# List of Abbreviations

| | |
|---|---|
| AIC | Akaike information criterion |
| APEC | Asia-Pacific Economic Cooperation |
| ASEAN | Association of Southeast Asian Nations |
| BIC | Bayesian information criterion |
| BRICS | Brazil, Russia, India, China, and South Africa |
| CCGT | Combined cycle gas turbine |
| CCHP | Combined cooling heat and power |
| CCMT | Carbon-change-mitigation technology |
| CDM | Clean development mechanism |
| CHP | Combined heat and power |
| CSP | Concentrated solar power plant |
| CVPP | Commercial virtual power plant |
| DER | Distributed energy resources |
| DG | Distributed generation |
| EEX | European Energy Exchange |
| EIA | Energy Information Administration |
| EKC | Environmental Kuznets curve |
| EMS | Environmental management system |
| EPBT | Energy payback time |
| ERGO | Electric recharging grid operator |
| EROI | Energy return on investment |
| ETS | Emission trading system |
| EV | Electric vehicle |
| EXAA | Energy Exchange Austria |
| FDI | Foreign direct investment |
| FE | Fixed-effect |
| FGLS | Feasible generalized least square |
| FIT | Feed-in tariff |
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| GLS | Generalized least square |

| | |
|---|---|
| GNP | Gross national product |
| GSHP | Ground source heat pump |
| Gt | Gigatonne |
| Gtoe | Gigatonnes of oil equivalent |
| GW | Gigawatt |
| ICT | Information and communication technology |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| IRR | Internal rate of return |
| JI | Joint implementation |
| kWh | Kilowatt hour |
| LCA | Life cycle analysis |
| MENA | Middle East and North Africa |
| MMT | Million tones |
| Mtoe | Million tones of oil equivalent |
| MW | Megawatt |
| NPV | Net present value |
| OECD | Organisation for Economic Co-operation and Development |
| PHES | Pumped hydro energy storage |
| PHEV | Plug-in hybrid electric vehicle |
| PHS | Pumped hydro storage |
| PTC | Production tax credit |
| PURPA | Public Utility Regulatory Policies Act of 1978 (US) |
| PV | Photovoltaic |
| RE | Renewable energy |
| RE | Random effect |
| RES | Renewable energy sources |
| RET | Renewable energy technology |
| RPS | Renewable portfolio standard |
| RPT | Renewable energy premium tariff |
| SAPV | Stand-alone solar photovoltaic |
| SHPP | Small-hydro power plant |
| SOFC | Solid oxide fuel cell |
| TJ | Terajoule |
| TOU | Time-of-use |
| TWh | Terawatt hour |
| V2G | Vehicle to grid |
| VAR | Vector autoregression |
| VPP | Virtual power plant |

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# Chapter 1
# Introduction

## 1.1 Background

Industry's electricity consumption will comprise an increasing share of the global energy demand during the next two decades. It is expected that the growth rate of electricity consumption will be more than that of the consumption of other sources of energy (e.g., liquid fuels, natural gas, and coal) (IEA 2012). The increasing prices of fossil fuels such as crude oil and the increasing concerns about the environmental consequences of greenhouse gas emissions have renewed the interest in the development of alternative energy resources. In particular, the Fukushima Daiichi accident was a turning point in the call for alternative energy sources. Renewable energy is now considered a more desirable source of fuel than nuclear power plants because of the absence of fatal risks.

Considering that carbon dioxide is the major greenhouse gas (GHG), there is a global concern about reducing carbon dioxide emissions. Different policies can be applied in this regard (e.g., enhancing renewable energy deployment and encouraging technological innovations). In addition, supporting mechanisms (e.g., feed-in tariffs, renewable portfolio standards, and tax policies) can be employed by governments to increase renewable energy generation and achieve energy efficiency. Many countries have started installing facilities for power generation that can use renewable energy sources. However, the share of a renewable energy supply differs by region and country. Europe is considered at the forefront of using renewable energy technologies.

The research literature on the relationship between energy consumption and economic growth is extensive. Many researchers have studied the effectiveness of conservative energy policies on economic activities. Some researchers (Fthenakis et al. 2008; Crawford 2009; Frick et al. 2010) have measured the amount of carbon saving by using the life-cycle analysis method. Other researchers have analyzed carbon emission saving by enhancing energy efficiency through cogeneration and advanced technology (Shipley et al. 2008; Kiviluoma and Meibom 2010;



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Wille-Haussmann et al. 2010). However, no previous study has measured the amount of carbon emission reduction and the interaction effects of different policy tools that support mechanisms to enhance renewable energy sources (generation and consumption), technological innovation, and market regulation.

The methodology used by early researchers to investigate the relationship between emissions and gross domestic product (GDP) per capita is not appropriate. Some researchers such as Stern (2004), Müller-Fürstenberger and Wagner (2007), and Wagner (2008) have cast doubt on the existence of an inverted U-shaped curve showing the relation between carbon emissions and GDP per capita. They argued that the results were obtained by commonly used estimation methods that have serious problems. For instance, the issues of causality and its direction are well established.

Furthermore, a study (Dasgupta et al. 2004) pointed out that this relationship is not as rigid as proposed as poor countries were mistakenly assumed to not have strong governance. The role of GDP growth in $CO_2$ emission reduction could be reduced by the regulations applied by the governments of such countries. In addition, other parameters such as technological innovation and environmental tax could play an important role in emission reduction. The direct impact of each parameter might change when it is affected by the impact of interactions between different variables.

## 1.2 The Objective

This research aims to analyze the effects of power generated by renewable energy sources, renewable energy production technology, energy efficiency, and market regulation on carbon emissions. These parameters have direct and indirect effects on carbon emission reduction. For example, environmental tax could reduce carbon emissions directly by decreasing fossil fuel consumption or stimulating energy savings through technological innovation. In addition, renewable energy sources could affect both economic growth and the environment. After analyzing renewable energy consumption, production technology, market regulation, and their relations in detail, we devised a model to measure the extent of their effectiveness and the result of interactions between these parameters. Based on these results, we proposed the structure of a marketplace for renewable energy sources and outlined the requirements for this market to function effectively.

As Europe is considered to be at the forefront of renewable energy deployment, this study selected the EU-15 countries[1] to examine the effects of renewable energy generation on carbon dioxide emission reduction. We examine the long-term effects

[1] The EU-15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, and United Kingdom.

of related policies on carbon dioxide emissions of individual countries and the group of EU-15 countries. We compare the effect of each variable over time and across countries. Three hypotheses are posed:

1. The power generated by renewable energy sources in the EU-15 has been able to affect carbon dioxide emission through the displacement of traditional capacity fueled by fossil fuels. Moreover, we expect a negative elasticity for renewable energy sources regarding carbon dioxide emission.
2. Technological advances are able to decrease carbon dioxide emissions by decreasing the costs of renewable energy sources and enhancing energy efficiency. Therefore, we expect a negative relation between technological innovation and carbon dioxide emission.
3. Environmental taxes applied by governments have a direct negative relation with carbon dioxide emissions. The size of this parameter could indicate its importance in comparing renewable energy development and technological innovation. We expect negative elasticity for environmental tax.

We review the relevant literature on the effectiveness of renewable energy development, production technology, and market regulation on reducing carbon dioxide emissions. Based on this, we derive appropriate variables for measuring their impacts on carbon dioxide emission reduction. The effectiveness of technological innovation will be determined by examining patent applications that adopt climate change mitigation and information and communications technology (ICT) patent applications. We apply the panel data method to develop our model in the form of the translog function to investigate the interaction effects of different parameters. After estimation of the model, the elasticity of carbon dioxide emission in relation to GDP, renewable energy generation, energy patent applications, ICT patents, and environmental taxation trends is calculated. In economics, elasticity is the measurement of how change in one variable affects another variable, assuming that all other variables are kept constant. We use this term to measure the effectiveness of the aforementioned variables on carbon dioxide emission.

Our results help identify the variables that have a greater impact on carbon dioxide emission reduction. In addition, the results indicate that policymakers should apply the policies that are the most effective in achieving targets.

The contribution of this research lies in defining three variables (i.e., renewable energy generation, technological innovation, and environmental tax) with regard to the Environmental Kuznets Curve and analyzing their effects on carbon dioxide emission per capita. For the analysis, we employ the number of patents and the amount of environmental taxes for measuring technology and market regulation impacts instead of research and development (R&D) expenditures, which were used by previous research. We also calculate the elasticity of carbon dioxide emissions per capita over time for each EU-15 country and for all EU-15 countries jointly. We also apply an estimation methodology to overcome the econometric issues neglected by the early researchers. Many researchers have estimated fixed-effect models without applying regression diagnostic tests (Cropper and Griffiths 1994; Shafik 1994; Horvath 1997; Moomaw and Unruh 1997; and Suri and Chapman 1998). Our estimation method differs from most studies in its use of feasible generalized least squares (FGLS) to correct heteroscedasticity and autocorrelation. The FGLS method is appropriate for this, as demonstrated by Stern (2002), Aldy (2005), and Luzzati and Orsini (2009) in their research.

## 1.3 The Outline

In the next chapter, we focus on the current situation of renewable energy consumption and the global outlook. We also review the roles of economic growth, energy security, and carbon dioxide emission reduction as the main drivers in the development of renewable energy. Chapter 3 provides a review of the literature on renewable energy supply technologies and energy efficiency technologies. While we analyze different regulations for increasing the renewable energy deployments in Chap. 4, we focus on financial supporting mechanisms and cross-national incentive policies for enhancing renewable energy deployment in Chap. 5. Based on these results, we propose the requirements and structure of a marketplace for trading small units of renewable energy in Chap. 6. In Chap. 7, we describe our model for evaluating the impact of renewable energy generation, economic growth, technological innovation, and environmental tax on carbon dioxide emission reduction in EU. The results of this model, which are discussed in Chap. 8, could be used by governments to make effective policies to achieve their targets of carbon dioxide emission reduction and climate change mitigation.

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# Chapter 2
# The Energy and Environment Relationship

## 2.1 Introduction

An expanding body of research shows that there is a strong relation between climate change and the carbon dioxide ($CO_2$) emissions that are produced through energy production and consumption.

Carbon dioxide emission pollutants are primarily produced by combustion of fossil fuels. According to the International Energy Agency (IEA) estimates, the share of energy production and consumption in carbon dioxide emissions was 81.6 % in 2010 (IEA 2012b). Therefore, energy consumption is the main cause of climate change. According to the *International Energy Outlook 2011* (IEO 2011), the global energy-related carbon dioxide emissions have risen from 30.2 billion metric tons in 2008 to 35.2 billion metric tons in 2020 and will rise to 43.2 billion metric tons in 2035 (Conti and Holtberg 2011). Developing non-OECD (Organization for Economic Co-operation and Development) countries that continue to be heavily dependent on fossil fuel consumption account for much of this growth. These countries need to meet their continuously rising energy demand. Moreover, fossil fuels are subsidized in many countries.

Government policies have played a crucial role in the recent growth in renewable energy sources, especially in the electric power sector. Reducing carbon dioxide emission and local pollutants constitutes a core part of environmental concerns. More than 70 countries are expected to implement policies for deploying renewable energy technologies in the power sector by 2017 (IEA 2012c). Among other objectives, these policies need to achieve an increase in power generation through renewable energy sources so that the unit cost decreases to the level of other energy sources.

Henrik Lund (2010) defines renewable energy as "energy that is produced by natural resources—such as sunlight, wind, rain, waves, tides, and geothermal heat—



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that are naturally replenished within a time span of a few years.” According to his view, all technologies that are able to convert natural resources (e.g., solar) to any kind of energy could help in the generation of renewable energy.

## 2.2 The General Trend of Energy Consumption

Energy consumption depends on different factors such as economic progress, population, energy prices, weather, and technology. Global consumption of primary energy in 2011 was 12.2 Gtoe (BP 2012). The consumption of crude oil, natural gas, and coal was 4.1, 2.9, and 3.7 Gtoe respectively. The USA, China, and Japan have been the major oil consumers at 833.6, 461.8, and 201.4 Mtoe respectively. While the USA, Russia, and Iran are the biggest consumers of natural gas at 626, 382.1, and 138 Mtoe, China is the biggest consumer in the coal market at 1.8 Gtoe followed by USA and India at 501.9 and 295.6 Mtoe.

According to the *BP Statistical Review of World Energy* (BP 2012), the average primary energy consumption has been 2,306.7 Mtoe during 2001–2010 compared with 2,140.5 Mtoe in 1991–2000, which shows a growth rate of 7.8 % per year. On the other hand, the average carbon dioxide emission was 6,315.9 Mtoe in 2001–10 as against 5,882.7 Mtoe in 1991–2000, showing a growth rate of 7.4 % per year. About 87 % of primary energy consumption in 2010 was from fossil fuels, while the share of nuclear energy, hydroelectricity, and renewable energy was 5.2, 6.5, and 1.4 % respectively. Compared with the primary energy consumption in 2011, the share of fossil fuels has barely changed, but the share of nuclear energy and hydroelectricity has decreased to 4.9 and 6.4 respectively, while the share of renewable energy has gone up to 1.6 %. Table 2.1 shows the global primary energy consumption by types of fuel.

**Table 2.1** Global primary energy consumption, end of 2011 (Mtoe)

| Region | Oil | Gas | Coal | Nuclear | Hydro | Renewable | Total |
|---|---|---|---|---|---|---|---|
| N. America | 1,026.4 | 782.4 | 533.7 | 211.9 | 167.6 | 51.4 | 2,773.3 |
| S. & C. America | 289.1 | 139.1 | 29.8 | 4.9 | 168.2 | 11.3 | 642.5 |
| Europe & Eurasia | 898.2 | 991.0 | 499.2 | 271.5 | 179.1 | 84.3 | 2,923.4 |
| Middle East | 371.0 | 362.8 | 8.7 | NA | 5.0 | 0.1 | 747.5 |
| Africa | 158.3 | 98.8 | 99.8 | 2.9 | 23.5 | 1.3 | 384.5 |
| Asia Pacific | 1,316.1 | 531.5 | 2,553.2 | 108.0 | 248.1 | 46.4 | 4,803.3 |
| **Total World** | **4,059.1** | **2,905.6** | **3,724.3** | **599.3** | **791.5** | **194.8** | **12,274.6** |
| OECD | 2,092.0 | 1,386.1 | 1,098.6 | 487.8 | 315.1 | 148.0 | 5,527.7 |
| Non-OECD | 1,967.0 | 1,519.5 | 2,625.7 | 111.5 | 476.4 | 46.8 | 6,746.9 |
| EU | 645.9 | 403.1 | 285.9 | 205.3 | 69.6 | 80.9 | 1,690.7 |
| FSU | 190.6 | 539.6 | 169.8 | 60.2 | 54.6 | 0.4 | 1,015.1 |

*Source*: *BP Statistical Review of World Energy, 2012*

### 2.2.1 Fossil Fuels

According to the *BP Statistical Review of World Energy* (BP 2012), at the end of 2011, 48.1 % of the proven oil reserves were located in the Middle East. As we see in Table 2.1, Europe and Eurasia have 8.5 % of the reserves, of which a majority is located in the Russian Federation (5.3 %) and Kazakhstan (1.8 %). Africa has 8 % of the global oil reserves, mostly in Libya (2.9 %) and Nigeria (2.3 %). In South America, the proven oil reserves are mostly located in Venezuela (91 % of the regional reserves and 17.9 % of the global reserves). North America has 13.2 % of oil reserves, most of which belongs to Canada (80.6 % of regional reserves and 10.6 % of total global reserves). This means that 87 % of proven oil reserves in the American continent are located in Venezuela and Canada. Natural gas reserves are more concentrated geographically than crude oil because 38.4 % of the reserves are located in the Middle East and 37.8 % can be found in Europe and Eurasia. Russia, Iran, and Qatar have almost half the global natural gas reserves. If we take a look at coal reserves, we will find that around 60 % of the global coal reserves are located in the USA, Russia, and China.

In terms of consumption, the share of the Middle East in global oil consumption is 9.1 % (BP 2012). The share of Europe and Eurasia is 22.1 % of the global oil consumption, which is less than the total oil consumption for China, India, Japan, and Korea. Africa has the least share of consumption, with 3.9 %, while North America has a share of 25.3 %. The USA has a share of 20.5 %, almost as much as Europe. This level of North American consumption is more than all countries in the European Union together. The Asia Pacific region has the biggest share in oil consumption, with 32.4 %. China is the second biggest consumer in the world (11.4 %), but its consumption is almost half of the USA. It would be interesting if we compare these numbers with the oil reserves in the USA (2 %) and China (10 %). China is the biggest energy consumer in the world followed by the USA, but the composition of fuel sources is different in these countries. Oil is the main source of energy consumption in the USA, while coal is the most important source of energy in China. Coal consumption in China was 1839.4 Mtoe in 2011, while that of oil and gas was 461.8 and 117.6 Mtoe respectively. Global oil consumption in 2011 has increased by only 0.7 % compared with 2010 because of the economic recession in the major oil consumer countries. Although the oil consumption growth rate is negative in 2011 for OECD countries (−1.2 %), it has been calculated as 2.8 and 5.7 % for the non-OECD and former Soviet Union (FSU) countries respectively. If we compare the growth rate of crude oil consumption and production, we will find that the former (0.7 %) is less than the latter (1.3 %) globally. But this varies across regions. Table 2.2 shows the growth rate of fossil fuel consumption in different regions around the world.

Based on these figures, we find that the consumption growth rate in Asia Pacific is much stronger than other regions. Although the oil consumption growth rate is negative in some regions like Africa and Europe, the rate of decrease in production is much higher than consumption. This means that there is a shortage of supply

**Table 2.2** Fossil Fuels production and consumption growth rate during 2010–2011

| | Oil | | Gas | | Coal | |
|---|---|---|---|---|---|---|
| | Prod. | Con. | Prod. | Con. | Prod. | Con. |
| North America | 3.0 | −1.4 | 5.5 | 3.2 | 1.2 | −4.6 |
| S. & Cent. America | 1.3 | 2.9 | 3.0 | 2.9 | 13.3 | 5.7 |
| Europe & Eurasia | −1.8 | −0.6 | 0.9 | −2.1 | 4.5 | 3.3 |
| Middle East | 9.3 | 1.8 | 11.4 | 6.9 | – | 2.1 |
| Africa | −12.8 | −1.4 | −5.1 | 2.7 | 0.3 | 1.7 |
| Asia Pacific | −2.0 | 2.7 | −0.9 | 5.9 | 7.8 | 8.4 |
| World | 1.3 | 0.7 | 3.1 | 2.2 | 6.1 | 5.4 |

*Source*: *BP Statistical Review of World Energy*, *2012*

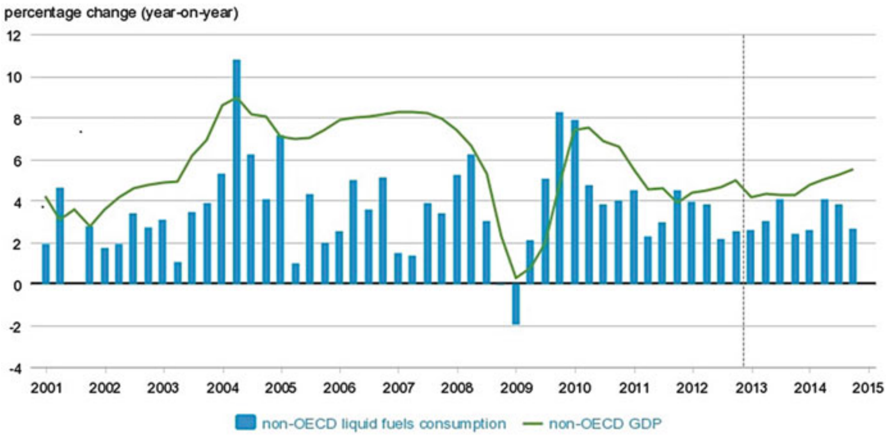


**Fig. 2.1** Non-OECD quarterly liquid fuels consumption and GDP (Source: U.S. Energy Information Administration, IHS Global Insight. Updated: Monthly|Last Updated: 2/12/2013)

in these countries. The Middle East is the only region in the world that has a big difference between the production and consumption growth rates for oil and gas.

As mentioned earlier, population growth and expanding economies are the main drivers for increasing energy consumption. According to an IEA report, "world population is projected to grow from an estimated 6.8 billion in 2010 to 8.6 billion in 2035 or by some 1.7 billion new energy consumers" (IEA 2012c). According to *IEA Outlook*, global GDP will increase at a rate of 3.5 % during 2010–2035. It predicts that economic growth in the non-OECD countries will be much more than the OECD countries. The other parameter for driving energy consumption is price. Of course, its direction may not be the same in different countries. Figures 2.1 and 2.2 show the strong impact of GDP on energy consumption in non-OECD countries and price effect in OECD countries.

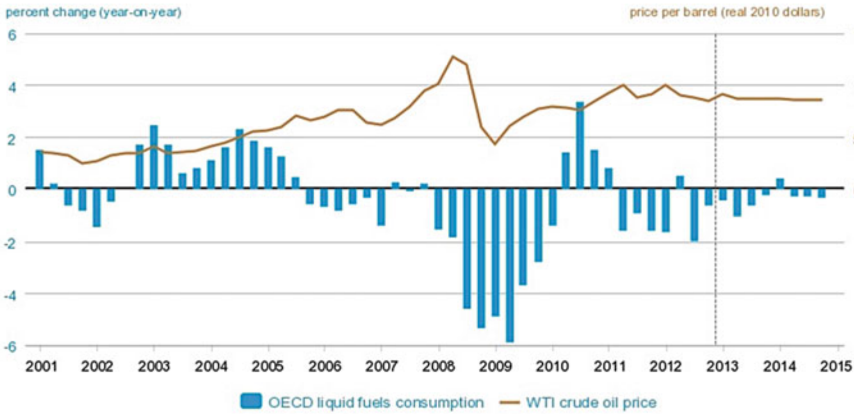


**Fig. 2.2** OECD quarterly liquid fuels consumption growth rate and WTI crude oil price development (Source: U.S. Energy Information Administration, Thomson Reuters. Updated: Monthly|Last Updated: 2/12/2013)

Oil consumption in the non-OECD has increased very fast in recent years. The growth rate of oil consumption in these countries in 2010 was more than 40 % compared with its level in 2000, while oil consumption in the OECD countries has decreased in this period. The largest growth in oil consumption has taken place in China, India, and Saudi Arabia (Conti and Holtberg 2011). Increasing oil demand indicates economic advancement in non-OECD countries. Commercial and individual transportation, manufacturing processes, and fuel for power generation in some countries require a huge amount of oil. On the other hand, the population of many non-OECD countries has increased, which supports this trend. Figure 2.1 shows that oil consumption decreased only in the fourth quarter of 2008 and the first quarter of 2009. Oil prices increased sharply in this period, but economic growth in these countries was influenced less than the corresponding for OECD countries (EIA 2013).

OECD countries consume more oil than non-OECD countries, but as Fig. 2.2 shows, the former have a lower oil consumption growth compared with the latter. Oil consumption in OECD countries has decreased from 2,217.3 Mtoe in 2000 to 2,092 Mtoe in 2011, while it increased in non-OECD countries from 1,354.5 to 1,967 Mtoe in the same period (BP 2012).

Due to the different economic structures in OECD and non-OECD countries, oil consumption follows different patterns in these countries. Many developing countries are using energy incentive technologies; also, they do not consider fuel efficiency in economic activities to the same extent as developed countries. In OECD countries, a higher rate of fuel taxes and even carbon tax is imposed on crude oil and petroleum products. Also, they try to improve fuel efficiency economy through policies and new technologies. It is interesting to note that there are some structural differences in energy consumption within economic sections in these countries. Vehicle ownership per capita in developed countries is higher than that of developing countries. There are many households in OECD countries that have more than one car, but this rate is lower for non-OECD countries. Therefore, the transportation sector usually has a bigger share of oil consumption in the former compared with the latter. Furthermore, the size of the service sector in developed countries is larger than developing countries; also, the effect of economic growth on oil consumption is not the same in these countries (EIA 2013).

According to *International Energy Outlook* (*IEO*), world energy consumption will increase by 53 % between 2008 and 2035 (Conti and Holtberg 2011). Although worldwide energy consumption has been limited by the global recession, world energy demand has started to increase with economies recovering from the recession. Economic recovery varies among OECD countries. For example, economic recession has officially ended in the USA, but the recovery is not as strong as those from past recessions. Also, there is a time lag for economic recovery in Europe. It is forecast that world energy demand will increase to a large extent as a result of economic growth in developing countries. Among these countries, China and India were least affected by the recession and continue to lead world economic growth and energy demand (Conti and Holtberg 2011)

The world is dependent on fossil fuels to generate electricity power, which is used for different purposes including industrial, agricultural, commercial, and residential consumption. Currently, the growth rate of energy consumption is 2.5 % per annum (BP 2012). Mason (2007) has mentioned that if energy consumption continues to grow at the rate of 2 %, then it will double in 35 years, which increases the urgency of concerns regarding energy sources. In this context, many scholars have tried to estimate the size of global fossil fuel reserves and the time it will take to diminish these reserves. Salameh (2003) believed that "global oil supplies will only meet demand until global oil production has peaked sometime between 2013 and 2020." Afterward, oil production will decrease and create a gap in the global energy market, which can be bridged by unconventional oil and renewable energy sources. On the basis of a compound growth rate, Asif and Muneer (2007) have estimated the years for exhausting coal in India, Russia, and USA as 190, 112, and 84 respectively. These numbers based on a nil growth rate will be 315, 1,034, and 305 years. Based on Shafiee and Topal's (2009) calculation, the depletion time for oil, gas, and coal is estimated at 35, 37, and 107 years. They emphasize that "coal reserves are available up to 2012, and will be the only fossil fuel remaining after 2042." These estimations prove that coal reserves are much larger than oil and gas; therefore, coal will be an important source of energy in the future.

### 2.2.2 *Renewable Energy*

Although renewable energy (RE) has been used as a major source of energy for centuries, currently it constitutes only a small percentage of the world's total primary energy supply. According to BP, the share of renewable energy in the global primary energy consumption was 1.6 % in 2011. The USA, Germany, and China have been the biggest consumers of renewable energy sources at 45.3, 23.2, and 17.7 Mtoe respectively. Renewable energy accounted for about half of the estimated 208 GW of new electricity capacity installed in 2011. By region, the EU has the largest nonhydropower capacity, which is 174 GW. The estimated share of renewable energy in global electricity production has been around 20 % (including hydropower). Renewable energy is also used in the form of biofuels in the transportation sector. Liquid biofuels constituted around 3 % of global road transport fuels in 2011 (Martinot and Sawin 2012).

Many countries have started to install facilities in order to use renewable energy sources for power generation. But the share of renewable energy supply varies by region and country. Europe is considered as a front-runner in renewable energy technologies, with RE industry in Europe already reaching an annual turnover of 10 billion euros and employing 200,000 people (Kaygusuz et al. 2007). According to *Renewables 2012 Global Status Report* (Martinot and Sawin 2012), "Significant technology and cost reductions of renewable energy technology, along with improved business and financing models, are increasingly creating clean and affordable renewable energy solution for individuals and communities in developing countries." China, the USA, Brazil, Canada, and Germany were the top five countries in 2011 in terms of their capacity to produce renewable energy electricity. If we consider nonhydroelectric renewable energy power capacity, this ranking is changed to China, the USA, Germany, Spain, and Italy. The fifth ranking in both cases is followed closely by India. China installed 70 GW (mostly wind power) last year, and the country's 282 GW of hydropower generation capacity is not included (Martinot and Sawin 2012).

According to an IEA report (IEA 2012c), renewable energy subsidies sharply increased to 88 billion dollars in 2011, which shows a growth rate of 24 % over 2010. "Government policies have been essential to recent growth in renewable energy, especially in the power sector. Environmental concerns have been a key policy driver, targeting emissions reduction of carbon dioxide and local pollutants. Renewables have also been supported to stimulate economies, enhance energy security and diversify energy supply." It has been mentioned in *GSR 2012* (Martinot and Sawin 2012) that worldwide new investment in renewable energy sources increased to 257 billion dollars in 2011, which is twice the investment in 2007 and six times higher than 2004. Wind and solar energy are the main sources of renewable energy used by many countries. Table 2.3 shows the figures for wind and solar energy consumption over 2010–2011.

As we see in Table 2.3, Europe is the front-runner in using renewable energy technologies; it has the biggest capacity for wind energy and the highest growth rate for solar energy. Also, Europe accounts for almost 42 % of global wind energy consumption. Wind energy usage for Germany, Spain, and the UK in 2011 was 46.5, 42.4, and 15.8 TWh respectively. According to Kaygusuz et al. (2007), "Impressive annual growth rates of more than 40 % between 1996 and 2003 have made Europe into the frontrunner in wind energy technology development." In the Asia Pacific

**Table 2.3** Wind and solar energy consumption over 2010–2011 (TWh)

| | Wind | | | Solar | | |
|---|---|---|---|---|---|---|
| | 2010 | 2011 | Change (%) | 2010 | 2011 | Change (%) |
| North America | 105.2 | 133.3 | 26.7 | 1.3 | 2.1 | 55.2 |
| S. & Cent. America | 3.6 | 4.4 | 22.7 | a | a | b |
| Europe & Eurasia | 152.5 | 182.0 | 19.4 | 23.2 | 44.6 | 92.2 |
| Middle East | 0.3 | 0.3 | 0.1 | a | 0.1 | 99.5 |
| Africa | 2.3 | 2.3 | 0.8 | a | 0.1 | 43.6 |
| Asia Pacific | 83.9 | 115.1 | 37.2 | 5.3 | 8.9 | 68.2 |
| World | 347.8 | 437.4 | 25.8 | 29.9 | 55.7 | 86.3 |

*Source*: *BP Statistical Review of World Energy, 2012*
Notes: *a* less than 0.05, *b* less than 0.05 %

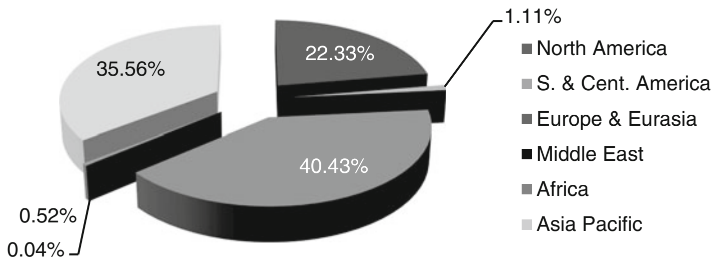


**Fig. 2.3** Cumulative installed wind turbine capacity, 2011 (Reproduced from BP (2012))

region, China's consumption in 2011 was 73.2 TWh, constituting more than 60 % of the Asia Pacific market and 16.7 % of the global market.

As an individual country, the USA has the first rank for wind energy consumption (121 TWh), which is comparable with total consumption in the top three consumer countries in Europe (135.1 TWh) and accounts for 27.7 % of the global market. Some development in wind energy has taken place in regions like the Middle East and Africa. Along with Ethiopia, which has joined the ranks of countries that have commercial-scale projects for using wind energy, the South African market is venturing into wind energy. In the Middle East, Iran is the only country with large-scale wind projects, and it had a total of 91 MW at the end of 2011 (Martinot and Sawin 2012). There was little development in Iran over 2010–2011 compared with the previous years' trend due, at least in part, to the imposition of sanctions on Iran and the economic difficulties it faced in developing these projects.

Regarding installed wind turbine capacity, the most significant growth was seen in Argentina and Brazil with 239.4 and 53.8 % respectively. The region of South and Central America has the highest growth rate (66 %) for cumulative installed wind capacity in the world. Almost 67 % of the current global capacity is installed in four countries. China leads the list followed by the USA, Germany, and Spain (BP 2012). The distribution of total installed global wind turbine capacity is shown in Fig. 2.3.

Although Europe is considered as a leader in terms of cumulative installed capacity, there are many installations outside Europe. If we will not experience any technological advance during this time period, then we can forecast that wind power will be able to generate 10–20 % of the global electricity by the year 2050—this has already been achieved in Denmark (Tester et al. 2005).

Solar energy is the second main source to deploy renewable energy. The use of photovoltaic energy is growing quickly. The size of global installed capacity was 2 GW in 2002 compared with 69 GW in 2011 when the solar photovoltaic (PV) had an extremely high growth rate, as was the case a year before. About 30 GW of new capacity has been installed globally, increasing worldwide cumulative installed photovoltaic power by 73 % to 69 GW, and it is almost 10 times the global capacity in 2006 (BP 2012) As we see in Table 2.3, Europe is the major area for using solar energy. Germany is the leader in this region followed by Italy and Spain. Most of the new photovoltaic systems have been installed in Europe, which has almost 74 % of the total capacity in the world. According to BP, the installed capacity in Germany and Italy was 24.8 and 12.8 GW respectively, which constitutes 54 % of the global installed photovoltaic power in 2011. Other top markets in Europe include France, the Czech Republic, Belgium, and the UK. The top five countries for cumulative installed solar PV at the end of 2011 were Germany, Italy, Japan, China, and the USA, closely followed by Spain.

According to the *Global Status Report 2012* (Martinot and Sawin 2012), “For the first time ever, solar PV accounted for more additional capacity than any other type of electricity generating technology: PV alone represented almost 47 % of all new EU electric capacity that came on line in 2011.” Although installation of PV power plants shows an extreme growth rate around the world, the size of solar energy consumption in the Middle East and Africa is much lower than other regions. There is a huge potential in these areas for deploying solar energy, but they have not used this source of energy as much as other countries so far as they have rich sources of fossil fuels. Fossil fuels are subsidized in petroleum-exporting countries, accounting for 34 % of the worldwide subsidies. Iran’s subsidies at a rate of 82 billion dollars were the highest in 2011 despite the introduction of energy price reforms in 2010. Saudi Arabia has the second-highest subsidies at 61 billion dollars (IEA 2012c). These subsidies are the main reason why these countries fall behind others in the deployment of solar energy. Breyer et al. (2010) have argued that PV power plants have achieved parity with oil power plants on a total cost basis and it is possible for the Middle East and North Africa (MENA) region to reach fuel parity for PV and fossil fuel power plants in the first half of the 2010s.

### 2.2.3 *Outlook of Energy Consumption*

It is expected that the global population will increase to 8.6 billion by 2035 (IEA 2012a). Consequently, there will be a growth in economic activities and energy consumption. Of course, some events cannot be forecast in the long term. The Asian financial crisis in 1997–1998 and the US subprime mortgage crisis in 2008–2009 are two examples of shocks for the global economy. Most projections are usually calculated on the basis of gradual trends. Economic growth, energy consumption, and environmental issues are affected by economic shocks. Economic recovery varies among different countries. The recession in the USA has finished officially, but Europe's recovery has a time lag. According to the *International Energy Outlook 2011* reference scenario, most countries will have resumed the economic growth rate forecast for the long term before the crisis by 2015 (Conti and Holtberg 2011). It states that global GDP will increase annually by 3.4 % on average over 2008–2035. This rate is estimated to be 4.6 and 2.1 % for non-OECD and OECD countries respectively. Figure 2.4 shows world energy consumption outlook by groups of countries and the world.

According to *IEO 2011*, world energy consumption will increase by 53 % over the years 2008–2035. The average annual percentage change is 1.6 % globally and is forecast as 0.6 and 2.3 % for OECD and non-OECD countries respectively. Energy consumption in non-OECD countries (led by China and India) shows a phenomenal growth rate of 117 % during the outlook period. China and India will account for 31 % of global energy consumption in 2035. The slowest growth rate among non-OECD countries will be Europe and Eurasia—just 16 % between 2008 and 2035—due to its population decline and energy efficiency achieved by replacing inefficient equipment (Conti and Holtberg 2011).

We should mention that different scenarios in *IEO 2011* are calculated on the basis of oil prices and energy demand. For example, alternative energy supply conditions are forecast on the basis of high and low oil prices. Also, the impact of high and low non-OECD demand on the global market is estimated. *World*

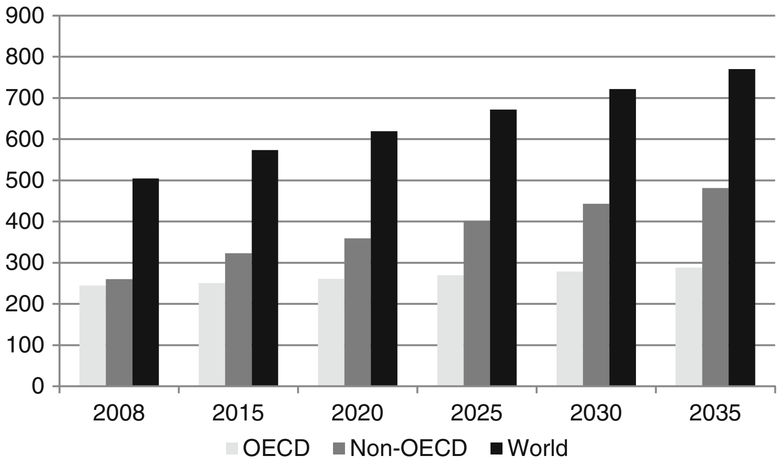


**Fig. 2.4** World energy consumption by country group (quadrillion British thermal unit, QBtu) (Reproduced from Conti and Holtberg (2011))

*Energy Outlook* (*WEO*) scenarios are defined by the underlining assumption about government policies. In this regard, four scenarios are differentiated by the IEA in the *WEO 2012* report: Current Policies Scenario, New Policies Scenario, 450 Scenarios, and Efficient World Scenario. Nonpolicy assumptions are economic growth, population, and energy prices, which are considered for each scenario.

New Policies Scenario, which is called the central scenario or reference in the IEA report, considers all policies and commitments already implemented alongside those policies that have been announced and are to be introduced. Current Policies Scenario includes those government policies that had been made as a law or implemented by mid-2012 without considering any possible policy in the future. 450 Scenarios is defined on the basis of the possibility of limiting the increase in global average temperature to 2 °C compared with preindustrial levels. Experts believed that GHGs should be limited to 450 ppm of carbon dioxide equivalent in order to meet this target. Efficient World Scenario quantifies the implication of major changes in energy efficiency for the economy, the environment, and energy security (IEA 2012c). Figure 2.5 shows the total primary energy demand (TPED) based on country grouping in the New Policies Scenario.

According to the IEA estimation, OECD energy demand in 2035 will be 3 % more than 2010, but fuel substitution will make some changes in the energy mix. The OECD oil and coal demand is forecasted to decrease over 2010–2035 by 21 and 24 % respectively. By contrast, the share of natural gas and renewable energy is rising. The biggest change is related to renewable energy, which will make for around 33 % of OECD power generation in 2035. Although the share of nuclear power has increased from 19 % to 21 % due to some changes made by Europe and Japan to reduce their reliance on nuclear power, it will increase in absolute figures due to nuclear generation growth in North America and South Korea (IEA 2012c).

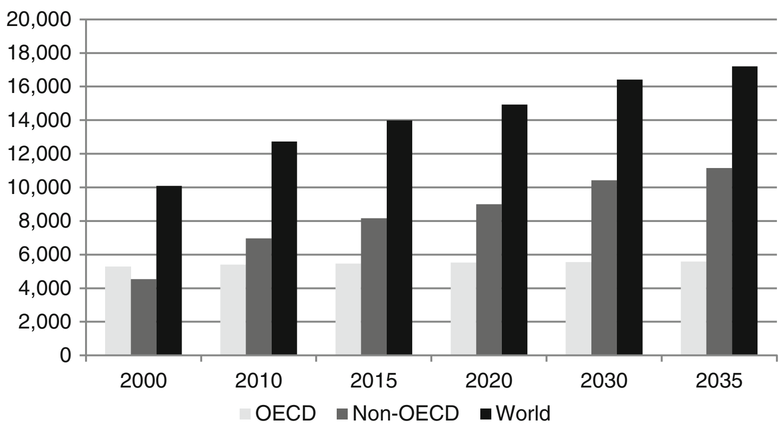


**Fig. 2.5** Total primary energy demand by country group (Mtoe (Reproduced from IEA (2012c))

## 2.3 Energy Consumption and Economic Growth

The level of economic activities plays a key role in energy consumption and is considered a key driver of energy markets. Many scholars have studied the relation between energy consumption and economic growth. Generally, four types of hypotheses are defined in this regard. If there is no causality, called neutral hypothesis, it means energy consumption is not related to GDP. Therefore, neither conservative nor expansive policies affect economic growth. Unidirectional causality may exist from economic growth to energy consumption (conservation hypothesis) or energy consumption to economic growth (growth hypothesis). Feedback hypothesis is applicable when there is bidirectional causality. Depending on each hypothesis, energy policies have different influences on economic growth. Discussion about the impact of energy consumption on economic activities got importance after the Arab oil embargo in 1973.

Early research in this regard was published in the 1970s. Allen et al. (1976) projected economic growth and energy demand for the USA over 1975–2010. Hitch (1978) discussed how much energy consumption conservation can contribute to energy supply and how it influences economic growth. The idea of causality relationship between energy consumption and economic growth was introduced by Kraft and Kraft (1978). They used the Granger causality test to define the relation between gross energy inputs and gross national product (GNP) and found that causality is unidirectional, running from GNP to energy for the postwar period in the USA. Akarca and Long (1980) and Yu and Hwang (1984) applied Sim's method by using US data and found no causal relationship between GNP and energy. Furthermore, Yu and Hwang argued that there is a slight unidirectional relation from employment to energy consumption. Yu and Jin (1992) showed that a long-run equilibrium relationship does not exist between energy consumption and real output or employment in the USA. Stern (1993) examined the causal relationship between GDP and energy use applying the vector autoregressive (VAR) model. He argued that the results of the Granger test are different for measuring impacts of quality-weighted final energy use and gross energy use on GDP. The former shows a causal relationship running from energy consumption to economic growth, but in the latter, it is vice versa. According to his research, conservative energy policy and rising tax on energy without specifying the ways for energy saving may reduce economic growth.

Cheng (1995) reexamined the causality between energy consumption and economic growth with both bivariate and multivariate models for US data over the period 1947–1990. According to his research, there is no causality relationship from GNP to energy consumption. In another research, Cheng (1998) used Hsiao's Granger causality and found that employment and real GNP directly cause energy consumption. Based on his findings, energy conservation policy may not affect a country like Japan. Also, Cheng (1999) applied the Johansen cointegration test to investigate this relationship for India and detected no causality from energy consumption to economic growth. He found that causality runs from economic growth to energy consumption instead. Stern (2000) extended his previous work on the analysis of the causal relationship between GDP and energy use in the USA for the postwar period by using the cointegration test, and his findings were similar to the Granger causality results.

In recent works, Wolde-Rufael (2005) examined the long-run relationship between energy use per capita and GDP per capita for 19 African countries applying two methodologies—the developed cointegration test proposed by Pesaran, Shin, and Smith and the Toda and Yamamoto test. His research showed a long-run relationship between energy use and GDP per capita for 8 of the 19 countries and a causal relationship for 12 countries. Lee and Chang (2008) applied panel models to reinvestigate the comovement causal relationship within a multivariate framework for 16 Asian countries. Their results indicate that energy consumption is caused by GDP in the long term but not vice versa, and there is no short-term or long-term relationship from GDP to energy consumption. It means more energy consumption comes with higher GDP, but it is not the same from GDP to energy consumption. Lee and Chang (2008) further divided the 16 countries into Asia-Pacific Economic Cooperation (APEC) and Association of Southeast Asian Nations (ASEAN) members. Their findings strongly support that energy consumption has a significant impact on economic growth in Asian countries. Therefore, continuous energy use can generate a continuous increase in economic output. In other words, GDP is fundamentally driven by energy.

Narayan and Prasad (2008) used a bootstrapped approach to causality for testing the mutual impact of electricity consumption and GDP for 30 OECD countries. They found causality from electricity consumption to GDP for eight countries. This means the electricity conservation policy has a negative effect on real GDP in these countries. But this policy does not influence the other 22 countries. Narayan and Prasad (2008) also indicated that real GDP causes electricity consumption for six countries and policymakers should have strategies to ensure enough energy supply to achieve the planned economic growth rate. Chontanawat et al. (2008) examined the causal relationship from energy consumption to GDP for 30 OECD and 78 non-OECD countries. They found that causality from energy to GDP in OECD countries is more prevalent than non-OECD countries, implying that energy conservative policies have a greater impact on the economic growth of developed countries than developing countries.

Huang et al. (2008) used a panel data of energy consumption and GDP for 82 countries to investigate causality. They classified these countries into four groups based on income levels defined by the World Bank: low-income group, lower middle-income group, upper middle-income group, and high-income group. According to their findings, using data for all countries as one group shows a bidirectional positive relationship between economic growth and energy consumption. But the result is different when the method is applied for different groups. Huang et al. (2008) detected a unidirectional positive relationship from economic growth to energy consumption for the middle-income group countries and a negative one for the high-income group countries.

Apergis and Payne (2010a) investigated the causal relationship between renewable energy consumption and economic growth for a panel of 20 OECD countries, applying the panel cointegration and error correction model. According to their findings, the short-run and long-run Granger tests detected positive bidirectional causality between renewable energy consumption and economic growth. Also, renewable energy influences economic growth because of its positive effect on the real gross fixed capital formation. Apergis and Payne (2010a) argued that this evidence proves the importance of renewable energy sources in the energy portfolio of the OECD countries. The estimation of the vector error correction model shows both short-run and long-run bidirectional causality between renewable energy consumption and economic growth. They indicated that this result emphasizes the benefits associated with supportive policies for renewable energy such as tax credits on production, rebate for the system installation, portfolio standards, and markets for renewable energy certificates.

In another research, Apergis and Payne (2010b) examined the causal relationship between real GDP, renewable energy consumption, real gross fixed capital formation, and labor force for 13 countries within Eurasia. Due to the importance of Russia in the Eurasia region, they categorized two data sets to run the causality test with and without it. The result of panel cointegration tests for both data sets shows a long-run relationship between real GDP, renewable energy consumption, real gross fixed capital formation, and labor force. The result of panel error correction models shows both a short-run and a long-run bidirectional causal relationship between renewable energy consumption and economic growth. Apergis and Payne (2010b) indicated that a multilateral effort to develop renewable energy and energy efficiency should be encouraged by policymakers. Also, they stated that a proper incentive mechanism to promote market availability of renewable energy should be introduced.

Wolde-Rufael and Menyah (2010) tried to test the causal relationship between nuclear energy consumption and real GDP for nine advanced countries applying the Toda and Yamamoto version of the Granger causality test. They found a unidirectional causality running from nuclear energy consumption to economic growth in Japan, the Netherlands, and Switzerland; a unidirectional causality from economic growth to nuclear energy consumption in Canada and Sweden; and a bidirectional causality in France, Spain, the UK, and the USA. Since the causality relationship in France, Japan, the Netherlands, and Switzerland is negative, they argued, energy conservative policies could help mitigate the negative effects of increasing nuclear energy consumption on economic growth. Lee and Chiu (2011) applied four methodologies—the Johansen cointegration test, the Granger noncausality test, the generalized impulse response function, and the generalized forecast error variance decomposition—to investigate the relationship between nuclear energy consumption, real oil price, oil consumption, and real income in six highly industrialized countries. Their results show a unidirectional causality running from economic growth to nuclear energy consumption in Japan. It means the conservation energy policy does not influence economic growth. Also, there is a bidirectional relationship between nuclear energy consumption and real income in Canada, Germany, and the UK, but no causality was found between these two parameters in France and the USA.

Unlike previous studies, Apergis and Payne (2012) investigated the simultaneous consumption of renewable and nonrenewable energy in order to examine the causal relationship between them and economic growth for 80 countries. According to their findings, there is a bidirectional causality between renewable and nonrenewable energy consumption and economic growth in both short-run and long-run periods. It means both types of energy sources are important for economic growth. Furthermore, the results show a negative bidirectional causality between these measures, implying substitutability of renewable and nonrenewable energy sources. Apergis and Payne (2012) argued that substitutability of renewable and nonrenewable energy sources supports continuation of governmental policies to promote renewable energy consumption as well as implementation of policies to reduce nonrenewable energy consumption.

Yildirim and Aslan (2012) applied both the Toda–Yamamoto procedure and the bootstrap-corrected causality test for 17 highly developed OECD countries to investigate the relationship between energy consumption, economic growth, employment, and gross fixed capital formation. They found a bidirectional causality between energy consumption and real GDP for Italy, New Zealand, Norway, and Spain. The authors believed that due to the support feedback hypothesis for these countries, the energy conservation policy should not be followed by these countries at the aggregated level because the total economy is influenced by opposite effects. It means economic growth will be reduced by lower levels of energy consumption and vice versa, making for a circular relationship. In this situation, the energy policy should be regulated carefully and diversified on the basis of sectors or energy kinds. According to the findings of this study, there is a unidirectional causal relationship from energy consumption to economic growth for Japan and in the opposite direction for Australia, Canada, and Ireland, whereas there is no causality relationship for all the other nine countries. Yildirim and Aslan (2012) also tested the importance of lag length in their research and found that the selection of lag length is important for Denmark, Ireland, Norway, and Spain. Table 2.4 compares the results of these empirical studies.

The causality relationship between energy consumption and economic growth is analyzed in order to examine the possible effects made by energy policies. As is evident from Table 2.4, there may be different results for some countries in the same period with different methodologies or even similar methodologies. Also, it should be taken into account that this analysis considers individual relationships between two variables (in this case, energy consumption and economic growth). Therefore, such analysis of effects is not reliable to be a basis for making decisions regarding energy policy. There are other parameters such as technological innovation and governmental taxes that may affect this relationship. The impacts of energy policies are conditional on the country, applied methodology, and time effects in the sample of data. Also, the interaction effects with other variables should be considered.

**Table 2.4** Comparing empirical studies on the energy consumption–growth nexus

| Author | Period | Country | Methodology | Causality relationship |
|---|---|---|---|---|
| Kraft and Kraft (1978) | 1947–1974 | USA | Granger causality | GNP → EC |
| Akarca and Long (1980) | 1950–1970 | USA | Sim's technique | Neutral |
| Yu and Hwang (1984) | 1947–1979 | USA | Sim's technique | Neutral |
| Yu and Jin (1992) | 1974–1990 | USA | Co-integration, Granger | Neutral |
| Stern (1993) | 1947–1990 | USA | Multivariate VAR model | EC → GDP |
| Cheng (1995) | 1947–1990 | USA | Co-integration, Granger | Neutral |
| Cheng (1998) | 1952–1995 | Japan | Hsiao's Granger causality | GNP → EC |
| Cheng (1999) | 1952–1995 | India | Co-integration, ECM, Granger | GDP → EC |
| Stern (2000) | 1948–1994 | USA | Co-integration, Granger | EC → GDP |
| Wolde-Rufael (2005) | 1971–2001 | 19 African countries | Co-integration, modified Granger | GNP → EC (5) |
| | | | | EC → GNP (3) |
| | | | | GNP ←→ EC (2) |
| | | | | Neutral (9) |
| Lee and Chang (2008) | 1971–2002 | 16 Asian countries | Co-integration, ECM | EC → GDP |
| Narayan and Prasad (2008) | 1960–2002 | 30 OECD | Bootstrapped causality | EC → GDP (8) |
| | | | | GDP → EC (22) |
| Chontanawat et al. (2008) | 1960–2000 | 30 OECD | Co-integration, Granger | EC → GDP (21 OECD, 36 non-OCED) |
| | | 78 Non-OECD | | |
| Apergis and Payne (2010a) | 1985–2002 | 20 OECD | Co-integration, ECM | GDP ←→ RE |
| Apergis and Payne (2010b) | 1992–2007 | 13 Eurasia | Co-integration, ECM | GDP ←→ RE |
| Wolde-Rufael (2005) | 1971–2005 | 9 developed countries | Modified Granger | NE → GDP (3) |
| | | | | GDP → NE (2) |
| | | | | GDP ←→ NE(4) |
| Lee and Chiu (2011) | 1965–2008 | 6 highly industrialized countries | Co-integration, Granger, generalized impulse response function | GDP → NE(1) |
| | | | | Neutral (2) |
| | | | | GDP ←→ NE(3) |

(continued)

**Table 2.4** (continued)

| Author | Period | Country | Methodology | Causality relationship |
|---|---|---|---|---|
| Apergis and Payne (2012) | 1990–2007 | 80 countries | Co-integration, ECM | RE, NRE ←→ GDP |
| Yildirim and Aslan (2012) | 1971–2009 | 17 highly developed OECD | Bootstrap-corrected test, modified Granger | EC → GDP (1) |
| | | | | GDP → EC (3) |
| | | | | GDP ←→ EC (4) |
| | | | | Neutral (9) |

*Notes*: *VAR* vector autoregressive model, *ECM* error correction model, *EC* energy consumption, *GDP* gross domestic product, *RE* renewable energy consumption, *NRE* non-renewable energy consumption, *NE* nuclear energy consumption
EC → GDP means that the causality runs from energy consumption to economic growth
GDP → EC means that the causality runs from economic growth to energy consumption
EC ←→ GDP means there is a bi-directional causality between energy consumption and economic growth
Neutral means there is no causality between energy consumption and economic growth

## 2.4 The Main Drivers for Using Renewable Energy

The first driver for seeking alternative energy sources has been energy security since the Arab oil embargo in 1973 or the first oil shock. The oil shocks in the 1970s stimulated interest in renewable energy sources. The global concern about climate change and sustainability encouraged countries to invest in renewable energies. We can define three main drivers for using renewable energy: energy security, economic impacts, and $CO_2$ emission reductions.

### *2.4.1 Energy Security*

As we have mentioned, concerns about the security of energy supply rose after the Arab oil embargo in 1973. There are other factors such as high oil prices, increasing dependency on oil imports, depletion of fossil fuels, increasing competition from emerging economies, political instability in major oil-producing countries, and the high impact of any disruption in energy supply on developed and rapidly developing countries (Bhattacharyya 2011). The level of insecurity is reflected by the risk of supply disruption and the estimated cost incurred for making security. Owen (2004) called security of energy supplies a key requirement for the economic, environmental, and social objectives of sustainable development policies. In his view, energy security risk could be classified into strategic and domestic system risks. He also defined damage costs and control costs as potential costs imposed by energy insecurity. He argued that damage costs could be evaluated by a potential decrease in GNP but it is difficult to estimate how much money is spent as control costs on energy security. For example, it is very difficult to estimate how much money has been spent by the USA to control oil security.

Delucchi and Murphy (2008) investigated the impact of US military costs on motor vehicle fuels and estimated that in the case of no oil in the Persian Gulf, US defense expenditure might be reduced by about \$27–\$37 billion per year, meaning \$0.03–\$0.15 per gallon (\$0.01–\$0.04 per liter). Hedenus et al. (2010) analyzed the expected economic cost of oil supply disruption by energy policies in the EU-25. They analyzed how energy policies affect the oil market and how much money could be gained by these policies. The results show that the expected cost of oil disruption is 29.5–31.6 billion euros a year, corresponding to roughly 9–22 euros/bbl or 6–14 c/l of gasoline. Delucchi and Murphy (2008) also estimated GHG benefits of 20 euros/ton carbon dioxide to substitute oil for pellets in the residential sector for heating.

Concerns about climate change have made energy security objectives more crucial. The diversification of energy supply to promote energy security could be considered as a policy for climate protection (Bhattacharyya 2011). Before the industrialization era and prior to using coal as a main source of energy in the mid-nineteenth century, renewable energy sources were used widely. There are huge potential sources of renewable energy such as hydropower, solar, wind, and biomass around the world, which are able to supply clean energy and enhance long-term sustainable energy supply (Asif and Muneer 2007). Renewable energy sources may have security issues due to intermittent characteristics of some kinds of energy such as solar and wind energy or the possibility of low rainfall for hydropower consumption. Therefore, such factors should be considered for the sectors that rely heavily on these sources. Renewable energy technologies are beneficial for countries that produce and consume energy. Renewable energy technologies reduce domestic demand for fossil fuels and increase the capability for export. For example, Iran was the fourth largest worldwide natural gas producer in 2011 but was a net importer because of high domestic demand. Also, high dependency on imports could pose serious problems if there is any disruption in energy supply. For example, European countries are dependent on Russia for importing natural gas. They experienced a difficult situation when Russia cut off all gas supply transmitted by Ukraine in 2006.

Generally, renewable energy technologies are considered as an expensive option, which are not compatible with traditional sources of energy, but some technologies like wind power are more feasible today, and the cost of other technologies such as solar photovoltaic is decreasing rapidly (IEA 2011). Furthermore, we should consider external costs that are spent for energy security indirectly in our calculation. Alongside storage costs and military expenditure, there is an extreme externality cost due to the possibility of accidents in nuclear power plants such as Three Mile Island (1979), Chernobyl (1986), and Fukushima Daiichi (2011). According to a report prepared for the international organization Chernobyl Forum (2003–2005), the total amount spent by Belarus over 1991–2003 is evaluated at more than 13 billion dollars. Also, the total losses over 30 years have been estimated at around 235 billion dollars by Belarus (Chernobyl Forum 2006). According to this report, in Ukraine 5–7 % of government expenditure is still allocated to Chernobyl-related programs. Around 6,000 thyroid cancers have been found in contaminated regions of the Chernobyl accident to date, and an additional 10,000–40,000 cases of cancer are estimated over the next decades (Ten Hoeve and Jacobson 2012). The number of accidents in nuclear power plants may be rare, but there will be an extreme cost in terms of economic, social, and environmental aspects. If we include all external costs including social and environmental security in our evaluation, renewable energy sources will be feasible.

### *2.4.2 Economic Impacts*

The emphases for economic impacts are job creation, industrial innovation, and balance of payment. Renewable energy technologies could enable countries with good solar or wind resources to deploy these energy sources to meet their domestic demand. In parallel, demand management policies are used in energy areas to reduce the demand through various energy-saving technologies and policies (Heshmati 2014). Also, renewable energy technologies may even enable these countries to deploy renewable energy sources with long-term export potential. Also, the cost of importing fuels can affect economic growth. Some major consumer countries like the USA have domestic resources that enable them to cover a part of the demand. The USA spent around 410 billion dollars in 2008 to import fossil fuels, constituting more than 3 % of its GDP, but this figure could be higher for developing countries without enough energy resources (IEA 2011) Therefore, if these countries could reduce their balance of payment by producing renewable energy to replace fossil fuels, they could make a capacity for investment in other sections. The IEA made a cost–benefit analysis for investment in low-carbon energy systems based on two scenarios: ETP 2012 6 °C (6DS), which assumes business as usual, and 2 °C (2DS), which is targeted at reducing carbon dioxide emissions by 50 % compared to 2005 levels. The results show that an estimated 103 trillion dollars will be saved during the years 2010–2050 by reducing fossil fuel consumption. It is indicated that this calculation is based on reduction in fossil fuel purchase (214 Gtoe) and it could be 150 trillion dollars if the impact of lower fuel prices is taken into consideration (IEA 2012a).

A main economic driver to enhance renewable energy technologies is their potential to create jobs. It is estimated that 5 million people work in renewable energy industries. Although total employment in these industries continues to increase, some countries such as Germany and Spain suffered recently because of the global recession and policy changes (Martinot and Sawin 2012). Figure 2.6 shows the distribution of estimated jobs in renewable energy worldwide by industry based on the *GSR 2012* report.

The *GSR 2012* has estimated the breakup of job creation by sector as follows: 1.5 million workers in biofuels, 820,000 in solar PV, and 670,000 in wind power. Currently, more than 1.6 million workers are employed in the renewable energy industry (Martinot and Sawin 2012). The majority of jobs in renewable energy

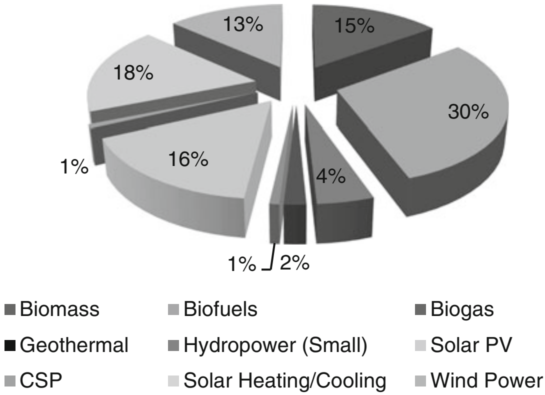


**Fig. 2.6** Estimated job in renewable energy worldwide, by industry (Reproduced from Martinot and Sawin (2012))

industries are located in China, Brazil, the USA, and the EU. Germany is the front-runner country in Europe for job creation in the renewable energy industry. Germany has increased power generation sharply by renewable technologies since the beginning of this century with a share of almost 15 % of total electricity production in 2008 (Frondel et al. 2010). Ragwitz et al. (2009) investigated the gross and net effects of renewable energy policies in the EU and analyzed the past, present, and future effects of renewable energy policies on employment and economics of countries in general and at the members' levels. They found that current high economic benefits of renewable energy sectors could be increased in the future "if the current policies are improved in order to reach the agreed target of 20 % renewable energies in Europe by 2020." They argued that increasing share of renewable energy sources not only has no negative effect on the economy but could also help the economy by job creation and increasing GDP. In their view, the economic advantage of renewable energy could be higher if external costs are included.

Mathiesen et al. (2011) examined a 100 % renewable energy system including transport by the year 2050 and considered two short-term transition targets in 2015 and 2030. They also indicated that implementing renewable energy technologies could have positive socioeconomic impacts including job creation and increasing exports. Several market leaders including Germany, Denmark, and Japan have focused on industrial and economic development objectives to support renewable energy technologies through stable policy frameworks, innovation chains, and a good environment for investment. They have specialized in the knowledge-based stage and became front-runners in terms of innovation in the renewable energy industry. This situation gives them a first-mover advantage in global renewable energy trade and technology development (IEA 2011). "International trade performance depends on technological capability. If a country has a comparatively high knowledge base, it also has an additional advantage in developing and marketing future technologies" (Walz et al. 2009).

### 2.4.3 $CO_2$ Emission Reduction

Renewable energy technologies could reduce carbon dioxide emissions by replacing fossil fuels in the power generation industry and transportation sector. Life-cycle $CO_2$ emissions for renewable energy technologies are much lower than fossil fuels. The life-cycle balance is also considered an important factor for heat and transportation sectors. Based on an analysis performed by IEA, renewable power generation enabled focused countries to save 1.7 Gt $CO_2$ emissions in 2008, which is more than the total power sector's $CO_2$ of the Europe region (1.4 Gt) (Ölz 2011). This analysis shows that hydropower technology constitutes the largest share for saving $CO_2$ emissions with 82 % followed by biomass and wind with 8 and 7 % respectively.

According to an IEA analysis, the potential saving of OECD and BRICS countries (Brazil, Russia, India, China, and South Africa) is estimated roughly at 5.3 Gt in 2030, almost the same as forecast for power-related $CO_2$ emissions in *WEO 2010* for these countries in 2030 under a 450 ppm scenario (5.8 Gt).

Figure 2.7 shows the $CO_2$ saving under the WEO 450 scenario compared with the no-RE scenario in 2030. The key point is that the largest $CO_2$ saving is concentrated in OECD countries and China. According to an IEA report, $CO_2$ saving in China on a 450 ppm scenario would be 2.2 Gt, constituting 64 % of the BRICS total saving (Ölz 2011). Edenhofer et al. (2010) examined technological feasibility and economic consequences of achieving GHG targets and found that these targets are low enough to be feasible technically and economically. They stated that this viability crucially depends on particular technologies. For example, the availability of carbon capture storage technology is very important to remove $CO_2$ from the atmosphere. They also argued that additional political and institutional prerequisites are required to achieve the targets.

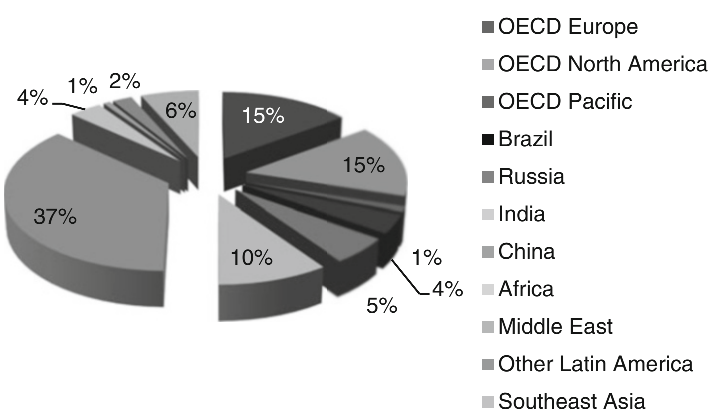


**Fig. 2.7** Saving in $CO_2$ emissions between no-RE and 450 scenarios in 2030 (Reproduced from Ölz (2011))

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