3

Increasing Utilisation of Renewable Energy Sources: Comparative Analysis of Scenarios Until 2050

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Introduction

This chapter views energy security through the lens of renewable energy sources (RES) as a major contributor to economic, environmental and social sustainability. Energy security is contextual, dynamic and multidimensional (Ang et al. 2015). This is because its conceptualisation is dependent on and influenced by the context it applies to; it evolves over time, following changes in our knowledge and understanding of the natural world and technological advances, and integrates numerous dimensions related to resource availability and accessibility, technological capacity, policy, governance and sustainable development. Energy

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security has increasingly been taking a central place on the policy agenda of many developed and developing nations. Meanwhile, there is an emerging consensus on the seriousness of the impact of climate change and the need for mitigating action. In view of this, the recent Paris Agreement has reinforced the requirement for a challenging low-carbon transformation of the global energy sector (UN 2015).

Regarding the link between renewables and energy security, it is recognised that RES have the potential to become one of the principal contributors supporting the energy security and sustainable development of both industrialised and developing countries (IPCC 2007; Ölz et al. 2007). RES are inexhaustible, contrary to fossil fuels. An abundant supply of solar, wind, hydro, biomass and geothermal resources is available in many regions worldwide with the potential to provide for over 10,000 times the current global energy needs. This is significantly more than other energy sources, such as geothermic or tidal energy, nuclear power and fossil fuel burning (Ellabban et al. 2014). Increasing the share of RES in the energy mix will gradually reduce nations' dependence on fossil fuels and their vulnerability to the impacts of price volatility, which characterises the energy commodities markets (Francés et al. 2013). Furthermore, RES infrastructure could be of a smaller scale than that of traditional energy, thus making it ideal for decentralised power generation in rural areas (Bassam 2001). Finally, RES energy production mitigates against the environmental impact of traditional energy generation, protecting the environment, local inhabitants, and their living conditions (Panwar et al. 2011).

RES are often studied in relation to their environmental impact and climate change (IPCC 2007), whilst little attention is paid to their potential contribution to nations' energy security. This chapter aims to use energy security indicators to examine the relationship between the deployment of renewable energy technologies and energy security in current and future scenarios. These indicators include the Total Primary Energy Supply (TPES[1]), the share of RES in TPES, the energy

[1]TPES: Total Primary Energy Supply is made up of the indigenous production plus imports minus exports, international marine and aviation bunkers, and plus/minus stock changes (International Energy Agency, https://www.iea.org/statistics/resources/balancedefinitions/#tpes, accessed on 05/12/2016).

import dependency, the energy intensity, electricity production technologies, energy-related carbon dioxide emissions, carbon emissions trading prices and energy prices. In particular, it aims to provide insights into the future energy consumption and supply mix; the depletion rate of natural resources; the technical and economic potential of renewable energy; the fluctuations/adjustments of energy and carbon emissions trading prices; and the plausible changes of the levels of energy-related emissions to the atmosphere.

The chapter begins with an overview of the criteria used for selecting the quantitative and qualitative scenario studies analysed, providing a brief summary of their elements and underpinning assumptions. It then discusses key drivers shaping the global energy supply and demand. Furthermore, it considers the plausible transformative impact of changes to the key drivers on different sectors of the energy system, within a time horizon of 2050. The chapter next discusses sources of uncertainty likely to affect the realisation of the RES' potential in the future. It finally concludes by summarising key learning points emerging from the scenario analysis and providing recommendations for developing strategies to enhance energy security.

Selected Scenarios

This study is based on the review and analysis of quantitative and qualitative scenario studies. Scenario studies are recognised as a useful approach to widen the focus of short-term policy debates, and to explore more radical system changes (Söderholm et al. 2011). Scenario studies can explore technologies, costs, policies, investments, emissions, social appropriateness and shares relative to fossil fuels and nuclear energy (Martinot et al. 2007). International governmental and non-governmental organisations design specific baseline and policy scenarios to predict the effects of different policies on future energy security performance at global and regional levels and their likely impact on energy security indicators.

In this study, energy scenarios were selected on the basis of the following criteria: a time horizon between 2010 and 2050; quantitative and qualitative analysis; assumptions on technical, demographic, economic, social, and political parameters; focus on renewable energy technologies and nuclear energy; geographic coverage of the Organisation for Economic Cooperation and Development (OECD) countries, China, India and other Asian non-OECD member countries. Furthermore, the selected scenarios were released in the last 7 years (between 2010 and 2017); are of international relevance; and in their totality, cover a broad range of stakeholder groups.

Using the above criteria, the following studies were selected:

- World Energy Outlook 2012 (IEA 2012);
- Energy Technology Perspectives—Pathways to a Clean Energy System to 2050 (IEA 2012);
- Energy Revolution: A Sustainable World Energy Outlook (EREC et al. 2012);
- The Energy Report: 100% Renewable Energy by 2050 (WWF and ECOFYS 2011);
- Global Energy Assessment: Towards a Sustainable Future (IIASA 2012);
- BP Energy Outlook 2030 (BP 2013);
- The Outlook for Energy: A View to 2040 (ExxonMobil 2012);
- Global Wind Energy Outlook (GWEC 2013);
- International Energy Outlook 2011 (US EIA 2011);
- Future World Energy Scenarios (Enerdata 2017).

Table 3.1 provides an overview of the selected scenarios with details on their time horizon and key characteristics.

Key System Drivers

This section focuses on key system drivers that shape global energy supply and demand. There are a number of drivers contributing to significant increases in energy demand. These are population dynamics and urbanisation, economic development and GDP growth, degree of policy action and geopolitical relationships, technical and structural

Table 3.1 Overview of analysed scenarios

Scenario title	Time horizon	Principal features
World energy outlook 2012 (IEA 2012)	2035	Three main scenarios were considered: the Current Policies Scenario (CPS); the New Policies Scenario (NPS); and the 450 parts per million of carbon dioxide equivalent (ppm CO_2eq) scenario. The CPS scenario takes into account policies announced and in place by various countries in the world. The NPS scenario takes into account long term energy and climate objectives and policies that have yet to be implemented. The 450 scenario has a different perspective, setting the target of a 2 °C rise of the global temperature and discussing policies necessary to decrease greenhouse gas emissions below current levels
Energy technology perspectives—pathways to a clean energy system to 2050 (IEA 2012)	2050	Three possible energy futures are considered, the boundaries of which are set by total energy-related CO_2 emissions: (a) 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 and that results in an average global temperature rise of at least 6 °C in the long term; (b) 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; (c) The 2 °C Scenario (2DS), which describes a vision of a sustainable energy system and emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2 °C
Energy revolution: a sustainable world energy outlook (EREC et al. 2012)	2050	Two scenarios are considered: Reference scenario and Energy Advanced [R]evolution Scenario. The Reference Scenario takes into account international energy and environmental policies worldwide. The Energy Advanced Revolution scenario (E[R]evolution) looks at the potential of reducing energy demand through energy efficiency and providing electricity through decentralised renewable energy sources. It explores the use of smart grids to connect these decentralised systems and assumes that hybrid electric cars will be predominant in 2050 and that nuclear energy will be phased out by 2050

(continued)

Table 3.1 (continued)

Scenario title	Time horizon	Principal features
The energy report: 100% renewable energy by 2050 (WWF and ECOFYS 2011)	2050	The study covers all countries and assesses the technical feasibility of achieving 100% renewable energy generation from 2010 up to 2050. The 100% renewables scenario assumes that all countries make extensive use of their renewable energy potentials and establish large-scale electricity storage facilities, smart electricity transmission grids and demand-side management
Global energy assessment (gea): towards a sustainable future (IIASA 2012)	2050	The report develops 60 alternative pathways through which energy systems could be transformed to address critical energy and environmental goals: stabilising global climate change to global temperature of 2 °C above pre-industrial levels; enhancing energy security through diversification of the energy supply; and eliminating household and ambient air pollution. The pathways are grouped into three different approaches for achieving these goals: GEA-Supply, GEA-Mix and GEA-Efficiency. GEA-Supply considers futures with radical developments such as hydrogen or carbon capture and storage. GEA-Mix relies more on today's advanced infrastructure such as biofuels. GEA-Efficiency relies more on today's advanced options such as efficiency and RES
BP energy outlook 2030 (BP 2013)	2030	The report encompasses two sets of data: a base case and a policy case. 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
The outlook for energy: a view to 2040 (ExxonMobil 2012)	2040	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?

(continued)

Table 3.1 (continued)

Scenario title	Time horizon	Principal features
Global wind energy outlook (GWEC 2013)	2050	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. The Advanced scenario explores the implications of achieving an ambitious plan to unleash the full potential of the wind industry
International energy outlook 2011 (US EIA 2011)	2050	The report is based on the US Energy Information Agency (EIA)'s outlook assessment of energy markets, focusing mainly on marketed energy. Projections are generated from the EIA's World Energy Projection Plus (WEPS+) model, which takes into account population growth, economic growth, energy intensity, and historical energy market data. It does not reflect the potential impact of proposed legislation, regulations, or measures
Future world energy scenarios (Enerdata 2017)	2040	The report presents three global energy scenarios developed by the POLES world energy-economy simulation model. The Ener-Brown scenario assumes the gradual improvement on energy intensity; high growth in developing countries (74% of the demand growth over 2015–2040 will come from Asia, and 15% from Africa); fossil fuels renaissance; lower energy prices; diffusion of unconventional energy sources; and continued efforts on renewables. The Ener-Green scenario considers ambitious energy efficiency policies; regular updates of efficiency targets; fossil fuel subsidies phase-out; strong development of renewables (RES+ nuclear development: ~ 70% of power capacities by 2040); and one kWh generated will produce 75% less CO_2 emission in 2040 vs 2015. The Ener-Blue scenario assumes tensions on available resources; increasing energy prices; and diversification towards renewables

Source Compiled by the authors

change, technology costs, fossil fuel prices and CO_2 emission pathways and allowance costs.

Demographic Change

Future population development is an important factor in energy scenario building because population size affects the size and composition of energy demand, directly and indirectly, through its impact on economic growth and development. Most of the scenarios use the United Nations Development Programme (UNDP) projections for population growth as shown in Table 3.2. Based on the UNDP's 2010 assessment, the world's population is expected to grow by 0.76% on average over the period 2010–2050, from 6.8 billion people in 2010 to nearly 9.4 billion by 2050 (UNDP 2010). From a regional perspective, the population of the developing regions will continue to grow most rapidly. The population of Eastern Europe/Eurasia will face a continuous decline, followed after a short while by the OECD Asia Oceania. The populations in OECD Europe and in OECD North America are expected to increase through 2050. Meanwhile, the share of the population living in today's non-OECD countries will increase from the current 82–85% in 2050. China's contribution to the world population will drop from 20% today to 14% in 2050, whilst Africa will remain the region with

Table 3.2 Population projections by regions (in millions)

Region	2010	2015	2020	2025	2030	2040	2050
World	6818	7284	7668	8036	8372	8978	9469
OECD Europe	555	570	579	587	593	599	600
OECD North America	458	484	504	524	541	571	595
OECD Asia and Oceania	201	204	205	205	204	199	193
Eastern Europe	339	340	341	340	337	331	324
India	1208	1308	1387	1459	1523	1627	1692
China	1342	1377	1407	1436	1452	1474	1468
Non-OECD Asia	1046	1128	1194	1254	1307	1392	1445
Latin America	468	499	522	544	562	589	603
Africa and Middle East	1202	1274	1528	1687	1857	2226	2450

Source Adapted by the authors from the UN world population prospects—2010 revision (UNDP 2010) the highest growth rate, with a share of 24% of the world population in 2050. This projected population growth will lead to an increased demand for energy.

Table 3.2 provides an overview of projected population growth in different regions of the world from 2020 to 2050.

Urbanisation

Increasing urbanisation is the second critical long-term demographic feature, frequently ignored in energy studies. More than 80% of the population of industrialised countries lives in urban areas, and many developing countries show similar high urbanisation rates. According to the UN's last estimate (UN 2014), 4.3 (60.6%) of 7.1 billion people worldwide live in urban agglomerations and, over the next decade, the urban population is projected to increase to almost 5.2 billion. An increasing percentage of this urban population will live in megacities with over 10 million inhabitants. Moreover, it is estimated that eight cities will have more than 15 million inhabitants each; only two of these, Tokyo and New York, are in highly industrialised countries. The remaining six (Beijing, Mumbai, Kolkata, Mexico City, Sao Paolo and Shanghai) are in developing countries. Providing adequate and clean energy services for a world in which the population lives predominantly in urban areas will be a challenging task, due to infrastructure (i.e. capital) requirements, enormous spatial energy demand densities and the need for clean energy in order to mitigate the creation of urban smog from coal fires and/or dense motorised traffic that currently plagues most megacities.

Macroeconomic Development

Economic growth is a key driver for energy demand. Since 1971, each 1% increase in global Gross Domestic Product (GDP) has been accompanied by a 0.6% increase in primary energy consumption (IEA 2012). The decoupling of energy demand and GDP growth is therefore a prerequisite for all scenarios as rapid economic development is propelling significant increases in energy use. GDP growth in all regions is expected to slow gradually over the coming decades (EREC et al. 2012). World GDP is assumed to grow on average by 2.2% per year over the period 2035–2050, compared to 3.1% from 1971 to 2010 (Table 3.3). China and India are expected to keep a higher GDP growth than other regions, followed by the Middle East, Africa, and the rest of non-OECD Asia. GDP in OECD Europe and in OECD Asia Oceania is assumed to grow by around 1.6 and 1.3% per year, respectively, over the projection period, whilst economic growth in OECD North America is expected to be slightly higher. Table 3.3 provides an overview of projected GDP development to 2050.

Development and Geopolitics

Examining demographics in relation to economic development, it becomes clear that there will be a long-term shift in the geographical focus of energy use. In 2010, developing countries' share of energy use was 40%. By 2050, the share of developing countries is estimated to range between 60 and 70%, i.e. a complete reversal of the current energy geopolitical situation. In fact, most scenarios (e.g. IEA 2012; Greenpeace 2012; BP 2013; ExxonMobil 2012) project faster energy demand growth in developing countries, particularly in China, India, Pakistan, Indonesia, Malaysia and countries in Latin America, the

Table 3.3 GDP development projections (in %)

Region	2010–2020	2020–2035	2035–2050	2010–2050
World	4.2	3.2	2.2	3.1
OECD North America	2.7	2.3	1.2	2.0
OECD Asia and Oceania	2.4	1.4	0.5	1.3
OECD Europe	2.1	1.8	1.0	1.6
India	7.6	5.8	3.1	5.3
China	8.2	4.2	2.7	4.7
Non-OECD Asia	5.2	3.2	2.6	3.5
Latin America	4.0	2.8	2.2	3.5
Middle East	4.3	3.7	2.8	3.5
Africa	4.5	4.4	4.2	4.4

Source Adapted by the authors from EREC et al. (2012)

Middle East and Africa. These trends will have an impact and lead to changes in energy systems and energy geopolitics (Umbach 2010; Lombardi and Gruenig 2016).

Infrastructure

Despite energy geopolitics, market exclusion remains a serious challenge. To date, some two billion people do not have access to modern energy services due to a lack of energy infrastructure. Many regions are overly dependent on a single, locally available resource, such as traditional fuelwood or coal, and have limited access to the clean flexible energy forms required for economic and social development (IEA 2012). Moreover, urban and rural poor populations need to get connected to energy grids in order to have access to modern energy services. Infrastructure is the backbone of the energy system, and the future requirements for new infrastructure will be truly vast (IEA 2012). New decentralised energy options could help to reduce energy costs in rural areas, with high cost decreasing through research and development efforts and experience gained in niche market applications. Meanwhile, improving interconnections of energy grids for natural gas and electricity on a continental scale remains a task ahead for many regions, in particular Asia, Latin America, and—in the long term—Africa. Moreover, development of the energy infrastructure is required in Eurasia, particularly to match the abundantly available resources of oil and gas in the Caspian region, Siberia and the Arctic Area with the newly emerging centres of energy consumption in Asia.

Technical and Structural Change

New energy technologies on the supply side and for energy-using devices are expected to lie at the heart of renewable energy development, efficiency improvements, cost reductions and better services provided by the energy sector. In high economic growth scenarios where large quantities of fuels will be required, there need to

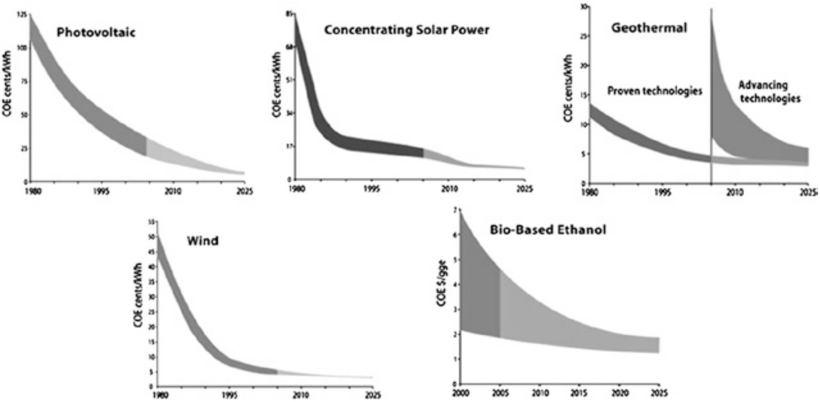

Fig. 3.1 Forecasted renewable energy technology cost (*Source* Adapted by the authors from NREL 2015)

be considerable advances in hydrocarbon exploration and extraction, renewable and nuclear electricity generation, hydrogen and biofuel production and conversion, and more efficient and smart grid systems. In ecologically driven scenarios, low-carbon fossil and renewable technologies are favored and renewable energy technologies costs—indicated as light areas on Fig. 3.1—are projected to decrease by 2025. In fact, the cost of photovoltaic panels, wind and solar power technologies and biotechnologies—shown as dark areas on Fig. 3.1—has dropped significantly over the last 20 years, and it is projected to continue decreasing in the future.

Figure 3.1 provides an overview of the projected cost of photovoltaic, concentrating solar power, geothermal, wind and bio-based ethanol technologies up to 2025.

Fossil Fuel Prices

The projections of energy prices are a very uncertain issue, as fuel prices will continue to be set by market supply, demand and regulatory dynamics. The recent increase of shale gas and shale oil production as well as the increase of renewable energy use has resulted in low price projections for fossil fuels. For example, under the 2014 oil and gas price scenario from Bloomberg, an oil price of just 45–50 USD per barrel was assumed for 2030 (Bloomberg 2015). According to Future World Energy Scenarios, based on supply-demand fundamentals, long-term oil prices should move in a range of 60–100 USD per barrel (Enerdata 2017). However, the projections in the WEO Current Policies scenario and Greenpeace scenario might still be considered too conservative; both scenarios have assumed a price development path for fossil fuels significantly higher than the Bloomberg scenario as can be seen in Table 3.4.

Table 3.4 provides projections of crude oil and natural gas imports and biomass prices up to 2050.

Emission Pathways

Over the last decade, CO_2 emissions have increased by an average of 3% per year, despite the increased focus on climate change and its mitigation. This was mainly the result of high economic growth, particularly in coal-based economies, and higher oil and gas prices which led to an increase in coal-fired power generation. In the future, emissions are expected to grow further. In the WEO 2012 Reference scenario, CO_2 emissions are expected to increase from 29 Gt (gigatons) CO_2 in 2007 to 40 Gt by 2030. CO_2 emissions continue to grow in the ETP 2012 Baseline scenario projections beyond 2030, reaching 57 Gt in 2050. Nearly all the growth in global CO_2 emissions in the Baseline scenario comes from outside the OECD; emissions from non-OECD countries are expected to grow from 15 Gt CO_2 in 2007 to 42 Gt CO_2 in 2050, whilst OECD emissions grow from 14 Gt CO_2 to 15 Gt CO_2 over the same period. Most of the increase in the OECD countries comes after 2030 and long-term emission projections are highly uncertain. In the WEO 2012 higher GDP case, CO_2 emissions reach 43 Gt by 2030, compared to 40 Gt in the Reference scenario and 38 Gt in the low GDP case. Similarly, the high energy demand projections for 2050 indicate that emissions could be up to 20% higher than the 57 Gt projected in the Baseline scenario for that date.

Table 3.4 Development projections for fossil fuel and biomass prices in USD 2010

Fossil fuel	Unit	2010	2020	2025	2030	2035	2040	2050
Crude Oil imports								
Historic price (WEO)		78						
WEO 450 ppm scenario	Barrel	78	97	97	97	97		
WEO current policy	Barrel	78	106	106	135	140		
Energy revolution (2012)	Barrel	78	112	112	152	152	152	152
Natural gas imports								
Historic price (WEO)								
USA	GJ	4.64						
Europe	GJ	7.91						
Japan	GJ	11.61						
WEO 450 ppm scenario								
USA	GJ	4.64	6.86	8.44	8.85	8.23		
Europe	GJ	7.91	10.34	10.34	10.23	9.92		
Japan	GJ	11.61	12.66	12.66	12.77	12.77		
WEO current policy								
USA	GJ	4.64	7.39	8.12	8.86	9.50		
Europe	GJ	7.91	11.61	12.56	13.29	13.72		
Japan	GJ	11.61	14.24	14.98	15.61	16.04		
Energy revolution (2012)								
USA	GJ	4.64	10.84	12.56	14.57	16.45	18.34	24.04
Europe	GJ	7.91	16.78	18.22	19.54	20.91	22.29	26.37
Japan	GJ	11.61	19.08	20.63	22.12	23.62	25.12	29.77
Biomass								
Energy revolution (2012)								
OECD Europe	GJ	7.80	9.32	9.72	10.13	10.28	10.43	10.64
OECD North America	GJ	3.44	3.85	4.10	4.36	4.56	4.76	5.27
Other regions	GJ	2.84	3.55	3.80	4.05	4.36	4.66	4.96

Source Adapted by the authors from WEO (2012), OECD and IEA (2012), EREC et al. (2012)

Table 3.5 The assumptions on CO_2 emissions cost development, in USD

Countries	2020	2030	2040	2050
Annex-B countries	25	40	55	75
Non-Annex-B countries	0	40	55	75

Source Adapted by the authors from UNFCCC (2011)

Cost of Carbon Emissions

Assuming that a carbon emissions trading system is established across all world regions in the longer term, the cost of CO_2 allowances needs to be included in the calculation of electricity generation costs. All analysed scenarios consider CO_2 emissions cost development as applied in the Kyoto Protocol for countries in Annex B (in which 37 countries have binding targets including Australia, European Union member countries, Belarus, Iceland, Kazakhstan, Lichtenstein, Norway, Russia, Switzerland and Ukraine) and non-Annex B countries without binding targets (including Argentina, Azerbaijan, Brazil, Chile, China, India, Iraq, Iran and Mexico) (Table 3.5).

Table 3.5 provides projected CO_2 emissions costs up to 2050 for Annex B and Non-Annex B countries of the Kyoto Protocol.

Plausible Transformations of the Energy System: Exploring the Impact of Scenarios on Sectors

This section discusses possible transformations of energy systems up to 2050 from a sectoral perspective. In particular, the section focuses on power generation, nuclear power and the transport and construction sectors. In addition, it considers plausible trajectories of carbon emissions reduction and the cost of transition to low-carbon energy.

Power Generation

World Energy Outlook (WEO 2012) develops three main scenarios: the Current Policies Scenario (CPS), the New Policies Scenario (NPS), and the 450 parts per million of carbon dioxide equivalent (ppm CO_2eq) scenario. The NPS 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. Furthermore, global primary energy demand is projected to 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 is projected to fall to about 35% by 2035. Oil, coal, and gas will thus remain the predominant sources of energy (Fig. 3.2). Nevertheless, renewable energy sources will continue to grow; from 13% of the global primary energy demand to 18% at the end of the outlook period, whilst the share of nuclear power will remain constant at around 6–7%.

Electricity demand is projected to increase by more than 70%, with over 9300 GW of installed capacity needed by 2035. Although the share of fossil fuels in electricity generation is expected to decrease to approximately less than 10% compared to 2010, fossil fuels will still provide more than 60% of the electricity supply in 2035 (Fig. 3.3). Electricity generated from renewables is projected to almost triple, and their share in the world electricity mix is expected to increase from 20 to 31%. Hydro energy provides and will continue to provide the largest share of renewables. The share of nuclear power is projected to remain

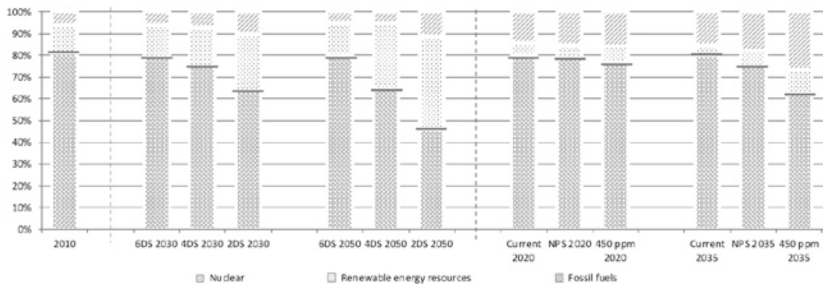

Fig. 3.2 Share of primary energy sources, in the energy demand worldwide, in % (*Source* Compiled by the authors)

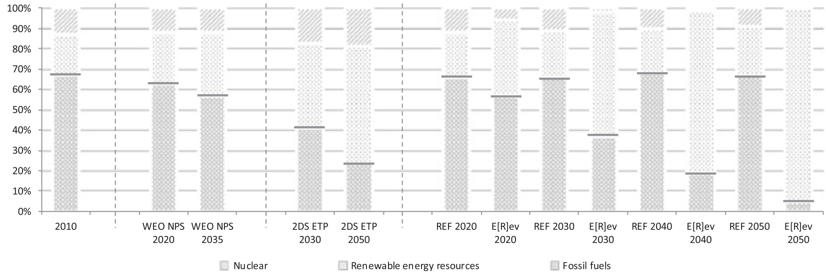

Fig. 3.3 Share of primary energy sources, in the electricity generation worldwide, in % (*Source* Compiled by the authors)

constant at around 12–13%, whilst wind power will have a growing role with its share in the electricity mix increasing to 7.3% in 2035, up from 1.6% in 2010. The contribution of biomass and solar energy technologies in power generation will also increase.

Figure 3.2 provides a comparative overview of the share of primary energy sources in worldwide energy demand between 2010 and (1) 2020 and 2035, for the three scenarios of the World Energy Outlook (WEO 2012) (CPS, NPS and 450 ppm); and (2) 2020 and 2050, for the three scenarios of the Energy Technology Perspective Report (IEA 2012) (2DS, 4DS and 6DS).

Figure 3.3 provides a comparative overview of the share of primary energy sources in electricity generation worldwide between 2010 and (1) 2020 and 2035, for the World Energy Outlook (2012) NPS scenario (WEO NPS); (2) 2030 and 2050, for the Energy Technology Perspective Report (IEA 2012) 2DS scenario (2DS ETP); and, (3) 2020, 2030, 2040 and 2050, for the two Energy Outlook scenarios (EREC et al. 2012), the Reference Scenario (REF) and the Energy Advanced Revolution Scenario (E[R]ev).

The Energy Technology Perspective Report (IEA 2012) develops three possible energy futures, the boundaries of which are set by total energy-related CO_2 emissions:

1. 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, resulting in an average global temperature rise of at least 6 °C in the long term.
2. 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.
3. The 2 °C Scenario (2DS), which describes a vision of a sustainable energy system and emissions trajectory that recent climate science research indicates would give an 80% chance of limiting the average global temperature increase to 2 °C.

The 2DS scenario reflects a concerted effort to reduce overall consumption and replace fossil fuels with a mix of renewable energy resources, and dramatic improvements in terms of energy efficiency. In the 2DS, Total Primary Energy Supply increases by approximately 37% between 2010 and 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% from 2010 to 2050. The share of renewables in the world energy mix will be 43% in the 2DS, 30% in the 4DS and 15% in the 6DS in 2050, compared to 13% in 2010 (Fig. 3.4). In all scenarios, fossil fuels remain a significant part of the global energy system through 2050.

Figure 3.4 provides a comparative overview of the share of primary energy sources in the energy demand worldwide, between 2010 and (1) 2020, 2030, 2040 and 2050, for the two Energy Outlook scenarios (EREC et al. 2012) (the Reference Scenario (REF) and the Energy Advanced Revolution Scenario [E[R]ev]); (2) 2020, 2030, 2040 and 2050, for the Energy Report (WWF and ECOFYS 2011); and (3) 2025 and 2040, for the ExxonMobil (2012) future energy vision.

Figure 3.5 provides a comparative overview of the share of primary energy sources in electricity generation worldwide between 2010 and (1) 2020, 2030, 2040 and 2050, for the two Energy Outlook scenarios (EREC et al. 2012) (the Reference Scenario (REF) and the Energy Advanced Revolution Scenario [E[R]ev]); (2) 2020, 2030, 2040 and 2050 for the Energy Report (WWF and ECOFYS 2011); and, (3) 2025 and 2040, for the ExxonMobil (2012) future energy vision.

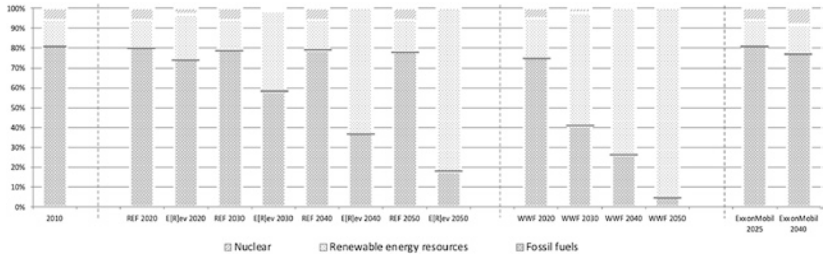

Fig. 3.4 Share of primary energy sources, in the energy demand worldwide, in % (*Source* Compiled by the authors)

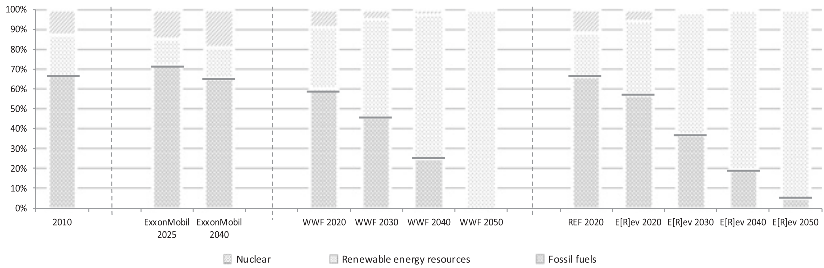

Fig. 3.5 Share of primary energy sources, in the electricity generated worldwide, in % (*Source* Compiled by the authors)

The Energy Outlook (EREC et al. 2012) uses a bottom-up, technology-driven approach to illustrate the possibility of 100% renewable power by 2050. Two scenarios are produced: the Reference Scenario and the Energy Advanced Revolution Scenario (E[R]ev). The E[R]ev looks at the potential of reducing energy demand through energy efficiency and providing electricity through decentralised renewable energy sources. It explores the use of smart grids to connect these decentralised systems and assumes that hybrid electric cars will be predominant in 2050 and that nuclear energy will be phased out by then. Under the E[R]ev, worldwide primary energy demand will decrease to 481.050 petajoules (PJ: energy unit equal to 1.0E+15 joules) in 2050 as a result of energy efficiency measures, the phase-out of nuclear power and a reduced dependence on fossil fuels. Meanwhile, the share of renewable energy will increase considerably, accounting for 82% of worldwide primary energy demand in 2050 (Fig. 3.3). Nearly 95% of the world's electricity is projected to come from renewable energy sources in 2050, reflecting the fact that a renewables-based future is possible (Fig. 3.5). Wind, solar PV and geothermal power are projected to represent approximately 60% of electricity generation and approximately 91% of heat energy is projected to come from renewables. Due in a large part, to the growth of offshore wind energy (to 892 GW in 2050), wind is expected to become the leading renewable energy source, followed by solar PV and solar thermal. Meanwhile, ocean energy will also expand significantly, surpassing geothermal and biomass power in installed capacity. In terms of geography, OECD developed countries are expected to lead in renewable energy production. Four scenarios with significant policy, business and civil society impact due to the high share of renewables in the electricity production were designed by the European Climate Foundation, Greenpeace and the European Commission. The percentage of electricity production from renewables in alternative energy scenarios (including the Energy Advanced Revolution scenario (EREC et al. 2012) and the 2050 Low-Carbon Economy from the European Climate Foundation [ECF 2010]) is projected to increase from 19% in 2012 to between 40% and 90% by 2050 (Fig. 3.6). In fact, the European Union (EU) is committed to reducing greenhouse gas emissions to 80–95% below the 1990 levels by 2050. To meet this climate target, the EU has established aggressive policy targets for the shares of electricity from different sources, such as 60–70% of electricity from renewables by 2050. In addition, all EU countries have individual targets for the RES share of electricity, ranging from 30 to 90%. Most scenarios project large shares (20–50%) in the electricity production profile from solar photovoltaic, wind, and solar thermal power (Fig. 3.7).

Figure 3.6 provides an overview of the share of different power sources in EU future electricity scenarios to 2050.

Figure 3.7 provides an overview of the share of electricity generation in 2050, by renewable energy source, for different EU future electricity scenarios.

Pessimistic assumptions regarding renewable power generation come from the Outlook for Energy: a view to 2040 report (ExxonMobil

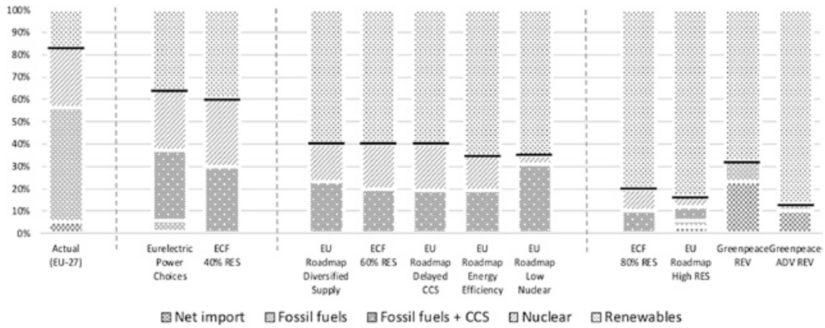

Fig. 3.6 Share of different energy sources, in the generated electricity in 2050, considering future EU electricity scenarios, in % (*Source* Compiled by the authors)

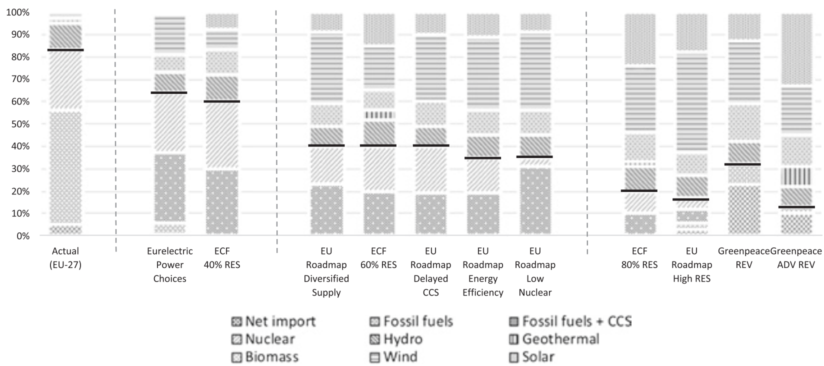

Fig. 3.7 Share of different RES, in the generated electricity in 2050, considering future EU Electricity Scenarios, in % (*Source* Compiled by the authors)

2012); the BP Energy Outlook 2030 report (BP 2013); and the Future World Energy Scenarios (Enerdata 2017). According to ExxonMobil's 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% of global energy consumption by 2040, followed by industry and transport. Energy intensity (calculated as units of energy per unit of GDP) will decrease by almost 45%. The share of fossil fuels in worldwide energy demand will remain very high, at nearly 78%, and the share of RES will increase slowly to nearly

15%; BP is projecting the same trends. Fossil fuels are projected to meet approximately 80% of worldwide primary energy consumption, whilst the share of modern renewables (including biofuels) is projected to be only about 6% in 2030. Renewable energy will grow by about 8% annually between 2010 and 2030. By 2030, RES (excluding hydro) will supply 11% of the world's electricity. According to the Future World Energy Scenarios (Enerdata 2017), the share of fossil fuels in electricity generation is projected, in 2040, to stay at 76% in the Ener-Brown scenario and 71% in the Ener-Blue scenario but will decrease to 50% in the Ener-Green scenario. Meanwhile, RES energy and nuclear energy vary from 24% (Ener-Brown scenario) to 50% (Ener-Green scenario) (Enerdata 2017).

Nuclear Power

Scenarios considered before the nuclear accident at the Fukushima power plant, which caused an earthquake followed by a tsunami, show an increase of nuclear power in the general energy mix. However, after the Fukushima accident, nuclear deployment in the long term, has been revised in many scenarios and national energy policies. For example, Germany announced the immediate closure of eight of its oldest reactors (built before 1980) and the decision to close the rest by 2022, Switzerland has banned the construction of new reactors and Belgium is considering phasing out its nuclear plants. Meanwhile, the Italians have voted overwhelmingly to keep their country non-nuclear.

The WEO (2012) released a scenario with limited development of nuclear power, assuming that no new reactors will be built in OECD countries and that non-OECD countries will only continue with half of their planned nuclear projects. The share of nuclear power is projected to decrease from 13 to 7% in 2035. This decrease is compensated by an increasing use of RES but also fossil fuels. However, it seems difficult to predict the future of nuclear power. Currently, developing nations including Russia, Turkey, Kazakhstan, some European countries (the UK, France, Slovakia, Romania, Poland), Asian countries (China, India, South Korea, Bangladesh, Pakistan) and even Middle East countries (Egypt, Jordan, Iran, UAE) are planning to build new nuclear power facilities.

Transport Sector

In the transport sector, the E[R]ev scenario predicts that electric cars will seriously penetrate the transport sector (Greenpeace 2012), with electric vehicles playing an important role in improving energy efficiency in transport and in replacing fossil fuel vehicles. According to the E[R]ev scenario, in 2030, electricity will provide 12% of the transport sector's total energy demand, whilst in 2050, the share will be 44%, replacing gasoline and diesel. According to Energy Technology Perspective (IEA 2012), the use of electricity in the transport sector will amount to 11% of the overall electricity demand by 2050.

Under the 100% Renewable Energy scenario (WWF and ECOFYS 2011), 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 the electrification of transport are a shift to plug-in hybrid and electric cars, energy efficient heavy vehicles, with mainly lithium-ion batteries used for electric vehicle batteries. The electrification of transport will enable this sector to be 100% powered by renewables.

Construction Sector

According to the ETP report, in the Baseline scenario, global final energy demand in the construction sector is projected to increase by 60% between 2007 and 2050 (OECD and IEA 2012), with the total energy demand increasing from 2759 Mtoe (Million Tonnes of Oil Equivalent) in 2007 to 4407 Mtoe in 2050. The residential sector is expected to account for 59% of this growth and the service sector for around 41%. Furthermore, the energy mix in this sector is expected to be dominated by the use of natural gas and, to a lesser extent, by coal. In the BLUE Map scenario, by setting the goal of reducing global energy-related carbon emissions by 50% by 2050 (compared to the 2005 level), energy consumption in the construction sector is expected to decrease by around one-third of the Baseline scenario level by 2050, whilst the consumption of fossil fuels is projected to decline significantly (OECD and IEA 2012). Moreover, solar power is projected to achieve the most growth, accounting for 11% of the total energy consumption in the sector. Its widespread deployment for water heating (30–60% of useful demand depending on the region) and, to a lesser extent, space heating (10–35% of useful demand depending on the region) will assist in improving the efficiency of energy use.

Under the 100% Renewable Energy by 2050 (WWF and ECOFYS 2011) in the construction sector, actions are projected to be taken in the existing building stock and in new buildings. In the existing stock, a retrofitting programme, to be completed by 2050, is key to reducing heating needs by 60%. Heating and hot water needs are expected to be met by solar thermal systems and heat pumps, whilst cooling will be provided by local renewable solutions. New buildings will be near-zero-energy and all-electric by 2030, with residual heat demand met by passive solar, solar thermal installations and heat pumps. Although there will be a decrease in heating demand, a rise in electricity demand will be inevitable as it is expected that buildings will be 'all-electric'. These changes will contribute to buildings being powered 100% by renewables in 2050, compared to a 60% dependence on fossil fuels in 2010.

Carbon Emissions Reduction

Table 3.6 and Fig. 3.8 provide a comparison of various CO_2 mitigation options and their expected contributions in 2050, according to the ETP scenarios (IEA 2012). By far the largest contributor to CO_2 emissions reduction is energy efficiency, accounting for between 31 and 53% of the reduction (below the baseline of 58 Gt by 2050) across all sectors. The ETP scenarios expect Carbon Capture and Storage (CCS) technologies to contribute only between 20 and 28% of the total CO_2 emissions reduction. As far as enhanced-oil-recovery (EOR) is concerned, ETP scenarios expect the potential for EOR to be relatively small, compared to the global emissions from the power generation sector. Fuel switching—defined as the change from traditional solid fuels and modern non-solid fuels—is third (11–16% reduction potential) amongst the CO_2 mitigation options.

Table 3.6 Share of different mitigating actions, in CO_2 reduction, in 2050

CO_2 reduction option	Share in total CO_2 reduction (%)
Energy efficiency	31–53
Carbon capture and storage	20–28
Fuel switching	11–16
Renewable energy in power production	5–16
Nuclear energy	2–10
Biofuels in transport	~6

Source Adapted by the authors from IEA (2012)

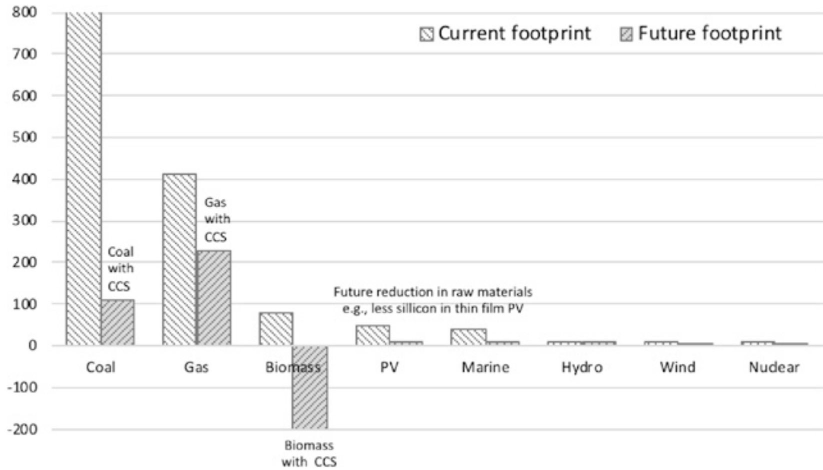

Fig. 3.8 Current and future carbon footprint by energy resource, in Gt (*Source* Adapted by the authors from IEA 2012)

In terms of technology, the carbon emission footprint varies widely within each technology. Overall, nuclear, wind and hydropower have the lowest CO_2e emissions impact (Fig. 3.8), whilst marine power and photovoltaics also have low emissions. For photovoltaics, most of the emissions are the result of electricity use during manufacturing and using raw materials. Coal and gas power have lower CO_2e emissions with CCS technologies. Biomass may also be used increasingly with CCS technologies. CCS technologies have been proposed as a potential method to allow the continued use of fossil-fuelled power stations whilst preventing emissions of CO_2 from reaching the atmosphere and are currently considered technically feasible on a commercial scale, using a range of technologies. CCS involves the CO_2 capture at the point of generation, compression to a supercritical fluid, and sequestration. To reiterate, the CCS methodologies comprise three steps: CO_2 capture/compression/sequestration, CO_2 transportation and CO_2 storage.

Table 3.6 outlines the share (in %) in the total CO_2 reduction for alternative mitigating actions.

Figure 3.8 provides an overview of the current and future carbon footprint of different energy resources including coal, gas, biomass, solar PV, marine, hydro, wind and nuclear.

Transition Costs

The Stern Report (Stern 2007) disseminated to a large audience the conclusions of the last IPCC report relating to emissions reduction costs, incurred mainly by the deployment of low-carbon technologies, including bioenergy with CCS technologies. The Fourth Assessment Report (AR4) showed that on average, the most severe target would cost 3% of worldwide GDP in 2030 and 5–10% in 2050 (Stern 2007). Similarly, to the Stern study, Strachan et al. (2008) find electricity generation a key sector for decarbonisation and highlight the role of critical zero-carbon technologies, including CCS. In general terms, a target of an 80% reduction, compared to the 1990 levels, in 2050 is expected to lead to macroeconomic losses between 0.3 and 1.5% of the world GDP (Strachan et al. 2008).

Similarly, the European Commission's energy project ADAM (Adaptation and Mitigation. Strategies—Supporting European Climate Policy) concluded that losses of GDP, relative to the baseline, vary from about 0.9–2.5% by 2100, compared to a range of 0.5–0.9% in the case of the 550 ppm Stabilisation Scenario, in which a mixture of cap-and-trade systems, sectoral agreements and national measures are adopted (EC 2011). Furthermore, Luderer et al. (2012) show that if the international community takes immediate action to mitigate climate change, the costs of stabilising atmospheric CO_2 concentrations in the case of 450 ppm Stabilisation Scenario will be 1.4% of the world GDP.

They also show that significant investments in the energy sector (of about 9.3 trillion USD to 2030) will be required. A delay in implementing an appropriate climate policy and restrictions to the deployment of low-carbon technologies could result in substantial increases of the mitigation costs.

Discussion

Despite the fact that all scenarios show that RES have the potential to become a major contributor to energy security and sustainable growth in both developed and developing countries, there are considerable uncertainties that could impact on the technical, economic and, in particular, the implementation potential of renewable energy technologies. It is therefore important that a wide range of factors with the potential to cause uncertainty are considered in scenario development and analysis as well as policy design and implementation.

Firstly, in the case of RES deployment, there are uncertainties rising from fuel and carbon emissions trading price fluctuations. In fact, even slight fluctuations in the price of fossil fuels could have wide-reaching impacts on energy and climate policies in developed and developing countries (Kalyuzhnova and Pomfret 2017). For example, environmental programs in resource-rich countries depend on revenues from the oil and gas industry. Secondly, there are social uncertainties. Economic and population growth are two socio-economic factors that affect future energy outcomes, whereas the social acceptability of energy solutions is key to the penetration of novel technologies. For example, there has been social opposition to energy infrastructure for new technologies (such as electricity grids, renewables, nuclear or shale gas) in some EU countries, Japan, South Korea and the United States (Devine-Wright and Batel 2017). Thirdly, there are technological uncertainties (Venetsanos et al. 2002). The price of photovoltaic panels has dropped significantly over the last 20 years and this will continue into the future. However, it is unclear how it will impact on the development of the power sector as a whole and the well-established oil and gas sectors. Furthermore, energy generation and demand, energy efficiency and economic forecasting are other uncertainties that need to be regularly reviewed and analysed (Al-Saleh 2009). Finally, the most challenging uncertainties are those concerned with policy (Barradale 2010). When governments change, their energy policies are also subject to change; reducing policy uncertainty is a crucial component of effectual scenario analysis and effective renewable energy development.

Conclusion

The analysis of medium- and long-term energy scenarios in this chapter shows different visions of a low-carbon energy system in 2050. The scenario assumptions vary significantly regarding the fuel mix, fuel prices, decreases in the cost of technology, future policy actions and transition to low-carbon energy costs. Despite these differences, all energy scenarios considered share some conclusions, mainly that the energy system in approximately 30–50 years will be different from that of today with RES potentially playing a more significant role. Moreover, most of the studies—with the exception of the ExxonMobil report (ExxonMobil 2012) and the BP Energy Outlook report (BP 2013)—agree that there is significant unused potential for renewable energy and that low-carbon energy scenarios, in which additional policies on renewable energy and energy efficiency, as well as carbon cap-and-trade systems are adopted, are plausible ways forward.

All scenarios consider the use of RES an effective way to reduce carbon emissions and to provide significant proportions of the global electricity supply by 2050. Whilst hydropower will maintain its important role, other RES, such as wind, solar and biomass with carbon capture and storage, will grow rapidly in most scenarios. The installation of RES energy facilities in buildings is expected to expand, whilst in the transportation sector many scenarios consider biofuels to be the principal alternative to fossil fuels. Furthermore, the cost of renewable energy technologies is expected to decrease and, within a few years, will most likely make the use of RES more competitive than the use of fossil fuels. This will directly affect the cost of electricity generation and, as a consequence, the profitability of fossil fuels' extraction, influencing the development of the power sector as a whole and the entrenched oil and gas sectors.

The key requirement in low-carbon/high-renewables energy scenarios is extensive government involvement in the promotion of renewable energy technologies, whilst the principal benefit is enhanced energy security, due to reduced carbon emissions, the growing diversification of the energy mix and consequently, the diminished reliance on fossil fuels. However, future policies for strengthening energy security should not focus on increasing the utilisation of RES alone. Rather, they should seek to complement initiatives and instruments for enhancing the penetration of RES by targeting improved energy efficiency and efficient trading of carbon emissions. It is by addressing the multidimensional nature of energy security within the relevant context, be it local, regional or national, that energy security can be bolstered in a sustainable fashion.

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