricity needs depending on total demand. The share of renewables in electricity consumption will be 100% by 2050.

For summaries of these projections, see Figures R-1, R-2, and R-3.

Figure R-1. Cumulative Wind Installed Capacity

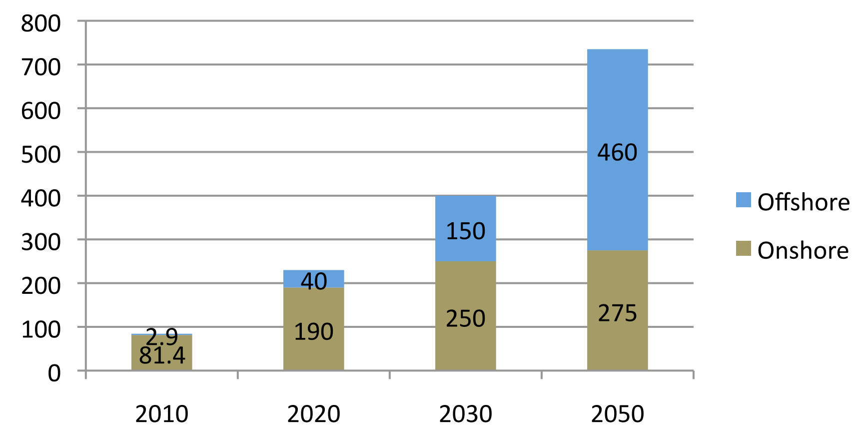


Figure R-2. Wind Electricity Generation

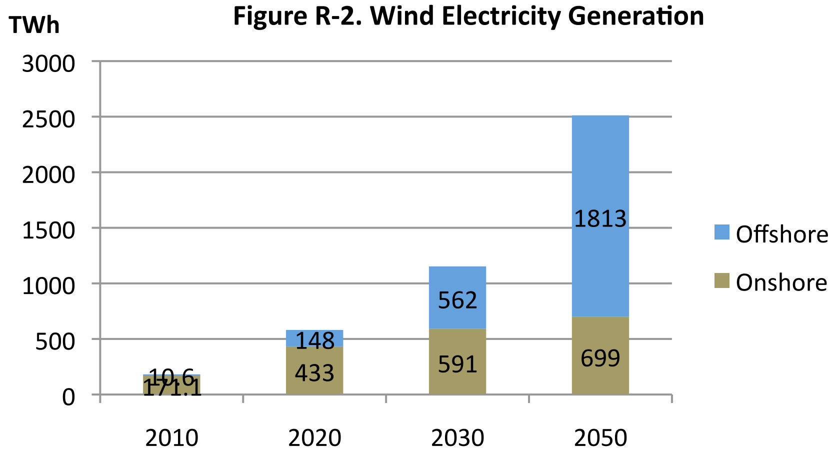
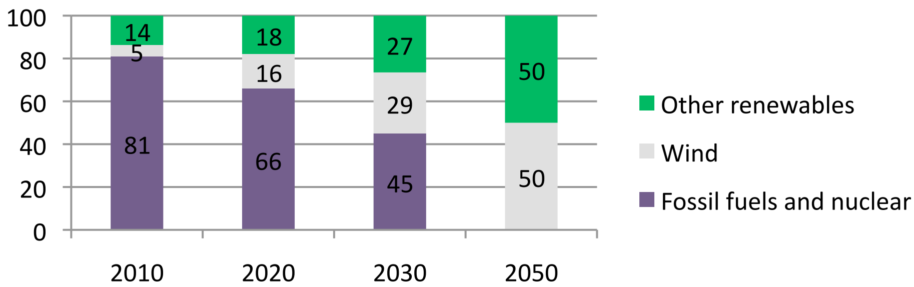


Figure R-3. Share of Primary Energy Sources in EU Electricity Generation



23. *Rethinking 2050: A 100% Renewable Energy Vision for the European Union* (European Renewable Energy Council (EREC), 2010)

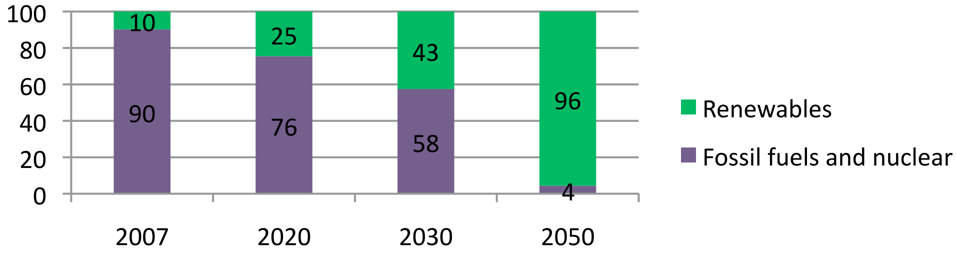
Scenario Description

The study aims to establish a long-term vision for the energy system in the EU, setting a pathway toward 100% renewable energy. It outlines a roadmap to 2030 and presents a vision for 2050 based on a set of assumptions from the European Commission's "New Energy Policy" scenario for a "moderate" and "high" price environment.

Key Projections/Results

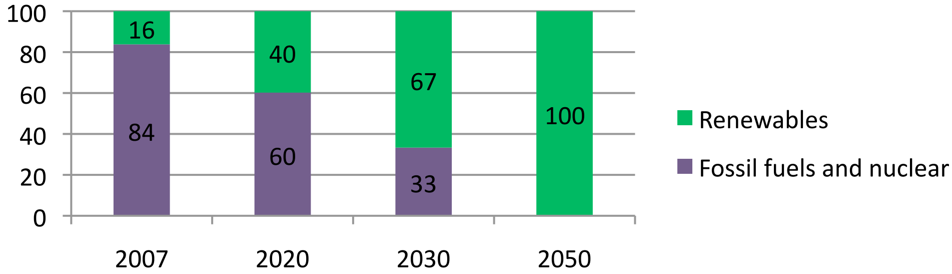
Under the Moderate Price projection, EU final energy demand is expected to decrease from 1,232 Mtoe in 2010 to 1,050 Mtoe in 2050. The share of renewable energy in final energy consumption will increase significantly to almost 96% in 2050. (See Figure S-1.)

Figure S-1. Share of Primary Energy Sources in EU Final Energy Consumption



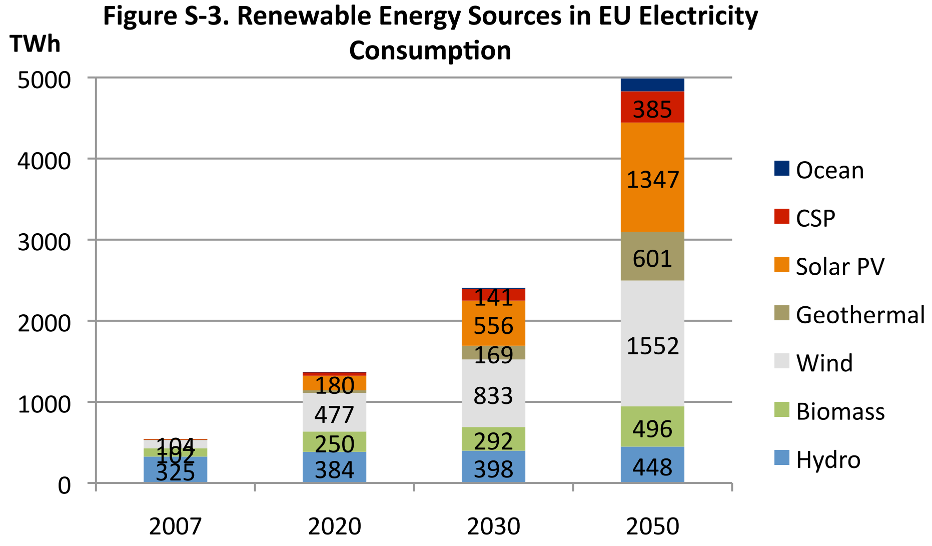
This considerable increase of renewables in final energy consumption is due to the greening of the power sector but also to changes in the transport and heating and cooling sectors. In the power sector, electricity generation in 2050 will come from 100% renewables. (See Figure S-2.)

Figure S-2. Share of Primary Energy Sources in EU Electricity Consumption



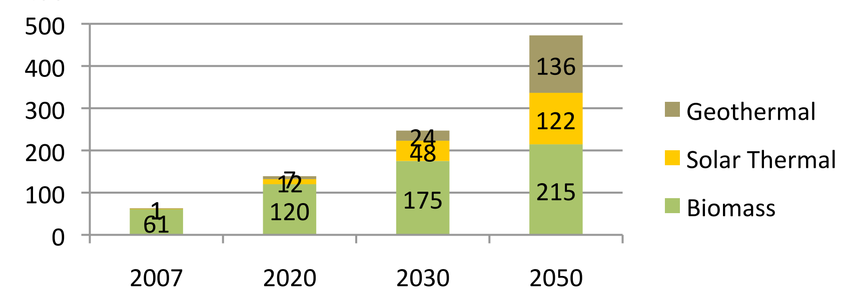
Among renewable energy technologies, wind will continue to lead by 2030, but during 2030–2050 solar PV will be deployed significantly to produce nearly the same amount of power as wind. (See Figure S-3.)

Figure S-3. Renewable Energy Sources in EU Electricity Consumption



By 2050, the heating and cooling sector will be 100% renewables driven, up from only 11% in 2007. If biomass continues to contribute significantly to the heating sector, then this as well as major developments in solar thermal and geothermal energy will help make heat 100% renewable by 2050. (See Figure S-4.)

Figure S-4. Renewable Heating and Cooling Consumption



By 2020, 9% of transport fuel will be met by biofuels and 11% by diesel and gasoline. By 2050, transport fuel will be met entirely by biofuels and renewable electricity.

Pathways to Implementation

The transition to 100% renewable energy by 2050 requires several policy milestones:

- Binding renewable energy targets by 2030;
- Full liberalization of the energy market;
- Phasing out of all subsidies for fossil fuels and nuclear energy; and
- Introduction of an EU-wide carbon tax to increase competitiveness of renewables technology.

The implementation of super-smart-grid infrastructure is also a crucial aspect connecting with information and communications (ICT) technologies in the North Sea offshore grid, the Mediterranean energy grid, and Baltic interconnection.

24. *Europe's Share of Climate Change* (Stockholm Environment Institute (SEI) and Friends of the Earth, 2009)

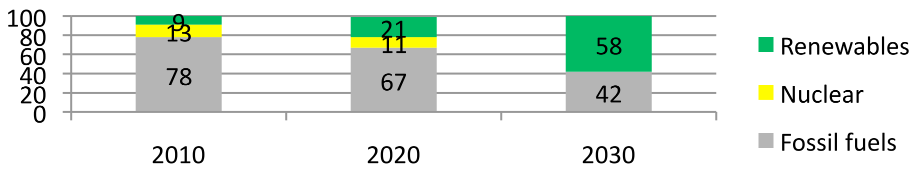
Scenario Description

The study aims to set a pathway for reducing European CO_2 emissions 40% by 2020 and 90% by 2050 (from the 1990 level). It presents two scenarios: a baseline scenario and a mitigation scenario. The baseline scenario, developed using the LEAP modeling tool, reflects a continuation of current EU policies, resulting in a modest rise in emissions with economic growth balanced by improvements in energy efficiency. The mitigation scenario starts with the goal of reducing emissions 40% by 2020 and to the extent possible by 2050. It assumes a nuclear phaseout by 2050, and that carbon capture and storage is non-commercial.

Key Projections/Results

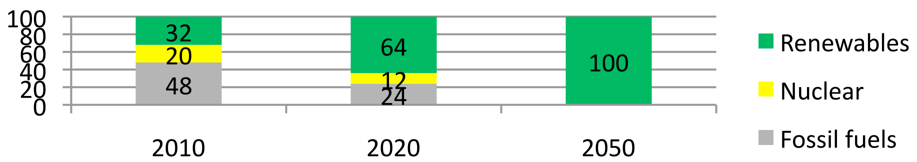
In the mitigation scenario, energy efficiency will help to considerably decrease the EU's primary energy demand from 77,000 PJ in 2010 to 24,000 PJ in 2050. Meanwhile, the share of renewable energy increases from 9% in 2010 to 58% in 2050, while the share of fossil fuels is almost halved. (See Figure T-1.)

Figure T-1. Share of Primary Energy Sources in EU Energy Demand



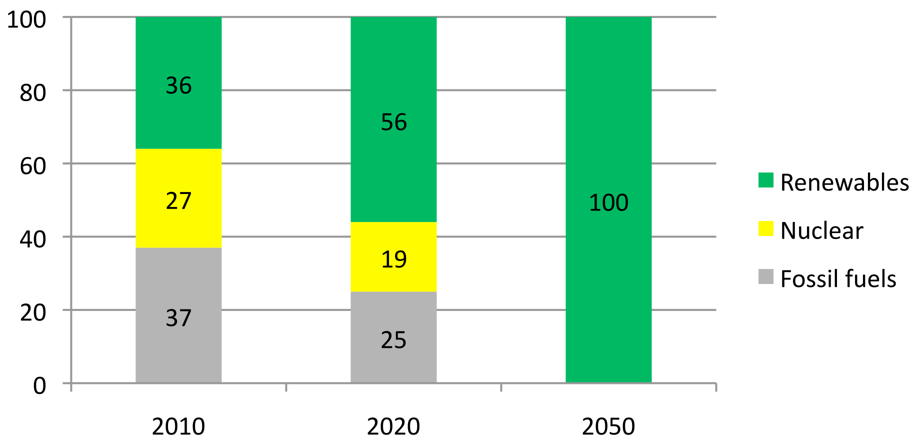
The total power capacity installed in the EU will increase from 600 GW in 2010 to 1,200 GW in 2050. By 2050, power generation facilities will operate using only renewable sources, due mainly to the phaseout of nuclear and fossil fuel plants. (See Figure T-2.) Between 2020 and 2030, wind generation facilities will be built at a rate of 25 GW per year, and by 2050, 40% of the installed capacity will be onshore wind.

Figure T-2. Share of Primary Energy Sources in EU Electricity Capacity



By 2050 100% of the electricity in Europe will be supplied by renewable energy sources. (See Figure T-3.)

Figure T-3. Share of Primary Energy Sources in EU Electricity Generation



Overall electricity demand in the EU will increase 6% by 2020 and 24% by 2050. Household electricity demand will increase 8% by 2020 and 14% by 2050, due to rising income levels and to increased appliance ownership, which will outweigh energy efficiency gains. In the industry sector, electricity consumption will decrease 12% by 2020 and 49% by 2050 as a result of efficiency gains.

The transport sector, meanwhile, will see a 219% rise in electricity demand by 2020 and a 606% increase by 2050 due to the uptake of electric vehicles. Electrification of the rail system will occur by 2030, and the build-out of electric infrastructure, such as vehicle charging stations, will be reinforced through 2050.

25. *Power Choices: Pathways to Carbon-Neutral Electricity in Europe by 2050* (Association of the Electricity Industry in Europe (Eurelectric), 2009)

Scenario Description

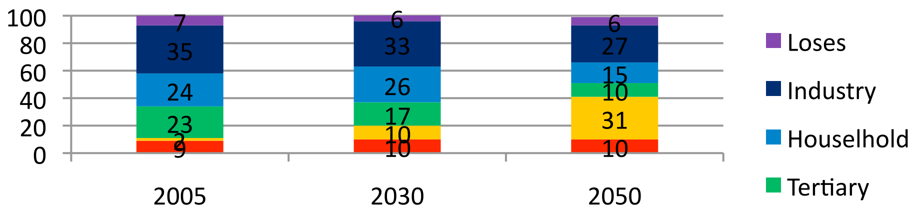
The study sets out to analyze the technologies and energy policies needed to attain the following goal: "Achieve carbon-neutrality in a cost efficient way through an integrated European market [while maintaining a] reliable energy supply…." It presents two main scenarios, one reflecting the continuation of current policies (as of 2008/2009), and the second a "Power Choice" scenario that uses the PRIMES model and is based on the goal of reducing European greenhouse gas emissions by 75% from 1990 levels.

The Power Choice scenario assumes that electricity is the main transport fuel through 2050, with the deployment of plug-in and hybrid vehicles and full electrification of rail transport. It also assumes that effective energy efficiency policies are implemented to support renewable power facilities. The price of oil reaches US$100 a barrel by 2030, and natural gas (indexed on oil) reaches US$15 per million BTU by 2050.

Key Projections/Results

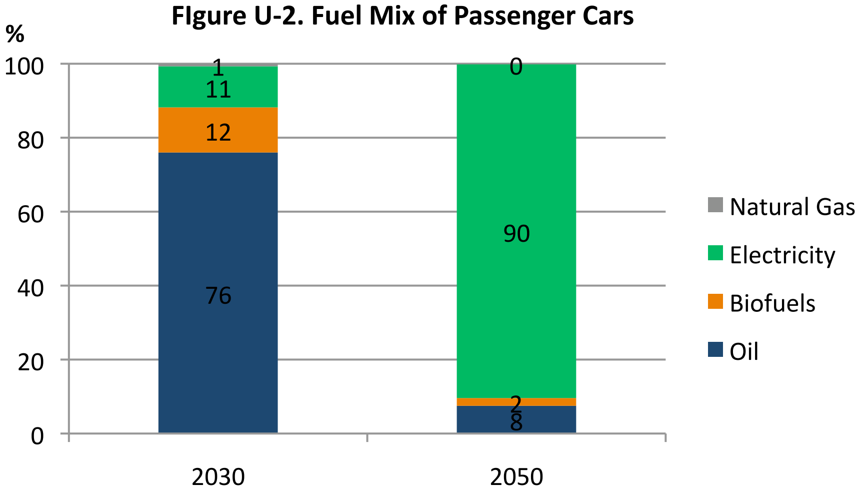
Under the Power Choice scenario, EU primary energy demand will decrease from 1,758 Mtoe in 2005 to 1,408 Mtoe by 2050, due to lower demand in the transport sector and decreases in the energy intensity of various activities. Electricity consumption by sector will shift significantly as transport replaces industry as the main driver of demand. (See Figure U-1.) And more-efficient technologies and better insulated structures will reduce household electricity consumption for heating and cooling.

Figure U-1. Share of Electricity Demand by Sector



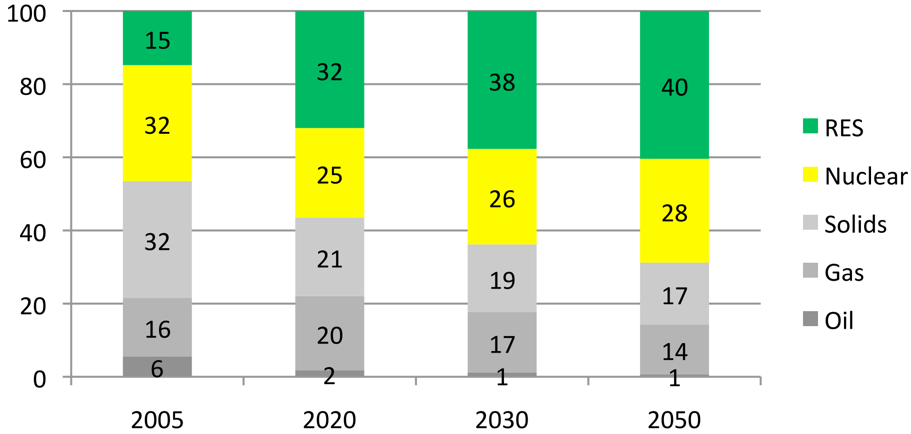
As electrification of the transport sector accelerates through the use of plug-in and electric vehicles, more than 90% of passenger cars will be powered by electricity by 2050. (See Figure U-2.)

FIgure U-2. Fuel Mix of Passenger Cars



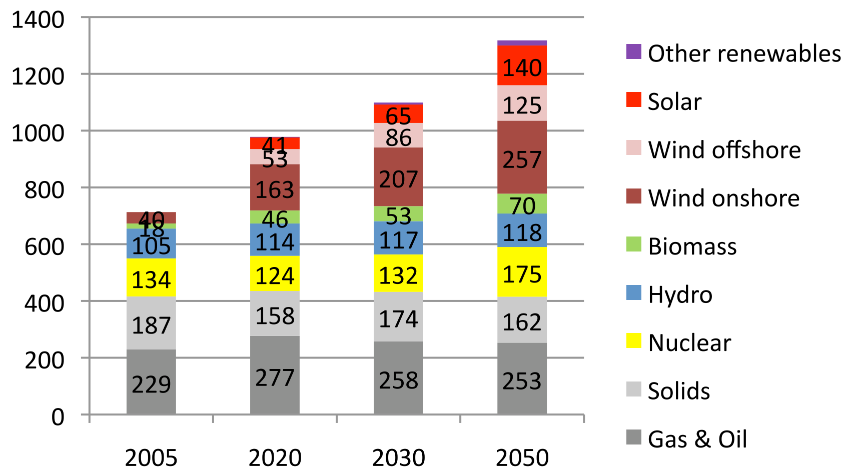
Power generation, boosted mainly by the transport sector, will rise from 3,100 TWh in 2005 to 4,800 TWh in 2050, with renewables representing 40% of total generation in 2050. Of this, 35% will come from onshore wind, 27% from offshore wind, and 13% from solar. Nuclear's share will not change considerably, dropping from 32% in 2005 to 28% in 2050. Despite a coal revival by 2025 with the commercialization of affordable and efficient carbon capture and storage technology, the share of solids in the electricity mix will decrease from 32% in 2005 to 17% in 2050. (See Figure U-3.)

Figure U-3. Share of Primary Energy Sources in Electricity Generation



The total power capacity installed in Europe will reach more than 1,300 GW by 2050, with renewables representing more than half of newly installed capacity. (See Figure U-4.) This will require a total investment of around €2 trillion (2005 euro) for the period up to 2050.

GW **Figure U-4. Net Power Capacity**



Pathways to Implementation

The goal of decreasing EU emissions 75% by 2050 will be achieved through two interlinked routes: decarbonization of the power sector and electrification (to a certain degree) of final energy usage. Decarbonization of the power sector will require investments in renewables and their large-scale uptake in the electricity system. Investments in smart grids are also needed, with a particular focus on transmission and distribution lines. Reform of existing carbon and electricity markets will be crucial to achieving the emissions reduction goal, and the cost internalization of greenhouse gases in all sectors should be explored with well-functioning markets. Governments will need to shift their national budget priorities and acknowledge the importance of investing in an intelligent energy economy.

26. *Energy Roadmap 2050* (European Commission, 2011)

Scenario Description

The report explores the challenges posed in achieving the European Union's objective of reducing regional greenhouse gas emissions 80–95% below 1990 levels by 2050. It explores different routes to decarbonization of the energy system and presents seven scenarios, including a Reference one and a High Renewable Energy Sources (RES) one.

The Reference scenario assumes that regional GDP will grow 1.7% annually through 2050, and it includes policies adopted as of March 2010, including the EU's 2020 targets for emissions reductions and renewables share and as well as the emissions trading scheme (ETS) directive. The High RES scenario assumes that the EU takes strong support measures for widespread development of green technologies. The analysis also assumes that decarbonization of the energy system will entail major changes in energy efficiency (of buildings, products, appliances, vehicles, etc), carbon prices, technologies, and energy networks (which are aging and need billions of euros of investment).

Key Projections/Results

In all scenarios, the share of renewable energy is expected to rise substantially, accounting for at least 55% of gross final energy consumption in 2050, up from only 10% today. This figure is reached due to the decreasing costs of renewables and to the economies of scale resulting from improved research, industrialization of the supply chain, and more-efficient policies and support schemes. This transition will require the development of new renewable technologies, such as ocean energy, solar thermal (CSP), and second- and third-generation biofuels, as well as the improvement of existing ones (e.g., increasing the size of offshore wind turbines and blades to capture more wind).

In all scenarios, electricity will play a much greater role than today, and its share in EU final energy demand will nearly double to 36–39% in 2050. Electricity could provide an estimated 65% of the energy demand of passenger cars and light duty vehicles.

In the High RES scenario, the share of renewables in gross final energy consumption will reach 75% in 2050, and their share in electricity consumption will be 97%. Getting there will require greater investments in balancing capacity, demand response, energy storage, and grids (smart grids). Cumulative investments in the grid alone could be between €1.5 trillion and €2.2 trillion during the outlook period.

Widespread use of renewables for power and heat generation will make these systems more decentralized, and they will have to increasingly complement centralized, large-scale systems such as nuclear and natural gas power plants. By 2050, power generation capacity from renewables will be more than twice today's total power generation capacity from all sources.

In the High RES scenario, wind power will provide more electricity than any other technology by 2050, with wind and solar power from Mediterranean countries making a substantial contribution. In the medium term, ocean energy can also significantly boost electricity supply. Biofuels will become a main option for aviation, long-distance road transport, and rail (where it cannot be electrified).

As a source of low-carbon electricity, nuclear will play a key role for the next few decades.

27. *Pathways Towards a 100% Renewable Electricity System* (German Advisory Council on the Environment, 2011)

Scenario Description

The report discusses the need for Germany's electricity system to become "sustainable and decarbonized" (i.e., renewables-based and non-nuclear) by 2050, in light of relevant technical, economic, legal, and political factors. It discusses wider European aspects in so far as they are relevant for the transition of the Germany's electricity supply. The authors also recommend certain legal and political measures to help the country transition to a wholly renewable electricity supply.

The report presents a reference scenario and also models several scenarios aimed at achieving specific targets (such as a 100% renewable electricity supply), showing how and under what conditions the targets can be reached. The target scenarios are elaborated using two calculation models: one from Stuttgart University's Department of Energy Resource Management and Rational Energy, and the other from the Wuppertal Institute.

The analysis assumes that energy efficiency is key to transitioning to an affordable, wholly renewable electricity supply; that the cost of currently available renewables (wind, solar, geothermal, and hydro) will decrease in the coming years as a result of technological improvements (better efficiency, lower materials use) and economies of scale resulting from increased production; and that energy storage and transmission capacities will be expanded in concert with renewable electricity generation capacities.

Key Projections/Results

According to the scenarios, Germany's annual gross electricity demand will increase from 580 TWh in 2010 to 500–700 TWh in 2050, and the latter demand will be met with renewable sources. In the "low" scenario, 500 TWh results from stringent energy-saving and efficiency optimization measures for traditional uses of electricity. The "high" scenario (700 TWh) results when these measures are not implemented and electricity is substituted for some or all fossil fuel use in sectors such as transport, heat, and process heat.

Excluding hydro, the costs of all renewables will decrease. (See Table V-1.) By 2050, wind will be the lowest-cost renewable, at €0.04–0.05 per kWh (offshore will be slightly more competitive than onshore). Solar PV costs will drop nearly 80%, from €0.44 per kWh in 2010 to €0.09 per kWh in 2050.

Table V-1. Cost of Renewables (€/kWh)

	2010	2050
Solar PV	0.44	0.09
Biomass	0.12	0.10
Offshore wind	0.12	0.04
Onshore wind	0.09	0.05
Hydro	0.04	0.05
Geothermal	0.22	0.19

In Germany, wind power benefits from low cost and great electricity generation potential, at 839 TWh per year. Hydro is also very cost competitive, but its generation potential is limited to about 28 TWh per year, due to the geography. Solar PV has greater potential, about 110 TWh per year, but it is projected to still cost almost twice as much as wind and hydro in 2050.

Germany's geothermal power potential is high, about 220 TWh, but it is very costly to develop. Biomass power is relatively inexpensive compared to geothermal but is limited to approximately 71 TWh per year; it may be further restricted by competing demand for biomass from the fuel and heating sectors. However, biomass could be used optimally in power plants that generate both heat and power.

The electricity share generated by each energy source will depend on demand. In a low demand case, more than 61% of electricity will be generated by offshore wind, about 17% by onshore wind, 9% by solar PV, and 5% by hydro and biomass. In this case, renewables capacity will reach just over 160 GW: 75 GW for offshore wind, 40 GW each for onshore wind and solar PV, and 4 GW each for hydro and biomass.

In a high electricity demand case, about 45% of electricity will be generated by offshore wind, 13% by onshore wind, 15% by solar PV, 5% each by hydro and biomass, and 16% by geothermal. In this case, renewables capacity will reach about 250 GW: 75 GW for offshore wind, 40 GW for onshore wind, 112 GW for solar PV, 4 GW each for hydro and biomass, and 15 GW for geothermal.

As electricity demand rises, Germany must resort to additional energy sources. Because the most competitive ones are already fully exploited in the low electricity demand case, the country will have no choice but to rely on the most expensive ones, solar and geothermal.

Electricity trade via international grids favors the massive integration of renewables, as this decreases the need for back-up installed capacities as well as large-scale development of storage technologies. In the case of Germany, Denmark and Norway would be ideal partners for trading electricity. However, transmission lines would need to be expanded to fully exploit this inter-regional network.

28. *Outlook for Alternative Renewable Energy in Brazil* (Brazilian Ministry of Mines and Energy, 2010)

Scenario Description

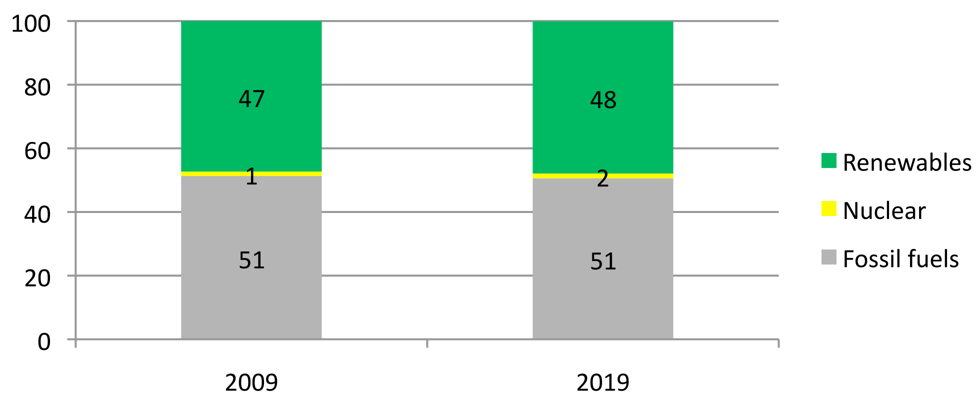
The report examines the current state of renewables in Brazil and their potential contribution to the country's energy mix by 2019. It focuses mainly on the future development of sugar cane and wind power.

Key Projections/Results

Renewables supplied 47% of Brazil's energy in 2009, up from 41% in 2000. This share is not expected to increase through at least 2019. (See Figure W-1.) However, the mix of renewables will change slightly. Sugar cane supplied 18% of the country's energy needs in 2009, and this share is expected to reach 22% by 2019. The share of hydro will decrease from more than 15% in 2009 to less than 13% in 2019.

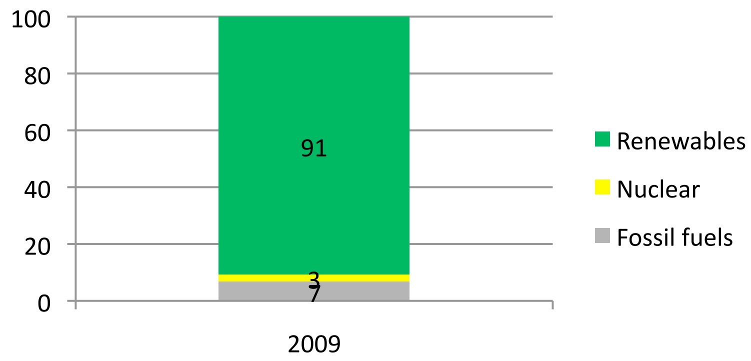
Brazil's reliance on oil will decrease from nearly 38% in 2009 to 31% In 2019, with the reduction offset by use of natural gas and coal. Nuclear role is minor and will remain so.

Figure W-1. Share of Primary Energy Sources in Brazil's Energy Supply



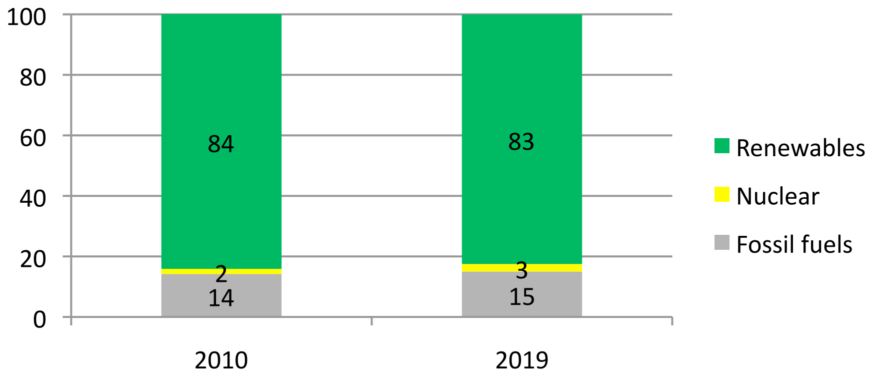
Brazil's electricity structure already relies largely on renewables, as almost 91% of the country's electricity is "green." (See Figure W-2.) The vast majority of this (85%) comes from hydro and 5% comes from biomass, produced mainly from cogeneration with sugar cane. Wind comprises only 0.24%, and other renewables are marginal.

Figure W-2. Share of Primary Energy Sources in Brazil's Electric Power Supply Structure



Projections for future installed capacity reveal a slight decrease in renewables capacity in favor of fossil fuels and nuclear. (See Figure W-3.) An estimated 21.4% of total new installed capacity in Brazil (63.48 GW) by 2019 will come from fossil fuels and nuclear, at 12.18 GW and 1.41 GW respectively. An estimated 14.66 GW (23.1%) of newly installed capacity by 2019 will be renewables (excluding hydro). Hydro will continue to grow, representing more than 55% of Brazil's newly installed capacity.

Figure W-3. Share of Primary Energy Sources in Brazil's Installed Capacity



Total demand for sugar cane, used widely for food and biofuel (ethanol), is expected to increase nearly 66%, from 685 million tons in 2010 1,135 million tons in 2019. This growth is due largely to rising ethanol demand, which is expected to increase 133%, from 27.5 billion liters in 2009 to 64 billion liters in 2019. More than 15% of Brazilian ethanol will be exported in 2019 (up from 12% in 2009); however, nearly 82% of consumption will be from the domestic market. The estimated cogeneration potential from sugar cane in 2019 is 17.4 GW, enough to generate 89.1 TWh, or 18% of Brazil's actual electricity supply (509 TWh).

Brazil had only 606 MW of installed wind power capacity in 2009, although significant growth is expected as the country aims to have about 6 GW of installed capacity by 2019. Wind will then account for 36% of Brazil's newly installed renewable energy capacity (excluding hydro). The estimated generation potential is about 271 TWh, or 53% of the country's actual electricity supply. Given that the share of wind power in Brazil's electricity generation mix was nearly 0% in 2009, the country has a long way to go before it fully exploits its wind potential. The greatest potential lies along the northeast coasts.

29. *Meeting the Balance of Electricity Supply and Demand in Latin America and the Caribbean* (The World Bank, 2011)

Scenario Description

The report provides an assessment of the electricity sector in Latin America and the Caribbean to 2030. It evaluates critical issues such as the expected rise in electricity demand, the supply of new generating capacity that is required, the technology and fuel mix needed to provide that generating capacity, and the carbon dioxide emissions of the power sector. The report also examines the important roles of hydropower and natural gas, ways to expand other clean and low-carbon resources, the potential and benefits of greater electricity trade, and the role of energy efficiency.

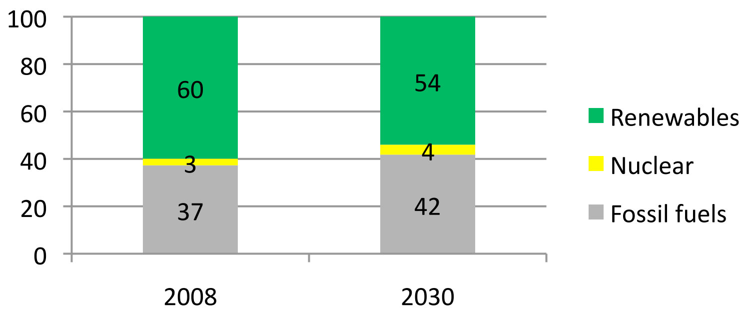
The report presents a baseline scenario, the ICEPAC (Illustrative Country Expansion Plans Adjusted and Constrained) Scenario, which is based on the OLADE (Organización Latinoamericana de Energía) SUPER (Sistema Unificado de Planificación Eléctrica Regional) model and which reflects current country expansion plans in the region. The scenario takes into account the renewable energy sources hydro, wind, biomass, and geothermal.

The main assumptions are the International Monetary Fund's GDP forecasts for each country to 2014, average GDP growth of 3% annually for 2015–2030, and an oil price of US$100 per barrel.

Key Projections/Results

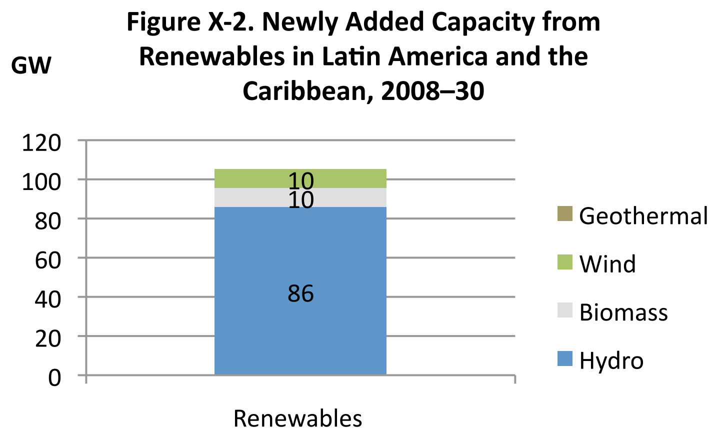
By 2030, the region's demand for electricity will reach nearly 2,500 TWh, up from some 1,150 TWh in 2008. The future electricity mix is not expected to change significantly during the outlook period, with hydro remaining the main energy source. (See Figure X-1.) However, a reduction in hydropower from 58.6% in 2008 to 50% in 2030, will mean a decline in the overall share of renewables, from 1.6% to 4.1%. Wind is estimated to grow at the fastest pace, 16.2% per year.

Figure X-1. Share of Primary Energy Sources in Electricity Generation in Latin America and the Caribbean



By 2030, the share of natural gas will increase from 22% to 29.4%, and coal from 4.6% to 7.9%. Nuclear expansion (concentrated in Argentina) will be minimal, from 2.8% to 4.2%.

Meeting rising electricity demand in Latin America and the Caribbean will require significant expansion of power-generating capacity. An estimated 239 GW of new installed capacity will be necessary, including 97 GW in Brazil, 45 GW in the Southern Cone, 44 GW in Mexico, 30 GW in the Andean Zone, 15 GW in Central America, and 7 GW in the Caribbean. Hydropower and natural gas will provide the majority of additional power capacity, at 36% and 35% respectively, due to their low costs. Other renewables, mainly biomass and wind, will provide 8% of the new installed capacity what is less than coal (11%). (See Figure X-2.)



Investment in new generation capacity is estimated to be about US$430 billion between 2008 and 2030.

The report notes that the contribution of non-hydro renewables to the region's future electricity mix is increasing, but their full potential remains underexploited. The region is home to large renewable resources, including wind in Argentina, hydroelectricity and biomass (such as sugarcane bagasse) in Brazil, geothermal in Central America, and ubiquitous solar resources. These renewables could provide between 15% and 30% of the total electricity supply in 2030 with development of the technologies, energy efficiency improvements, and increasing regional electricity trade linking countries and regions, which would allow for the optimization of electricity supplies to help address the variability of new renewables.

With regard to renewable energy potentials in the region, the report notes:

- Wind appears to have the largest potential of the new renewables over the coming two decades. Variations in wind and hydroelectric output are largely independent of one another, which, together with the storage capabilities of hydropower dams, make them complementary.

- Biomass, particularly residues from the sugar industry, currently provides a significant amount of electricity in Brazil and could make a further contribution there and elsewhere in the future.

- Geothermal potential is highly uncertain because of limited exploratory drilling. The greatest potential is concentrated along the tectonically active Pacific Rim from Mexico to Chile and in some Caribbean islands.

- Solar power, mainly solar thermal (CSP) power, will require breakthroughs to reduce costs if it is to contribute significantly to grid-supplied electricity in the next 20 years.

30. *Renewable Electricity Futures Study*, volumes 1 to 4 (National Renewable Energy Laboratory (NREL), 2012)

Scenario Description

The study assesses a variety of scenarios that aim for specific levels of renewable electricity generation in 2050 (from 30% to 90%), although the primary focus is on 80% renewable power, with nearly 50% of this coming from wind and solar PV. It identifies the characteristics of a U.S. electricity system that would be needed to accommodate such levels, and describes some of the challenges and implications of realizing such a future.

Because the focus of the report is on grid integration and not on the potential advances of specific technologies, the scenarios consider only commercially available technologies as of 2010, including wind, PV, solar thermal (CSP), hydropower, geothermal, and biomass. The study omits technologies such as enhanced geothermal systems, ocean energy technologies, floating offshore wind technology, and others that are currently under development or pilot testing.

The report models and analyzes more than two dozen scenarios, based on low and high demand baselines. The low-demand baseline assumes the adoption of energy efficiency measures and improvements in technology cost and performance. The high-demand baseline represents a business-as-usual case that assumes no radical changes in available technologies or consumer behavior, and no enactment of new regulations or laws.

The primary focus is on 80% share of electricity from renewable sources, with the following scenarios applying the low electricity demand assumptions:

- The No RE Technology Improvement (80% RE-NTI) scenario assumes that the performances of the considered renewable technologies will be maintained at their 2010 level.

- The Incremental RE Technology Improvement (80% RE-ITI) scenario reflects only partial achievement of the future technical advancements that may be possible.

- The Evolutionary RE Technology Improvement (80% RE-ETI) scenario reflects a more complete achievement of possible future technical advancements. However, further technical advancements beyond the RE-ETI are possible.

- The Constrained Transmission scenario evaluates how limits to building new transmission might impact the location and mix of renewable resources used to meet an 80%-by-2050 future.

- The Constrained Flexibility scenario seeks to understand how institutional constraints to and concerns about managing the variability of wind and solar resources, in particular, might impact the resource mix of achieving an 80%-by-2050 future.

- The Constrained Resources scenario assumes that environmental or other concerns may reduce the developable potential for many of the renewable technologies in question, and evaluates how such constraints could impact the resource mix of renewable energy supply.

The study's main assumptions are annual average GDP growth of 2.4% and population growth of 0.9%. Most of the scenarios also assume the adoption of energy efficiency (including electricity) measures in the residential, commercial, and industrial sectors, which result in flat demand growth over the 40-year study period. Most scenarios assume a shift of some transportation energy away from petroleum and toward electricity in the form of electric and plug-in hybrid electric vehicles. The study also assumes improvements in electric system operations to enhance flexibility in both electricity generation and end-use demand, as well as expanded transmission infrastructure and access to existing transmission capacity. Most scenarios assume project siting and permitting regimes that allow for renewable electricity development and transmission expansion subject to standard land-use exclusions.

To address the variability and uncertainty associated with integrating higher levels of renewables, the report notes the need to increase the overall flexibility of the power system through measures such as energy storage, demand response, and more-flexible conventional fossil power plants. The study does not take into account the rapid development of domestic unconventional natural gas resources that has contributed to historically low natural gas prices.

The study employs two models; the NREL Regional Energy Deployment System (ReEDS), which explores the adequacy of geographically diverse U.S. renewable resources to meet electricity demand over future decades, and the ABB model GridView, which explores the hourly operation of the U.S. grid with high levels of variable solar PV and wind generation.

Key Projections/Results

According to the analysis, U.S. electricity demand will increase from 3,700 TWh in 2008 to 3,920 TWh in the low demand baseline and 5,100 TWh in the high demand baseline, in 2050. The main conclusion is that renewable power from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country. A green electricity system is not only possible, but the abundance and diversity of U.S. renewable resources can support multiple combinations of renewable technologies. (See Table Y-1.) There is no insurmountable long-term constraint to technology manufacturing capacity, materials supply, or labor availability.

Table Y-1. Estimated Installed Capacity Potential of Renewable Energy in the United States

Renewable Energy Source	Potential Installed Capacity (GW)
Biomass	100
Geothermal	500
Hydro	152–228
Utility-scale solar PV	80,000
Rooftop solar PV	37,000
Solar thermal (CSP)	700
Wind	10,000

However, such a transition would require a transformation of the electricity system that involves every element of the grid, from system planning through operation. It would need to ensure adequate planning and operating reserves, increased flexibility of the electric system, and expanded multi-state transmission infrastructure, and would likely rely on the development and adoption of technology advances, new operating procedures, evolved business models, and new market rules. The most impactful lever for reducing the cost of this transition is improvement in the cost and performance of renewable technologies.

Figures Y-1 and Y-2 show the installed capacity and generation mix in 2050 for different levels of electricity generated from renewables (the low-demand baseline case, and under the RE-ITI technology improvement scenario, which is a relatively conservative scenario reflecting only partial achievement of the future technical advancements that may be possible).

Figure Y-1

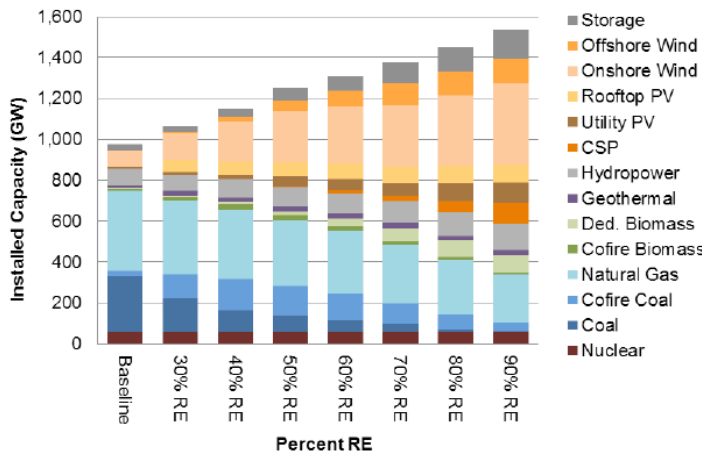
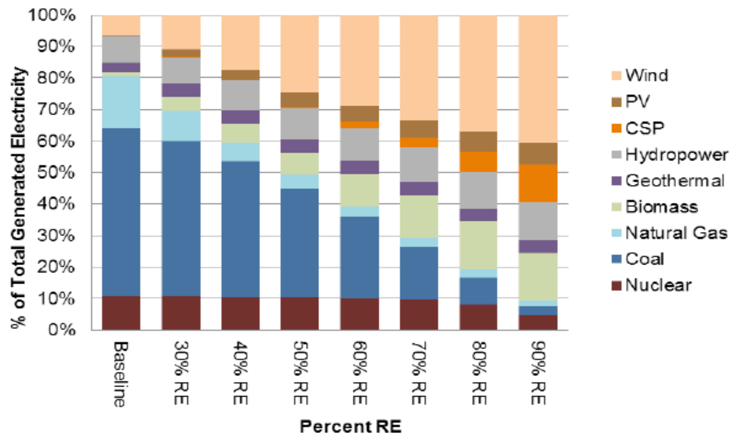


Figure Y-2



Wind power, particularly onshore, has the greatest potential: of the 1,390 GW capacity required, under the 90% renewable energy RE-ITI scenario, 517 GW is wind. This scenario also includes 102 GW of CSP installed capacity in 2050.

Table Y-2 shows the deployment of renewable installed capacity (in GW) in 2050 under 80% renewable energy scenarios:

Table Y-2

		Different 80% Scenarios						
		Low-Demand						**High-Demand**
		RE-NTI	RE-ITI	RE-ETI	Constrained Transmission	Constrained Flexibility	Constrained Resources	High- Demand Renewables
Renewable Energy Sources	Dedicated Biopower	80	82	83	84	81	40	84
	Co-fired Biopower	13	13	11	14	14	11	16
	Hydrothermal	25	24	24	24	24	12	24
	Solar PV	90	168	171	294	149	203	421
	CSP	1	56	126	33	89	120	79
	Onshore	441	349	330	280	322	395	463

	Onshore Wind	441	349	330	280	322	395	463
	Offshore Wind	115	112	56	185	100	103	141

Biomass power is significant in all 80% renewable energy scenarios modeled, excluding the Constrained Resources scenario. Biomass deployment shows little variation among the other six 80%-renewables scenarios, due to the limited feedstock supply. Geothermal is similar in many of the scenarios because of the limited resource supply.

Use of solar power is linked largely to future reductions in the costs of PV and CSP. Additionally, PV use will increase and CSP will decrease if transmission expansion is limited due to the greater location-dependence of CSP resources. CSP use will increase and PV will decrease if institutional flexibility is limited due to the variability and uncertainty inherent in PV systems without storage.

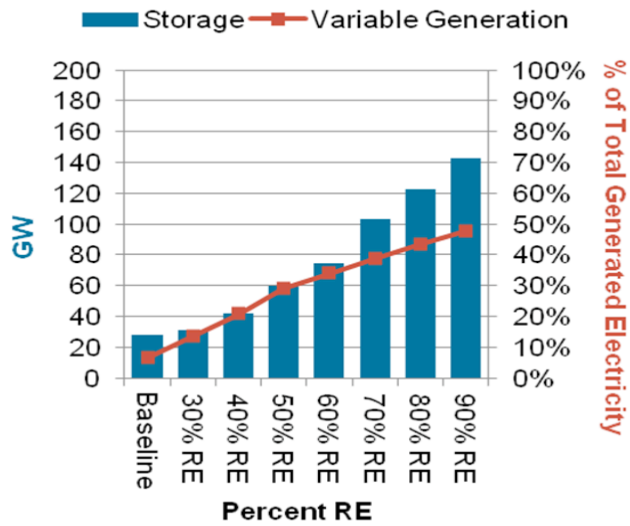
Wind energy technologies play a significant role in all renewable futures scenarios. Among the low-demand 80%-renewable scenarios, wind deployment is greatest when no cost or performance improvements are assumed (80% RE-NTI scenario) for any renewable technology, due to the fact that wind is a relatively mature renewables technology. Offshore wind realizes the greatest installed capacity in the Constrained Transmission scenario, with 185 GW deployed by 2050, because of the facilities' proximity to load centers on the East Coast, which reduces new transmission requirements.

The study makes numerous projections about the flexibility of the power system. Concerning storage, it focuses on three different technologies that can provide energy management services or store and discharge continuously for 8–15 hours: high-energy batteries, pumped-storage hydropower (PSH), and compressed air energy storage (CAES). The report estimates the total amount of storage deployed, but not the share of each technology type. Battery deployment is expected to be limited due to the high cost and assumed minimal cost reduction, as well as to a lack of valuation of the benefits to the distribution system. Most of the new storage is projected to be CAES, not PSH, with the developable potential of new PSH at 35 GW and of CAES at more than 120 GW.

The role of vehicle-to-grid (V2G) is not explicitly evaluated. The report includes the value of controlled charging, but because of uncertainty in the ultimate acceptance among original equipment manufacturers, utilities, and consumers, the potentially very large role of V2G has not been taken into account

Not surprisingly, the study notes that the more renewables, in particular variable renewables, that are deployed, the more storage capacity will be needed. (See Figure Y-3.) By 2050, storage capacity is estimated at 28 GW in the Low-Demand Baseline scenario, 31 GW in the 30%-renewables scenario, 74 GW in the 60% scenario, and 142 GW in the 90% scenario

Figure Y-3.



In the framework of the 80% scenarios, between 80 and 131 GW of new storage capacity will be installed by 2050 in addition to the 20 GW of existing (PSH) storage capacity. (See Figure Y-4.)

Figure Y-4

	Different 80% Scenarios						
	Low-Demand						**High-Demand**
	RE-NTI	RE-ITI	RE-ETI	Constrained Transmission	Constrained Flexibility	Constrained Resources	High-Demand Renewables
Dedicated Biopower	142	122	100	129	152	131	136

The Constrained Flexibility scenario, which takes into account greater institutional and technical barriers to managing variable generation, projects the greatest level of storage deployment, at 152 GW of installed storage capacity by 2050. The lowest level is found under the 80% RE-ETI scenario, which includes high levels of CSP use with thermal storage and a corresponding lower use of variable generation technologies. Conversely, greater wind use in the 80% RE-NTI scenario and greater wind and PV use in the high-demand 80% renewable energy scenario require high levels of storage deployment.

With regard to demand response, the report considers a fairly limited set of options:

- Interruptible load (for provision of operating reserves) is considered using regional supply curves based in large measure on FERC (2009). Annual interruptible load resource availability is based on a percentage of peak demand within a region, and is assumed to grow from a range of 1%–8% in 2010, to 11%–17% in 2030 and 16%–24% in 2050.

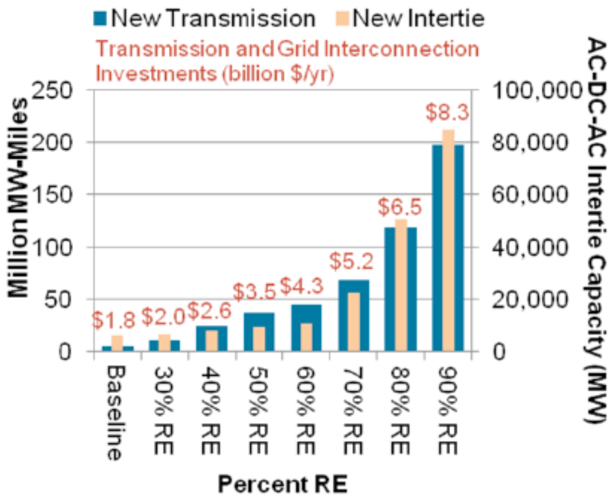
- New controllable loads could absorb otherwise unusable variable generation output. The study notably deals with scheduling charging of electric vehicles, so that electricity consumption at the recharge station would increase or decrease according to the net supply of renewable resources. The reports thus assumes that a substantial fraction (~40%) of the passenger transportation fleet transitions to electric and plug-in electric vehicles by 2050 (in the low-demand projection) and that of the 356 TWh of electric vehicle load in 2050, 165 TWh will operate under utility-controlled charging. The remaining EV load not under utility control is assumed to have a daily charging profile that peaks during evening hours.

- Demand-side thermal energy storage in commercial buildings is also considered. In particular, chilled water and ice storage cooling capable of shifting air conditioning loads are represented.

With regard to the flexibility of conventional fossil power plants, the report assumes that existing and future plants could be used to provide increased system flexibility. Newer generators have the capability to have faster ramp rates, larger ramp ranges, and minimal part-load heat-rate degradation, which enhances the ability of such units to follow load. In some cases, existing equipment can also be modified to enhance flexibility. Natural gas-fueled assets are normally more-flexible resources, and taking full advantage of their flexibility may involve new operational practices, including additional gas storage.

As renewable electricity supply grows, greater investments in transmission and grid interconnection will be needed. (See Figure Y-5.) The Low-Demand Baseline scenario requires 5.1 million MW-miles of new transmission lines and US$1.8 billion of investments per year, whereas the 90% RE scenario requires 197 million MW-miles and US$8.3 billion per year.

Figure Y-5.



As demand increases, variable wind and PV will be deployed to a greater extent in absolute and percentage terms due to their greater availability. As a consequence, additional flexible supply- and demand-side technologies, such as storage facilities, natural gas combustion turbine power plants, and interruptible load, will be deployed and greater transmission expansion will be needed to connect remotely located renewable resources of all types.

31. *Annual Energy Outlook 2012* (U.S. Department of Energy, Energy Information Administration (US DOE EIA), 2012)

Scenario Description

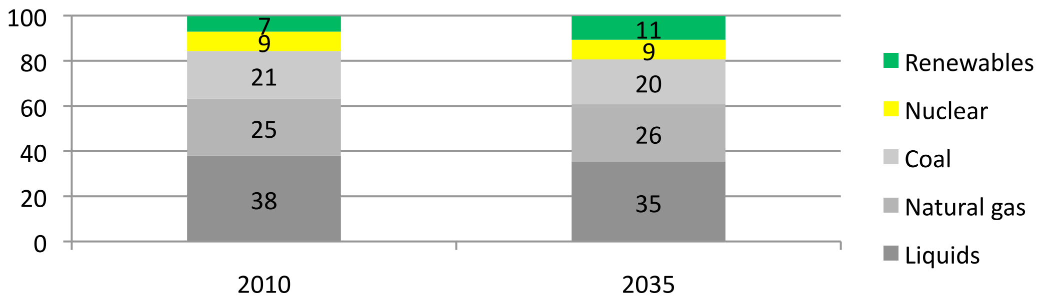
The report presents long-term projections of energy supply, demand, and prices in the United States through 2035. These are based on results from the EIA's National Energy Modeling System (NEMS), which includes modules representing the individual supply, demand, and conversion sectors of domestic energy markets, as well as international and macroeconomic modules such as GDP, disposable income, value of industrial shipments, new housing starts, sales of new light-duty vehicles, interest rates, and employment.

The analysis assumes GDP growth of 2.5% annually from 2010 to 2035, energy intensity growth of -2.1% annually during this period, and an oil price of US$145 per barrel in 2035.

Key Projections/Results

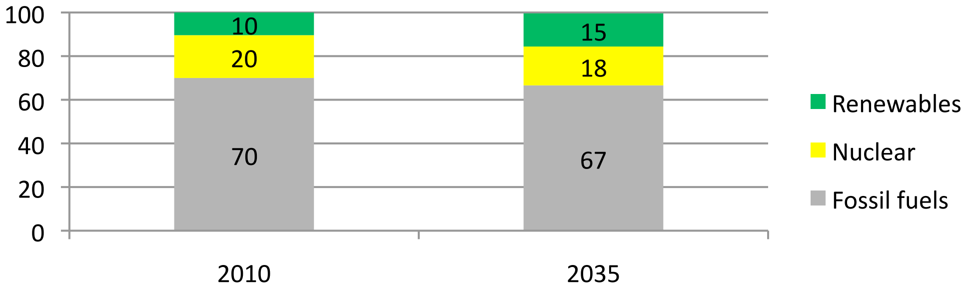
According to the study, U.S. energy consumption will grow at an average annual rate of 0.3% from 2010 to 2035 (an overall increase of about 9%) to reach 106.93 quadrillion BTU. Fossil fuels will still largely dominate the American energy mix, although their share will decrease slightly from 84% to 81% during the outlook period, due mainly to a lessening reliance on oil. (See Figure Z-1.) The share of natural gas will increase due to rising exploitation of shale resources. The declining share of fossil fuels will be offset by the increasing share of renewable energy, from 7% to 11%. Nuclear's share will remain under 10%.

Figure Z-1. Share of Primary Energy Sources in U.S. Total Energy Consumption



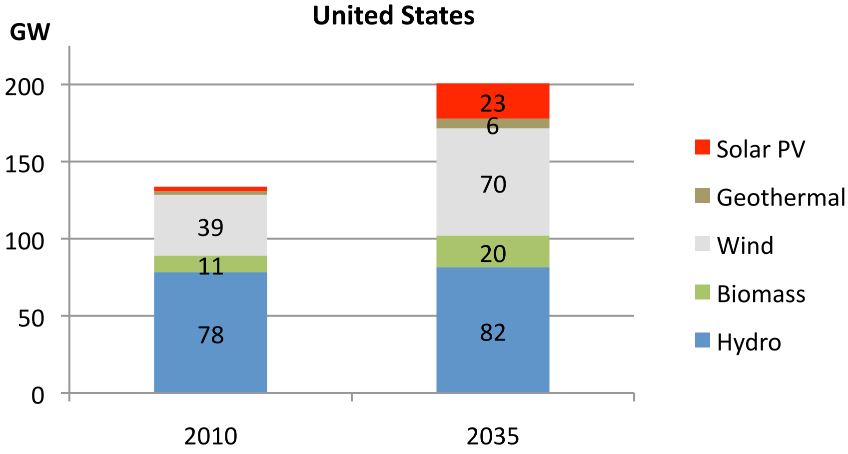
Electricity generation will increase by nearly 21%. The share of coal will decrease significantly from 45% in 2010 to 38% in 2035. This decrease will be offset first by generation from renewables, which will increase 2.3% annually on average to reach an approximately 15% share of U.S. electricity by 2035, and then by natural gas, which will achieve a 28% share (up 4 points over 2010). (See Figure Z-2.) Renewables installed capacity in the power sector (power only) will increase from 125.2 GW in 2010 to 169.3 in 2035, to represent 16% (up 3 points over 2010) of U.S. installed capacity.

Figure Z-2. Share of Primary Energy Sources in U.S. Electricity Generation



Total renewables installed capacity in all sectors will increase 50%, from about 134 GW in 2010 to nearly 201 GW in 2035. (See Figure Z-3.) Solar will have the fastest annual growth in terms of both installed capacity (8.6%) and generation (9.6%) during the outlook period.

Figure Z-3. Cumulative Renewable Energy Capacity in the United States



32. *Energy [R]evolution: A Sustainable (United States) Energy Outlook* (Greenpeace and European Renewable Energy Council (EREC), 2010)

Scenario Description

The scenario uses a bottom-up, technology-driven approach to illustrate the possibility of 100% renewable power in the United States by 2050. It presents three distinct scenarios: a Reference scenario, an Energy [R]evolution scenario (EREV), and an Advanced Energy [R]evolution scenario (AEREV).

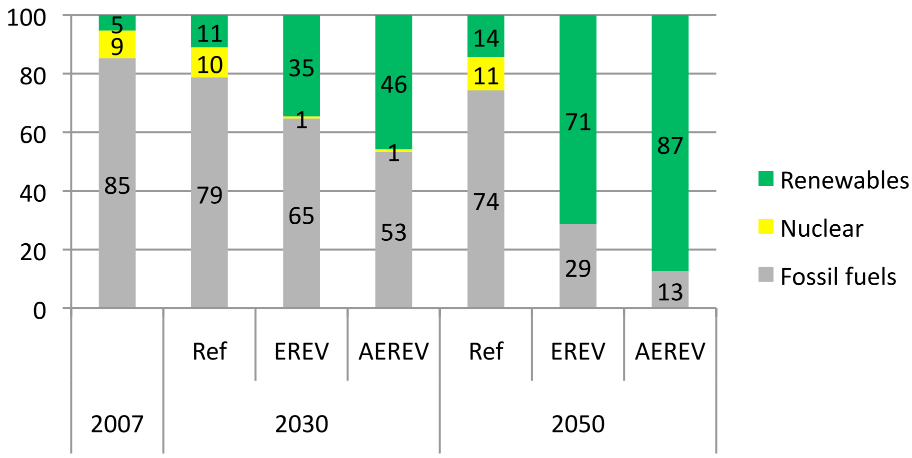
The two Energy [R]evolution scenarios look at the potential of first reducing electricity demand through energy efficiency and then providing electricity through decentralized renewable sources. It explores the use of smart grids and expanded super grids as a way to connect the decentralized systems. In the transport sector, the main evolutions are significant development of hybrid/electric vehicles by 2050 and the use of biofuels. Nuclear energy is to be phased out by 2050.

The main assumptions are a U.S. population of about 404 million, an average crude oil price of about US$150 per barrel in 2050, and a coal price of about US$172.3 per tonne in 2050.

Key Projections/Results

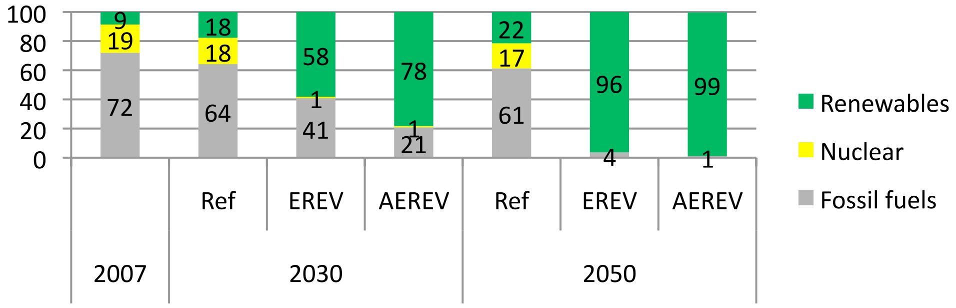
In both "revolution" scenarios, U.S. energy demand will decrease to approximately 59,000 PJ per year in 2050, as a result of energy efficiency measures, the phasing out of nuclear, and reduced dependence on fossil fuels. Meanwhile, the share of renewable energy will increase considerably. By 2050, renewables will account for 71% of U.S. primary energy demand under the EREV scenario, and 87% under the AEREV scenario. (See Figure AA-1.)

Figure AA-1. Share of Primary Energy Sources in U.S. Energy Demand



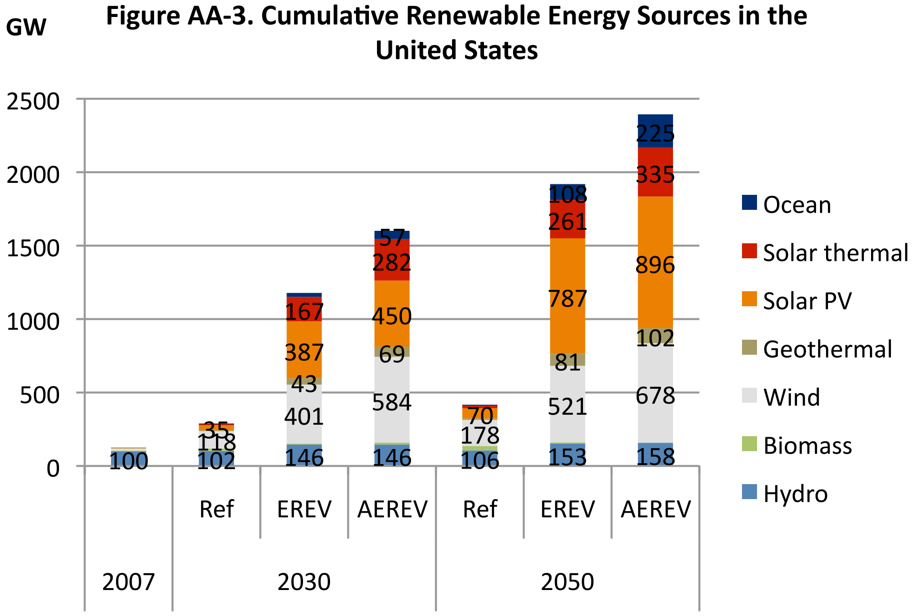
By 2050, renewables will account for 99% of U.S. electricity under the AEREV scenario, and more than 96% under the EREV scenario, reflecting the fact that a renewables-based future is possible. (See Figure AA-2.) Wind, solar thermal, and solar PV will represent some 62% of total generation, and renewables will provide 74% of total heat, mainly from biomass and solar collectors.

Figure AA-2. Share of Primary Energy Sources in U.S. Electricity Generation



In terms of installed capacity, solar PV will have the biggest growth, reaching nearly 800 GW in the EREV scenario and 900 GW in the AEREV scenario. Wind will follow, and solar thermal will also show significant growth. In the reference scenario, wind will pass hydro as the main renewable energy source. (See Figure AA-3.)

Figure AA-3. Cumulative Renewable Energy Sources in the United States



33. *Climate 2030: A National Blueprint for a Clean Energy Economy* (Union of Concerned Scientists, 2009)

Scenario Description

The report aims to provide a comprehensive set of smart policies ("the Blueprint policies") that would help the United States transition to a greener and more sustainable economy. These policies include an economy-wide cap-and-trade program (with auctioning of all carbon allowances) combined with minimum federal energy efficiency standards for specific appliances and equipment, advanced energy codes and technologies for buildings, and a renewable electricity standard for retail electricity providers. If these policies are pursued, the report concludes that U.S. heat-trapping emissions will decrease 56% in 2030 compared to their 2005 level.

The report explores two main scenarios; a Reference one, which assumes no new climate, energy, or transportation policies beyond those in place as of October 2008, and a Blueprint one, which results from the policies described above and that includes only technologies that are commercially available today or likely to be available within the next two decades. Thus, the analysis excludes technologies such as thin-film solar, wave and tidal power, advanced storage and smart grid technologies, dramatic expansion of all-electric cars and trucks, and breakthroughs in third-generation biofuels.

The study relies on a modified version of the U.S. Department of Energy's National Energy Modeling System, which has been supplemented with an analysis of the impact of greater energy efficiency in industry and buildings by the American Council for an Energy Efficient Economy, and results from research on the potential for crops and residues to provide biomass energy.

Key Projections/Results

With implementation of the Blueprint policies, which stimulate significant consumer, business, and government investments in new technologies and measures by 2030, U.S. energy use will decrease by one-third by 2030, with associated reductions in carbon emissions. Consumers and businesses will reap significant net savings, while the United States will see strong GDP growth of 81% between 2005 and 2030 (only 3 points less than in the Reference scenario).

The resulting savings on energy bills from reductions in electricity and fuel use will more than offset the costs of these additional investments. The carbon price will be relatively low, with carbon allowances reaching US$70 in 2030 (in 2006 dollars). By 2030, the use of renewable energy from wind, solar, geothermal, and biomass will increase 25%, to supply 40% of U.S. electricity. Renewable electricity use in advanced vehicles such as plug-in hybrids will also begin to grow significantly by 2030.