CHAPTER TWO

Increasing utilisation of renewable energy sources: Comparative analysis of scenarios until 2050

Galiya Movkebayeva, Zhibek Bimagambetova, Marat Karatayev

This chapter examines the relationship between the development of renewable energy technology and energy security by assessing a range of scenarios at the global, regional and sectoral levels. It provides insights into the future energy consumption and supply mix, and the rate at which certain natural resources may be depleted. It discusses the forecast for technological development that supports the increasing power generation from RES, highlights scenarios of energy-related emissions to the atmosphere and analyses how energy prices might respond to the changing economic and technological conditions.

The analysis is based on a review of quantitative and qualitative scenarios released by international organisations, governments, companies and NGOs. The following studies have been compared and contrasted: 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 (GWEC, EREC, 2012), The Energy Report: 100% Renewable Energy by 2050 (WWF and ECOFYS, 2011), Global Energy Assessment: Toward 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 DOE EIA, 2011), Future World Energy Scenarios (Enerdata, 2017).

The chapter argues that, under certain conditions, it is likely that scenarios forecasting a significant increase in the volume of renewable energy will materialise. The core requirement is extensive government involvement in the promotion of renewable energy technologies, whilst the principal benefit for most nations is that their energy security could improve by enhanced diversification of the energy supply. Nonetheless, despite the optimistic outlook, renewable energy technologies could undermine energy security in the short and medium term by diverting resources from the highly profitable and well-established oil and gas sectors to the marginally profitable (or subsidised) and nascent RES sector. This challenge implies the need to re-frame the existing approach to energy security and promote renewable energy.

1. Introduction

The analysis of energy security in academic literature recognizes that meaning of energy security varies from one context to another (Ang et al., 2015). Nevertheless, energy security is commonly understood and discussed as security of supply, price and quantity risks. Asia Pacific Energy Research Centre defines energy security as the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy (Yergin, 2006). The universal and internationally accepted definition of energy security does not exist because the energy security itself is contextual, dynamic and multi-dimensional issue in nature. Therefore, there are different approaches how energy security is conceptualized, measured and assessed. The common energy security indicators are total primary energy supply, share of renewables in total primary energy supply, energy import dependency, energy intensity, electricity production technologies, energy related carbon dioxide emissions, carbon and energy prices. With regards to renewable energy resources (RES) and energy security, it is recognised that renewable have the potential to become one of the major and important contributors to provide energy security and future sustainable development in industrialized countries as well as in developing countries (IPCC, 2000; Ölz et al., 2007). Renewable energy sources are inexhaustible, contrary to fossil fuels. An abundant supply of solar, wind, hydro, biomass and geothermal resources are available in many regions around the world with these renewable energy resources having the potential to provide over 10,000 times the current global energy needs, which is greatly more than other energy sources available at the ground level, such as geothermic or tidal energy, nuclear power and fossil fuel burning (Ellabban et al., 2014). Because RES is abundant, increasing their share in the energy mix might reduce dependence on imported fossil fuels and prevent the impacts from price volatility that have characterized the energy commodities markets (Francés et al., 2013). As an additional plus, renewable energy could be built on a smaller scale than traditional power plants, thus making them ideal for decentralised power generation in rural areas (Bassam, 2001). Finally, renewable energy protects the environment, local inhabitants, and living conditions (Dincer, 2000; Panwar et al., 2011). However, despite all these benefits, the RES is often studied in terms of environmental contribution and climate change (IPCC, 2000), while energy security component needs proper assessment. Therefore, this chapter aims to apply energy security indicators and examine the relationship between deployment of renewable energy technologies and energy security in current and future scenarios. In particular, it aims to provide insight in the future energy consumption and supply mix, in the rate the resources may be depleted, in what is the technical and economic potential of renewable energy, in how the energy and carbon prices may develop, and in possible developments of energy-related emissions to the atmosphere.

2. Selected scenarios

In this study, the analysis is based on a review of quantitative and qualitative scenario studies. Scenarios are recognised as a useful approach to widen the focus from the short-term policy debate, and to envisage the more radical system changes (Söderholm et al., 2011). Scenarios 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 performances at the global and regional levels. Energy security indicators are likely to develop in different ways in these scenarios. For this study, energy scenarios have been selected according to the following requirements: a minimum time horizon until 2010; a maximum time horizon until 2050; quantitative and qualitative analysis; assumptions on technical, demographical, economic, social, and political parameters; focus on renewable energy technologies, and nuclear; geographic coverage of the OECD countries, China, India and Asia. Furthermore, these scenarios have been released quite recent, between 2010 and 2017, have international relevance, and are in totally covering a broad range of stakeholders groups. Thus, using these criteria, the following studies have been selected to be analysed and compared: 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 (GWEC, EREC, 2012), The Energy Report: 100% Renewable Energy by 2050 (WWF and ECOFYS, 2011), Global Energy Assessment: Toward 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 DOE EIA, 2011), Future World Energy Scenarios (Enerdata, 2017).

Table 2.1: Overview of investigated scenarios, key characteristics

Scenario title	Time horizon	Principal features
World Energy Outlook 2012 (IEA, 2012)	2035	Three main scenarios include the Current Policies Scenario (CPS), the New Policies Scenario (NPS), and the 450 parts per million of carbon-dioxide equivalent (ppm CO_2-eq) scenario. The CPS scenario takes into account everything that already been announced by various countries in the world. In the NPS scenario takes into account long-term energy and climate objectives and things that have not been implemented at this moment. The 450 scenario comes from different perspectives and it sets targets for 2°C for global temperature rise and shows what policies need to be in place in order to keep greenhouse gas emissions below the current level.
Energy Technology Perspectives - Pathways to a Clean Energy System to 2050 (IEA, 2012)	2050	It develops three possible energy futures, 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 what 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 consistent with 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	2050	Two scenarios are produced: Reference Scenario and Energy Advanced [R]evolution one. The Energy Advanced Revolution scenario (E[R]evolution) looks

Energy Outlook (GWEC, EREC, 2012)		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.
The Energy Report: 100% Renewable Energy by 2050 (WWF and ECOFYS, 2011)	2050	The report covers all countries and assesses a technical feasibility to achieve 100% renewable energy system from 2010 up to 2050. The 100% renewables scenario assumes that all countries make extensive use of their renewable energy potentials. The large-scale storage of electricity, smart electricity transmission grid and demand side management is established.
Global Energy Assessment: Toward 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: stabilizing global climate change to 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, GEAMix, 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.
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?
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 DOE EIA, 2011)	2050	The report is based on the U.S. 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 is taken into account a 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 POLES 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, and continued efforts on renewables. The Ener-Green scenario have 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), one kWh generated will produce 75% less CO_2 emission in 2040 vs 2015. The Ener-Blue scenario assumes the tensions on available resources, increasing energy prices, diversification towards renewables.

Source: compiled by the authors

3. Key system drivers

This section deals with key system drivers that shape global energy supply and demand. Drivers contributing to significant increases in energy demand are population dynamics and urbanization, economic development and GDP growth, technical and structural change, technology costs, fossil fuel prices, degree of policy action, and geo-political relationships.

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 through its impact on economic growth and development. Most of the scenarios use the United Nations Development Programme (UNDP) projections for population development as shown in Table below. Based on UNDP's 2010 assessment, the world's population is expected to grow by 0.76% on average over the period 2010 to 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 Eastern Europe/Eurasia will face a continuous decline, followed after a short while by the OECD Asia Oceania. The population in OECD Europe and OECD North America are expected to increase through 2050. The share of the population living in today's non-OECD countries will increase from the current 82% to 85% in 2050. China's contribution to world population will drop from 20% today to 14% in 2050. Africa will remain the region with the highest growth rate, leading to a share of 24% of world population in 2050. This will increase the demand for energy.

Table 2.2: 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 UN world population prospects - 2010 revision

Urbanization

Increasing urbanization is the second critical long-term demographic features, frequently ignored in energy studies. More than 80% of the population of industrialized countries live in urban environment, and many developing countries show similar high urbanization rates. According to UN last estimate (UN, 2014) of 4.3 of 7.1 billion people live in urban agglomerations. Over the next decade the urban population is projected to increase to almost 5.2 billion. An increasing fraction will live in megacities with over 10 million inhabitants. It is estimated that eight global cities will have more than 15 million inhabitants each – and only two of these, Tokyo and New York, are in highly industrialized countries. The remaining six (Beijing, Bombay, Calcutta, Mexico, Sao Paolo and Shanghai) are in countries now developing. Providing adequate and clean energy services for a world whose population lives predominantly in urban areas will be a daunting task due to infrastructure (i.e. capital) need and enormous spatial energy demand densities. And energy carries will need to be clean in order to cease the creation of urban smog from coal fires or the dense motorized traffic that currently plagues most megacities.

Macro-economic 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, 2016). The decoupling of energy demand and GDP growth is therefore a prerequisite for all scenarios. Rapid economic development is propelling significant increase in energy use. GDP growth in all regions is expected to slow gradually over the coming decades (GWEC and EREC, 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 2.3). China and India are expected to keep higher GDP growth than other regions, followed by the Middle East, Africa, remaining non-OECD Asia. GDP in OECD Europe and OECD Asia Oceania are assumed to grow by around 1.6 and 1.3% per year over the projection period, while economic growth in OECD North America is expected to be slightly higher.

Table 2.3: 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 GWEC and EREC (2012)

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 consumed 40% of modern energy use. By 2050, the share of developing countries ranges 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, 2012; ExxonMobil, 2012) project faster energy demand growth in developing countries, particularly in China, India, Pakistan, Indonesia, Malaysia, Latin America, Middle East and Africa. The most obviously, these trends will lead to changes in energy systems and energy geopolitics (Umbach, 2010; Lombardi and Gruenig, 2016).

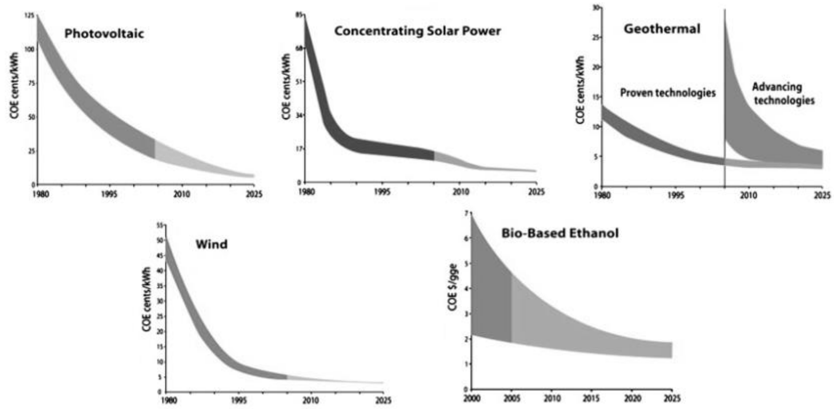
Infrastructure

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 infrastructures. Many regions are overly dependent on a single, locally available resource, such as traditional fuel wood or coal, and have limited access to the clean flexible energy forms required for economic and social development (IEA, 2015). Infrastructure are the backbone of the energy system, and the requirements for the new infrastructure will be vast indeed (IEA, 2012). Urban and rural poor people need to get connected to energy grids in order to have access to modern energy services. New decentralized energy options could help to reduce cost in rural area, but high cost need to be brought down through research and development efforts as well as stepped-up experience gained in niche market applications. Improved 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. Energy infrastructure also needs in Eurasia in particular to match the large available resources of oil and gas in the Caspian region, Siberia, Arctic Area with the newly emerging centers of energy consumptions 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 energy. In high economic growth scenarios where large quantities of fuels will be required there need to be considerable advances in hydrocarbon exploration and extraction, renewable and nuclear electricity generation, hydrogen and bio-fuel production and conversion, and more efficient and smart grid systems. In ecologically driven scenarios low-carbon fossil and renewable technologies are favoured and renewable energy technology cost reductions are projected to 2010 and 2025 (Fig. 2.1). In fact, the price of PV panels drops significantly over the last 20 years and this will continue into the future.

Fig. 2.1: Forecasted renewable energy technology cost



Source: adapted by the authors from NREL, 2005

Fossil fuel prices

Projections of energy prices are very uncertain issue. The fuel prices would still be set by market supply, demand and regulation dynamics. The recent increase of shale gas and shale oil production as well as increase of renewable energy use has resulted in low price projections for fossil fuels. Under the 2014 oil and gas price scenario from the Bloomberg, for example, an oil price of just US dollars 45-50 per barrel was assumed in 2030 (Bloomberg, 2014). According to Future World Energy Scenarios, based on supply-demand fundamentals, long-term oil prices should move in a range of US dollars 60-100 per barrel (Enerdata, 2017). 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 as can be seen in Table 2.4.

Table 2.4: 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; ETP, 2012; GWEC and EREC, 2012

Emission pathways

Over the last decade, CO_2 emissions increased by an average of 3% a year, despite the increased focus on climate change. This was mainly as a 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 future, emissions are expected to grow. In the WEO 2012 Reference scenario, CO_2 emissions increase from 29 Gt 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 grow from 15 Gt CO_2 in 2007 to 42 Gt CO_2 in 2050. OECD emissions grow from 14 Gt CO_2 to 15 Gt CO_2 over the same period. Most of the increase in OECD countries comes after 2030. 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 show that emissions could be up to 20% higher than the 57 Gt projected in the Baseline scenario for that date.

Cost of carbon emissions

Assuming that 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 studied scenarios consider CO_2 emissions cost development which have been applied in Kyoto Protocol for Annex B (in which 37 countries have binding targets: Australia, the European Union, Belarus, Iceland, Kazakhstan, Liechtenstein, Norway, Russia, Switzerland and Ukraine) and non-Annex B countries without binding targets including Argentina, Azerbaijan, Brazil, Chile, China, India, Iraq, Iran, Mexica (Table 2.5).

Table 2.5: 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, 2010

4. Transformation of the energy system

This section shows possible transformation of energy systems up to 2050 perspective at sectorial level. In particular section focuses on power system, nuclear sector, transport, construction sector, and manufacturing. In addition, it provides possible trajectory of carbon emissions reduction and a low-carbon energy transition cost.

Power generation

The World Energy Outlook (WEO) develops three main scenarios: The Current Policies Scenario, the (NPS), and the 450 parts per million of carbon-dioxide equivalent (ppm CO_2-eq) scenarios. The New Policies Scenario 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. In the new policy scenario, 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. Oil, coal, and gas will thus remain the predominant sources of energy (Fig. 2.2). 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%.

The 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% points compared to 2010, fossil fuels will still provide more than 60% of the electricity supply in 2035 (Fig. 2.3). 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 energy technologies in power generation will also increase.

Fig. 2.2: Share of primary energy sources in the world energy demand, %

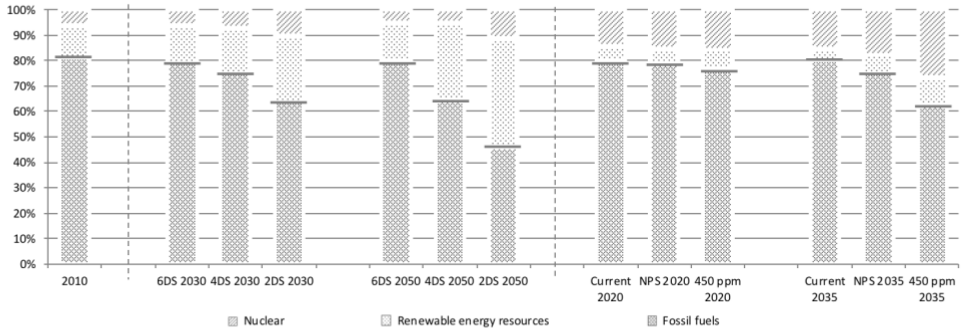
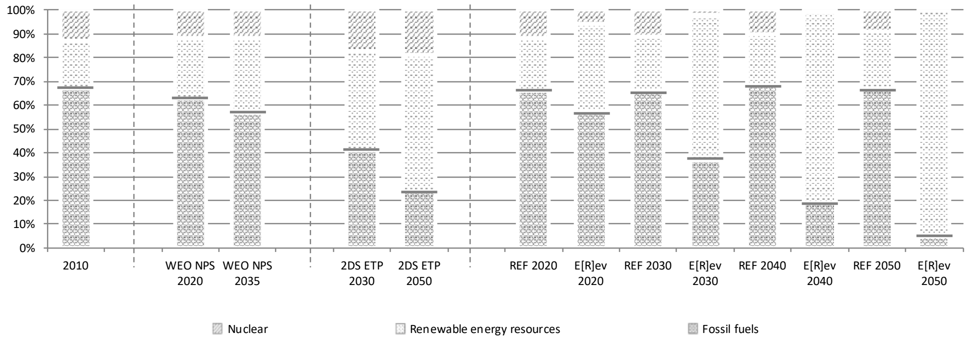


Fig. 2.3: Share of primary energy sources in world electricity generation, %



Source: compiled by the authors

Energy Technology Perspective Report (IEA, 2012) develops three possible energy futures, 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 what 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 consistent with and emissions trajectory that recent climate science research indicates would give an 80% chance of limiting 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, TPES increases by approximately 37% from 2010 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 2010. 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. 2.4). In all scenarios, fossil fuels remain a significant part of the global energy system through 2050.

Fig. 2.4: Share of primary energy sources in the world energy demand, %

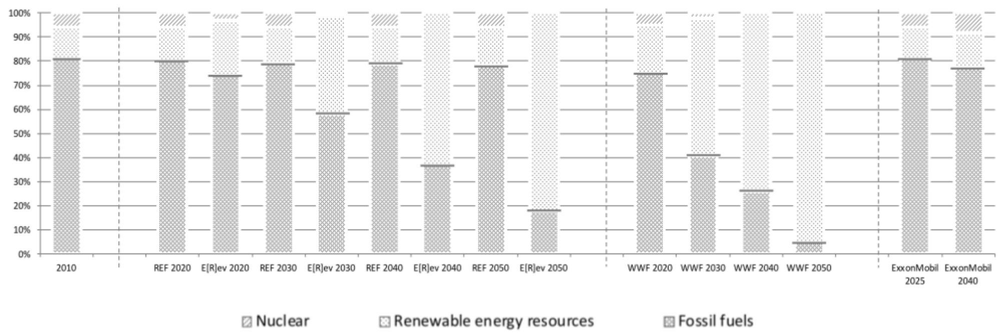
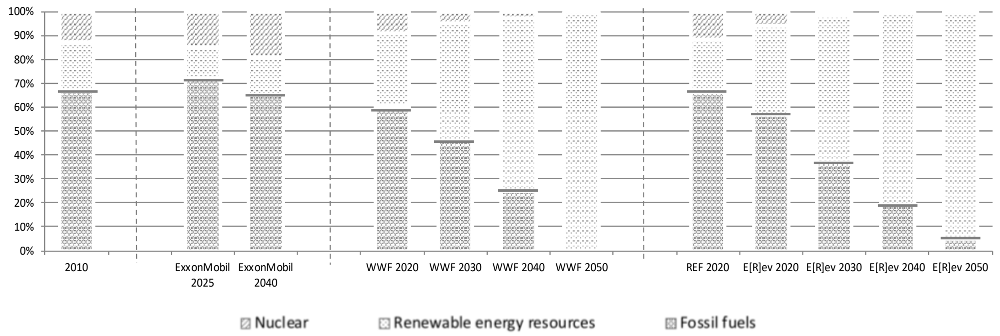


Fig. 2.5: Share of primary energy sources in world electricity generation, %



Source: compiled by the authors

Energy Revolution Scenario uses a bottom-up, technology-driven approach to illustrate the possibility of 100% renewable power by 2050. Two scenarios are produced: Reference Scenario and an Energy Advanced Revolution Scenario. The Energy Advanced Revolution scenario 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. Under the Energy Revolution scenario (Greenpeace, GWEC, EREC, 2012), world primary energy demand will decrease to 481.050 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 (Fig. 2.3). 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 (Fig. 2.5). Wind, solar PV, and geothermal will represent some 60% of electricity generation, and approximately 91% of heat energy will come from renewables. 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. Ocean energy will also expand significantly, surpassing geothermal and biomass in installed capacity. In terms of geography, OECD developed countries is expected to be leader in renewable energy production. Electricity share in alternative scenarios increases from 19% in 2012 to 40% to 90% by 2050 in the alternative scenarios (Fig. 2.6). In fact, the European Union (EU) is committed to reducing greenhouse gas emissions to 80–95% below 1990 levels by 2050. To meet climate target, the EU has established aggressive policy targets for shares of electricity (60-70%) from renewables by 2050. All EU countries also have individual targets for share of electricity, ranging from 30% to 90%. Most 90-100% scenarios give large shares to solar PV, wind, and solar thermal power and most imply large shares (i.e., 20% to 50%) of electricity generation (Fig. 2.7).

Fig. 2.6: Future EU Electricity Scenarios 2050

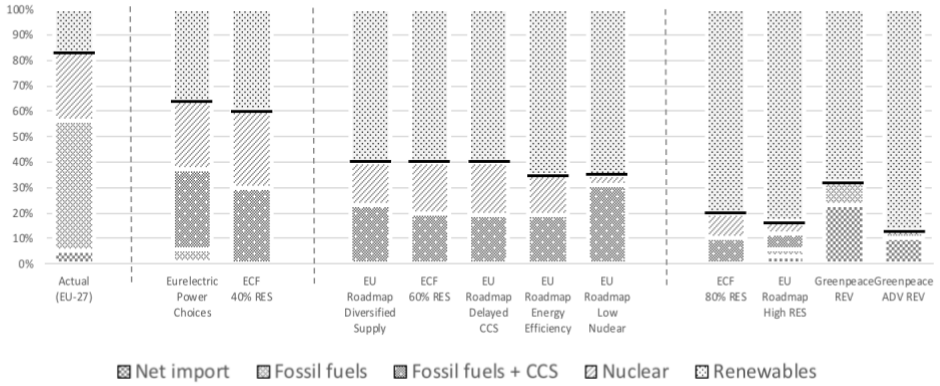
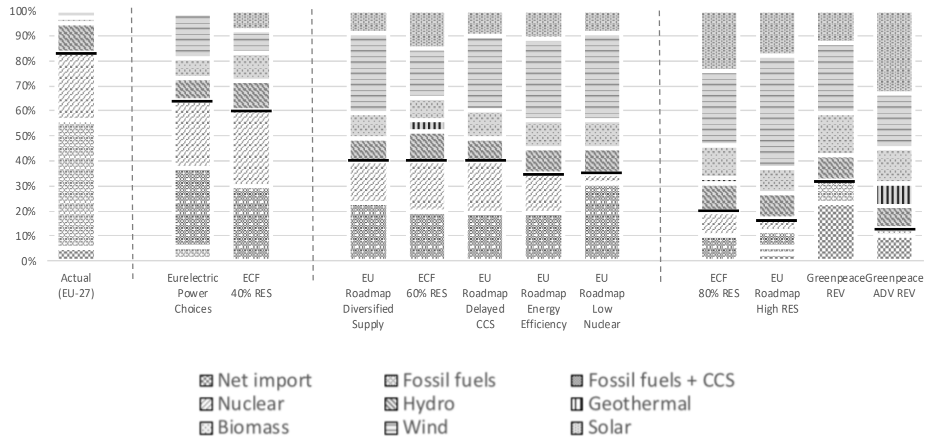


Fig. 2.7: Shares in electricity generation by RES source, %



Source: compiled by the authors

Pessimistic assumptions regarding to renewable power generation comes from Outlook for Energy: a view to 2040 (ExxonMobil, 2012), BP Energy Outlook 2030 (BP, 2013) and Ener-Brown Future World Energy Scenarios (Enerdata, 2017). According to the 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 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%. BP is expected the same trends. 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. Renewable energy will grow by about 8% annually during 2010–2030. By 2030, renewables (excluding hydro) will supply 11% of world electricity. According to Future World Energy Scenarios, fossil fuels stay at 76% in 2040 in Ener-Brown and 71% in Ener-Blue, but fall down to 50% in Ener-Green. Renewable energy resources and nuclear energy vary from 24% (Ener-Brown) to 50% (Ener-Green) (Enerdata, 2017).

Nuclear sector

Scenarios carried out before nuclear catastrophe in Fukushima power plant caused by tsunami and earthquake show a rise of nuclear in general energy mix. However, after the Fukushima accident, nuclear deployment in the long term has been revised in many scenarios as well as national energy policies. For example, after accident in Fukushima, Germany has announced the immediate closure of eight of its oldest reactors (built before 1980). It also announced a decision to close the rest by 2022. The Italians have voted overwhelmingly to keep their country non-nuclear. Switzerland has banned the construction of new reactors. Belgium is considering phasing out its nuclear plants, perhaps as early as 2015. The WEO (2012) developed a scenario with low development of nuclear assuming no new reactor built in OCDE and non OCDE countries only support half of their projects. The share of nuclear goes down from 13% to 7% in 2035. It is compensated by an increasing use of renewables but also to fossil fuel. 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, Korea, Bangladesh, Pakistan) and even Middle East countries (Egypt, Jordan, Iran, UAE) are planning to build new nuclear power facilities.

Transport

In the transport sector, Energy Revolution scenario believes that electric cars can seriously enter the transport sector (Greenpeace, 2012). Electric vehicles will play an even more important role in improving energy efficiency in transport and substituting for fossil fuels. According to Greenpeace scenarios, in 2030, electricity will provide 12% of the transport sector's total energy demand in the Energy Revolution, while in 2050 the share will be 44%, replacing gasoline and diesel. According to Energy Technology Perspective (IEA, 2012) by 2050, electricity use in the transport sector amounts 11% of overall electricity demand.

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 electrification of transport are a shift to plug-in hybrid and electric cars, energy efficient heavy vehicles. Electric vehicle batteries will be mainly lithium Ion. Electrification will enable the transport sector to be 100% powered by renewables.

The construction sectors

According to ETP report, in the Baseline scenario, global final energy demand in building sector increases by 60% between 2007 and 2050 (ETP, 2012). Total energy demand in the buildings sector increases from 2 759 Mtoe in 2007 to 4 407 Mtoe in 2050 in the Baseline scenario. The residential sector accounts for 59% of this growth and the service sector for around 41%. In baseline scenario, the energy mix of this sector is dominated by natural gas or to a lesser extent by coal. In the BLUE Map scenario (ETP, 2012), energy consumption in the buildings sector is reduced by around one-third of the Baseline scenario level in 2050. The energy consumption of fossil fuels declines significantly. Solar grows the most, accounting for 11% of total energy consumption in the buildings sector, as its widespread deployment for water heating (30% to 60% of useful demand depending on the region) and, to a lesser extent, space heating (10% to 35% of useful demand depending on the region) helps to improve the efficiency of energy use in the buildings sector.

Under the other scenarios 100% Renewable Energy by 2050 (WWF and ECOFYS, 2011) 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 a 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.

Carbon emissions reduction

Table 2.6 and Figure 2.8 below provides 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 31-53% of the reduction (below the baseline of 58 Gt by 2050) across all sectors. The ETP scenarios expect CCS technologies to contribute only between 20-28% of the total CO_2 emissions reduction. As far as enhanced-oil-recovery (EOR) is concerned, ETP expect the potential for EOR to be relatively small compared to the global emissions from the power generation sector. Fuel-switching is third (11-16% reduction potential) among the CO_2

mitigation options. Fuel switching is defined as the choice between traditional solid fuels and modern non-solid fuels.

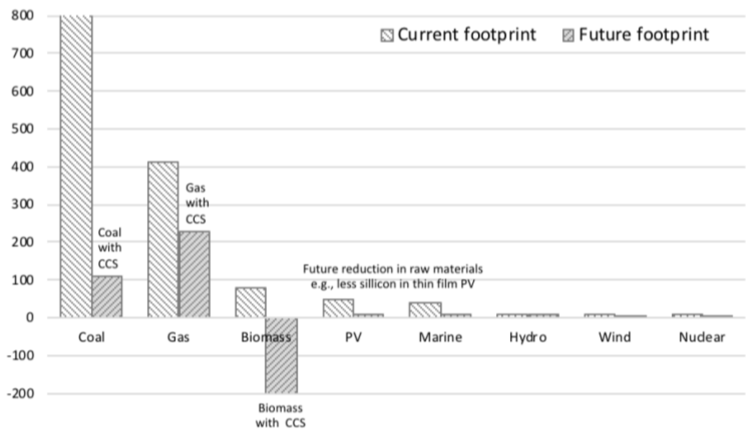
In terms of technology, the carbon emission footprint varies widely within each technology. Overall, nuclear, wind, hydro has the lowest CO_2-e emissions impact (Figure 2.8). Marine and photovoltaics also have low emissions. For photovoltaics most of the emissions are the result of electricity use during manufacturing and using raw materials. Coal and gas powers power have lower CO_2-e emissions, with carbon capture and storage technologies. Biomass may also be used increasingly with CCS technologies. CCS has 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. It involves the CO_2 capture at the point of generation, compressing it to a supercritical fluid, and then sequestering it. The CCS methodologies comprise three steps: CO2 capture, CO2 transportation and CO2 storage. The CCS is currently considered to be technically feasible at commercial scale using a range of technologies.

Table 2.6: CO_2 mitigation options in the energy sector

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%
Bio-fuels in Transport	~6%

Source: adapted by the authors from IEA, 2012

Fig. 2.8: Current and future carbon footprint by technologies, Gt



Source: adapted by the authors from IEA, 2012

A transition costs

The Stern Report disseminated to a large audience the conclusions of the last IPCC report relating on emission cost. The AR4 shows that on average, the most severe target would cost 3% of the world GDP in 2030 and 5-10% in 2050 (Stern, 2007). Similar to Stern's study, Strachan et al. (2008) finds the electricity generation as a key sector for decarbonisation and highlights the role of critical zero-carbon technologies including CCS. In general terms an 80% reduction target in 2050 compared to 1990 level leads to macro-economic losses between 0.3% and 1.5% of GDP in 2050. The European Commission's energy project (Adaptation and Mitigation. Strategies - Supporting European Climate Policy) concludes that losses of GDP vary from about 0.9% to 2.5% by 2100 relative to the baseline, compared to a range of 0.5 to 0.9% in case of the 550 ppm scenario (EC, 2011). Luderer et al. (2012) shows that if the international community takes immediate action to mitigate climate change, the costs of stabilizing atmospheric CO_2 concentrations at 450 ppm (roughly 530–550 ppm) discounted at 3% are estimated to be 1.4% of GDP. A delay in climate policy and restrictions to the deployment of low-carbon technologies could result in substantial increases of mitigation costs.

5. Conclusion

The scenario analysis is widely used to show the range of possible alternative ways that energy system may change in the future. Scenarios are often considered as useful tools for learning about the behaviour of complex systems, and for policy-making. Based on scenario analysis, it might be concluded that all scenarios show different visions of a low-carbon energy system in 2050. The scenario outcomes vary significantly with regards to fuel mix, fuel prices, carbon prices, technology cost reductions and future policy actions. Despite differences in assumptions, all energy scenarios considered in this chapter share some common conclusions, one of which is that the energy systems in nearly 30 or 50 years will be different from that of today and renewable energy resources can play a large role in future energy systems. Moreover, most of all studies except ExxonMobil and BP Energy Outlook agree that high renewable energy scenarios are possible and there is significant unused renewable energy potential. Renewable energy resources are considered as a powerful way to reduce carbon emissions in all scenarios. The key requirement for scenarios with high level of renewables is extensive government involvement in the promotion of renewable energy technologies, whilst the principal benefit for most nations is that their climate and energy security could improve by enhanced diversification of the energy supply and reduced carbon emissions.

However, there are there are major uncertainties which will influence the technical and economic and in particular the implementation potential of renewable energy technologies. The uncertainties include carbon and fuel 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. For example, environmental programs in resource-rich countries depends on revenue from oil and gas industry. Other things include social uncertainties. Economic growth and population size are two driving socioeconomic factors that affect future energy outcomes, and it is important that a wide range of other factors that might cause uncertainty are considered. For example, there has been social opposition to energy infrastructure (whatever it is electricity grids, renewables, nuclear or shale gas) in some European Union countries, Japan, South Korea and United States. Therefore, social factor should be considered more fully for the development of future energy scenarios. In addition, there are technological uncertainties. The price of PV panels drops significantly over the last 20 years and this will continue into the future but how it will impact on the development of the whole power sector and well-established oil and gas sectors. The most challenging things is policy uncertainties. When the government is changed, their energy policy is also subject of change. The reducing policy uncertainty is a crucial component of effective renewable energy development. Furthermore, energy generation and demand, energy efficiency level, and economic forecast are other uncertainties have to be regular reviewed and analysed in future energy scenarios.

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