Ph.D. Dissertation in Engineering

The Impact of Renewable Energy Development on Carbon Emission Reduction

탄소 배출 절감에 대해 재생 에너지 개발이 미치는 영향

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Abstract

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Ongoing concerns about climate change have made renewable energy sources as an important topic of research in world energy consumption. Several scholars have applied different methodologies to examine the relationship between the energy consumption and economic growth of individual countries and groups of countries in order to analyze the effects of energy policies. Moreover, previous studies have analyzed carbon emission savings made by using renewable energy usage as an individual source or in combination with traditional sources of energy (e.g., hybrid plants) by applying life-cycle analysis method.

Previous research has shown that after a certain period, economic growth leads to the promotion of environmental quality. However, econometric critiques have opposed the results of these studies. Moreover, the

effectiveness of governance-related parameters has been neglected. In this research, we analyze the impact of renewable energy development on carbon emission reduction.

In this regard, we discussed a market design for trading electricity generated by renewable energy sources in order to enhance the deployment of renewable energy. Distributed power generation, which is the basis of renewable energy production, encourages the production of renewable energy resources and, decreases transmission loss, increases saving energy, and enhances energy efficiency. Therefore, the integration of distributed, renewable energy sources and smart grids within local marketplaces that trade renewable energy in small units is a promising combination. We propose a marketplace for renewable energy sources, design a market mechanism for trading in this market, and outline the requirements for this market to function.

We also estimate a model to evaluate the effectiveness of renewable energy development, technological innovation and market regulations in carbon emission reduction. For this purpose, we apply a panel data model to the EU-15 countries from 1995 to 2010 to investigate this relationship. Furthermore, we calculate the elasticities of CO_2 emissions in order to evaluate the effectiveness of each parameter. Our finding showed that the effects of climate change could be mitigated by governance-related parameters instead of economic development.

Keywords: renewable energy, technological innovation, environmental tax, carbon emission, economic growth, market mechanism

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Chapter 1: Introduction

1.1 Motivation

Because it is important in industry, electricity consumption will comprise an increasing share of global energy demand for energy during the next two decades. It is expected that the growth rate of electricity consumption will be more than that of the consumption of the other sources of energy, such as liquid fuels, natural gas, and coal (IEA, 2012c). In recent years, increasing prices of fossil fuel, such as the high crude prices recorded in 2008, in addition to 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 risk.

Considering that the major part of greenhouse gases (GHGs) is carbon dioxide, there is a global concern about reducing carbon emissions. In this regard, different policies could be applied to reducing carbon emissions, such as enhancing renewable energy deployment and encouraging technological innovations. In addition, supporting mechanisms, such as feed-in tariffs, renewable portfolio standards, and tax policies are employed by governments to develop renewable energy generation along with implementing energy efficiency for saving energy. Many countries have started to install facilities in order to use renewable energy sources for power generation. However, the share of a renewable energy supply differs by region and country. Europe is considered at the forefront of using renewable energy technologies.

1.2 Problem description

The literature on the relationship between energy consumption and economic growth is extensive. Many researchers have studied this relationship in order to evaluate the effectiveness of conservative energy policies on economic activities. However, few studies have examined that impact of renewable energy sources and governmental policies on carbon emissions. Some researchers (Fthenakis, 2008; Crawford, 2009; Frick et al., 2010) measured the amount of carbon saving by using the life-cycle analysis method. Other researchers analyzed carbon emission saving by enhancing energy efficiency through cogeneration and advance technology (Shipley, 2008; Kiviluoma and Meibom, 2010; Haussmann, 2010). However, no previous study has measured the amount of carbon emission reduction and interaction effects of different policy tools that supporting mechanisms to enhance renewable energy sources (generation and consumption), technological innovation, and market regulation.

The methodology used by the early researchers to investigate the relationship between emissions and GDP per capita is not appropriate. Some researchers, such as Stern (2004), Muller-Furstenberger and Wagner (2007), and Wagner (2008) cast doubt on the existing 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.

Furthermore, a recent study (Dasgupta et al., 2004) pointed out that this relationship is not as rigid as proposed by previous researchers, because poor countries were mistakenly not considered to 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 effect of interactions between different variables. Therefore, the present study investigates the impacts of these important factors and with effects of interactions between them.

1.3 Research 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 estimate a model to measure the size of their effectiveness and the result of interactions between these parameters. Furthermore, we proposed the structure of a marketplace for renewable energy sources, and we outline the requirements for this market to function.

1.4 Research hypothesis

This study examines the effects of renewable energy generation on carbon emission reduction in EU-15 countries. Because Europe is considered at the forefront of renewable energy deployment, these countries are selected to evaluate the effectiveness of enhancing renewable energy on climate change. We study the long-term effects of related policies on individual countries and the group of EU-15 countries. We compare the effect of each variable over time and across the countries. Three hypotheses are posed:

1) The power generated by renewable energy sources in the EU-15 has been able to affect carbon emission through displacing traditional capacity fueled by fossil fuels. Moreover, we expect a negative elasticity for renewable energy sources regarding carbon emission.

2) Technological advances are able to decrease carbon emissions through decreasing the costs for renewable energy sources and enhancing energy efficiency. Therefore, we expect a negative relation between technological innovation and carbon emission. Furthermore, we expect a negative elasticity for technological innovation.
3) Environmental taxes applied by governments have a direct negative relation with carbon 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.

1.5 Methodology

We review the relevant literature on the effectiveness of renewable energy development, production technology, and market regulation on reducimg carbon emissions. We then derive appropriate variables in order to measure their impacts on carbon emission reduction. The effectiveness of technological innovation will be determined by examining energy patent applications that adopt climate change mitigation and ICT (Information and communications technology) patent application. The translog function is employed to investigate the direct impacts and interaction effects of these variables. We apply panel data method to estimate our model in the form of the translog function to investigate the interaction effects of different parameters and calculate the elasticities.

After estimating the model, the elasticities of carbon emission in relation to GDP (Gross domestic product), renewable energy generation, energy patent applications, ICT patents, and environmental taxation trends will be calculated. In economics, elasticity is the measurement of how changing 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 emission. Our experimental results indicate the variables that have more impact on carbon emission reduction. In addition, the results indicate that the decisions of policy makers should apply the policies that are the most effective in achieving targets.

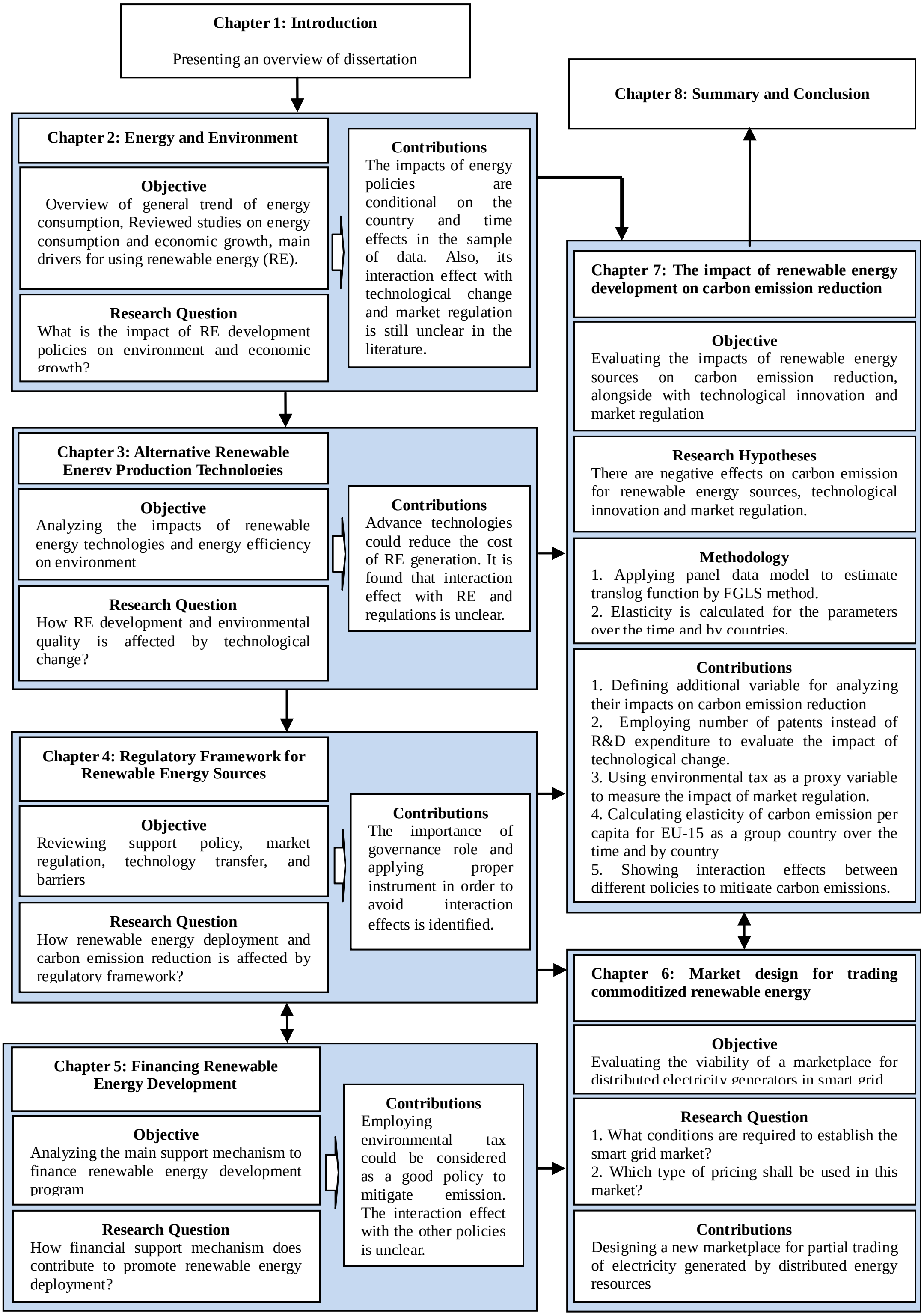
1.6 Contributions

The contribution of this research is to define additional variables including renewable energy generation, technological innovation, and environmental tax to the Environmental Kuznets Curve and analyzing their effects on carbon emission per capita. We employ the number of patents and the amount of environmental taxes instead of R&D expenditures in order to measure technology and market regulation impacts. We also calculate the elasticity of carbon emissions per capita to each variable for EU-15 countries as a group over time and as well as by individual country. We applied a different methodology to the estimate model in order to overcome the econometrics problems neglected by the early researchers. Many researchers, such as Cropper and Griffiths (1994), Shafik (1994), Horvath (1997), Moomaw and

Unruh (1997), and Suri and Chapman (1997), have estimated fixed-effect models without applying regression diagnostic tests. Our estimation method differs from most studies in its use of Feasible Generalized Least Squares (FGLS) to correct heteroscedasticity and autocorrelation. Stern (2002), Aldy (2005), and Luzzati and Orsini (2005) successfully employed the FGLS approach in order to correct cross-sectional heteroscedasticity and serial correlation.

1.7 Outline

In Chapter two, we focus on the current situation of renewable energy consumption and the global outlook in chapter two. We also examine the rolesof economic growth, energy security, and carbon emission reduction as the main drivers in the development of renewable energy. Chapter Three provides a review of the literature on renewable energy technologies, including renewable energy supply and energy efficiency. In Chapter Four, we analyze the regulations for the renewable energy. In Chapter Five, we analyze the supporting mechanism to enhance renewable energy deployment, and in Chapter Six, we propose the structure of a marketplace for renewable energy sources. A market mechanism is designed for trading in this market, and we outline the requirements for the function of this market. In Chapter Seven, we estimate a model in chapter seven in order to evaluate the impact of renewable energy generation, economic growth, technological innovation and environmental tax on carbon emission reduction. The results of this model could be used by the governments to make effective policies to achieve their targets of carbon emission reduction and climate change mitigation.


Chapter 1: Introduction
Presenting an overview of dissertation
Chapter 2: Energy and Environment
Objective
Overview of general trend of energy consumption, Reviewed studies on energy consumption and economic growth, main drivers for using renewable energy (RE).
Research Question
What is the impact of RE development policies on environment and economic growth?
Contributions
The impacts of energy policies are conditional on the country and time effects in the sample of data. Also, its interaction effect with technological change and market regulation is still unclear in the literature.
Chapter 3: Alternative Renewable Energy Production Technologies
Objective
Analyzing the impacts of renewable energy technologies and energy efficiency on environment
Research Question
How RE development and environmental quality is affected by technological change?
Contributions
Advance technologies could reduce the cost of RE generation. It is found that interaction effect with RE and regulations is unclear.
Chapter 4: Regulatory Framework for Renewable Energy Sources
Objective
Reviewing support policy, market regulation, technology transfer, and barriers
Research Question
How renewable energy deployment and carbon emission reduction is affected by regulatory framework?
Contributions
The importance of governance role and applying proper instrument in order to avoid interaction effects is identified.
Chapter 5: Financing Renewable Energy Development
Objective
Analyzing the main support mechanism to finance renewable energy development program
Research Question
How financial support mechanism does contribute to promote renewable energy deployment?
Contributions
Employing environmental tax could be considered as a good policy to mitigate emission. The interaction effect with the other policies is unclear.
Chapter 8: Summary and Conclusion
Chapter 7: The impact of renewable energy development on carbon emission reduction
Objective
Evaluating the impacts of renewable energy sources on carbon emission reduction, alongside with technological innovation and market regulation
Research Hypotheses
There are negative effects on carbon emission for renewable energy sources, technological innovation and market regulation.
Methodology
1. Applying panel data model to estimate translog function by FGLS method.
2. Elasticity is calculated for the parameters over the time and by countries.
Contributions
1. Defining additional variable for analyzing their impacts on carbon emission reduction
2. Employing number of patents instead of R&D expenditure to evaluate the impact of technological change.
3. Using environmental tax as a proxy variable to measure the impact of market regulation.
4. Calculating elasticity of carbon emission per capita for EU-15 as a group country over the time and by country
5. Showing interaction effects between different policies to mitigate carbon emissions.
Chapter 6: Market design for trading commoditized renewable energy
Objective
Evaluating the viability of a marketplace for distributed electricity generators in smart grid
Research Question
1. What conditions are required to establish the smart grid market?
2. Which type of pricing shall be used in this market?
Contributions
Designing a new marketplace for partial trading of electricity generated by distributed energy resources

Chapter 2: Energy and Environment

2.1 Introduction

Carbon emission pollutants primarily are produced by combustion of fossil fuels. Based on IEA, share of energy in 2010 for carbon emission production has been 81.6 percent (IEA, 2012a). Therefore, energy consumption is the main subject when we are talking about climate change issues. According to the *International Energy Outlook 2011(IEO 2011)*, global energy-related carbon emissions rise from 30.2 billion metric tons in 2008 to 35.2 billion metric tons in 2020 and 43.2 billion metric tons in 2035 (Conti, 2011). Most part of this growth belongs to developing non-OECD countries that continue to be dependent heavily on fossil fuels consumption in order to meet energy demand which is going up continuously. Government policies are crucial for recent growth in renewable energy, especially in the power sector. The core part of environmental concerns is reducing carbon emission and local pollutants. More than 70 countries are expected to impose supported policy for deploying renewable energy technologies in the power sector by 2017 (IEA, 2012e). A growing number of researches show that there is a strong relation between climate change and the carbon dioxide (CO_2) emissions which are produced through energy production and consumption.

Currently, fossil fuels are subsidized in many countries and power generation by renewable energy sources is not compatible with these sources. Power generation by renewable energy sources should be increased as much enough in order to decrease unit cost and make it compatible with the other sources. Then, it will be feasible for consumers to replace it with traditional electricity network. Based on Lund H. (2010) definition “renewable energy is defined as energy that is produced by natural resources-such as sunlight, wind, rain, waves, tides, and geothermal heat-that are naturally replenished within a time span of a few years.” According to his view, all technologies which are able to convert natural resources like solar to any kinds of energy to be used for different purposes could be considered as renewable energy.

2.2 General trend of energy consumption

Energy consumption depends on deferent factors such as: economic progress, population, energy prices, weather, technology, etc. 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 sequentially. US, China and Japan have been the major oil consumers with 833.6, 461.8 and 201.4 Mtoe, respectively. While US, Russia and Iran are the biggest consumer for natural gas with 626, 382.1 and 138 Mtoe. China is the biggest consumer in Coal market with 1.8 Gtoe followed by US and India with 501.9 and 295.6 Mtoe.

Based on BP statistical review of world energy (BP, 2012), the average primary energy consumption has been 2,306.7 Mtoe during 2001-2010 comparing with 2,140.5 Mtoe in 1991-2000 which shows a growth rate of 7.8 percent per year. On the other hand, average of carbon dioxide emission in the same periods would be 6,315.9 against 5,882.7 Mtoe and shows a growth rate of 7.4 percent per year. About 87 percent of primary energy consumption in 2010 is described by fossil fuels, while this rate for nuclear energy, hydro electricity and renewable is 5.2, 6.5 and 1.4 percent. Comparing with primary energy consumption in 2011, the share of fossil fuels is almost not changed but share of nuclear energy and hydro electricity is decreased to 4.9 and 6.4, while share of renewable goes up to 1.6 percent. Table (2-1) shows global primary energy consumption by fuel.

Table (2-1): Global Primary Energy Consumption, End of 2011

(Mtoe)

Regions	Oil	Gas	Coal	Nuclear	Hydro	Ren.	Total
N. America	1026.4	782.4	533.7	211.9	167.6	51.4	2773.3
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	2923.4
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	1316.1	531.5	2553.2	108.0	248.1	46.4	4803.3
Total World	**4059.1**	**2905.6**	**3724.3**	**599.3**	**791.5**	**194.8**	**12274.6**
OECD	2092.0	1386.1	1098.6	487.8	315.1	148.0	5527.7
Non-OECD	1967.0	1519.5	2625.7	111.5	476.4	46.8	6746.9
EU	645.9	403.1	285.9	205.3	69.6	80.9	1690.7
FSU	190.6	539.6	169.8	60.2	54.6	0.4	1015.1

Source: BP Statistical Review of World Energy, 2012

2.2.1 Fossil fuels

According to BP statistical review of world energy (BP, 2012), at the end of 2011, 48.1 percent of the proved oil reserves have been located in the Middle East. As we see in Table (2-1), Europe and Eurasia have 8.5 percent of the reserves which most part of this percentage is located in Russian Federation (5.3%) and Kazakhstan (1.8%). Africa has 8 percent of global oil reserves, mostly in Libya (2.9%) and Nigeria (2.3%). In South America, oil proved reserves are mostly located in Venezuela (91% of regional reserves and 17.9% of global reserves). North America has 13.2 percent of oil reserves which most part of it belongs to Canada (80.6% of regional reserves and 10.6% of total global reserves). It means 87 percent of proved oil reserves in the American continent are located in Venezuela and Canada. Natural gas reserves are more centralized than crude oil, because 38.4 percent of reserves are located in Middle East and 37.8 percent can be found in Europe and Eurasia. Russia, Iran and Qatar have almost half of global natural gas reserves. If we take a look at coal reserves, we will find that around 60 percent of global coal reserves are located in US, Russia and China.

In view of consumption, share of Middle East in global oil consumption is 9.1 percent. Europe and Eurasia has 22.1 percent of global oil consumption; it’s less that total oil consumption for China, India, Japan and Korea. Africa has the least share of consumption with 3.9 percent. 25.3 percent of global oil consumption belongs to North America and US with 20.5 percentages, almost as much as Europe, is the biggest consumer in the world. This level of consumption is more than all countries in Europe Union together. Asia Pacific region has the biggest share in oil consumption with 32.4 percent. China is the second biggest consumer in the world (11.4%), but its consumption is almost half of US. It will be interesting if we compare these numbers with oil reserves in US (2%) and China (10%). China is the biggest energy consumer in the world followed by US, but order of fuel sources is different in these countries. Oil is the main source of energy consumption in US, while coal is the most important source of energy in China. Coal consumption in China was 1839.4 Mtoe in 2011, while this number for oil and gas is 461.8 and 117.6 Mtoe. Global Oil consumption has been increased only 0.7 percent comparing with 2010 because of economic recession in major oil consumer countries. Although, oil consumption growth rate is negative in 2011 for OECD countries (-1.2 percent), it has been calculated 2.8 and 5.7 percent for Non-OECD and FSU countries, respectively. If we compare growth rate for crude oil consumption and production, we will find former (0.7 percent) is less than last (1.3 percent) globally. But, it’s not the same in different region. Table (2-2) shows growth rate of fossil fuel consumption in different region around the world.

Table (2-2): Fossil Fuels production and consumption growth rate During 2010-011

	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

Based on these figures, we find that consumption growth rate in Asia Pacific is much stronger than the other regions. Although oil consumption growth rate is negative in some regions like Africa and Europe, but the rate of decreasing in production is much higher than consumption. It means there is a shortage of supply in these countries. Middle East is the only region around the world which has a big difference between production and consumption growth rate for oil and gas.

As mentioned earlier, population growth and expanding economics are the main drivers for increasing energy consumption. Based on 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, 2012e). According to IEA outlook, global GDP is increasing with the rate of 3.5

percent during 2010-2035. It predicts that economic growth in non-OECD countries will be much more than OECD countries. Next parameter for driving energy consumption is price. Of course, its direction may be not the same in different countries. Figures (2-1) and (2-2) show strong impact of GDP on energy consumption in non-OECD and price effect in OECD countries.

Oil consumption in non-OECD has been increased very fast in recent years. Growth rate of oil consumption in these countries in 2010 is more than 40 percent comparing with its level in 2000, while oil consumption in OECD countries has decreased for this period. The largest growth in oil consumption belongs to China, India and Saudi Arabia (Conti and Holtberg, 2011). Increasing oil demand shows economic advance in non-OECD countries. Commercial and individual transportation, manufacturing process and also as fuel for power generation in some countries require a huge amount of oil. On the other hand, population has been increased in many non-OECD countries which support this trend. This figure shows that oil consumption decreased only in 4^{th} quarter of 2008 and 1^{st} quarter of 2009. Oil prices increased sharply in this period but economic growth in these countries were influenced less than OECD countries (EIA, 2013)

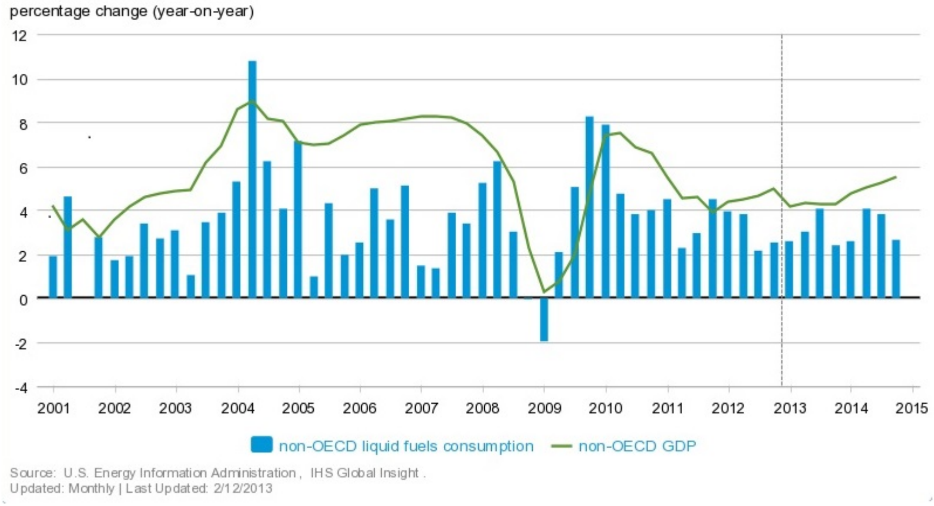


Figure (2-1): Non-OECD quarterly liquid fuels consumption and GDP

OECD countries consume more oil than non-OECD countries, but as figure (2-2), they have a lower oil consumption growth comparing to them. Oil consumption in OECD countries has decreased from 2217.3 Million tons in 2000 to 2092 Million tons in 2011, while it increased in non-OECD countries from 1354.5 to 1967 Million tons in the same period (BP, 2012).

Because of different economic structures in OECD and non-OECD countries, oil consumption follows different pattern in these countries. Many developing countries are using energy incentive technologies, also they don't consider fuel efficiency in economic activities as much as developed countries. In OECD countries, 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. By the way, we can find some structural differences in energy consumption within economic sections in these countries. Vehicle ownership per capita in developed countries is seen more than developing countries. There are many household in OECD countries that have more than one car, but this rate is lower for non-OECD countries. Therefore, transportation sector usually has a bigger share of oil consumption in former comparing with the last. Furthermore, size of service sector in developed countries is larger than developing countries; then, effect of economic growth on oil consumption is not the same in these countries (EIA, 2013).

According to International Energy Outlook, world energy consumption will be increased by 53 percent from 2008 to 2035 (Conti and Holtberg, 2011) Although, worldwide energy consumption has been limited by global recession but world energy demand is started to increase as economies recover from the recession. Economic recovery varies among the OECD countries. For example, economic recession has officially ended in United States but it’s not as strong as recoveries from past recessions. Also, there is a time lag for economic recovery in Europe. It is forecasted that world energy demand will be increased strongly as a result of economic growth in developing countries. Among these countries, China and India were affected the least by the recession and continue to lead world economic growth and energy demand (Conti and Holtberg, 2011)

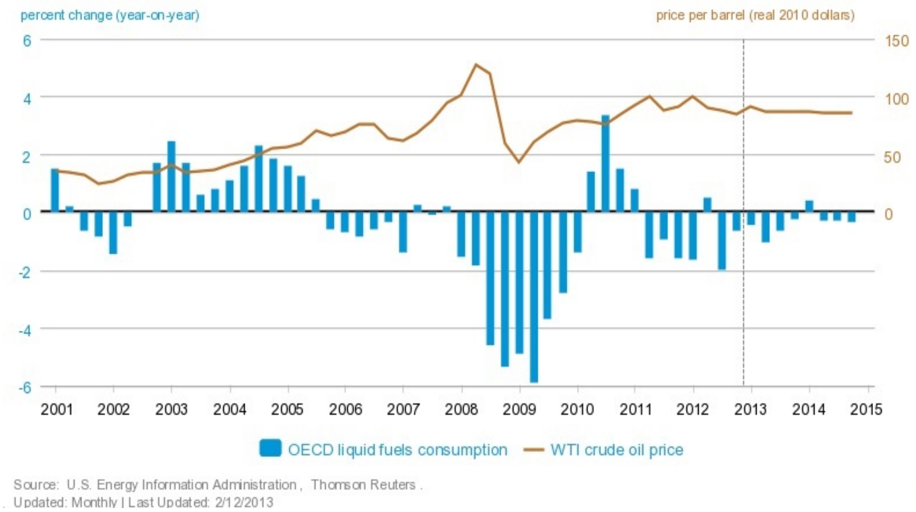


Figure (2-2): OECD quarterly liquid fuels consumption growth rate and WTI crude oil price development

Because of different economic structures in OECD and non-OECD countries, oil consumption follows different pattern in these countries. Many developing countries are using energy incentive technologies, also they don't consider fuel efficiency in economic activities as much as developed countries. In OECD countries, 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. By the way, we can find some structural differences in energy consumption within economic sections in these countries. Vehicle ownership per capita in developed countries is seen more than developing countries. There are many household in OECD countries that have more than one car, but this rate is lower for non-OECD countries. Therefore, transportation sector usually has a bigger share of oil consumption in former comparing with the last. Furthermore, size of service sector in developed countries is larger than developing countries; therefore effect of economic growth on oil consumption is not the same in these countries (EIA, 2013).

The world is relied on fossil fuels to generate electricity power which is used for different purposes, include industrial, agriculture, commercial and residential consumption. Currently, growth rate of energy consumption is 2.5 percent per annum (BP, 2012). Mason (2007) has mentioned that if energy consumption continues to grow at the rate of two percent, then it will be double in 35 years which increase concerns regarding energy sources. In this regard, many scholars have been looking to find the size of global fossil fuel reserves and time of diminishing these reserves. Salame (2003) believed that "global oil supplies will only meet demand until global oil production has peaked sometime between 2013 and 2020". Afterwards, oil production will be decreased and it makes a gap in global energy market which is bridged by unconventional oil and renewable energy sources. According to Asif and Muneer (2007), Years to exhaustion coal for India, Russia and USA based on a compound growth rate has been estimated 190, 112 and 84 years, respectively. These numbers based on a nil growth rate will be 315, 1034 and 305 years. Based on Shafiee and Topal (2008) calculation, depletion times for oil, gas and coal is estimated 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, it will be an important source of energy in the future.

2.2.2 Renewable energy

Although renewable energy (RE) had 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 BP, share of renewable energy in global primary energy consumption was 1.6 percent in 2011. U.S., Germany and China have been the biggest consumer of renewable energy sources with 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, Europe Union has the biggest non-hydro power capacity which is 174 GW. Estimated share of renewable energy in global electricity production has been around 20 percent (included hydro-power). They also are used in the form of biofuels in transportation sector. Liquid biofuels constitute around 3 percent of global road transport fuel in 2011 (Martinot, 2012).

Many countries have started to install facility in order to use renewable energy sources for power generation. But, the share of Renewable energy supply is different by region and country. Europe is considered as a front runner in renewable energy technologies, as RE industry in Europe has already reached an annual turnover of 10 billion Euro and employs 200 thousand 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, United States, Brazil, Canada and Germany were top five countries in 2011 which made capacity to produce renewable energy electricity. If we consider no-hydro renewable energy power capacity, this ranking is changed to China, United States, Germany, Spain and Italy. Of course, the fifth countries in both cases (Germany and Italy) are followed closely by India. China installed 70 GW (mostly wind power) last year and it’s 282 GW if hydropower generation capacity is included (Martinot and Sawin, 2012).

Based on IEA report (IEA, 2012e), renewable energy subsidies sharply increased to 88 billion dollars in 2011 which shows a growth rate of 24 percent 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 reductions 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 more than 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.

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%

a Less than 0.05.
b Less than 0.05%.
Source: BP Statistical Review of World Energy, 2012

As we see in table (2-3), Europe region as a front runner for using renewable energy technologies has the biggest capacity for wind energy and the highest growth rate for solar energy. Also, Europe is accounted for almost 42 percent of global wind energy consumption. Wind energy usage for Germany, Spain and UK in 2011 has been 46.5, 42.4 and 15.8 TWh, respectively. Based on Kaygusuz et al. (2007), “Impressive annual growth rates of more than 40 percent between 1996 and 2003 have made Europe into the frontrunner in wind energy technology development” Regarding Asia Pacific, China’s consumption in 2011 was 73.2 TWh that means to constitute more than 60 percent of Asia Pacific and 16.7 percent of global market.

As an individual country, United States has the first rank for wind energy consumption (121 TWh) which could be compared with total consumption in top three consumers in Europe (135.1 TWh) and accounted for 27.7 percent of global market. There was a little development in some regions like Middle East and Africa. Alongside with Ethiopia which joined the countries which have commercial scales projects for using wind energy, South African market is going to start. In the Middle East, Iran is the only country with large scale wind projects and has a total of 91 MW at the end of 2011(Martinot, 2012). There was a little development in Iran over the years 2010-2011 comparing to previous trend, due at least in part to impose sanction on Iran and facing economic difficulties to develop these projects.

Regarding installed wind turbine capacity, the most significant growth was seen in Argentina and Brazil with 239.4 and 53.8 percent respectively. South and Central America has the highest growth rate (66%) for cumulative installed wind capacity in the word. Almost 67 percent of the current global capacity is installed in 4 countries. China leads the list, followed by United States, Germany and Spain (BP, 2012). The distribution of total installed global wind turbine capacity is shown in Figure (2-3).

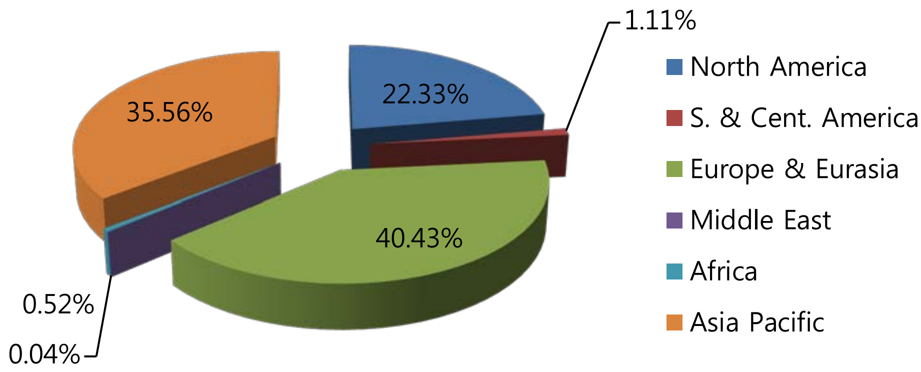


Figure (2-3): Cumulative installed wind turbine capacity, 2011

Although Europe is considered as a leader in terms of cumulative installed capacity, there are many installations outside Europe. If we don't have any technical advance from this time, we can forecast that wind power is able to generate 10-20 percent of the global electricity by the year 2050 which is already achieved in Denmark (Tester, 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 has been 2 GW in 2002, comparing with 69 GW in 2011 when the solar photovoltaic (PV) had extremely high growth rate, similar a year before. About 30 GW of new capacity has been installed globally, increasing worldwide cumulative installed photovoltaic power by 73 percent to 69 GW and it's 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 leader in this region, followed by Italy and Spain. Most of the new photovoltaic systems have been installed in Europe, almost 74 percent of total capacity in the world. According to BP, The installed capacity in Germany and Italy was 24.8 and 12.8 GW which constitutes 54 percent of global installed photovoltaic power in 2011. Other top markets in Europe include France, Czech Republic, Belgium and UK. Top five countries for cumulative installed solar PV at 2011 year-end were Germany, Italy, Japan, China and United States, closely followed by Spain. According to GSR 2012 report (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 percent 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 Middle East and Africa is much lower than the 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 the other countries so far due to have rich sources of fossil fuels. Fossil fuels are subsidized in petroleum exporting countries accounted for 34 percent 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 reform in 2010. Saudi Arabia has the second highest subsidies at 61 billion dollars (IEA, 2012e). These subsidies are the main reason why these countries fall behind the others to deploy solar energy. Breyer et al. (2010) argued that PV power plants have been achieved parity to oil power plants on a total cost basis and it’s possible for MENA region (Middle East and North Africa) to reach fuel-parity for PV and Fossil Fuels power plants in the first half of the 2010s.

2.2.3 Outlook of energy consumption

It's expected global population will be increased to 8.6 billion by 2035 (IEA, 2012c). Therefore, economic activities and energy consumption grow up consequently. Of course, some events cannot be forecasted in long term. Asian financial crisis in 1997-1998 and US subprime mortgage crisis in 2008-2009 are two examples of the shocks for the global economy. Most projections are usually calculated based on gradual trends. Economic growth, energy consumption and environmental issues are affected by economic shocks. Economic recovery varies among different countries. The recession in United States has finished officially but Europe's recovery has a time lag. According to *International Energy Outlook 2011* reference scenario, most countries will have resumed economic growth rate forecasted for long term before the crisis by 2015 (Conti and Holtberg, 2011). It's stated global GDP will increase annually by 3.4 percent on average over 2008-2035. This rate is estimated 4.6 and 2.1 percent for non-OECD and OECD countries, respectively. Figure (2-4) shows world energy consumption outlook by group:

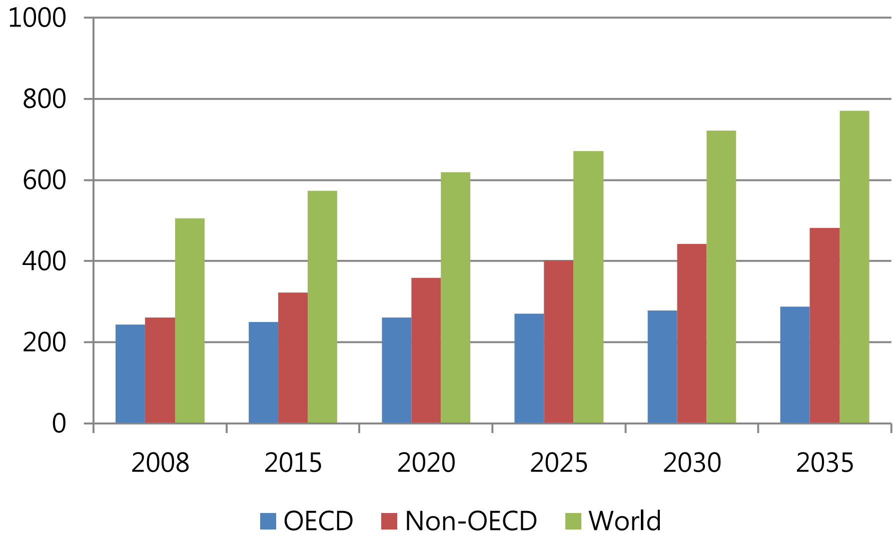


Figure (2-4): World energy consumption by country group (QBtu)

It's stated in *IEO 2011* that world energy consumption will be increased by 53 percent over the years 2008-2035. Average annual percent change is 1.6 percent globally and it's forecasted 0.6 and 2.3 percent for OECD and non-OECD countries, respectively. Energy consumption in non-OECD countries (led by China and India) shows an extreme growth rate by rising 117 percent during outlook period. China and India are accounted for 31 percent of global energy consumption in 2035. The slowest growth rate among non-OECD countries is related to Europe and Eurasia which is just 16 percent from 2008 to 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 based on oil prices and energy demand. For example, alternative energy supply conditions are forecasted based on high and low oil prices. Also, the impact of high and low non-OECD demand on global market is estimated. *World Energy Outlook (WEO)* scenarios are defined by underline assumption about government policies. In this regard, four scenarios are differentiated by IEA in *WEO 2012* report include Current Policies Scenario, New Policies Scenario, 450 Scenario and Efficient World Scenario. Non-policy assumptions are economic growth, population and energy prices which are considered for each scenario.

New Policies Scenario which is called as central scenario or reference in IEA report considers all policies and commitments implemented already alongside with those policies that have been announced and to be introduced. Current Policies Scenario shows those government policies which had been made as a law or performed by mid-2012 without considering any possible policy in the future. 450 Scenario is defined based on possibility to limit increasing in global average temperature to two degree Celsius comparing with pre-industrial 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 change in energy efficiency for the economy, environment and energy security (IEA, 2012e) Figure (2-5) shows total primary energy demand (TPED) based on country grouping in the New Policies Scenario:

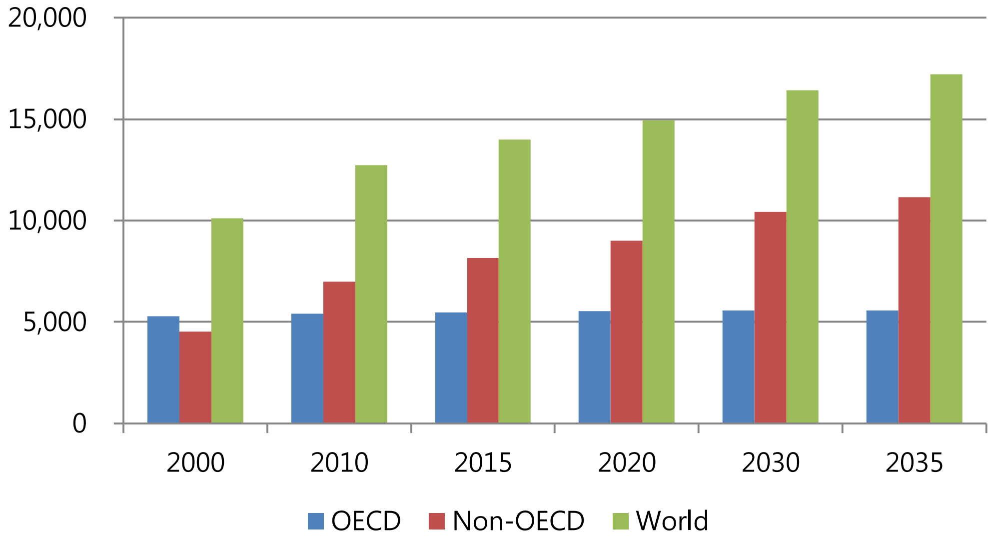


Figure (2-5): Total primary energy demand by country group (Mtoe)

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

2.3 Energy consumption and economic growth

The level of economic activities plays a key role in energy consumption which is considered a key driver of energy markets. Relation between energy consumption and economic growth has been studied by many scholars. Generally four type of hypothesis 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. The uni-directional 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 bi-directional causality. Depends on each hypothesis, energy policies have different influence on economic growth. Discussion about the impact of energy consumption on economic activities got important following Arab oil embargo in 1973.

Early researches in this regard have been published in 1970s. Allen et al. (1976) project economic growth and energy demand for United States over 1975-2010. Hitch (1978) discussed how much energy consumption conservation can contribute to energy supply and how it influence economic growth. The idea of causality relationship between energy consumption and economic growth was introduced by Kraft and Kraft (1978). They used Granger causality test to define relation between gross energy inputs and GNP and found that causality is unidirectional running from GNP to energy for the post war period in United States. 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 there is a slight unidirectional relation from employment to energy consumption. Yu and Jin (1992) show that long-run equilibrium relationship doesn't exist between energy consumption and real output or employment in United States. Stern (1993) examined causal relationship between GDP and energy use applying VAR model. He argued the results of Granger test is 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 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 finding, energy conservation policy may not affect a country like Japan. Also, Cheng (1999) applied 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 about analysis of the causal relationship between GDP and energy use in the USA for the post-war period by using cointegration test and his finding was similar to 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 methodology include developed cointegration test proposed by Pesaran, Shin and Smith, alongside with Toda and Yamamoto test. Based on his research, there was a long-run relationship between energy use and GDP per capita for eight of 19 countries and causal relationship for 12 countries. Lee and Chang (2008) applied panel models to re-investigate co-movement causal relationship within a multivariate framework for 16 Asian countries. Based on their result, energy consumption is caused 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's not the same from GDP to energy consumption. Furthermore, they divided these countries to APEC and ASEAN members. Their finding strongly support that energy consumption have had a significant impact on economic growth in Asian countries. Therefore, continuous energy use can generate a continuous increase in economics output. In other words, GDP is fundamentally driven by energy.

Narayan and Prasad (2008) used a bootstrapped approach to causality for testing mutual impact of electricity consumption and GDP for 30 OECD countries. They found causality from electricity consumption to GDP for 8 countries. It means electricity conservation policy has negative effect on real GDP in these countries. But, this policy doesn't influence other 22 countries.

Furthermore, they indicated that real GDP causes electricity consumption for the six countries and policy makers should have strategies to ensure enough energy supply to achieve planned economic growth rate. Chontanawat et al. (2008) examined 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 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 to four groups based on income level defined by World Bank: low income group, lower middle income group, upper middle income group and high income group. According to their finding, using data for all countries as one group shows a bi-directional positive relationship between economic growth and energy consumption. But, the result is different when the method is applied for different groups. They detected a uni-directional positive relationship from economic growth to energy consumption for middle income group countries and negative one for 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 panel cointegration and error correction model. According to their finding, 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 positive effect on real gross fixed capital formation. They argued that this evidence proves the importance of renewable energy sources in the energy portfolio of OECD countries. The estimation of vector error correction model shows both short-run and long-run bi-directional causality between renewable energy consumption and economic growth. They indicated this result emphasize 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 in another research. Due to importance of Russia in Eurasia region, they categorized two data sets to run 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 short-run and long-run bi-directional causal relationship between renewable energy consumption and economic growth. They indicated that a multilateral effort to develop renewable energy and energy efficiency should be encouraged by policy makers. Also, they stated that a proper incentive mechanism to promote and market availability of renewable energy should be introduced.

Wolde-Rufael and Menyah (2010) tried to test causal relationship between nuclear energy consumption and real GDP for nine advanced countries applying Toda and Yamamoto version of Granger causality test. They found uni-directional causality running from nuclear energy consumption to economic growth in Japan, Netherland and Switzerland; uni-directional causality from economic growth to nuclear energy consumption in Canada and Sweden; and a bi-directional causality in France, Spain, UK and United States. The argued since the causality relationship in France, Japan, Netherland and Switzerland is negative; energy conservative policies could help to mitigate negative effects of increasing nuclear energy consumption on economic growth. Lee and Chiu (2011) applied 4 methodologies include Johansen cointegration test, Granger non-causality test, generalized impulse response function and generalized forecast error variance decomposition to investigate relationship between nuclear energy consumption, real oil price, oil consumption and real income in six highly industrialized countries. The result shows uni-directional causality running from economic growth to nuclear energy consumption in Japan. It means conservation energy policy doesn't influence economic growth. Also, there is a bi-directional relationship between nuclear energy consumption and real income in Canada, Germany and UK, but no causality was found between these two parameters in France and United States.

Unlike to previous studies, Apergis and Payne (2012) investigated the simultaneous consumption of renewable and non-renewable energy in order to examine causal relationship between them and economic growth for 80 countries. According to their finding, there is a bi-directional causality between renewable and non-renewable energy consumption and economic growth in both short-run and long-run period. It means both types of energy sources are important for economic growth. Furthermore, the results show a negative bi-directional causality between these measures implying substitutability of renewable and non-renewable energy sources. They argued that substitutability of renewable and non-renewable energy sources supports continuation of governmental policies to promote renewable energy consumption as well as implementing policies to reduce non-renewable energy consumption. Yildirim and Aslan (2012) applied both methods of Toda-Yamamoto procedure and 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 bi-directional causality between energy consumption and real GDP for Italy, New Zealand, Norway and Spain. The authors believed that due to support feedback hypothesis for these countries, they should not follow energy conservation policy at aggregated level because total economy is influenced by opposite effects. It means economic growth will be reduced by lower level of energy consumption and vice versa, and it makes a circle. In this situation, energy policy should be regulated carefully and diversified based on sectors or energy kinds. According to their finding, there is uni-directional casual relationship from energy consumption to economic growth for Japan and in opposite side for Australia, Canada and Ireland, whereas there is no causality relationship for all other 9 countries. Also, Yildirim and Aslan tested the importance of lag length in their research and found that selection of lag length is important for Denmark, Ireland, Norway and Spain. Table (2-4) compares the result of these empirical studies.

Table (2-4): Comparing empirical studies on energy consumption-growth nexus

Authors	Period	Countries	Methodology	Causality relationship
Kraft and Kraft (1978)	1947-1974	USA	Granger causality	GNP → EC
Akarca & Long (1980)	1950-1970	USA	Sim’s technique	Neutral
Yu & Hwang (1984)	1947-1979	USA	Sim’s technique	Neutral
Yu & 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
Wold-Rufael (2005)	1971-2001	19 African countries	Co-integration, Modified Granger	GNP→EC (5) EC → GNP (3) GNP←→EC (2) Neutral (9)
Lee & Chang (2008)	1971-2002	16 Asian countries	Co-integration, ECM	EC → GDP
Narayan & Prasad (2008)	1960-2002	30 OECD	Bootstrapped causality	EC→GDP (8) GDP→EC (22)
Chontanawat et al.(2008)	1960-2000	30 OECD 78 N-OECD	Co-integration, Granger	EC→GDP (21 OECD, 36 n-OCED)
Apergis & Payne (2010a)	1985-2002	20 OECD	Co-integration, ECM	GDP←→RE
Apergis & Payne (2010b)	1992-2007	13 Eurasia	Co-integration, ECM	GDP←→RE

Rufael & Menyah (2010)	1971-2005	9 Developed countries	Modified Granger	NE→GDP (3) GDP→NE (2) GDP←→NE (4)
Lee & Chiu (2011)	1965-2008	6 Highly industrialized countries	Co-integration, Granger, Generalized impulse response function	GDP→NE (1) Neutral (2) GDP←→NE (3)
Apergis & Payne (2012)	1990-2007	80 countries	Co-integration, ECM	RE, NRE←→GDP
Yildirim & Aslan (2012)	1971-2009	17 Highly Developed OECD	Bootstrap-corrected test, Modified Granger	EC→GDP (1) GDP→EC (3) GDP←→EC (4) Neutral (9)

Note: 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.
*Abbreviations are defined as follows: 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

The causality relationship between energy consumption and economic growth is analyzed in order to examine the possible effects made by energy policies. As it is realized from table (2-4), there may be different result for some countries in a same period with different methodology or even similar methodology. Also, it should be taking into account that this analysis considers individual relationship between two variables (here, energy consumption and economic growth). Therefore, it's not reliable to be a basis for making decision 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.

2.4 Main drivers for using renewable energy

The first driver for seeking alternative energy sources has been energy security since Arab oil embargo in 1973 or first oil shock. The oil shocks in 1970s stimulated interest in renewable energy sources. The global concern about climate change and sustainability encouraged countries to invest on 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 mentioned, concerning about security of energy supply raised after Arab oil embargo in 1973. There are more 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 producers and 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 estimated cost which is spent for making security. Owen (2004) called security of energy supplies as a key requirement for the economics, environmental and social objectives of sustainable development policies. In his view, energy security risk could be classified to strategic and domestic system risks. Also, he defined damage costs and control cost as a potential cost imposed by energy insecurity. He argued damage cost could be evaluated by potential decreasing in GNP, but it's difficult to estimate how much money is spent as control cost on energy security. For example, it's very difficult to estimate how much money has been spent by United States to control oil security.

Delucchi and Murphy (2008) investigated the impact of US military cost on motor vehicle fuels and estimated that in case of no oil in Persian Gulf, US defense expenditure might be reduced about $27-$37 billion per year, meaning $0.03-$0.15 per gallon ($0.01-$0.04 per liter). Hedenus et al. (2009) analyzed the expected economic cost of oil supply disruption by energy policies in EU-25. They analyzed how energy policies affect oil market and how much money could be gained by these policies. The results show that expected cost of oil disruption is 29.5-31.6 billion Euros a year corresponds to roughly 9-22 euro/bbl, or 6-14 c/l of gasoline. Also, they estimated greenhouse gas benefits of 20 euro/ton carbon dioxide to substitute oil for pellets in residential sector for heating.

Concerning about climate change made additional view to energy security objectives. The diversification of energy supply to promote energy security could be considered as a policy for climate protection (Bhattacharyya, 2011). Before industrialization era and using coal as a main source of energy in the mid 19^{th} century, renewable energy sources were used widely. There is a huge potential source 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 for some kind of energy such as solar and wind energy or possibility of low rainfall for hydropower consumption. Therefore, such factors should be considered for the sectors which are relied heavily on these sources. Renewable energy technologies are beneficial for both energy-producing and consuming countries. Renewable energy technologies reduce domestic demand for fossil fuels and make more capability for export. For example, Iran was 4^{th} biggest worldwide natural gas producer in 2011, but it was a net importer because of high domestic demand. Also, high dependency to import could make a serious problem if there is any disruption in energy supply. For example, European countries are dependent on Russia to import natural gas. They experienced 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 is not compatible with traditional sources of energy, but some technologies like wind power is more feasible today and the cost of other technologies such as solar photovoltaic is decreasing rapidly (IEA, 2011). Furthermore, we should consider external cost which is spent for energy security indirectly in our calculation. Alongside with storage cost and military expenditure, there is an extreme externality cost due to possibility of accidents for nuclear power plants such as Three Mile Island (1979), Chernobyl (1986), and Fukushima Daiichi (2011). According to a report prepared for international organization in Chernobyl Forum (2003-2005), total spending amount by Belarus over 1991-2003 is evaluated more than 13 billion dollars. Also, total losses over 30 years has been estimated around 235 billion dollar by Belarus (Chernobyl Froum, 2006) Based on this report, in Ukraine, 5-7 percent of government expenditure is still allocated to Chernobyl-related programs. Around 6,000 thyroid cancers have been found in contaminated regions of Chernobyl accident to date and it’s estimated an additional 10,000-40,000 cancer over the next decades (Hoeve and Jacobson, 2012) The number of accidents for nuclear power plants may be rare, but there will be an extreme cost in terms of economics, social and environmental view. If we include all external cost 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. 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 United States have domestic resources which enable them to cover a part of demand. US spent around 410 billion dollars in 2008 to import fossil fuels constitutes more than 3 percent 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 with fossil fuels, it could make a capacity for investment on the other sections. IEA made a cost-benefit analysis for investment on low-carbon energy systems based two scenarios: ETP 2012 6˚C (6DS) which assumes business as usual and 2˚C (2DS) is targeted to reduce carbon dioxide emissions by 50 percent, comparing to 2005 levels. The result shows an estimated 103 trillion dollars will be saved during the years 2010-2050 by reducing fossil fuels consumption. It's indicated that this calculation is based on reduction in fossil fuels purchase (214 Gtoe) and it could be 150 trillion dollars if the impact of lower fuel prices is taken into consideration (IEA, 2012c).

A main economic driver to enhance renewable energy technologies is their potential to create job. It's estimated 5 million people work in renewable energy industries. Although, total employment in these industries continue to increase, but some countries such as Germany and Spain suffered in recently because of global recession and policy changes (Martinot and Sawin, 2012). Figure (2-6) shows distribution of estimated jobs in renewable energy worldwide by industry based on *GSR 2012* report.

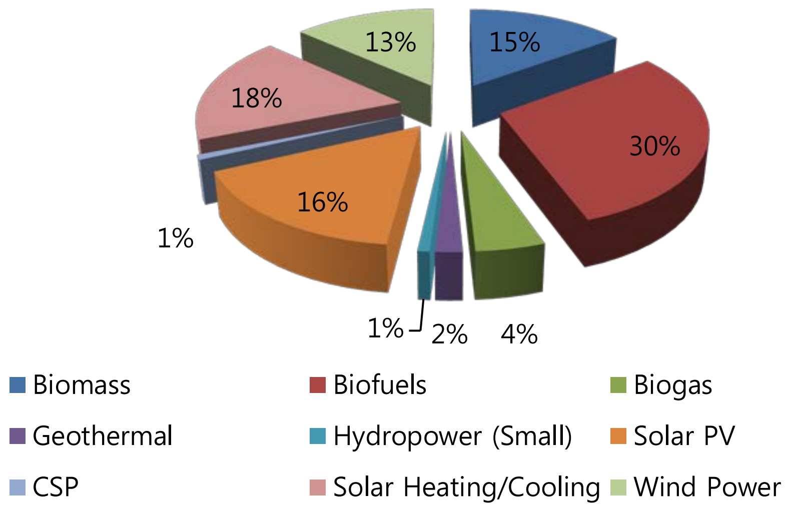


Figure (2-6): Estimated job in renewable energy worldwide, by industry

In GSR 2012 report, job creation's break down has been estimated 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 renewable energy industry (Martinot and Sawin, 2012). The majority of jobs in renewable energy industries are located in China, Brazil, United States and the European Union. Germany is front runner country in Europe for job creation in renewable energy industry. Germany has increased power generation sharply by renewable technologies since beginning of this century, with a share of almost 15 percent of total electricity production in 2008 (Frondel et al., 2010). Ragwitz et al. (2006) investigated the gross and net effects of renewable energy policies in Europe Union and analyzed the past, present and future effects of renewable energy policies on employment and economics as a general and members level. They found that current high economic benefits of the renewable energy sectors can be increased in future "if the current policies are improved in order to reach the agreed target of 20 percent renewable energies in Europe by 2020." They argued that increasing share of renewable energy sources not only has any negative effect on the economy, but also could help the economy by job creation and increasing GDP. In their view, the economic advantage of renewable energy could be higher if external costs were included.

Mathiesen et al. (2010) examined 100 percent renewable energy system including transport by the year 2050 and considered two short-term transition target in 2015 and 2030. They also indicated that implementing renewable energy technologies can have positive socio-economic impacts including job creation and increasing export. Several market leaders including Germany, Denmark and Japan have focused on industrial and economic development objectives to support renewable energy technologies by implying stable policy framework, innovation chain and good environment for investment. They specialized in knowledge based stage and became front-runner in terms of innovation in 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 with fossil fuels in power generation industry and transportation section. Life-cycle CO_2 emissions for renewable energy technologies are much lower than fossil fuels. The life-cycle balance is also considered as an important factor for the 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 total power sector's CO_2 of Europe region (1.4 Gt) (Ölz, 2011). This analysis shows hydropower technology constitutes the largest share for saving CO_2 emissions with 82 percent, followed by biomass and wind with 8 and 7 percent, respectively.

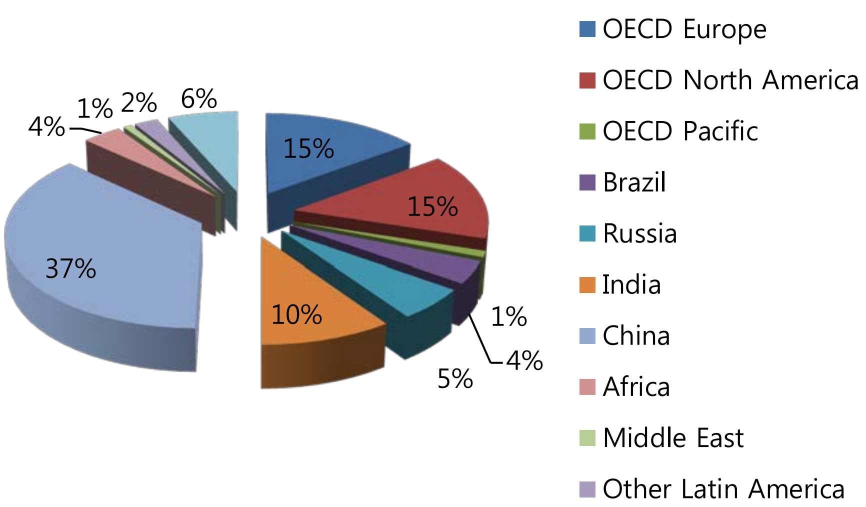


Figure (2-7): Saving in CO_2 emissions between no-RE and 450 scenarios in 2030

According to IEA analysis, the potential saving of the OECD and BRICS countries is estimated roughly 5.3 Gt in 2030, almost the same as forecasted power-related CO_2 emissions in *WEO 2010* for the these countries in 2030 under 450 ppm scenario (5.8 Gt).

Figure (2-7) shows the CO_2 saving under WEO 450 scenario comparing with no renewable energy scenario in 2030. The key point is the most CO_2 saving has been concentrated in OECD countries and China. According to IEA report, CO_2 saving in China on a 450 ppm scenario would be 2.2 Gt constitutes 64 percent of the BRICS total saving (Ölz, 2011). Edenhofer et al. (2010) examined technological feasibility and economic consequences of achieving greenhouse gas targets and found that these targets are low enough to be feasible technically and economically. They stated that this viability crucially depends on particular technology. For example, the availability of carbon capture storage technology is very important to remove CO_2 from the atmosphere. Also, they argued that additional political and institutional prerequisites are required to achieve the targets.

Chapter 3: Alternative Renewable Energy Production Technologies

3.1. Introduction

The importance of alternative energy sources comes together with climate change challenges associated with excessive use of fossil fuels. As we mentioned earlier, there are three drivers to stimulate renewable energy technologies: energy security, economic impacts and carbon dioxide emission reduction. The term of alternative energy refers to any form of energy other than conventional source of energy including hydropower. In recent years the focus has been on renewable energy sources. “Two significant global trends should characterize the deployment of renewable technologies over the medium term. First, as renewable electricity technologies scale up, from a global total of 1,454 GW in 2011 to 2,167 GW in 2017, they should also spread out geographically. Second, renewable technologies are becoming increasingly competitive on a cost basis with their alternatives in a number of countries and circumstances.”(IEA, 2012d) According to IEA calculation, wind is the most competitive type of renewable energy technology among the others if local conditions such as financing, CO_2 emission levels and fossil fuel prices are favorable (OECD, 2010).

There are two concepts of energy technologies when we are talking about clean technologies: energy supply technologies, means alternative source of renewable energy such as wind and solar power; and energy efficiency technologies, means those technologies which are hired to enhance energy efficiency such as combined heat and power (CHP), virtual power plant (VPP) and smart meters. It should be noted that transforming the energy sector and replacing conventional energy with renewable energy is evolutionary associated with technological change and forming markets. Jacobsson and Bergek (2004) indicated that transforming process for those kinds of renewable energy such as wind and solar will be happened after 2020; even the growth rate of consumption is increasing strongly during next decade. Also, renewable energy markets are not formed easily due to cost disadvantage and subsidizing for fossil fuels.

3.2. Renewable energy supply technologies

Renewable energy supply is increasing continuously. A large amount of investment has been made during several recent years and advance technologies enable countries to produce renewable energy more cost effective. It’s forecasted the number of countries producing above 100 MW renewable energy increase significantly by 2017 (IEA, 2012d). Due to some negative and irreversible externalities coming with conventional energy production, it’s necessary to promote and develop renewable energy supply technologies. As we mentioned earlier, these technologies may be incompatible comparing with conventional fuels in view of unit production cost; but they could be compatible if we consider their associated externalities such as environmental and social effects. Also, it should be noted that economies of scale could play a key role to reduce the unit production cost. Transmission and distribution costs and technologies do not differ much among the two main types of energies.

3.2.1. Hydro power

Hydro power is the largest renewable energy source for power generation around the world. Hydro electricity generation has increased strongly over the past 50 years. It was 340 TWh in 1950 and covered about one-third of global demand. It increased to 1,500 TWh in 1975 and further to 2,994 in 2005. We can compare it with global consumption of 15,000 TWh and global production of 18,306 TWh in 2005 (Ngô and Natowitz, 2009). Currently, hydro power development is difficult due to large initial investment (high capital cost, despite its low operational cost) and environmental concern. It makes some problems for local residents because of relocation of large populations. Also, considering that building dams is permanent and sunk cost of utilities which cannot be removed, environment is influenced by hydro power construction because of large engineering works. On the other hand, hydro power is attractive due to supply of water for agriculture, household and industrial use, and is clean and ability to storage energy. Also, it could be used for both application of base-load and peak time power plant.

The largest worldwide capacity hydro power plant is Itaipu installed in Parana River, developed jointly by Brazil and Paraguay. The initial capacity was 12.6

GW in 1984 and extended to 14 GW in 2006 (Ngô and Natowitz, 2009) Many argue that hydro plant construction project could improve local economy. For example, US employed hundreds workers through Hoover dam project when it experienced depression in 1930s (Tester, 2005). Hydro power plays a key role for some countries such as Norway. Based on BP statistics (2012), Hydro electricity demand in Norway (122 TWh) constituted almost 64 percent of primary energy consumption in 2011, comparing with share of 26 and 8 percent for oil and natural gas, respectively. Also, around 30 percent of energy consumption in Sweden has been supplied by hydro power (66.5 TWh). China, Brazil and Canada are top three hydro electricity producers worldwide with 694.0, 429.6 and 376.5 TWh. Although hydro electricity consumption in Norway and Sweden cannot be compared with these countries, but they have significant hydropower generation, particularly relative to their size and total electricity supply. Figure (3-1) shows the general trend of worldwide hydroelectricity consumption from 1965 to 2011.

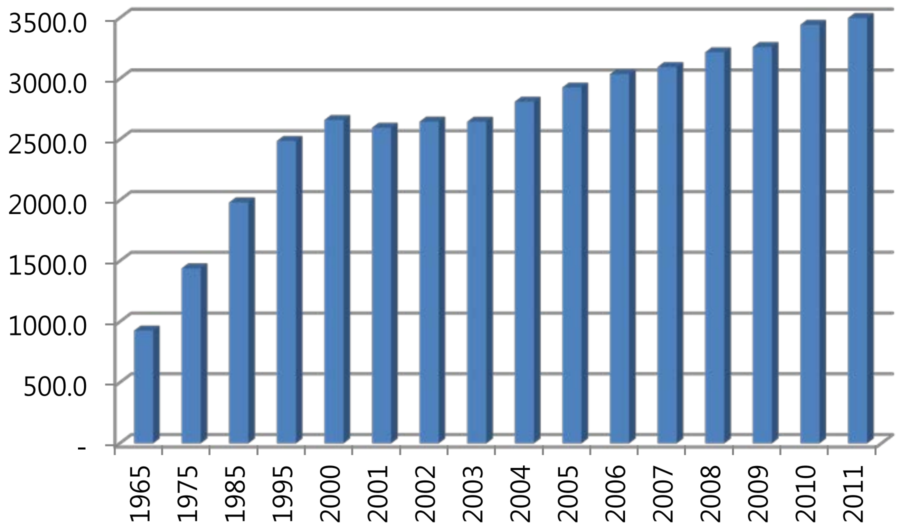


Figure (3-1): Worldwide hydro electricity consumption (TWh)

Total hydropower capacity is forecasted to increase from 1,607 GW in 2011 to 1,680 GW in 2035 (IEA, 2012e). According to WEO 2012 report, China is going to make its capacity almost doubled which enables this country to have 420 GW installed hydropower capacity in 2035. It is close to the entire OECD countries in 2011. IEA estimated capacity will be increased sharply in India and Brazil, too. It’s forecasted that capacity grows from 42 GW to 115 GW in India and from 89 GW to 130 GW in Brazil (IEA, 2012e). Some regions such as Europe and North America where hydropower sector is matured, are going to modernize current plants and develop storage capacity instead of developing new traditional facilities (Martinot and Sawin, 2012). Based on IEA survey, some issues such as availability of funding, political and market risk, and local environmental concerns are considered as barriers to develop hydropower capacity in Africa. Figure (3-2) shows worldwide primary energy consumption by fuel in 2011, based on BP statistics (2012). Energy technology differs among the two groups of countries in respect with coal, nuclear and hydro. The difference is attributed to their technological capabilities.

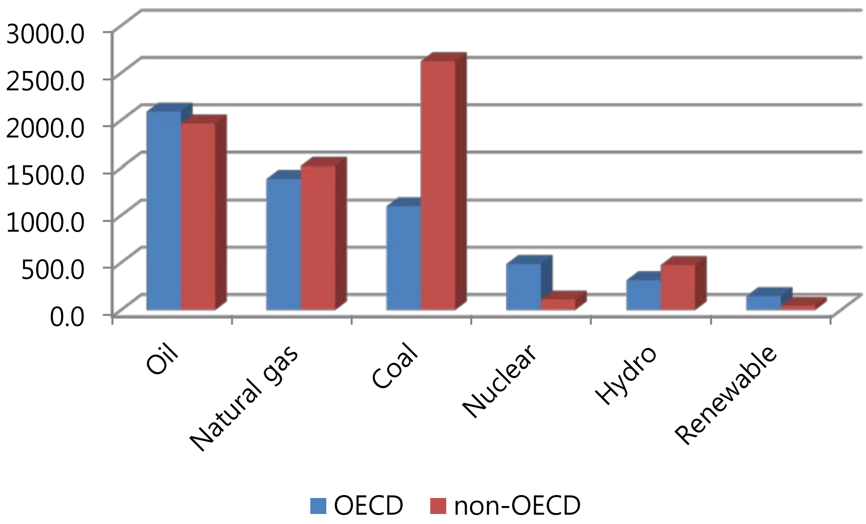


Figure (3-2): Global primary energy consumption in 2011

There are three kinds of hydropower generation plants: run of river, where the power is generated by flow of a river; reservoir, where power is generated due to release of stored water; and pumped storage, where stored water is backed to reservoir in order to be pumped again. Small scale hydropower stations are run-of-river in most cases. Wirl (1989) examined conventional standards to evaluate hydropower plant projects and argued that conventional cost-benefit analysis is not able to evaluate expansion of plant appropriately. Wirl believed that actual cost of hydropower plant is underestimated because of negative environmental externality and positive dynamic spillover effects.

Sinha (1992) estimated a model for a hypothetical site to simulate performance and economic aspects of combined wind/hydro/diesel power plants with pumped storage. His model is constituted by a wind energy conversion system, a mini/micro hydro plant, a diesel generator and a pump. The results show that pumped storage doesn't have significant effect when wind and water system are applied. But, it could be used in sites without natural inflow. Gagnon (1997) discussed GHG emissions from hydropower plants and shows hydropower is a good alternative comparing to fossil fuel power plants in most cases. Based on the results, a typical GHG emission factor is 15 g CO_2 equivalent/kWh which is 30-60 times less than conventional fossil fuel power plants. Paish (2002) argued that there are main advantages for small-scale hydropower includes: more concentrated energy resource than wind or solar, predictability, on demand availability, limited maintenance, long-lasting technology, no fuel, and no environmental impact. Also, he mentioned some points as shortcomings: site-specific technology, limitation of expansion activities, monsoon condition, conflicts with fisheries, and lack of knowledge to apply this technology in many areas.

Lehner et al. (2005) applied a model to analyze impacts of climate change on Europe's hydropower potential at a country scale. They analyzed gross hydropower potential and developed potential of current plants in order to capture a real picture of present and future power generation. The results strongly indicated that hydropower potential in Europe is influenced by climate change and it makes a reduction by 25 percent and more for southern and southeastern European countries. It’s estimated that gross hydropower potential for Europe is decreased about 6 percent by 2070s, while reduction rate for developed hydropower potential will be 7-12 percent. The stated that significant adoption is required to be considered for water management in the future and support the necessity of developing mitigation strategies for whole Europe. Ehnberg and Bollen (2005) investigated the availability of hybrid power plant when it is constituted by a combination of solar and small hydro installation. They used a small reservoir instead of flow-of-river unit and assumed that hydro energy is not used during sunny period. A model is simulated for four different combinations: solar power, solar power and storage, solar and hydro power, and solar and hydro power with storage. The results show that a combination of different sources should be hired in order to have reliable supply. Also, they found that a combination of solar power and small reservoir is favorable comparing with the other options.

Kaldellis et al. (2010) introduced a methodology to measure size of pumped hydro storage (PHS) systems to take advantage of excess wind energy generated by local wind farms and rejected by local power grid because of electrical limitation. Their finding shows that ability of PHS system has significant contribution in electrification of remote islands. They stated this methodology could be developed in order to apply for all hybrid projects constituted combination of wind farms, pumped storage and hydro-turbine. Kapsali and Kaldellis (2010) investigated feasibility of a wind-based PHS system which is able to supply local power in an Aegean Sea island. PHS systems located at isolated sites are able to use rejected wind energy produced by wind farms. Based on the results, the project is viable in point of technical and economical view. Also, share of renewable energy sources (RES) will be increased by 9 percent after installation of project, reaching about 20 percent of local power consumption. It is indicated that PHS project could be considered more environmental friendly than conventional plants because it takes required energy during low demand period of local grid when the thermal units operation generate less gas emissions.

Deane et al. (2010) reviewed current and planned pumped hydro energy storage (PHES) and analyzed technical and economical drivers for developing PHES. Based on the results, current trends for developing PHES shows an intention to enhance or build pump back plant instead of pure pumped storage which is partly due to lack of new feasible sites in economic view. Capital cost for proposed project in reviewed sites is estimated 470-2,170 Euro/kWh. It's stated that developers of new PHES, particularly in Europe, intend to have hybrid wind-hydro power plants. Raadal et al. (2011) reviewed life cycle GHG emissions form wind and hydro electricity production comparing with conventional fuels, nuclear and other types of renewable energy sources. Based on the result, GHG emissions produced by run-of-river hydro plant life cycle analysis shows the lowest variation among the examined technologies.

Yang and Jackson (2011) investigated historical development of PHES in United States and analyzed case studies, disputed projects and challenges about future development of these projects in United States. Their finding show that interest to PHES systems has been increased worldwide in recent years and it's expected a capacity of 76 GW will be installed by 2014. There are 32 preliminary permits granted to 25 licensees in United States by Federal Energy Regulatory Commission to develop new PHES facilities. Yang and Jackson pointed that PHES development may be influenced by increased supply of unconventional natural gas and make it uncompetitive for using in peak time of electricity network. But, they argued that possibility of new law for price or put limitation for carbon emission could stimulate economic outlook of PHES.

Connolly et al. (2011) applied a deterministic model to compare three operation strategies for optimizing profit in a PHES facility with a 360 MW pump, 300 MW turbines, and 2 GWh storage utilizing price arbitrage on 13 electricity spot markets. They found that an optimal strategy is achieved based on day-ahead electricity prices and 97 percent of profits could be earned by this strategy. It's indicated that long-term forecast is not required in order to maximize profit using electricity price arbitrage. Monteiro et al. (2013) estimated a short-term forecasting model for hourly average power generation of small-hydro power plants (SHPPs). This model is constituted by three modules: estimation of daily average, final forecast of hourly average power generation and dynamic adjustment by recent historical data. They argued that practical solution for technical and economical problems made by SHPPs are available due to this model. It is concluded that power generation forecast is required to operate SHPPs appropriately for preparing bid offers in the markets and maintenance schedule of power plants.

Table (3-1): Empirical research about power generated by hydro power

Authors	Subject	Result
Sinha (1992)	Modeling the economics of combined power systems	Pumped storage doesn't have significant effect when wind and water system are applied. But, it could be used in sites without natural inflow.
Gagnon (1997)	GHG emissions from hydropower	A typical GHG emission factor is 15 g CO_2 equivalent/kWh, 30-60 times less than fossil fuel generation.
Paish (2002)	Small hydropower technology	Main advantage: more concentrated energy, predictability, on demand availability, limited maintenance, long-lasting technology, no fuel, no environmental impact.
Lehner et al. (2005)	Impact of climate change on hydropower in Europe	Climate change makes a reduction by 25% and more in hydropower potential for southern and southeastern Europe.
Ehnberg & Bollen (2005)	Reliability of a small power system with solar and hydro	A combination of different sources should be hired to have reliability. Combination of solar power and small reservoir is more favorable.
Kaldellis et al. (2010)	Analysis of wind-based pumped hydro energy storage (PHES)	The ability of PHES has significant contribution in electrification of remote islands.
Kapsali & Kaldellis (2010)	Combining hydro and variable wind power generation	PHS systems are viable in point of technical and economical view at isolated sites.
Deane et al. (2010)	Techno-economics review of pumped hydro energy storage	Capital cost for PHES is estimated 470-2170 Euro/kWh. It is intended to have hybrid wind-hydro power plants in Europe.
Raadal et al. (2011)	Life cycle GHG emission from the generation of wind and hydro power	GHG emission from wind and hydro power varies from 0.2 to 152 g CO_2-equivalents per kWh. Run-of-river hydro plant has the lowest.
Yang & Jackson (2011)	Opportunities and barriers to PHES in the US	PHES may be influenced by developing unconventional natural gas and make it uncompetitive. The possibility of new law for price or emission could stimulate its outlook.
Monteiro et al. (2013)	Forecasting model for power production of small-hydro	Power generation forecast is required to operate small hydro power plants appropriately for preparing bid offers in the markets and maintenance schedule of power plants.

3.2.2. Wind power

Wind power installed capacity has increased from 4.8 MW in 1995 to more than 239 GW in 2011. Today, wind turbines could generate electricity as much as a conventional power plant. Wind energy has made its most significant contribution in China, US and Germany, where cumulative installed capacity are 62, 47 and 29 GW, respectively. Figure 3.3 shows wind's installation capacity trend worldwide based on BP 2012.

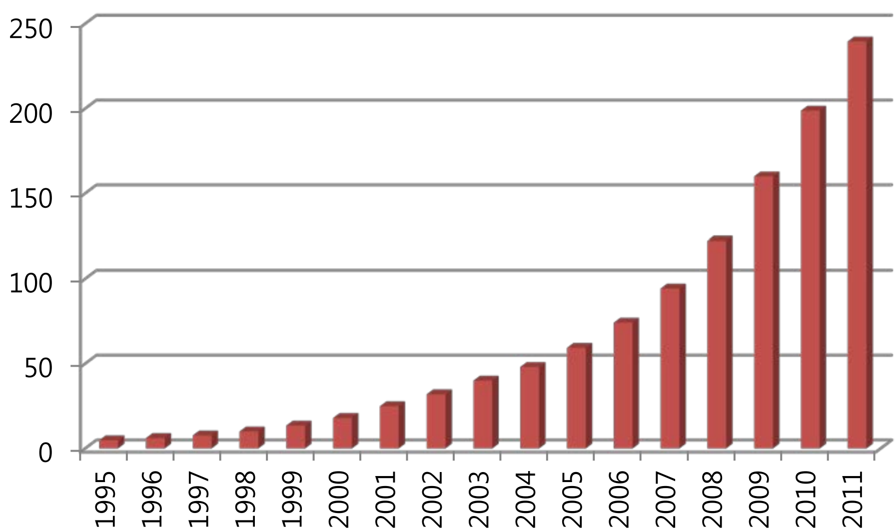


Figure (3-3): Cumulative installed wind turbine capacity (GW)

Trend shows that wind capacity installation has been increased continuously during last two decades. IEA estimates that global capacity will be increased from 238 GW in 2011 to almost 1,100 GW in 2035 which 80 percent is constituted by onshore wind turbines (IEA, 2012e). According to this report, offshore wind capacity is growing quickly from 4 GW in 2011 to 175 GW by 2035 due to be given governmental support. This target will be achieved if required investment is made based on designed plan. It's forecasted that around 980 billion USD is required to invest during 2010-2020 and it is increased to 1,634 and 3,307 billion USD for 2020-2030 and 2030-2050, respectively (IEA, 2012e). Figure (3-4) shows group countries breakdown for investment needs.

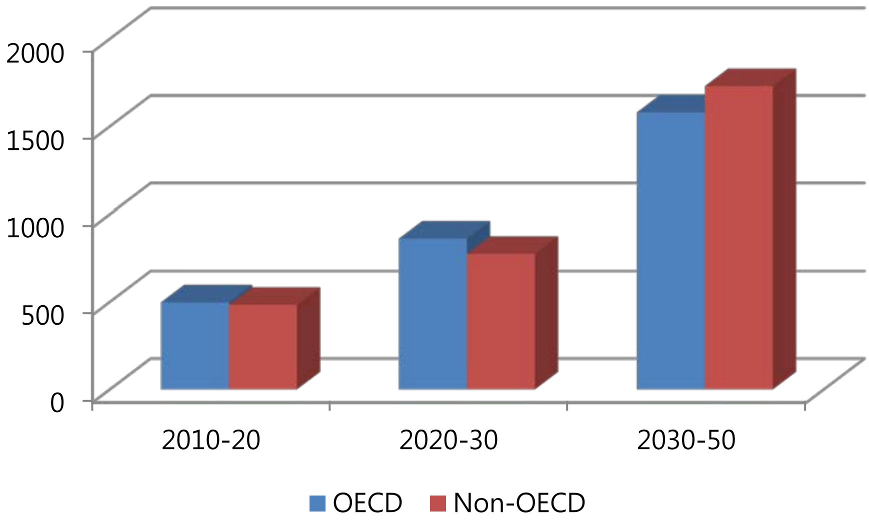


Figure (3-4): Investment to achieve wind generation targets (USD billion)

Figure (3-4) shows that OECD countries will fall behind non-OECD countries by 2030-50. The main portion of investment in non-OECD group (almost 50 percent) belongs to China.

"Of all solar (renewable) technologies, wind turbines are the closest to being economically competitive with fossil-fired systems". (Tester, 2005) Generally, renewable energy technologies are classified based on source of energy such as solar, wind, biomass and etc. But Tester (2005) mentioned that each renewable energy type comes from one of three primary energy sources: solar radiation, gravitational forces and heat generated by radioactive decay. They argued that solar, thermal and photovoltaic energy are produced by capturing a fraction of incident solar. Wind, hydro, wave, ocean thermal, and biomass energy also are produced by solar indirectly. According to Tester (2005), this competency could improve in long-term. Also, they estimated lifetime-levelized cost for wind power equal to 6.5 cents per kilowatt hour which could be more compatible with natural-gas combined cycle gas turbine (CCGT) and coal power plants if the externality cost such as SO_x, NO_x and CO_2 emissions are considered. Furthermore, the authors added more advantages for wind power plants, including: installation as turnkey contracts within a short period, lower investment comparing with nuclear and hydroelectric plants, economies of mass production, free of fuel cost, and improvement in the operating and maintenance cost.

Based on Ngô and Natowitz (2009), there are some problems for using wind energy sources includes intermittency of wind energy, and adding cost for power transmission to residential areas. Because, wind turbines are installed in windy sites where the population density are usually low. Offshore wind turbine is considered as an alternative for land-based turbine. Due to land limitation in some countries and probable local opposition from local residential, offshore turbine could be used. The largest offshore wind farm has been installed in Denmark including 80 turbines with a power of 2 MW. Ngô and Natowitz mentioned that Denmark exports the most part of power generated by wind turbine because there is no domestic demand at the time of production.

Gipe (1995) argued there are some crucial factors to use wind energy successfully. In a financial view, these factors include cost, revenue, and expected return on investment. Other factors such as national energy policy may be important but financial targets could be managed by tax. Cost include both installation and operation expenditures. Revenue is calculated based on wind resources, turbine's performance and quantity of energy produced. For a wind plant, this value is defined by purchase power rate or feed-in tariff. In view of a household living off-grid, the value is calculated based on the price of the electricity that they have to buy from the utility, plus transmission cost to their house. The price of wind energy depends on how much energy is necessary for local residents. Therefore, feasibility and minimum required speed for wind turbine in order to be economical is related to this issue how much wind energy is worth.

Gipe (1995) made conducted two case studies in Europe and Great Britain and explained that wind energy is high valued in northern Europe and 5.0-6.5 m/s is enough for wind speed to generate feasible energy but average speed in Great Britain should be over 7.0 m/s due to risk associated with tariffs. Gipe argued that wind turbines could be successful when there is a market for power generated. Some households may need to sell a part of wind turbines' excess power generation back to local utility. An agreement is required between parties to process this transaction. At this step, feasibility depends on government policy for pricing. In United States, utilities are allowed to determine the price what is paid to individual generators and it would be just a fraction of retail price. Consequently, these individual producers may install smaller and less cost-effective wind turbine than a comparable producer in Denmark where they are allowed to sell surplus electricity at higher price and it enables them to install the most cost-effective turbine.

Devine (1977) used an input-output approach to calculate energy in a 1,500 kW(e) wind turbine used to displace fossil fuel in a power system. He compared five rations for delivered electricity and found this system is able to displace a part of fossil fuel equivalent. Haack (1981) calculated the net energy of a small wind conversion system in USA and compared with other electricity sources such as coal-fired power plant, coal gasification gas-fired power plant, gas-fired power plant, nuclear power plant and other generation sources. He estimated the amount of energy through a simulation model which takes into account wind speeds, residential electricity demands and parameters from the generator, inverter and storage components. The results show that net energy obtained by this wind system is better than other systems. Haack argued additional steps which are used in the process of obtaining fuels by new technologies decrease the efficiency of conversion. Also, increased energy cost of materials which are used in different steps such as extraction, processing or transportation of fuels will be decreased; while energy cost of wind generated is not expected to be increased during the time.

Schleisner (2000) examined energy consumption and emissions generated through production and manufactured of materials for onshore and offshore wind farm based on a life cycle analysis (LCA) model in Denmark. He calculated the weight of materials and required energy for producing, manufacturing and disposal process. The emissions of N_2O, CH_4 and CO have been converted to CO_2 equivalent by related factors. Also, he compared the primary energy used in production and disposal of materials in order to calculate energy payback time. Based on his research, the energy payback time would be 0.39 years or less than 2 percent of a 20-years life time if an estimation of 40 percent is assumed for energy efficiency. He estimated that external cost of CO_2 emissions for wind farm on land and offshore is 0.8-1.2 mECU/kWh and 1.0-1.6 mECU/kWh, respectively. The result shows that damages for offshore wind turbines are larger due to amount of materials used for foundation and sea cables. As an example to compare, the external cost for nuclear power plant in Germany has been estimated 4.4-7.0 mECU/kW (Bodansky, 2005).

Lenzen and Munksgaard (2002) conducted a review of energy and CO_2 life cycle analysis of wind turbines. They found that small wind turbines of 1 kW requiring considerably higher life cycle energy than large size of 1 MW and argued that this deviation is made due to values for the energy required for the materials, analysis scope, methodology, country of manufacture, recycling component and choice of concrete or steel for tower. Based on their research, it is suggested to minimize uncertainties in life cycle assessment by using a standardized methodology and input-output based hybrid techniques. Liberman (2003) employed Monte Carlo simulation to analyze economic payback and life cycle assessment of 11 modern, utility-scale wind turbines in

United States and used hourly meteorological data to evaluate 239 locations. The result shows wind turbines are not feasible at all locations, but they could be superior to generators using natural gas or coal at locations with favorable wind sources.

Korpaas et al. (2003) used an algorithm to analyze the optimal energy exchange together with energy storage in the market for a certain period. Transmission constraints and intermittence character of wind energy have been taken into account in this research. The result shows that energy storage enables wind power plants' owners to take advantage of spot markets. They argued energy storage devices are an expensive alternative comparing with developing power network but it could be a feasible option for those places where grid expansions is not possible due to unwanted environmental effects.

Lenzen and Wachsmann (2004) conducted a life-cycle assessment to compare energy and CO_2 embodied in a particular wind turbine (E-40) with a nominal power of 500 or 600 kW manufactured in Germany and Brazil. Comparing economic structure and using energy resources shows that CO_2 balance is much lower in Brazil than Germany. Because natural gas and nuclear power plant plays key role in Germany but firewood and sugar-cane-based alcohol are used exclusively in Brazil. They investigated five scenarios for production and operation of a particular wind turbine in these countries and found that CO_2 emission is considerably lower if turbine is manufactured in Brazil. The result shows that a production shift abroad could be a good solution in order to achieve emission reduction.

Wagner and Pick (2004) calculated energy yield ration and cumulative energy demand for two types of wind turbines (1.5 and 0.5 MW) in three sites including coastal, near coastal and inland. Based on the result, energy payback time would be 3-7 months and energy yield ratio is 38-70 depends on type and site. They also found that deviation of energy yield ration for different type is just 10 percent. Klaassen et al. (2005) used learning curve to examine how cost reducing innovation is influenced by public R&D support for wind farms in Denmark, Germany and UK. They found that small wind turbine in Denmark has been developed due to support by R&D and demonstration projects together with investment subsidies. R&D support to develop large scale wind farm was failed in Germany but it was successful in case of small wind turbines. In UK, R&D support was insufficient regarding type of wind turbine but subsidy program was able to decrease the cost. Based on the results, they estimated a rate of 5.4 percent for learning-by-doing and 12.6 percent for learning-by-research.

Benitez et al. (2008) used a nonlinear optimization program by load data for Alberta’s grid in Canada to examine economic and environmental effects of wind energy penetration in power network and how hydropower storage is able to be used to control wind energy intermittency. Based on calculation, generation cost of wind energy turbines is estimated 37-68 USD/MWh and reduction cost of CO_2 emissions would be 41-56 USD/tone. The results show that hydropower could offset most of the peak load demand and eliminate building gas-fired generators for peak time. Tremeac and Tremeac and Meunier (2009) used life cycle assessment to examine environmental impacts of 4.5 MW and 250 MW wind turbines and considered all steps including manufacturing, transports, installation, maintenance, disassembly and disposal in their analysis. They found that wind energy could be the best environmental solution to mitigate climate change and supply electricity in off-grid areas if three conditions are considered: first, using high efficient turbines on a proper site in view of wind source; second, less energy should be consumed in transportation step; and third, recycling process should be performed correctly. Blanco (2009) investigated recent studies about wind energy manufacturers in order to categorize generation cost for onshore and offshore turbines. Also, she analyzed supply chain constraint and main factors that made a cost increase of 20 percent during last 3 years. Based on the result, generation cost is estimated 4.5-8.7 Eurocents/kWh for onshore and 6.0-11.1 Eurocents/kWh for offshore wind turbines. Rising price of key raw materials and unexpected increasing in demand for wind turbines have been the main reasons for adding 20 percent on generation cost. Blanco believed that an appropriate, stable and long term policy framework is required to decrease generation cost of wind energy in long term. She argued these policies could be focused on R&D in optimization of size of turbine and new materials for blades, remote-control devices for operation and management, advanced forecasting techniques, and availability of enough fund.

Crawford (2009) used a hybrid embodied energy analysis approach to assess life cycle energy and GHG emissions for 850 kW and 3.0 MW wind turbines and examine the impact of turbine size on energy yield ratio. He argued that methodologies used for previous researches regarding life cycle energy studies are incomplete due to some limitations and errors in quantification of inputs to product and valuation of energy requirements for supporting goods and services. Based on the result, energy yield ratios of 21 and 23 are estimated for small and large scale wind turbines. Crawford found that the size of wind turbine is not an important parameter to optimize life cycle energy performance. Kubiszewski et al. (2010) reviewed the literature on the net energy return for wind turbines' power generation examining 119 wind turbine from 50 different research published during 1977-2007. The results show that average energy return on investment (EROI) for all studies including operational and conceptual is 25.2, while it is 19.2 for operational studies which places wind in a good position comparing to fossil fuels, nuclear power and solar power generation in view of EROI.

Sundararagavan and Baker (2012) applied a cost analysis for different types of energy storage technologies which are useful to mitigate uncertainty of integrating wind turbines and power grid due to intermittency of wind power. They argued there are three key factors which are required for this integration, include: load shifting, frequency support at transmission and distribution level, and power quality to smooth power fluctuations. The results show that no single technology could dominate all these three applications. The authors believed that assumptions about interest rates play a crucial role to make difference between technologies and selecting good technology depends on perspective of decision makers importantly.

Table (3-2): Empirical research about power generated by wind power

Authors	Subject	Result
Haack (1981)	Net energy analysis of small wind energy conversion systems	Small wind electric system are energetically competitive and at an advantage over other electricity generating systems.
Schleisner (2000)	Life cycle assessment of a wind farm and its externalities	Energy payback time (EPBT) would be 0.39 years or less than 2 percent of a 20-years life time if an estimation of 40 percent is assumed for energy efficiency.
Lenzen & Munksgaard (2002)	Review of energy and CO_2 life cycle analysis of wind turbines	It is suggested to minimize uncertainties in life cycle assessment by using a standardized methodology and input-output based hybrid techniques.
Liberman (2003)	Economic payback and life cycle assessment of utility-scale wind turbines in US	Wind turbines are not feasible at all locations, but they could be superior to generators using natural gas or coal at proper locations.
Korpaas et al. (2003)	Operation and sizing of energy storage for wind power plants	Energy storage enables wind power plants' owners to take advantage of spot markets. They are expensive but it could be a feasible option.
Lenzen & Wachsmann (2004)	Geographical variability in life-cycle assessment	A production shift abroad could be a good solution in order to achieve emission reduction.
Wagner & Pick (2004)	Energy yield ration for wind energy converters	Energy payback time (EPBT) would be 3-7 months and energy yield ratio is 38-70 depends on type and site.
Klaassen et al. (2005)	The impact of R&D on innovation for wind energy in Denmark, Germany and UK	A rate of 5.4 percent is estimated for learning-by-doing and 12.6 percent for learning-by-research to develop wind farms.
Benitez et al. (2008)	The economics of wind power with energy storage for Alberta in Canada	Generation cost of wind energy turbines is estimated 37-68 USD/MWh and reduction cost of CO_2 emissions would be 41-56 USD/tone.
Meunier (2009)	Life cycle analysis of 4.5 MW and 250 MW wind turbines	Wind energy could be the best environmental solution to mitigate climate change and supply electricity in off-grid areas.
Blanco (2009)	The economics of wind energy	Generation cost is estimated 4.5-8.7 Eurocents/kWh for onshore and 6.0-11.1 Eurocents/kWh for offshore wind turbines.

Authors	Subject	Result
Crawford (2009)	Life cycle analysis and GHG emission analysis for wind turbine	The size of wind turbine is not an important parameter to optimize life cycle energy performance.
Kubiszewski et al. (2010)	Net energy return for wind power systems	Average energy return on investment (EROI) for all studies including operational and conceptual is 25.2, while it is 19.2 for operational studies.
Sundararagavan & Baker (2012)	Evaluating energy storage technologies for wind power	Assumptions about interest rates play a crucial role to make difference between technologies and selecting good technology depends on perspective of decision makers importantly.

3.2.3. Solar power

During last decades, economic feasibility of solar power for residential, commercial and industrial consumption has been investigated by researchers. Industrial countries like Japan and Germany are looking for alternative sources of energy such as solar power due to limited natural primary energy sources. In early 1990s, Japan started to take advantage of large-scale electricity generation by solar photovoltaic followed by Germany. Currently, both countries with multibillion-dollar industries in solar power have taken the lead in manufacture and production of solar power technologies. In view of industrial economic, China developed an extensive solar power capacity resulted to be a dominant in global market and decreased the cost of solar power generation due to cheap labor and government subsidies.

Alongside with cost reduction of power generated through conventional solar PV technologies, advancement and high efficiency in concentrated solar power technologies in US made more reduction for cost of electricity in solar power industry (Gevorkian, 2012). On the other hand, there are some negative effects caused by solar technologies which include visual impact on buildings' aesthetics, routine and accidental releases of chemicals, land use, impact on ecosystems for large PV system, and construction activities for solar thermal energy (Tsoutsos et al., 2005). Solar photovoltaic (PV) market has experienced an extraordinary growth during last five years. The market increased from 9,564 MW in 2007 to 69,371 MW in 2011. Figure 3.5 shows its trend since 1996 to 2011 based on BP 2012.

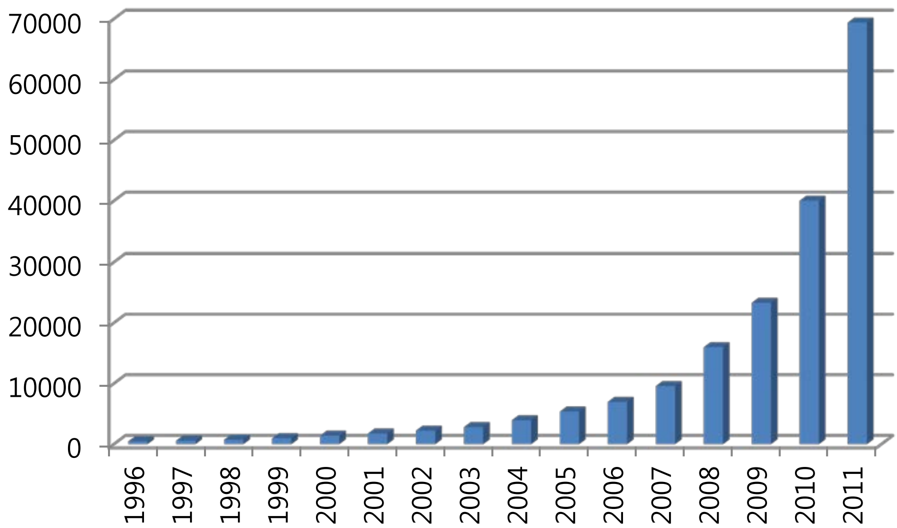


Figure (3-5): Cumulative installed solar PV capacity (MW)

Almost 30 GW of new capacity have been installed worldwide in 2011, leading to increased total world capacity to 69 GW. Major part of this new capacity has been surged in end of year due to tariff support policies, coming expiration date of some policies and price reductions. Turkey increased its capacity by 1,353 percent in 2011 over 2010. Bulgaria, Italy, Slovakia, and Greece also increased their capacity more than threefold. It is forecasted worldwide to establish PV industrial mass production during 2010-2020 and then, integrating of PV systems in the power grid beyond 2020. Figure 3.6 shows investment needs to install solar PV systems by 2050 (IEA, 2012c)

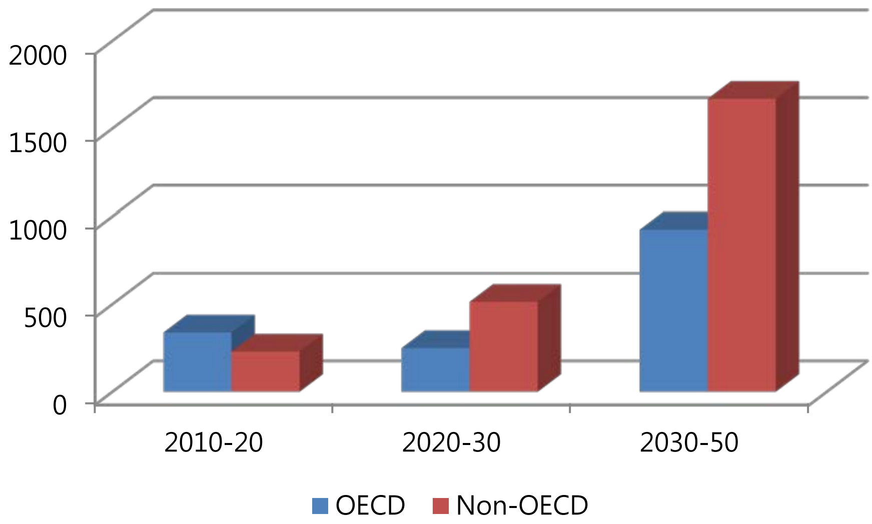


Figure (3-6): Investment to achieve solar PV power generation targets (USD billion)

Similar to wind energy, solar energy is depending on weather conditions. Variation in weather such as clouds and pollution could affect solar power generation. There is a major difference between wind and solar power due to time limitation usage, because solar energy is available just during daylight hours. Therefore, solar power generation is varied by season, location and daytime. Many technologies are used to deploy solar radiation including: thermal solar energy, concentrated solar power plant (CSP), solar chimneys or towers, and photovoltaic systems (Ngô and Natowitz, 2009). An advantage of photovoltaic technology comparing with the other technologies is the opportunity to integrate PV collector into the building and turn external walls, windows and roofs into a PV collector. Although, some environmental and health concerns could be arisen because of materials used for PV systems (Tester, 2005). Furthermore, PV performance could be reduced because of dust effects on glass and transparent materials. Sarver et al. (2013) examined and summarized the research and challenges regarding dust problems for solar panels.

Gordon (1987) analyzed optimal sizing of stand-alone photovoltaic power generation systems to design a cost effective alternative for conventional fossil fuel generators in developing countries where most people live in rural and off-grid areas. Frankl et al. (1997) evaluated benefits of building-integrated PV systems comparing with conventional PV power plants through life cycle analysis, maximizing energy efficiency and CO_2 reduction potential. The results show favorable effects for building-integrated PV systems in terms of energy production and CO_2 reduction emissions. They estimated CO_2 yield of 2.6 and 5.4 for conventional PV power plants and building-integrated systems, respectively. Also, they forecasted that these benefits will be increased in the future by advanced PV technologies.

Market interest to deploy renewable energy including solar power is increasing globally. Oliver and Jackson (1999) proposed some markets as the main markets for solar PVs. They argued that satellites, remote industrial, remote communities, solar home systems, remote houses, and consumer products (indoor applications) could be considered as a niche market for solar PV power. Nieuwenhout (2001) investigated experimental evidences for solar home systems (SHS) in developing countries and found that an adequate level of service infrastructure is required for solar PVs project viability. The results show that a few problems such as: lack of information on user experience, possible negative impacts of subsidies, limited choice of system size, and insufficient market transparency are appeared to present difficulties. Kolhe et al. (2002) analyzed economic feasibility of a stand-alone solar photovoltaic (SAPV) system comparing with a diesel power plant as a conventional alternative for India. The results show that PV system has the lowest cost up to 15 kWh and it could be increased to 68 kWh/day when the economic conditions is more favored. They argued that break-even point is going up if the cost of PV decrease and diesel costs increase.

Waldau (2006) examined European photovoltaic market and mentioned considering a growth rate of 40 percent during five years, photovoltaic is one of the fastest growing industries. He argued this industry needs reliable political framework to ensure return on investment and continuous research to find cost effective material, device designing, and increasing efficiency. Nawaz and Tiwari (2006) analyzed energy payback time and CO_2 emissions of PV system in India. They estimated embodied energy to produce PV modules at macro and micro level with assumed irradiation of 800-1200 W/m^2

in different sites and concluded that energy payback time (EPBT) depends on solar radiation, efficiency of PV system and balance of system. Also, it's estimated that EPBT is in the range of 7-26 years and CO_2 emissions reduction by existed technology are calculated in the range of 18-160 kg/m^2/year.

Shum and Watanabe (2007) compared deploying PV technology in Japan and US and applying two models named manufactured technology and information technology to explain differences in strategies. Ito et al. (2008) examined five types of 100 MW very large-scale photovoltaic power (VLS-PV) generation in economic and environmental point of view. They compared five types of PV modules installed in the Gobi desert (China) and investigated three studies about interest ratios, transmissions distances, and ambient temperatures. The results show that energy payback time is 1.5-2.5 years and CO_2 emission rate is 9-16 g/kWh. Also, the generation cost was estimated 11-12 US Cent/kWh for using 2 USD/W PV modules, and 19-20 US Cent/kWh for using 4 USD/W PV module price.

Fthenakis and Kim (2007) considered entire life cycle energy for solar and nuclear power generation to compare their potential for GHG emission reduction in US. They used data from 12 photovoltaic companies, and review of nuclear-fuel life cycles in US, Europe, and Japan. The results show that GHG emissions (based on CO_2 equivalent) are 22-49 g/kWh (average US) and 17-39 g/kWh (south west) for solar energy and 16-55 g/kWh for nuclear power. In another study Fthenakis et al. (2008) analyzed life cycle GHG, criteria pollutant, and heavy metal emissions for four types of PV technologies including multicrystalline silicon, monocrystalline silicon, ribbon silicon, and thin-film cadmium telluride. They found that thin-film cadmium telluride has the least amount of emissions among the four types. The differences in emissions for various PV technologies are too small comparing with conventional energy which is supposed to be replaced with PV systems. Feltrin and Freundlich (2008) examined different solar PV technologies ranging from silicon to thin films, and concentrated systems based on global available material reserves for large scale power generation at terawatt level deployment of photovoltaic energy. Based on their finding, in spite of enough availability of silicon, crystalline Si-based solar cells could not be reached terawatt level easily in large scale-up of technology. Therefore, improvement and innovation are required to overcome the material challenge.

Raugei and Frankl (2009) proposed three alternative scenarios for the future development of PV systems up to 2050 and argued they are likely to play an important role in the future energy mix if economic incentives are continued as enough for next two decades. Fthenakis et al. (2009) used hourly load data for the entire US and 45-years solar irradiation data from the southwest region and proposed a plan based on PV and CSP technologies, integrated with compressed air energy storage (CAES) for PV and thermal storage for CSP. They believed that solar energy has been a minor contributor so far due to cost and intermittency character of solar energy but cost reductions made by new emerging technologies enable solar power to be compatible with fossil fuels. They show that solar power has capability to supply 69 percent of total electricity demand and 35 percent of total energy demand in US by 2050.

Based on their research, it could be increased to 90 percent if the scenario is extended to 2100.

In a recent study Huo et al. (2011) applied Granger causality relationship between PV market sale and manufacturing development in US, Germany, China and Japan. The results show that growth of market sale affects innovation scale in US, Germany and Japan. Also, there is a bidirectional relationship between PV market sale and manufacturing development in US and Germany. They argued that manufacturing sector can influence the dynamics of market sale. Lin (2011) investigated key development factors to create competitiveness of solar PV industry in Taiwan and causal effects of these factors. It is indicated that local demand conditions, government support, and related supporting industries are three factors that influence solar PV industry strongly. Branker et al. (2011) calculated levelized cost of electricity (LCOE) generation of solar PV for a case study in Canada. They considered grid parity of PV system comparing with electricity price of conventional technology to analyze cost effectiveness and found that solar PV already met grid parity in some locations due to cost reduction. It is stated that feasibility of solar PV system will be increased in the future as it expands geographically.

Table (3-3): Empirical research about power generated by solar power

Authors	Subject	Result
Frankl et al. (1997)	Life cycle analysis of PV systems in buildings	They estimated CO_2 yield of 2.6 and 5.4 for conventional PV power plants and building-integrated systems.
Oliver and Jackson (1999)	Market for photovoltaic	Satellites, remote industrial, remote communities, solar home systems, remote houses, and consumer products could be considered as a niche market for solar PV.
Nieuwenhout (2001)	Experience with solar home systems in developing countries	Lack of user experience, possible negative impacts of subsidies, limited choice of size, and insufficient market transparency are appeared to present difficulties.
Kolhe et al. (2002)	Economic feasibility of stand-alone solar PV compared with diesel in India	PV system has the lowest cost up to 15 kWh and it could be increased to 68 kWh/day. The break-even point is going up if the cost of PV decrease and diesel costs increase.
Waldau (2006)	European PV in worldwide comparison	Reliable political framework is required to ensure return on investment and continuous research to find cost effective material, device designing, and increasing efficiency.
Nawaz and Tiwari (2006)	Energy analysis of PV based on marco- and micro level in India	It's estimated that EPBT is in the range of 7-26 years and CO_2 emissions reduction by existed technology are calculated in the range of 18-160 kg/m^2/year.
Fthenakis and Kim (2007)	GHG emissions from solar and nuclear power	GHG emissions (based on CO_2 equivalent) are 22-49 g/kWh (average US) and 17-39 g/kWh (south west) for solar energy and 16-55 g/kWh for nuclear power.
Ito et al. (2008)	Comparative study on cost and life cycle analysis for very large scale PV	EPBT is 1.5-2.5 years and CO_2 emission rate is 9-16 g/kWh. Also, the generation cost was estimated 11-12 US Cent/kWh for using 2 USD/W PV modules, and 19-20 US Cent/kWh for using 4 USD/W PV module price.
Fthenakis et al. (2008)	Emissions from PV life cycle	Thin-film cadmium telluride has the least amount of emissions among the four types technology. The differences in emissions for various PV technologies are too small.

Authors	Subject	Result
Feltrin & Freundlich (2008)	Material consideration for terawatt level deployment of PV	In spite of enough availability of silicon, crystalline Si-based solar cells could not be reached terawatt level easily in large scale-up of technology.
Raugei & Frankl (2009)	Life cycle impacts and costs of PV systems	If economic incentives are continued as enough for the next two decades, PV systems likely play a significant role in the future energy mix.
Fthenakis et al. (2009)	Feasibility for solar energy to supply the energy needs of US	Solar power has capability to supply 69% of total electricity demand and 35% of total energy demand in US by 2050. It could be increased to 90% if time is extended to 2100.
Huo et al. (2011)	Relationship between PV market and its manufacturing	Growth of market sale affects innovation scale in US, Germany and Japan. Feasibility of solar PV system will be increased in the future as it expands geographically.
Branker et al. (2011)	Solar PV levelized cost of electricity	Solar PV already met grid parity in some locations due to cost reduction. Feasibility of solar PV system will be increased in the future as it expands geographically.

3.2.4. Geothermal

Geothermal is a type of thermal energy generated and stored in the Earth. It has been used for bathing, heating and cooking for a long time. Geothermal energy is created by radioactive decay with a main temperature reaching 4,000˚C at core of the Earth. While geothermal energy is available worldwide there is an important factor called geothermal gradient to indicate a region as favored place for deploying such energy. It measures the rate of increasing temperature when depth in the Earth is increasing. For example, geothermal gradient average in France is 4˚C/100m with a broad variation from

10˚C/100m in the Alsace region and 2˚C/100m in Pyrenees Mountains. In Iceland and volcanic regions, 30˚C/100m may be reached (Ngô and Natowitz, 2009).

Geothermal is not the only dominant factor to measure accessibility of geothermal energy. Permeability of the rocks which determines the rate of flowing heat to the surface is considered as another important measurement to deploy geothermal energy. Geothermal has a big advantage comparing with wind and solar energy, availability for 24 hours through the year. According to Ngô and Natowitz (2009), annual percentage of 80-90 could be reached. They estimated CO_2 emission produced by geothermal resources is 55 g/kWh employing data from survey of 73 percent of the geothermal power plants. This value may be decreased to zero if geothermal fluid is reinjected into the ground. A total of 24 countries are using geothermal power plants now. Total installed capacity has been 11 GW in 2011. Figure 3.7 shows cumulative installed geothermal power capacity worldwide based on BP 2012.

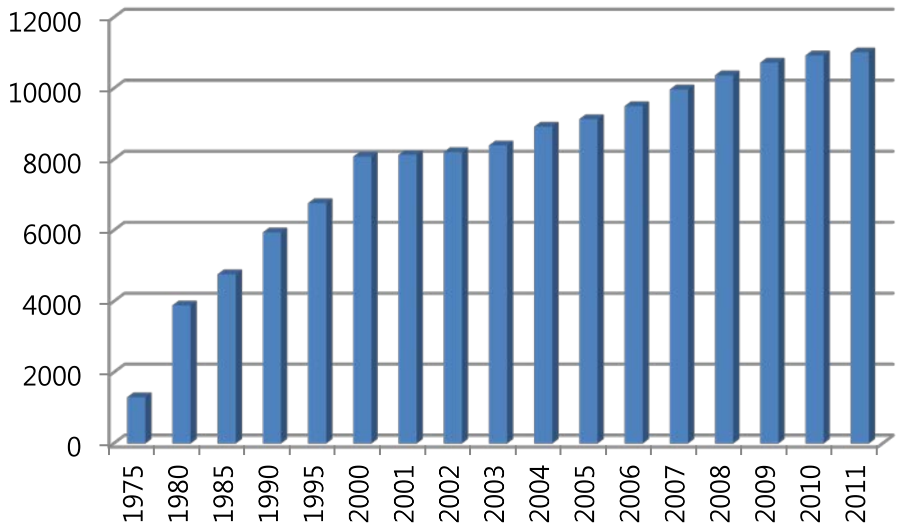


Figure (3-7): Cumulative installed geothermal capacity (MW)

Costa Rica, Turkey and Iceland have increased their capacity in 2011 over 2010 by 25.3, 21.2 and 15.7 percent, respectively. The majority of worldwide capacity (GW) has been installed in 8 countries: United States (3.1), Philippines (almost 2.0), Indonesia (1.2), Mexico (0.9), Italy (0.9), New Zealand (0.8), Iceland (0.7), and Japan (0.5) (BP, 2012). Geothermal capacity is expected to develop deploying co-production geothermal power by exploited water from oil and gas wells throughout 2015. Figure (3-8) shows investment needs for geothermal development by 2050 for group of countries based on IEA estimation (IEA, 2012c).

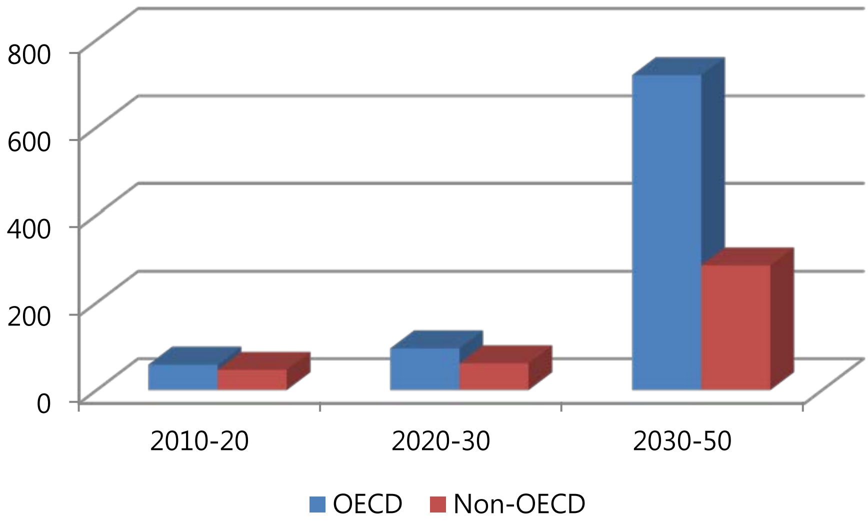


Figure (3-8): Investment to achieve geothermal generation targets (USD billion)

Fridleifsson and Freeston (1994) investigated geothermal energy development based on worldwide experiences and forecasted an estimate of 15-20 billion dollars for total investment cost of geothermal in the world during next decade. But, this estimation was increased fivefold in IEA report when declared the amount of 104 billion dollars as worldwide required investment in 2010-2020 to meet desired targets (IEA, 2012c). Fridleifsoon and Freeston pointed that considering geothermal independence from weather condition and storage capability, it could be used both for base load and peak power plants. It was stated that environmental problems created by release of steam and gases and hot water to the river could be reduced by advanced technologies. Also, they argued that many countries, particularly developing countries, try to deploy geothermal energy with available technology but there are some difficulties due to lack of finance and knowledge infrastructure for training technicians.

They proposed more training centers should be established through international programs.

Murphy and Niitsuma (1999) mentioned about strategies for compensating for higher costs of geothermal electricity with environmental benefits and suggested some fiscal policy measures such as carbon tax to support and monetizing the advantages of geothermal. They pointed Japan, Indonesia and Philippine as countries that geothermal growth remained high due to supportive policies performed by their governments. Stefansson (2002) applied statistics methodology and employed data from Iceland to estimate investment cost required to build a power plant for an unknown geothermal fields. He believed that price levels in Iceland are similar to Europe and US, therefore the result could be applied for the other countries. Based on his finding, total investment cost of geothermal power plants in the range 20-60 MW is estimated 1,267 USD/kW in a known field and 1,440 USD/kW in an unknown field.

Lund et al. (2005) reviewed worldwide direct application of geothermal energy by employing data from 72 countries. The results showed that using 273,372 TJ/year of energy consumption in 2005 and assuming 6.06×10^9 J for each barrel of fuel oil, estimated energy saving could be 128.9 million barrels of oil or 19.2 million tons of oil per annum. They argued there will be an additional saving of 41.2 million barrels (6.2 million tons) of fuel oil or 7 million tons of carbon emissions if saving in the cooling mode of geothermal heat pump is considered.

Frick et al. (2010) applied a Life Cycle Analysis method on geothermal power generation from EGS (enhanced geothermal system) low temperature reservoirs in order to show how much environment is affected by geological conditions. They found that geothermal binary power plants cannot be explained by environmental indices because of different geological conditions. The results show that a life cycle geothermal binary power plant is determined by materials and energy inputs. Therefore, successful access to reservoir by minimum drilling is an important factor for low environmental impacts. It's stated that less favorable geothermal heat and power generation could have contribution in energy system to enhance sustainability. In a related study Saner et al. (2010) discussed energy consumption and GHGs emissions and applied life cycle assessment to examine environmental impacts due to install ground source heat pump (GSHP) for deploying geothermal energy. The results classified environmental impacts of GSHP system as resource depletion (34%), human health (43%) and ecosystem quality (23%). Also, CO_2 emission equivalent has been estimated an average of 63 tons for a life cycle of 20 years, means 31-88 percent emission saving for Europe, comparing with conventional heating system.

Purkus and Barth (2011) analyzed German geothermal industry and emphasized importance of political support and framework conditions in electricity market. They argued that high investment cost and risk of insufficient heat are considered as disadvantage of geothermal technology, but the core advantage of non-intermittency comparing with the other kinds of renewable energy sources could enable it to be considered as a reliable supply of base load power. Kaya et al. (2011) investigated a worldwide experience of reinjection in geothermal fields employing data from 91 geothermal power plants and found that a reinjection plan is required in order to reduce the risk of groundwater contamination. The results show that response of the geothermal reservoir to different strategies for reinjection depends on geothermal system. Also, the authors stated that reinjection is an environmental friendly method of waste water disposal and should be performed properly, because the consequent effects may be irreversible.

In a recent study, Chamorro et al. (2012) reviewed worldwide status of geothermal energy and found that high temperature technologies flash and dry steam are the most developed geothermal power generation technologies. They defined four model plants; include 1FMP (single flash model plant), 2FMP (double flash model plant), 3FMP (triple flash model plant) and DSMP (dry steam model plant) to analyze geothermal systems. The results show that DSMP has the highest NPV amount and IRR factor with 1,013.6 M$ and 22.8 percent. Also, cost of electricity is 29.38 $/MWh for DSMP which is estimated as minimum among the different models.

Table (3-4): Empirical research about power generated by geothermal

Authors	Subject	Result
Fridleifsson & Freeston (1994)	Geothermal energy R&D	It is forecasted an estimate of 15-20 billion dollars for total investment of geothermal in the world during next decade. It could be used both for base load and peak power plants.
Murphy & Niitsuma (1999)	Strategies for compensating higher costs of geothermal	They suggested some fiscal policy measures such as carbon tax to support and monetizing the advantages of geothermal electricity.
Stefansson (2002)	Investment cost for geothermal power plants	Total investment cost of geothermal power plants in the range 20-60 MW is estimated 1,267 USD/kW in a known field and 1,440 USD/kW in an unknown field.
Lund et al. (2005)	Application of geothermal energy	Using 28,268 MWt installed capacity in 2005, estimated energy saving could be 128.9 million barrels of oil or 19.2 million tons of oil per annum.
Frick et al. (2010)	Life cycle assessment of geothermal binary power plants	A life cycle geothermal binary power plant is determined by materials and energy inputs. Successful access to reservoir by minimum drilling is an important factor.
Saner et al. (2010)	Life cycle perspectives on geothermal systems	CO_2 emission equivalent has been estimated an average of 63 tons for a life cycle of 20 years, means 31-88 percent emission saving for Europe, comparing with conventional system.
Purkus & Barth (2011)	Geothermal power production in future electricity markets	High investment cost and risk of insufficient heat are disadvantage of this technology. Non-intermittency could enable it to be considered as a reliable supply of base load power.
Kaya et al. (2011)	Reinjection in geothermal fields	A reinjection plan is required in order to reduce the risk of groundwater contamination. It is an environmental friendly method of waste water disposal.
Chamorro et al. (2012)	Energy, environmental and economic study of geothermal technology	Dry steam model plant (DSMP) has the highest NPV amount and IRR factor with 1,013.6 M$ and 22.8 percent. Also, cost of electricity is 29.38 $/MWh for DSMP which is estimated as minimum among the different models.

3.2.5 Other renewable sources

There are some other types of renewable energy sources including: biomass, ocean waves and tides. Biomass is defined as living plant and organic waste which is made by plants, human, marine life, and animals. Based on Tester (2005), the main advantage of biomass is availability, it could be found widely in all places. Many kinds of energy can be made from biomass: electricity, cooking, chemical feedstock, etc. As a feedstock, biomass has lower sulfur content than coal. Therefore, lower emission is produced by combustion. In early 2000, the United States had an installed capacity of 11 GW from biomass including: forest product and agricultural industry (7.5 GW), municipal and solid waste (3 GW) and other sources (0.5 GW) (Ngô and Natowitz, 2009).

Deploying energy from ocean is considered as an interested option because of wide availability of ocean sources. There are six different resources which are available from oceans: offshore wind energy, wave power, marine current energy, ocean thermal energy conversion, tidal power, and osmotic power. The Bay of Fundy has the largest tidal range worldwide enables it to support a power station with a capacity of 2 GW or more (Tester, 2005). We considered hydro, wind, solar and geothermal because of main contribution in power generated by renewable energy sources.

3.3 Energy efficiency technologies

As we mentioned already, there are two main solutions in order to reduce CO_2 emissions and overcome climate change problem: by replacing fossil fuels with renewable energy sources as much as possible and through enhancing energy efficiency. We discussed state of the art for technical and economical feasibility of deploying renewable energy sources and possibility of substitution in previous section. At this section, we are talking about energy efficiency technologies. Energy efficiency for electricity network could be considered in different stages including: power generation (here the focus is on small size), transmission, distribution and consumption. For this purpose, different technologies are available such as: electric vehicle (EV), combined heat and power (CHP), virtual power plant (VPP) and smart grid.

3.3.1 Electric Vehicle (EV)

Electric Vehicles (including battery, fuel cell, and hybrid) have potential to be considered for both electricity storage and power generation sources. Considering that transportation sector is one of the main sources of emissions, improving fuel efficiency enables to achieve the largest fuel saving and CO_2 reduction in short term. Thus, implementation of EVs and increasing their share in vehicle fleet can play a key role in long term. IEA forecasted (IEA, 2012c) that increased share of PHEVs is getting more important for next two decades and it will be increased by up to 50 percent by 2050 in ETP 2012 2DS scenario (2DS scenario is consistent with the world energy outlook 450 scenario through 2035). “In long-term, smart grid technology may enable EVs to be used as distributed storage devices, feeding electricity stored in their batteries back to the system when needed (vehicle to grid), to help provide peak-shaving capability.”(IEA, 2012e)

Ford (1995) examined the impact of large scale use of electric vehicles in southern California and analyzed that Southern California Edison company is able to accommodate a large number of EVs with existing capacity, particularly if the charging system could be managed by smart control. Ford argued that EVs can improve load management, enhance efficiency and saving energy. Also, he calculated that EVs are able to reduce emissions valued about 9,000 USD per vehicle. Kempton (1997) calculated present value costs for EV owner and benefits to utility and found that it’s highly profitable for the utility. Based on the results, all three vehicle/battery combination are cost-effective power sources in peak time for near-term. He argued that if a part of transportation section is utilized to electric vehicles and connected to electricity network, there will be less demand for base-load generation and using intermittent renewable energy sources becomes more applicable due to lack of concerning about time-of-day match between demand and supply.

Kempton and Tomic (2005) investigated the systems and procedures required to use energy in vehicles and implementation of vehicle to grid (V2G) technology. The most important role of V2G could be to support renewable energy in emerging power markets through managing load and supply fluctuation made by intermittency of renewable energy sources such as photovoltaic and wind turbines. They argued that after initially tapping EVs for high value, market saturation and cost reduction, V2G fleet could be used as storage capacity for renewable energy power generation. Tomic and Kempton (2007) examined economic feasibility of two battery-electric vehicles to supply power for a particular market in four US regulation service markets. The results show that V2G electricity is able to provide a significant income flow, helping feasibility of grid connected vehicles and further support for adoption. Lund and Kempton (2008) evaluated integration of renewable energy into the transport and electricity sectors by V2G. They applied a model to analyze energy integration for electricity, transport and heating. V2G technology is able to provide storage for matching time of generation and time of load. Lund and Kempton found that adding EVs and V2G to power network enables system to be integrated with higher level of wind electricity without extra power generation and make a huge reduction for CO_2 emissions. Steenhof and McInnis (2008) analyzed three scenarios to evaluate impacts of increasing ethanol 85, hydrogen, and electricity powered vehicles into the passenger transportation fleet started to be implemented in 2010, and reaching 100 percent of new market by 2050. The results show that CO_2 emissions will be reduced from 153 Mt for electric vehicle to 156 Mt for hydrogen fuel cell vehicle by 2050. It's forecasted that ethanol driving cars will be cellulosed based by 2050, generating significant reduction in CO_2 emission, but unsustainable amount of crops residues will be required.

Andersen et al. (2009) introduced an intelligent electric recharging grid operator (ERGO) for creating a market to coordinate production and consumption of renewable energy. They argued that ERGO model could overcome both problems of GHG emissions and power fluctuations (CO_2 emissions produced by private transport sector and fluctuation in supply made by intermittent resources) through converting EVs to distributed storage devices for electricity. An introduction of V2G distributed power sources, IT intelligence to the grid, creating virtual power plants through distributed resources, and providing new applications for carbon credits have been stated as associated benefits which are achieved by ERGO model.

Weiller (2011) applied a model to examine the impacts of different charging scenario for PHEVs in the United States on electricity demand, in view of time of day and charging place (owner's home, workplace, and public area). The results show that possibility of charging in places other than home increases the fraction of daily energy use of PHEV from 24 percent to 29 percent (1.5-2.0 kWh/day). Based on the results, PHEV-20 (vehicles with a 20 mile range) makes a shift of 45-65 percent of miles traveled to electricity, comparing with 65-80 percent for PHEV-40. Furthermore, it's explored that PHEVs enable US drivers to cut gasoline consumption by more than 50 percent through shifting 45-77 percent of miles traveled to electricity. Weiller indicated that PHEVs could be considered as a cost-effective solution when we compare electricity costs about $0.03/mile ($0.13/kWh) with gasoline costs $0.12/mile ($3/gallon). Environmental and transportation policy in terms of supporting EVs plays a key role to measure their effects on electricity network in the future. Financial incentives and governmental policy regarding carbon tax can influence early and comprehensive implementation of EVs strongly.

3.3.2 Combined Heat and Power (CHP)

Cogeneration or combined heat and power are the use of heat and electric power together. It is expected to enable us to have substantial gain in efficiency. Most power distribution company supply only electricity, not hot water or steam. Considering that almost 30-40 percent of a country's total energy load is used for heating, the lack of possibility to purchase thermal energy is not fortune. CHP is an efficient use of fuel when some energy is discarded as waste heat. It captures some or all waste energy as by-product for heating. In Reykjavik (capital city of Iceland) and New York, end users are able to purchase both electricity and thermal energy from a utility company (Tester, 2005). A good example of cogeneration is the CHP unit in Avedore, Denmark. It was built as a multifuel plant with the possibility of using coal, natural gas and biomass. But, Danish government prohibited burning coal in 1996 and Avedore switched to gas and biomass, achieving an efficiency of 55 percent in CHP (Ngô and Natowitz, 2009). Shipley et al. (2008) calculated that increasing CHP capacity of United States to 20 percent by 2030 which leads to 5.3 Quads reduction in energy consumption and 848 MMT carbon dioxide emissions. Based on his finding, United States saved more than 1.9 Quadrillion British thermal Unit (Quads) of fuel consumption and 248 million metric tons carbon dioxide emissions by employing CHP. According to *WEO 2012*, average efficiency of power plants is 41 percent worldwide and almost

60 percent of the primary energy is converted to waste heat (IEA, 2012e) CHP could transform a significant part of waste heat to economic value for industrial process or heating in residual and commercial buildings. It is stated that new CHP units could improve energy efficiency to more than 85 percent.

Madiment and Tozer (2002) investigated application of combined cooling heat and power (CCHP) for supermarkets in UK and compared it with energy saving/capital cost of conventional technology. The results show that CCHP is able to provide significant primary energy and CO_2 reduction comparing with conventional scheme, but it should compete with more efficient technologies in long term. They argued that new technologies such as fuel cell could provide more improvement in energy efficiency for CCHP in refrigeration in the long term.

Hawkes and Leach (2007) examined cost effecting operating strategies of three alternatives micro-CHP technologies including Stirling engine, gas engine, and solid oxide fuel cell-based (SOFC) system for residential application in UK. They evaluated economic and environmental attributes of three operating strategies: heat-led, electricity-led, and least-cost to apply above mentioned technologies. The results show that SOFC-based system obtained maximum operating cost and CO_2 emission reduction following least-cost operating strategy. You et al. (2009) examined the electricity export capability of aggregated micro-CHP units as a virtual power plant (VPP) through participating in electricity wholesale market without any difference compared to conventional power plants. They found that export capability of micro-CHP systems strongly depends on technical parameters, associated energy price, and demand profile. Based on applied model, it’s explored that marginal price for a micro-CHP system is higher than spot price in most part of a year. Furthermore, they argued that variable price for electricity export could be better than fixed price.

Kiviluoma and Meibom (2010) applied a model to analyze the impact of variable power generation by wind turbine and utilizing EVs store electricity for later consumption in order to enhance flexibility of power grid. Based on the results, CHP units could make a good potential for power system to be flexible in terms of production and use of heat. Christidis et al. (2012) investigated contribution of heat storage to optimize CHP units in liberalized electricity markets, applying a model to measure economic potential and optimal capacity of heat accumulators. They concluded that separating electricity production and heat demand could provide a profitable pay back periods for storage device in the proposed energy system.

3.3.3 Virtual Power Plant (VPP)

Virtual Power Plant (VPP) is a cluster of distributed energy resources such as micro-CHP, wind turbines, and solar photovoltaic panels which are controlled and managed by a central control unit. The term of distributed energy resources (DER) can be used for fossil or renewable energy fuels. DER system has been defined in order to overcome energy waste problem due to long distance and transmission losses. Therefore, DERs generally are located close to distribution network. The concept of VPP is used for DER integration.

According to Europe FENIX project: "*A Virtual Power Plant (VPP) aggregates the capacity of many diverse DERs, it creates a single operating profile from a composite of the parameters characterizing each DERs and can incorporate the impact of network on aggregate DERs output. A VPP is a flexible representation of a portfolio of DERs that can be used to make contracts in the wholesale market and to offer services to the system operator. There are two types of VPP, the Commercial VPP (CVPP) and the Technical VPP (TVPP). DERs can simultaneously be part of both a CVPP and a TVPP*" (Kieny et al., 2009). Commercial VPP is defined as portfolio that could be used by DER to participate in electricity markets. CVPPs can represent DER from any geographic place in electricity network. Technical VPP enables operators to facilitate deploying DER energy capacity and optimize power balance in the system with the minimum cost (Pudjianto et al., 2007).

The share of distributed generation (DG) in electricity network is getting important continuously and VPP is considered as an emerging technology to enhance energy efficiency. Schulz et al. (2005) analyzed the technical and economical feasibility of operating a VPP with micro-CHP units. They explained that due to Germany's plan to abandon nuclear power plant until 2020 and building new plants with a capacity of 40 GW, a part of this new capacity should be renewable energy sources and CHP utility which are considered as distributed generation units. VPP is an alternative to manage these units, as lack of control is a big advantage for renewable energy technology. Based their finding, the power generated by an individual owner is too small to supply, because the size of power output should be 30 MW or higher based on existing regulation. VPP operator can integrate a large number of DERs and provide 30 MW through aggregating 6,000 micro-CHP units of 5 kW power output. They estimated that every unit is charged 300 Euro for connection to integrated system and returns flow are divided as a share of 45 percent for unit's owner and 55 percent for operator. Ruiz et al. (2008) applied a model to manage a VPP constituted a large number of customers with controlled home appliances in order to optimize load reduction over a certain time schedule. They estimated the size of load reduction provided by each unit of DGs in energy market and in the same time, helping to optimize network congestion and balance between supply and demand. It's indicated that capability of applying optimization algorithm on actual system has been tested in northern Spain and results show that contribution of a large number of customers with controlled appliances could improve energy efficiency effectively.

Jansen et al. (2010) examined an architecture and communication pattern for employing a large number of electric vehicles to be integrated in a VPP system. They argued that EVs have a good potential to be a part of electricity network if a fleet of vehicles are managed appropriately and proposed an integrated VPP constituted electric vehicles. It's indicated that intelligence is required to optimize charging of EV batteries in order to manage integration of EVs into the electricity network. You et al. (2009) proposed a market-based VPP model constituted DERs units which have access to electricity markets. Based on the model, general bidding and price signal are considered as two operation scenarios performed by one market-based virtual power plant.

Haussmann et al. (2010) developed a mathematical optimization model for the management of CHPs. Considering the main task of a VPP to increase generated electricity by DG units, operation of individual generators should be optimized and then, it's calculated how much their contribution to output of VPP is. They applied this model for a local heating system constituted 5 CHP units and the results show 10 percent increasing in benefits compared with a general CHP system. It's stated that an extended version of this model could be used in European Energy Exchange to optimize management of CHP in the form of VPP.

3.3.4 Smart meter

They most important objective for power generation companies in demand side management is to reduce peak demand during a certain period of hours. In this regard, Smart meter is a device to record consumption of electricity in hourly intervals and the information is monitored by utility and customer. Smart meter is able to have two way communication and intelligence management for home appliance. Hartway et al. (1999) examined application of smart meter and customer choice control in order to show that time-of-use (TOU) strategy can be beneficial for a utility company. The results show that TOU rate option could make a 107 kWh energy saving for each customer per year. They calculated an annual bill saving of $77 for customers and cost saving of $134 per customer for utility company. Applying smart meters could enable electricity network to make a significant change in energy efficiency.

Faruqui et al. (2007) calculated that 5 percent decreasing in US peak demand through installation of advanced metering infrastructure can make a substantial saving in generation, transmission, and distribution cost which is enough to eliminate 625 peak load power plants and associated infrastructure, roughly $3 billion in a year. Karnouskos et al. (2007) indicated that "smart meters empower and advanced metering infrastructure which is able to react almost in real time, provide fine-grained energy production or consumption info and adapt its behavior proactively." They argued that smart meters could provide new opportunities in electricity network and system integration through process data and making decision based on capabilities. This role enables managers and policy makers to take advantage of real-time data. It is forecasted that smart meters could be gateway of home appliance communication through internet and will enable to use advanced communication capabilities in the future. They concluded that combination of energy domain and ICT could provide a great opportunity for business in coming years.

Faruqui et al. (2010) quantified long term cost-benefit of investing in dynamic pricing and installing smart meters for EU. They estimated that installation cost of smart meters will be 51 billion Euros, compared with operational saving 26-41 billion which make a gap around 10-25 billion Euros. They argued that smart meters have capability to cover this gap by dynamic pricing and reducing peak demand. They suggested that policy makers and utility companies are able to increase adoption rate by applying innovative policy in order to encourage customers for more participation. It is expected that amount of saving due to reduction in associated capacity and transmission costs will be 67 billion if 80 percent of customers reduce their electricity consumption during peak hours.

Depuru et al. (2011) examined different features and technologies enabled to be integrated with smart metering in order to figure out requirements to implement a network appropriated for smart grid communication. It is indicated that worldwide deployment of smart meters is estimated to be almost 212 million units by 2014. They indicated that Home Area Networks technology (HAN) could support PHEVs and DG units in communication network. Considering significant growth rate of PHEVs penetration in the future, there could be a great demand for smart meter application. Due to increasing fuel prices and high initial cost to develop conventional infrastructure for supply side of electricity network, energy efficiency and implement demand response (DR) program through smart metering is an attractive option for policy makers and utility companies' managers. Baltimore Gas and Electric company has estimated that capital cost of DR program at $165/kW is much less than building new peak demand generation facilities at $600-800/kW (Vojdani, 2008).

Krishnamurti et al. (2012) discussed consumers' expectation and their behavioral decision, applying a model to measure the impacts of smart meters installation on beliefs about smart metering. Based on the results, there is a misconception for consumers about impact of smart metering deployment. They suggested this misconception could be eased by electric utilities through explaining potential risk and benefits clearly and take an action to provide communicate safeguard for concerns about privacy and loss of control. McKenna et al. (2012) analyzed consumer privacy concerns about smart metering and some applications of smart meters' data required for electricity industries. They examined how much sensitivity is acceptable for obtaining data and investigated whether deploying personal data can be minimized or avoided. Based on the results, it is suggested that power supply requirements for sensitive smart metering could be reduced by applying appropriate privacy techniques. Because privacy concerns has strong potential to delay smart meter penetration if they are not applied appropriately.

McHenry (2013) discussed technical and governance consideration for smart meters infrastructures; includes technical and non-technical requirements, cost and benefits smart meters infrastructures, and impact smart meters installation on stakeholders (market operators, distributors, customers, etc.). He argued that full benefits of advanced metering infrastructure (AMI) alongside with other technologies enable stakeholders to take advantage of intelligent management in order to minimizing cost, improving efficiency and remote monitoring. Although the potential benefits of AMI could be significant, it is stated that scale of smart meters investment is considered as unprecedented challenge for policy makers, because there is some uncertainties of associated benefits such as retailer investment on smart metering, transferring investment cost to customers, and residential behavior influenced by current tariff and payment methods.

Chapter 4: Regulatory Frameworks for Renewable Energy Sources

4.1 Introduction

Regulation refers to the process of making, monitoring, and enforcing of rules that are established by the state or authorized by the state. These rules are mandated by the state to produce appropriate and desirable outcomes. According to Gunningham and Grabosky (1998), the various regulatory instruments include the following command and control regulation, self-regulation, voluntarism, education and information instruments, economic instruments, property-rights, market creation, fiscal instruments and charge systems, financial instruments, liability instruments, performance bonds, deposit refund systems, and the removal of perverse incentives.

The interaction between players and organizations (either state or non-state) in markets and their reciprocal influence should be considered in effective policymaking. Environmental regulations could affect the commercial policies and strategic decisions made by companies. According to Bosselmann and Richardson (1999), regulations provide "*planning frameworks for resource use and environmental protection, limitation on market entry and exit, specifications relating to the methods of production, and controls on the quality of the products supplied*." Interactions take place between government policies, commercial policies and environmental policies. For example, in the case of liberalization, some governments may reduce the restrictions imposed by environmental regulations in order to help domestic companies compete with their international rivals.

The main objective in this chapter is to conduct a comprehensive review of the literature on regulation frameworks that are employed around the world and are related to the use of renewable energy sources. An attempt is made to classify the frameworks and identify the strength and weaknesses of different regulatory frameworks. Finally, based on the findings, a set of optimal frameworks is proposed and procedures to facilitate their effective implementation are suggested.

In our discussion, the regulatory framework is related to different dimensions of renewable energy sources and includes the following: environmental policy, public policy, commercial policy, and economic policy. These regulations are required to overcome market failure and produce desirable outcomes. Such regulatory interventions could be classified into three main groups: economic regulation, regulation of anti-competitive behavior, and social regulation (Bhattacharyya, 2011). A broader classification includes support policy, market regulation, technology transfer, barriers, and international regulatory policies. It is important to mention that national environment regulation may be influenced by regional and international regulatory frameworks. Examples of this case are the different scenarios defined by the IEA for OECD countries and the Kyoto Protocol.

This Chapter is organized in a number of sections. In Section 2 through

Section 5 we review the literature on support policy, market regulations, technology transfer and barriers. Section 6 provides a review of national and international environmental policies.

4.2 Support policy

Although the deployment of renewable energy has increased during recent decades, fossil fuels supported by subsidies remain dominant as primary global energy sources. Support policies have also played a key role in enhancing renewable energy consumption. Therefore, these policies could direct a society's use of energy to generate power, transportation, heating, etc. For example, regulatory reforms in China pushed energy consumption upward from approximately 130 bcm in 2011 to 545 bcm in 2035 (IEA, 2012e). Regarding renewable energies, in addition to parameters, such as decreasing technology costs caused by advancement and economies of scale, the rapid growth of renewable energy was focused mainly by supporting policies. Because some sources of energy, such as natural gas and coal, are available on the market at lower prices, renewable energy could not be economical without government support. There may be different drivers of support policies, based on governmental priorities, including energy security, economic effects, and carbon dioxide reduction, which were discussed in chapter two. Support policies could be applied from the research stage to commercialization for both the supply side (i.e., academia, research centers, and firms) and the demand side (i.e., consumers, public and private sectors, imports and exports).

(IEA, 2012c).

Many OECD countries have implemented national strategies to support sustainable development through environmentally friendly technological advances. These strategies deal with different objectives and cover a wide range of policies, including the environment, science and technology, transport, competition, and energy (OECD, 2011). As we discussed in chapter three, there are different kinds of technology are used to overcome difficulties caused by climate change. Concern about the effects of climate change and the depletion of fossil fuel reserves has urged many governments to design and implement policies to support the spillover of renewable energy technologies to different areas of use. By early 2012, at least 109 countries had applied some kinds of renewable power support policies, which was an increase from the 96 countries reported in the Renewables Global status report in 2011 (Martinot and Sawin, 2012). These policies are performed at the state or national level. Table (4-1) shows renewable energy support policies in the EU-15 countries.

Table (4-1): Renewable energy support mechanism in EU-15 countries

	Regulatory policies						Fiscal incentives				Public finance	
	Feed-in tariff	quota obligation	Net metering	Biofuels obligation	Heat obligation	Tradable REC	Capital subsidy	Investment or production tax credit	Other taxes	Energy production payment	Public investment	Public competitive bidding
Austria	n			n		n	n	n			n	
Belgium		s	n	n		n	s	n	n			n
Denmark	n		n	n		n	n	n	n		n	n
Finland	n			n		n	n		n	n		
France	n			n	n		n	n	n		n	n
Germany	n			n	n		n	n	n		n	
Greece	n			n			n	n	n		n	
Ireland	n			n	s	n						n
Italy	n	n	n	n	n	n						n
Luxembourg	n						n					
Netherlands	n			n		n	n	n	n	n	n	
Portugal	n	n	n	n	n		n	n	n		n	n
Spain	n			n	n		n	n	n		n	
Sweden		n		n		n	n	n	n		n	
UK	n	n		n	n	n	n		n	n	n	

n: national-level policy
s: state/provincial level policy
Source: Renewable Global Status Report, 2012.

A number of options could be utilized by governments to enhance renewable energy deployment. Sawin (2006) gave three options of instruments in the support policy mechanism: 1) the first was supporting voluntarism through education and information; 2) supporting environmental standards and energy taxes; and 3) supporting renewable energy technologies directly. Education is a crucial component in using renewable energy technologies. Sawin has stated that the effectiveness of government policies depends on the design and enforcement of policies. There is no guarantee that a particular policy will be successful. Based on this finding, support policies should focus on end to promote renewable energy technologies on a small-scale and distributed basis. Gunningham and Grabosky (1998) divided education and information instruments into five major categories: education and training, corporate environmental reporting, community right-to-know and pollution inventories, product certification, and award schemes. Education and training are considered a crucial part of the mechanism to develop renewable energy technologies in the industry and residential sectors. They are essential in changing mind and facilitating customer acceptance.

Corporate environmental reporting is considered a useful practice (i.e., prepared as a part of annual report or a separate report) in enhancing the environmental protection activities performed by firms. Community right-to-know (CRTK) is used as a policy to inform communities about the environmental impacts of pollution caused by a firm’s activities. Providing customers who care about energy consumption with information is facilitated by product certification. Evidence shows that eco-labeling as a form of sustainability measurement enables customers to consider environmental concerns in combination with education and information strategies as a mixed policy of regulatory regime.

Dinica (2006) discussed support systems for the diffusion of renewable energy technology from the point of view of investors. She analyzed the investor perspective in order to examine the potential of support policies for the spillover effects of renewable energy and found that the investor's decision-making is influenced by the risk/profitability of policies, not the kind of instrument used. The study emphasized that including the investor's perspective in examining governmental policies enables them to support the diffusion of renewable energy technologies for the generation of electricity generation. Moreover, such policies could be more effective if they were based on risk and profitability for investors. Dinica's (2006) main point of view is the importance of the investor's perspective in achieving successful outcomes. Many policy makers favor a support policy regardless of the result and relationship between the policy and the policy takers. Fouquet and Johansson (2008) examined European renewable energy policy and focused on support mechanism for electricity. They argued that renewable energy could not be developed in energy markets and that some support mechanism should be considered for expanding the use of renewable energy to enhance energy security, reduce greenhouse gases, and improve economies. The results showed that the feed-in tariff policy is more effective than tradable green certificates are.

Verbruggen (2009) evaluated the performance of a support system for renewable energy sources to generate electricity. He compared the results of Flemish system with simulations applied in Germany. The finding showed that the tradable certificate system in Flanders had not been developed properly. The market does not have the required functions, such as economic structure, professional constructors and supervisors. Verbruggen also indicated three crucial objectives that should be clarified before designing a support policy: target setting, qualification of RES-E (electricity produced from renewable energy) sources and technologies, and the robustness of achieved levels of effectiveness. He stated that the qualification of RES-E sources and technologies is the basic task in establishing a functional market.

In recent research, Dinica (2011) discussed how production cost is influenced by national-contextual factors, observing that a framework is required to help policy makers in making decision regarding renewable energy support. The study emphasized that "*policy decisions regarding the long-term strategy for governmental RET (renewable energy technology) price support should not be exclusively based on experience curve*." Dinica suggested an analytical framework for policy makers to use as a cost effective instrument to support renewable energy technology and maximize the share of low carbon electricity in energy consumption.

Del Rio and Bleda (2012) compared the innovatie effects of policy instruments that support renewable energy technology spillover. They found that the effects vary according to different renewable electricity instruments. However, Feed-in-tariff (FIT) policy is better than other policy instruments, such as tradable green certificates. Del Rio and Bleda argued that market creation should be focused instead of increasing competition between different kinds of technologies because it is able to generate broad support for renewable energy technologies. Therefore, del Rio and Blenda supported the idea of market formation, and they believed that market creation could indirectly influence other functions.

Steinbach et al. (2013) investigated policies that were formed to develop renewable heating and cooling, and they applied a quantitative analysis to evaluate the costs and benefits of different scenarios in six Member States (Austria, Greece, the Netherlands, Lithuania, Poland, and the United Kingdom). The results showed that intended target could be achieved by harmonized obligations and decreased generation costs, which were facilitated by better resource allocation. Levels of policy harmonization were categorized by Steinbach et al. (2013) to common target settings, central co-ordination, convergence of instrument type, and convergence of instrument design. Their quantitative assessment was based on the following criteria: cost optimal resource allocation, enforced target compliance, minimization of transaction cost, minimization of total policy cost, and avoidance of market distortion in order to support the idea of a harmonized European internal market.

4.3 Market regulation

The regulatory mechanism has a central role in developing the generation of power using renewable energy sources. Governmental support is required to facilitate new technology applied to developing renewable energy. The lack of a regulatory framework and market environment to support new technology and investment increases the probability of market failure. In addition to grid modernization, efforts to enhance energy efficiency and adapt current policy, regulatory frameworks, and market environments are crucial to support investment in new technology. Therefore, it will be a major challenge for stakeholders in the electricity sector. A survey by the International Energy Agency (IEA) found that technology improvement together with targeted policy and regulation are essential in achieving the scenarios' targets by 2050 (IEA, 2012c).

Based on evidence from the US manufacturing sector, Jaffe et al. (1995) analyzed the arguments regarding environmental regulation and negative impact on market competitiveness caused by significant cost and slow productivity growth and found little evidence to support this argument. They stated that additional costs imposed by environmental regulations are a small portion of unit costs for most heavily regulated industries. Jaffe et al. believed that international differences between environmental regulations in the US and the other countries are not considered a threat to the market competitiveness of US industry. Jaffe and Palmer (1997) investigated the effects of environmental regulations in a panel of manufacturing industries and found that environmental expenditures have a significantly positive effect on R&D. The results showed that the severe effects of environmental regulation stimulate innovative activity in firms. They argued that there is little evidence to support the idea that the inventive output of industries as measured by successful patent applications is related to compliance cost. Murphy and Gouldson (2000) analyzed interactions between environmental policy and industrial innovation and argued that clean technologies, organizational change, and the adoption of long-term radical innovation is the only solution to achieve targets in ecological modernization. They indicated that environmental regulation is able to both force and facilitate the adoption of innovation.

Ackerman et al. (2001) evaluated existing government instruments and market schemes that support implementation of renewable energy power generation with the aim of analyzing market regulations that stimulate distributed generation resources. They examined seven different instruments to find a solution to the issue of cost reduction. The results showed that tax reduction, investment subsidies, feed-in tariffs, and net metering could be used as interim solutions, but might not able to reduce generation costs. They argued that the bidding process is one way to achieve this target, but it is not useful to apply in large-scale renewable energy projects because of the high level of transaction costs. Furthermore, a combination of instruments, such as fixed quotas and green certificate trading or power exchange and green pricing, may result in similar cost reductions. This concept was emphasized by Gunningham and Grabosky (1998). Based on a policy framework and target setting, market instruments should be selected properly. These instruments could be used as wither complementary or sequential. It is recommended to avoid policies that affect each other negatively. For example, applying economic instruments, such as tradable emission permits may have adverse effects if they are used with liability.

Menanteau et al. (2003) evaluated the efficiency of different policy instruments in the development of renewable energy sources. They applied a theoretical approach by comparing the price-based approach with the quantity-based approach. They found that feed-in-tariff mechanism is more efficient than bidding system because it enables countries to achieve targets regarding renewable energy development. Based on these results, an increasing number of countries may use the quota-based green certificate trading system in order to achieve their targets through a cost-effective solution. Anton et al. (2004) examined the impact of market regulation on environmental management systems (EMS) by applying standard Poisson and negative binomial models. EMS is constituted by different environmental management practices, such as environmental policy, training and rewarding workers to find solutions to reduce pollution, setting internal standards, and doing internal environmental audits. The results showed that public policy is able to prevent toxic pollution by creating a regulatory framework and market-based pressures imposed by EMSs.

Wang (2006) evaluated the development of renewable energy policy making in Sweden, including policy context and changes in policy instruments, in order to analyze successes and failures in regulations. The Swedish government faced a dilemma in supporting renewable energy development and phasing out nuclear power: first, there was a political decision to replace nuclear power with renewable energy, and second, they were concerned about the negative effects of this policy on industrial competitiveness. Wang argued that lack of government commitment because of this uncertainty was an essential factor and was apparent in policies. Preferred short-term subsidies instead of a long-term support mechanism caused interruptions to development. Wang indicated that future renewable energy policies, particularly regarding high-cost technology, would strongly depend on nuclear policies. Such uncertainty as well as a significant share of major electricity companies in nuclear power would lead to instability in the regulations made for the development of renewable energy.

Costantini and Crespi (2008) estimated an empirical model to show that severe environmental regulations could be a positive signal for increasing investment in new technology by providing a source of comparative advantage. They found that countries with strong environmental regulation and higher innovation capability had greater export capacity and could be exporters of environmental technology. Costantini and Crespi used a gravity model to examine the determinants and transmission channels in exporting environmental technologies for renewable energy and energy efficiency from the EU to advanced and developing countries. They emphasized, "*the stringency of environmental regulation supplemented by the strength of the National Innovation System is a crucial driver of export performance in the field of energy technologies*." De Joode et al. (2009) analyzed the effect of growing penetration of decentralized electricity generation (DG) on distribution system operators (DSO). They considered network characteristics, technologies, and network management. They found that current market regulations should be improved in order to enable DSOs to continue facilitating the integration of DG in the network. Based on the results, they suggested implementing a regulatory framework that would affect both operating and capital costs of DG.

Recently, Zhao et al. (2011) analyzed policy frameworks to examine the influence of renewable energy regulations on the structure of power generation in China. The results showed a strong positive relationship between the diffusion of energy regulations and the growth rate of renewable energy deployment. They indicated that national laws, regulations, policies, and strategic plans are essential to promote the structure and penetration of renewable energy projects. Considering China's plan to achieve a share of 15 percent of non-fossil fuel in primary energy consumption by 2020, Zhao et al. stated that the elasticity of policies to ascertain sustainable growth rates of renewable energy in power generation should be taken in account. Nykamp et al. (2012) applied Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) to examine the effects of incentive regulations on the investment decisions of power network operators to integrate renewable energy sources. The results showed that grid operators intended to avoid new investments. They also found that current regulations do not provide enough incentive for operators to invest in smart solutions. Therefore, changes in regulations are required to provide incentives for grid operators.

Table (4-2): Empirical studies regarding the impact of environmental regulation on renewable energy development

Author	Subject	Result
Jaffe (1995)	Environmental regulation and the competitiveness of US manufacturing	Additional cost imposed by environmental regulation is a small portion of unit cost for most regulated industries.
Jaffe & Palmer (1997)	Environmental regulation and innovation	Severe effect of environmental regulation stimulates innovation activity by firms.
Murphy & Gouldson (2000)	Environmental policy and industrial innovation	Clean technologies, organizational change and adoption of radical innovation in long term is only solution to achieve targets for ecological modernization.
Ackermann et al. (2001)	Government and market driven programs	Combination of instruments such as fixed quotas and green certificate trading or power exchange and green pricing may have cost reduction effect.
Menanteau et al. (2003)	Choosing policies for promoting renewable energy	Feed-in-tariff mechanism is more efficient than bidding system. Increasing number of countries may use green certificate trading system in order to achieve their targets.
Anton et al. (2004)	Incentives for environmental self-regulation	Public policy is able to prevent toxic pollution by creating regulatory framework and market-based pressures made by environmental management system.
Wang (2006)	Analysis of policy and regulation in Sweden	Future renewable energy policies strongly depend on nuclear policies. This kind of uncertainty and significant share of major electricity company in nuclear power leads to instability of regulation.
Dinica (2006)	Support system for the diffusion of renewable energy technologies	An investor perspective for examining governmental policies enables them to support diffusion of renewable energy technologies for electricity generation.
Costantini & Crespi (2008)	Environmental regulation and export dynamic of energy technologies	Countries with strong environmental regulation and higher innovation capability have a greater export capacity and could be an exporter of environmental technology.

Author	Subject	Result
Joode et al. (2009)	Increasing penetration of renewable and distributed electricity generation (DG)	Current market regulation should be improved in order to enables distribution system operators to continue facilitating integration of DG in the network.
Zhao et al. (2011)	Impacts of renewable energy regulation on the power generation in China	There is a strong positive relationship between diffusion of energy regulation and growth rate of renewable energy deployment. Elasticity of policies to make certain of sustainable growth rate of renewable energy should be taken in account.
Nykamp et al. (2012)	Standard incentive regulation	Current regulations do not make enough incentive for operators to invest in smart solutions. It is required to make change in regulation in order to make it more incentive.
Rio & Bleda (2012)	Comparing the innovation effects of support schemes	Market creation should be focused instead of increasing competition between different kinds of technologies. It could influence other functions indirectly.

4.4 Technology transfer

Advanced technology and investment in new technology are essential in promoting renewable energy consumption. The unit cost for power generation through renewable energy sources is more than for conventional resources, such as fossil fuels. However, this cost could be reduced by advanced technology and economies of scale. "*A technology transfer typically includes the transfer of the technology design as well as the transfer of the property rights necessary to reproduce the technology in a particular domestic context*"(Lewis and Wiser, 2007). In this regard, designing appropriate regulations to promote technological innovation is crucial. In particular, it is necessary for governments who set targets for emission reduction within a certain period to facilitate investment in low-carbon technologies from the demonstration to the commercial stage. There should be a proper link between actors in order to take advantage of interactive learning and new ideas. Moreover, appropriate capability is required to learn rapidly and effectively. Otherwise, it is not possible to transfer and apply new technology.

Various scholars, including Carlsson and Jacobsson (1997), Smith (1997), and Johnson and Gregersen (1994), examined system failures and found that infrastructure failure, transitional failure, hard institutional failure, network failure, and capability failure are considered system imperfections that could be lead to system failure (Woolthuis et al., 2005). System imperfection are serious problem in applying, transferring, learning, or adapting to new technological development, and they make it almost impossible to achieve targets in time. An analysis by the IEA showed that the process of technological change in some cases takes decades, and there are limits to the rate of deploying new energy technology. In contrast, the possibility of acceleration in information technology depends on government policy (IEA, 2012c).

Jaffe et al. (2005) investigated the interaction of market failures associated with environmental pollution and market failures associated with the innovation and diffusion of new technologies. Theoretical and experimental research has shown that technological advances are affected by market and regulatory incentives. Jaffe et al. believed that appropriate market regulations are able to create these incentives. Because of the lack of enough resources to support all new technologies, the government has to focus on the commercialization of technologies that lead to increased public benefits. Technology spillover and the achievement of associated benefits could be stimulated by proper incentive instruments, such as tax credits for new equipment, in order to make them cost-effective.

Lewis and Wiser (2007) analyzed the strategies of local industry in wind turbine manufacturing, technology acquisition, and incentives for technology transfer. They did a cross-country comparison of support policy mechanisms applied in 12 countries: Denmark, Germany, Spain, US, Netherlands, UK, Australia, Canada, Japan, India, Brazil and China. They argued that technology policy is influenced by short-term and long-term goals to the degree of the localization of new technology in domestic manufacturing (including assembly, components, or entire turbines). The application of appropriate policies is essential in stimulating incentives for technology localization. Lewis and Wiser indicated that technology policy may be changed over time and incentive instruments can be adapted according to the new policy. Therefore, governments may turn to foreign direct investment for turbine manufacturing, use local transferred technology for the components, and local manufactures for the turbines. The results showed that the annual size and stability of the market is a crucial parameter that influences policy mechanisms.

Nemet (2009) analyzed demand-pull, technology push, and government-led incentives for non-incremental technological change. This study determined the reasons that the inventors of the most important inventions were not positively influenced by strong demand-pull policies. Previous research by Dosi (1988) suggested that incremental innovation responds to demand-pull policy more than technology push does. Kemp (1997) found that incentives required for incremental and non-incremental innovation vary, based on their stringency. Nemet argued that there are three main reasons for the inconsistency between these policies: first, convergence on a single dominant design; second, uncertainty about the lifetime of incentives; and declining R&D funding. The combination of these three factors is able to offset incentive instruments.

Loock (2012) investigated a database of 249 renewable energy investment managers including banks, funds, investment advisors, private equity, and venture capitalists. He estimated three generic business models to calculate share of preference for investors and found that investors prefer to be supported by better services than lower prices or better technology. Loock suggested that policy makers focus on policies that support service-driven business models instead of price or technology. Recently, Lema and Lema (2013) analyzed technology transfer in the clean development mechanism (CDM), which is focused on wind power. They explored how quantity flows in CDM are affected by technological capability in the host country. Based on evidence form China and India, they argued that CDM wind projects tend to take advantage of existing transfer mechanisms instead of creating new mechanisms to support low carbon technology. The results showed an important relationship between international law regarding technology transfer mechanisms and domestic technological infrastructure, which should be taken into account by policy makers.

El Fadel et al. (2013) provided knowledge management mapping in renewable energy to design a framework for defining activities in different time spans. They argued that renewable energy development in developing countries relies on financial and technological aid provided by developed countries as well as international and regional organizations. I is crucial for developing countries to facilitate appropriate capabilities (e.g., knowledge exchange, technical capability, financial mechanism, etc.) in order to take advantage of supportive instruments.

4.5 Barriers

The most important challenge in deploying renewable energy is the intermittent character of some renewable energy sources, such as wind and solar energy. This intermittency causes uncertainty in using electricity on demanded. Moreover, when power generation is faced with a shortage of demand, a solution should be available. For example, Denmark is forerunner in the generation of electricity through offshore wind turbines. It exports excess electricity to Norway and Sweden, which use mostly hydro energy. In those countries, water is stored behind dams for later use when excess electricity is transmitted by Denmark. Although, hydro is considered a stable renewable energy source, environmental conditions (e.g., landscape) are impacted by the building of dams across rivers. Wind turbines and economic factors, such as other renewable energy sources, are taken into account in environmental issues because of their impacts on flora and fauna and the noise impacts on neighborhood residents.

In terms of economics, the unit cost of power generated by renewable energy sources is generally higher than by conventional sources of energy, such as fossil fuels and nuclear power plants. This cost has decreased notably during the last decade because of technological advancements, which was achieved by supportive government policies. Lack of the knowledge and education of consumers is another challenge in taking advantage of renewable energy sources. Social acceptance and buyer readiness are among the most important factors for market implementation. Renewable energy development policies will not be successful if they cannot influence customer acceptance at the stage of buyer readiness. All these barriers should be overcome by appropriate policies in order to develop renewable energy sources.

Painuly (2001) proposed a framework to identify the barriers for renewable energy development and find measurement to bypass these barriers. In Painuly's view, major barriers to penetrating renewable energy technology (RET) are categorized as follows: market failure/imperfection (highly controlled energy sector, restricted access to technology, lack of information), market distortion (subsidies for fossil fuels, externalities, trade barriers), economic and financial conditions (high payback period and small size of market, capital intensive, lack of financial institution to support RET), institutions (lack of institution/mechanisms, lack of regulatory framework, clash of interest, lack of private sector contribution), technical staff (lack of standards, lack of skilled personnel/training facilities, lack of entrepreneurs), social and cultural factors (lack of consumer acceptance of the product; lack of social acceptance of RET), and other barriers, such as uncertain governmental policies and the high risk of RET. Painuly argued that barriers could be overcome through a literature survey, site visits and interactions with stakeholders, including RET industries, consumers, NGOs, experts, policy makers, and professional associations. Considering that dimensions vary across countries, the solutions to overcome the barriers may be specific to a country.

Reddy and Painuly (2004) carried out a survey among households, industries, commercial firms, and policy makers to determine their points of view regarding the barriers to the diffusion of RETs. They emphasized that "*the RETs problem is a complete lack of market-based approach and it is important to initiate such a mechanism.*" The results showed cost and awareness issues have significant effects, which are considered potential barriers to RETs penetration. Reddy and Painuly suggested that an innovative policy network is required to overcome these barriers and that government plays a key role in creating a competitive market based on efficiency.

Foxon et al. (2005) examined the UK innovation system for renewable energy technologies, including wind, marine, solar PV, biomass, hydrogen, and micro-CHP (combined heat and power) in order to enhance the efficiency of the system. The results showed that sustainable investment is required for these technologies in order to take advantage of their potential, and a stable policy framework is necessary to make it possible. Owen (2006) investigated the effects of market failure constraints on the adoption of RETs by estimating the damage costs incurred by fossil fuels and analyzing externalities of power generation in financial terms. The results showed that if external effects of fossil fuel combustion were internalized into electricity generated by conventional energy sources, a number of RETs would be competitive from the economic point of view. Owen believed that incorporating externality effects into electricity prices could stimulate the deployment of renewable energy sources for power generation. The Middle East region has a great potential for generating electricity by using renewable energy sources.

Patlitzianas et al. (2006) examined RET development in the Arab States of the Persian Gulf region and found a combination of constraints, including the lack of a regulatory framework, commercial skills, and required knowledge. They argued that these countries should cooperate with developed countries in order to develop renewable energy appropriately and enhance their knowledge and information through the Kyoto Protocol. They stated that a scientific and political framework should be focused and that close interaction between research centers and markets is required in order to produce new products.

Sovacool (2009a) analyzed renewable energy from the perspective of social and cultural barriers to energy efficiency technology in the US. He argued that the clash between conventional systems of power generation and renewable energy sources is based on social concerns regarding welfare, profits, consumption, control, and trust, instead of a disagreement over technology. Sovacool also believed that US government should focus on efforts to enhance the social understanding of energy systems, instead of allocating supportive incentives to promote the efficiency and technical capacity of renewable energy technologies. Sovacool (2009b) performed a survey to gather data on the common argument regarding the intermittency and unreliability of renewable power generators through 62 formal and semi-structured interviews at 45 different institutions in the US. He argued that all conventional power plants have some degree of uncertainty because of supply and demand imbalances, fuel prices, and unplanned outages. Wind and solar generators would be more efficient if they are used on large scales in geographically spaced locations, such as Denmark and Spain, which have increasing shares of renewable energy contributions in continuous electricity supply. Sovacool believed that the counter-argument was based on social, political, and practical parameters, not technical restrictions and barriers. The intermittency and uncertainty of renewable energy sources could be managed, but managers in the traditional system are not interested in new and radical technology because it might lead to reducing their dominance over the system. Wang and Chen (2010) examined the opportunities for and barriers to CDM in enhancing renewable energy deployment to achieve ambitious targets in China. In terms of primary energy consumption, more than 70 percent of electricity is generated by coal in China, making it the one of the biggest CO_2 emitters in the world. They concluded that there are three barriers to utilizing CDM activities in China: additional conditions (based on article 12 of Kyoto Protocol), lower proportional certified emission reduction credit revenues and the lack of incentives for technology transfer. Wee et al. (2012) evaluated renewable energy sources from a supply chain perspective and examined renewable energies based on supply chains, performance, barriers to RETs deployment, and strategies used to overcome these barriers. They identified conversion cost, location constraints, and complex distribution networks as main barriers to developing RETs and argued that they could be removed through the participation of governments, researchers, and other stakeholders in the development of renewable energies.

Egbue and Long (2012) investigated barriers to the widespread adoption of electric vehicles through an internet-based survey, and they analyzed consumers' insights regarding the purchase of an EV. The results showed that consumers viewed the limitation of the battery operation of EVs as the most important concern, followed by high cost and charging infrastructure. Egbue and Long also found that 25 percent of respondents agreed, and 43 percent of respondents were neutral regarding perceptions of the sustainability of EVs relative to other vehicles. The results indicated that attitudes and knowledge regarding EVs differed according to age, gender, and education. They argued that although there are major technical challenges, including battery, cost, and infrastructure, the most important factor, which should be taken into account by policymakers, is consumer acceptance as the key to the commercialization of EVs. The importance of social acceptance, buyer readiness and informing customers about the benefits of new technology was emphasized in this research.

4.6 National and international environmental policies

Climate change is considered a global challenge, and international cooperation is required to overcome this problem. In general, environmental policy refers to the commitment of an entity at the level of an organization, government, or group of countries (regional or international) to regulations regarding environmental issues. International institutions, such as the United Nations Environmental Program (UNEP), World Environment Organization (WEO), and Intergovernmental Panel on Climate Change (IPCC) for global environmental management have made several efforts in this direction. Many bilateral and regional agreements and international organizations (e.g., OECD) deal with environmental issues. Both groups, resource-rich and resource-poor countries, have tried to apply degrees of environmental protection to overcome climate change issues. The possibility of using energy transition and new technology has created challenges in terms of energy security and environmental management (Bhattacharyya, 2011). A few organizations, such as the International Maritime Organization (IMO), a specialized agency of the United Nations that addresses various aspects of international shipping, have the power to enforce the performance of regulations made by IMO regarding the control and prevention of marine pollution. Most policies made by organizations are performed by the members based on their commitments. Because of the state-centric nature of international cooperation, states play the most important role in making international environmental regulations (Axelrod et al., 2011).

Denmark is considered a front-runner in renewable energy deployment because 33 percent of its power supply is generated by renewable energy sources (20 percent wind and 13 percent biofuels), and it exports excess electricity generated by off-shore wind turbines to neighboring countries (i.e., Norway and Sweden). On 17 June 2005, the government released *Energy Strategy 2025*, which focused on initiatives for energy saving, renewable energy, climate change, energy markets, and technology. It set the long-term target of 100 percent independence from fossil fuels (IEA, 2012b). They applied incentive policies to achieve ambitious targets such as hydrogen-fuelled and electric cars which will be tax-free, 35 million DKK financial support for research on electric cars and a further 25 million DKK for research on solar, wave power and other renewable energy annually for four years. The Danish government released *Energy Strategy 2050* in February 2011, which outlined a number of new short- and medium- term policy incentives. Based on the IEA report, the key elements in the future Danish energy system were identified as follows: highly efficient energy consumption; electrification of heating, industry, and transport; more electricity from wind power; efficient utilization of biomass resources; utilization of biogas; PV solar modules and wave power as supplements; widespread energy-based district and individual heating; and intelligent energy system.

In Germany, renewable energy sources comprise 22 percent of electricity generation. Germany has progressed during the last two decades in reducing carbon emissions and the energy intensity of its economy. Energy Package 2011 is constituted by the Energy Industry Act, Renewable Energies Act, Nuclear Energy Act, Energy and Climate Act, Act to Strengthen Climate-compatible Development in Cities and Municipalities, Act on Tax Incentives for Energy-Related Modernization of Residential Buildings, and Ordinance on the Award of Public Contracts (IEA, 2013). Germany has set its energy policy to make it a world leader in the field of energy efficiency and environmental protection. Its targets include ambitious environment protection indices as an essential part of energy policy, including 40 percent reduction in GHGs by 2020, 55 percent by 2030, 70 percent by 2040, and 80 to 95 percent by 2050, compared to 1990 levels. In Germany, the elements of the integrated energy and climate program and GHG emission reduction targets are the following: reduce electricity consumption; modernize fossil-fired power stations; promote electricity generation from renewable energies; promote CHP generation; modernize building and heating systems; use renewable energies in heat production; and implement energy saving measures in the transport sector. This achievement of these targets would lead to the equivalent reduction of 270 Mt carbon dioxide per year by 2020. The Renewable Energy Sources Act is considered the key support instrument in generating electricity by renewable energy sources.

It has been forecasted that by 2050, Earth’s population will have increased to more than nine billion people. Without new policies and with increasing emissions caused by the combustion of fossil fuels, the global GDP will quadruple, and energy consumption is projected to grow by more than 80 percent. Because no single policy is considered a solution to climate change, a mix of policy instruments is applied to cut GHG emissions. The essential parts of this policy mix, according to the OECD, are the followings: national climate change strategies; price-based instruments (cap and trade); carbon taxes and removing fossil fuels subsidies; command and control instruments and regulations; technology support policies, including R&D; voluntary approaches; public awareness campaigns and information tools (OECD, 2012). The coverage and scope of work for each instrument vary among countries. For example, carbon pricing is a main policy in Australia, EU, Korea, and UK. Canada, China, France, Germany, India, Italy, Japan, Russia, and Portugal focus on policies regarding energy efficiency. Some policy tools for climate change mitigation which could be used as price-based instruments, include the following: taxes on CO_2 emissions; taxes on inputs or outputs of process; removal of environmentally harmful subsidies; subsidies for emission-reducing activities; and emission trading systems.

Hirschl (2008) provided an analysis of renewable energy policies at the international level. This analysis showed that the dominant role of fossil fuels and nuclear energy supported by subsidies make it difficult for renewable energy technologies to play an effective role in international energy and climate change policy. Hirschl argued that international organizations, such as the IEA and World Bank, have provided minimum financial support to enhance renewable energy deployment and that they prefer to focus on conventional centralized energy systems. In his view, emissions trading could be developed if carbon dioxide prices stay high, but so far, this has not been sufficient. Although feed-in-tariffs create better incentives for investment in renewable energy markets, they have made only small contributions to the development of renewable energy sources worldwide because of the small number of feasible CDM projects. On the other hand, policymaking within the EU seems influenced by political consideration. Based on Axelrod et al. (2011), from an integrated perspective political will and public support have played key roles in the EU's success in formulating and implementing environmental policy. While they mentioned EU as the most advanced regional organization of states and as having a comprehensive environmental policy regime, they also noted a debate regarding whether the "*EU is an intergovernmental organization dominated by the interests of individual Member State or a functional regime that represents common transactional interests and actors.*" In this regard, there is much evidences of conflict among member states, based on their interests. An example is the carbon dioxide standard for new cars, which created conflict among the owners of powerful automobile industries (i.e., Germany and France) and other member states.

Chapter 5: Financing Renewable Energy Development

5.1 Introduction

Economics view is an essential part of renewable energy deployment and its progress. If they do not have an economic advantage, renewable energy technology is not able to compete with conventional resources technologies. On the other hand, it is difficult to establish a transparent figure for the unit cost of renewable energy compared to conventional sources. External cost, such as social and environmental costs is included in conventional sources such as social and environmental cost. Moreover, the subsidies paid for the consumption of fossil fuels play as a barrier and make it expensive for the alternatives sources to compete. The aim of increasing the contribution of renewable energy to the total primary source of energy supply is of worldwide importance in mitigating the negative effects of climate change.

In reality, there is a gap between the actual share and optimal level of renewable energy consumption in the world. Furthermore, a huge amount of investment is spent on conventional energy sources compared with renewable energy sources. Alternative policies for environmental protection are applied in the form of economic incentives and non-incentive regulations. Regulatory frameworks and relative policies have been discussed already. Economic policies could be an incentive for using renewable energy or charging taxes imposed on emission generation or fossil fuel consumption. Although developed countries that import crude oil have impose carbon taxes for many years, but these taxes have been not applied for environmental purposes.

Three types of support mechanisms are used widely: feed-in-tariffs, tax incentives, and tradable green certificates. We do not consider direct monies paid to producers or consumers because our purpose is to apply a mechanism to encourage the creation of a renewable energy market. Direct financial transfer may lead to the enhancement of renewable energy consumption, but the main target (i.e., market creation) is not achieved. Generally, different kinds of economic instruments such as capital grants, grants to infrastructure, utility procurement, etc. are available for renewable energy technologies. However, most of them are not appropriate for electricity produced by individually distributed generators. Considering that many of the most promising technologies to deploy renewable energy to achieve targets for energy efficiency or carbon reduction require investment in small-scale energy production system (such as residential building), these mechanisms could be used to enhance renewable energy development at the desired scale. In particular, they will be applicable to the renewable energy market, which is constituted by a large number of individual energy suppliers.

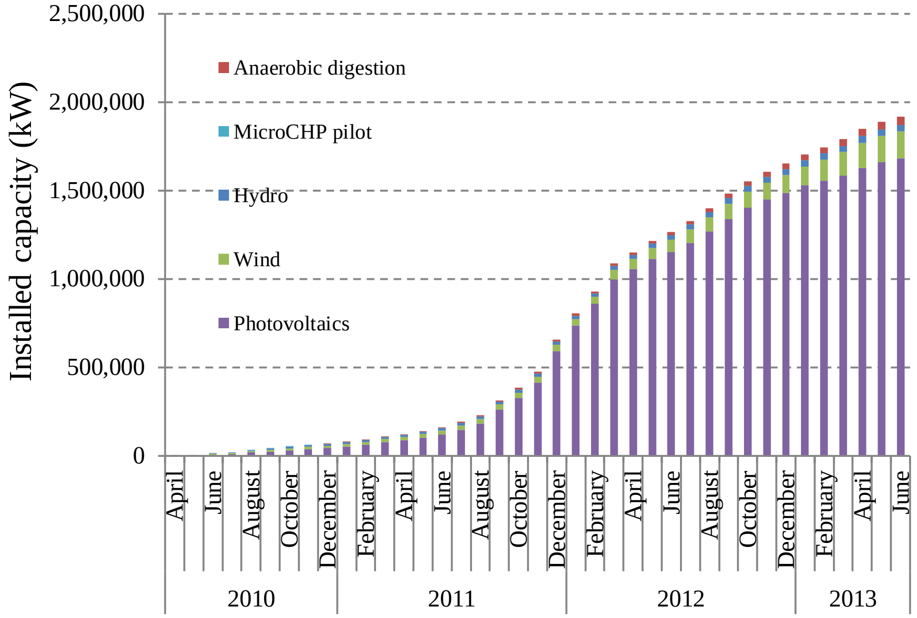
In chapter two, we discussed about the steadily increasing use of hydropower and the rapid growth rate of renewable energy during recent decades, as well as the setting of targets for future decades. The rapid growth of renewable energy has been possible through decreasing technology costs, increasing fossil-fuel prices, and the continued payment of subsidies by the state. According to an IEA report in 2012, the subsidies will increase from $88 billion in 2011 to almost $240 billion in 2035 (IEA, 2012e). On the other hand, fossil-fuel consumption subsidies were estimated at $523 billion in 2011, which is nearly six times more than the financial support allocated to renewable energy. This means that the support of conventional sources of energy overshadows the support of renewable energy sources.

In this chapter, we discuss the three main support mechanisms used to finance renewable energy development programs: feed-in-tariffs, tax incentives, and tradable green certificates. Finally, we explain cross-national incentive policies for clean development mechanisms, which are based on the Kyoto Protocol.

5.2 Feed-in-Tariff

A feed-in-tariff (FIT) is a policy used as a support mechanism to accelerate investment in renewable energy (RE) technologies. According to Couture et al. (2010), *"a feed-in tariff (FIT) is an energy supply policy focused on supporting the development of new renewable energy projects by offering long-term purchase agreement for the sale of RE electricity."* Couture et al. pointed to three essential provisions for the success of FIT policies: guaranteed access to the grid; stable and long-term power purchase agreements; and prices should be calculated based on the unit costs of power generated by renewable energy sources. Technologies such as wind power are priced lower than solar PV because of the latter's higher cost. However, FIT policies could be considered a controlling regulation because of the ability of governments to direct the market according to the rates in the contracts. An expectation of lower rates in the future could cause a rush in the market to receive the existing FIT rate. The tariffs may be used as fixed rate (higher than market price) or as a mark-up that is added to the current market price.

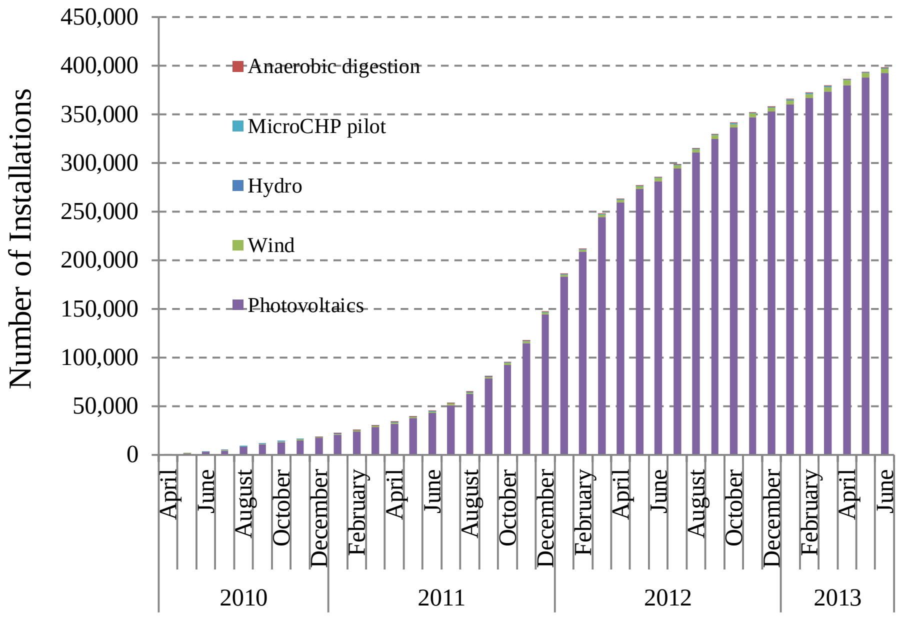
According to Renewables Global Status Report (GSR 2012), at least 109 countries had used some type of FIT policy by early 2012. FIT policies had been used in at least 65 countries and 27 states by 2012 (Martinot and Sawin, 2012). In late 2011, Germany was successful in connecting its one-millionth PV system mainly because of the low rate of FIT and the expectation that prices would continue to decrease. Based on the GSR 2012, this new connected PV system (around 7.5 GW) set 24.8 GW as the cumulative installed capacity, accounting for 3.1 percent of Germany's power generation and almost 8 percent of peak load demand. Future examples for using FIT contract rates as the stimulus for PV system installation are as follows: Italy brought 9.3 GW of PV to benefit from more advantageous rates in 2010; UK increased its capacity to 1 GW, driven by two rounds of rate reductions; France operated more than 1.6 GW by changing its FIT rates; China's market has quadrupled mostly because of the national FIT policy, increasing and its cumulative installed capacity to 3.1 GW, becoming the dominant player in Asia (Martinot and Sawin, 2012). Figure (5-1) shows the effects of FIT policy on developing renewable energy installation in the UK. As the figure shows, PV installation has been affected widely by FIT policy.



Source: Department of Energy and Climate Change, 2013,

Figure (5-1): Cumulative installed capacity of renewable energy based on FITs in the UK

The UK government introduced a FIT supporting mechanism 1 April 2010 in order to enhance small-scale renewable energy deployment and low-carbon power generation technologies. This policy covers five technologies, including: solar PV, wind, hydro, anaerobic digestion, and micro CHP plants. As Figure (5-1) shows, almost 2 million kW has been installed based on the FIT supporting mechanism, and the majority of the installed capacity is from solar PV sources. Figure (5-2) shows the number of cumulative installations in the same period.



Source: Department of Energy and Climate

Figure (5-2): Cumulative installed number of renewable energy based on FITs in the UK

Financial support mechanisms are gaining importance in enhancing renewable energy development. Conventional sources of energy could be replaced with renewable energy technologies (RET) in order to mitigate environmental damage caused by old electricity power generation technology. Ringel (2006) examined the most common types of support system in the European Union (EU), including FITs and green certificates, in order to evaluate their advantages and disadvantages in terms of effectiveness and efficiency. Based on this analysis, both mechanisms contributed to enhancing the share of power generation by renewable energy. However, many member states tried to shift from a feed-in system to green certificates while experiencing both systems. The results show that FITs are successful in encouraging individuals to use renewable energy sources, mainly wind energy in Denmark and Germany. However, FITs does not have enough capability to create a liberalized single electricity market. With regard to the EU market, there is an intention to promote the use of green certificates instead of FITs because of the up-coming market for emission certificates. It has been argued that the installation of a harmonized FIT system is almost impossible for reasons of feasibility and politics at the European level. It has been concluded that no single policy is capable of solving the renewable energy development in a harmonized European market for electricity, so the debate regarding the application of appropriate support policies continues.

Rickerson et al. (2007) analyzed support mechanisms in Europe and evaluated their application to policies in the US. They pointed to the debate in Europe about FITs and Renewable Portfolio Standard (RPS), with the aim of applying a single harmonized policy in the US market. They emphasized that US states are not under federal pressure to comply with a harmonized energy policy. Therefore, they can apply different approaches to take advantage of the renewable energy policy. Considering the experience in Europe and the emerging FIT system as a viable policy in US, it is expected that this policy will continue to set specific targets for renewable technologies. Some studies have held that FITs could be used for emerging technologies, such as PV, and RPS should be used to enhance near-market renewable energy technologies. Butler and Neuhoff (2008) compared FITs with quota and auction mechanisms to support wind energy development in the UK and Germany by surveying project developers. The result showed that, "*a frequent criticism of the feed-in tariff is that it does not generate sufficient competition*." They concluded that deployment levels are much higher in Germany compared to the UK in terms of installed capacity, which is attributed to the limitation of procedure and cost factors in the UK.

Lesser and Su (2008) examined an economically efficient FIT structure to enhance renewable energy deployment, proposing a two-part FIT system that used both capacity- and market-based payments to achieve targets. Based on the finding of this research, the following actions should be performed in a two-part FIT: define technologies that are eligible to receive subsidies, set a desired capacity goal for each technology, establish a contract period for each FIT, and set a payment period for the winning auction prices. They argued that the proposed two-part FIT system could be able to eliminate cost errors caused by difficulties faced from using the system based on the Public Utility Regulatory Policies Act of 1978 (PURPA). This Act required utilities to buy electricity from independent renewable energy and co-generation plants, and it proved to be a controversial policy. Under PURPA, the purchase price was based on avoided cost and was left to individual states (Rickerson and Grace, 2007). This Act caused some difficulties because it imposed an expensive burden on the utility rate paid by consumers. Lesser and Su (2008) indicated that a two-part FIT policy would create competition and lead to long-term financial stability, thus avoiding overestimates or underestimates in payments to RET developers.

Solana-Peralta et al. (2009) proposed a FIT scheme to take advantage of renewable energy, using conventional sources as a hybrid system in isolated areas. They introduced a model that integrated a photovoltaic (PV) generator into a diesel system for off-grid regions in Ecuador. They compared the results with the existing diesel system. They proposed that the Renewable Energy Premium Tariff (RPT) plan is an alternative mechanism to deploy renewable energy in off-grid regions. The results showed, PV-diesel hybrid system is more cost effective than the stand-alone diesel system. They found that if the optimistic lower value in terms of life cycle cost is considered for PV-diesel hybrid generators, the RPT value for a model with neutral net present value (NPV=0) is estimated at 0.59 $/kWh and 0.57 $/kWh for 62 and 79 percent PV fraction scenarios, compared to the FIT values of 0.52 $/kWh paid for PVs installed in the mainland of Ecuador. This scheme could be applied to other renewable energy technologies. Hence, it could assist in the introduction of RETs as a sustainable energy option for residents located in isolated off-grid areas.

Couture and Gagnon (2010) analyzed a variety of feed-in tariff payment models for power generated by renewable energy sources in order to determine the advantages and disadvantages of different FIT models, based on dependency on the market price of electricity. They argued that the overall rate of renewable energy enhancement is influenced by the FIT payment structure and its impact on investor risk. They found that market-independent policies are stronger and more cost-effective than market-dependent options because of their greater investment security and lower cost of renewable energy deployment. This condition could lead to lower risk and enable investors to have a predictable cash flow. It is also attractive to small investors and community-based projects because of purchase obligations and lower barriers to entry. Therefore, the advantages associated with market-independent policies are that they are able to increase public support, which may lead to the greater participation of individuals and higher levels of renewable energy penetration into the electricity market. Rigter and Vidican (2010) developed an equation for the cost of PV to calculate optimal FIT which must be applied in China in order to achieve its ambitious target to expand the share of electricity generated by solar power. Their calculation for a program starting in 2010 for 25 years with an assumption of applying 5 percent for discount rate and 2 percent for increasing the rate of electricity per year estimated that government is charged almost 3.13$ for the installation of 1 watt of small scale solar energy. The figure will change to 2.45$ if the program is postponed by the end of 2011. This calculation shows why the Chinese government is hesitant about the starting date of the program. They argued that the FIT policy is able to compensate the negative effects of low electricity prices on the feasibility of solar PV. Moreover, these costs could decrease rapidly over the time because of innovation and technology development.

Wand and Leuthold (2011) employed a partial equilibrium approach to analyze the potential effects of a FIT policy in Germany for small roof-top solar PV systems installed between 2009 and 2030. They applied a dynamic optimization model that considered learning-by-doing, technology diffusion, and yield dependent demand in order to maximize social welfare. Wand and Leuthold calculated a wide range of effects on social welfare, including the net social cost of 2.014 billion Euros under the Business As Usual (BAU) scenario and net benefits of 7.586 billion Euros from the benefits of solar PV deployment. They argued that the BAU scenario underestimated actual prices, while the positive scenario reflected FIT policies established recently in Germany for the residential PV market. We should also take into account that the negative welfare effect is viewed differently by policymakers in Germany because of its dependency on fossil fuels and concerns for a secure energy supply in the future. Krajacic et al. (2011) examined the FIT system used to implementing energy storage technologies to overcome the intermittency of renewable energy sources and technical capability of power networks. They analyzed FIT applications for pumped hydro storage (PHS), hybrid wind-pumped hydro storage (WHPS), a hydrogen storage system (HSS), PV and batteries, and desalination systems. They also evaluated the FIT mechanism to apply these technologies in some islands and outer areas. After the successful application in these areas, they argued that energy storage tariffs could be applied in main power systems to enhance energy storage usage and to optimize existing utilities in the market.

In a recent study, Schallenberg and Haas (2012) evaluated two alternative options of FIT, fixed and premium, and examined the evolution of the implementation of both mechanisms in Spain. These mechanisms, which are employed in Spain, have led to successful renewable energy deployment for power generation. The results showed that the direct burden of customers generated by a fixed-FIT policy is smaller than that imposed by the premium, and it provided higher security for investors compared to the premium option. On the other hand, the premium mechanism is market oriented and provides slightly higher income, which could be more attractive for investors. They stated that the premium mechanism might lead to overcompensation when prices are increase quickly, but this problem could be avoided by setting a cap value. is the findings indicated that a fixed-FIT policy should be used for technologies that have not achieved high market penetration and in cases that require the building a market environment.

In Portugal, FITs have been the main policy used to enhance power generated by renewable energy sources. Proenca and Aubyn (2013) simulated a model to evaluate economic and environmental impacts of a FIT policy in Portugal. They employed a hybrid top-down/bottom-up general equilibrium model to analyze the interaction among energy, economics, and environmental issues in relation to energy policies. The results showed that the FIT policy provided an effective and cost-efficient instrument to promote renewable energy sources for electricity generation. In addition, economic adjustment cost was low, and the deployment of renewable energy led to significant reductions in carbon emissions. Jenner et al. (2013) estimated a panel-data model over the years 1992-2008 to analyze effectiveness of FIT policies for developing solar PV and onshore wind turbine in EU-26. They applied a fixed-effect model at the country-level and introduced a measure of the return on investment (ROI) to evaluate the strength of the policy. The results showed that solar PV development in Europe was been driven by FIT policies through their impact on ROI for investors. The results also implied that the combination of FIT policy, electricity price, and unit cost served as a more accurate determinant for power generation by renewable energy sources than a stand-alone policy measure did.

Table (5-1): Some empirical studies regarding FIT policies

Author	Subject	Result
Ringel (2006)	Fostering use of renewable energies in EU, comparing FIT and green certificate	There is an intention to promote green certificate instead of FITs due to up-coming market for emission certificates. Using a harmonized FIT is almost impossible at the Europe.
Rickerson et al. (2007)	Using FIT to meet US renewable targets	US can apply different possible approaches to take advantage of the renewable energy policy. FIT could be used for emerging technologies and RPS should be used to enhance near-market energy technologies.
Butler & Neuhoff (2008)	Comparison of FIT, quota and auction to support wind power	They noted a very low levels of competition at the operational stage for all three funding scheme. Deployment levels are much higher in Germany compared to UK.
Lesser & Su (2008)	Design of an economically FIT structure	They proposed a two-part FIT system constituted both capacity and market-based payment to achieve targets.
Solano-Peralta et al. (2009)	Custom-made support scheme for hybrid system in isolated regions	The proposed Renewable Energy Premium Tariff (RPT) plan for off-grid regions. RPT value for a model with NPV=0 is estimated 0.59 $/kWh and 0.57 $/kWh for 62 and 79 percent PV fraction scenarios, compared to 0.52 $/kWh FIT values paid for PV installed in mainland of Ecuador.
Couture & Gognon (2010)	Analysis of FIT remuneration models	Market-independent policies provide a stronger and most cost-effective policy compared to market-dependent options due to greater investment security and lower cost for renewable energy deployment.

Author	Subject	Result
Rigter & Vidican (2010)	Cost and optimal FIT for small scale PV in China	FIT policy is able to compensate negative impacts of low electricity prices on feasibility of solar PV and these costs could be decreased rapidly over the time as a result of innovation and technology development.
Wand & Leuthold (2011)	FIT for PV in Germany	They found a wide range of impacts on social welfare, from net social cost of 2.014 billion Euros under Business As Usual (BAU) scenario to net benefits of 7.586 billion Euros under positive perspective of solar PV deployment.
Krajacic et al. (2011)	FIT for promotion of energy storage technologies	Energy storage tariffs could be applied in main power systems to enhance energy storage usage and to optimize existing utilities in the market.
Schallenberg & Haas (2012)	Fixed FIT versus premium in Spain	Fixed-FIT policy should be used for those technologies which have not achieved a high market penetration and where it is required to build a market environment.
Proenca & Aubyn (2013)	Effects of FIT to promote renewable energy in Portugal	FITs policies provided an effective and cost-efficient instrument to promote renewable energy source for electricity generation. Deployment renewable energy led to significant carbon emission reduction.
Jenner et al. (2013)	Assessing the strength and effectiveness of FIT in EU	Combination of policy with electricity price and unit cost are more important to serve as determinant for power generation by renewable energy sources than a stand-alone policy measure.

5.3 Tax incentives

Tax exemption is used as a fiscal incentive measure to enhance renewable energy deployment in many countries. Tax credits could be applied for the investment, production, or consumption segments of electricity generated by renewable energy sources. Policies aimed at encouraging renewable energy consumption could apply tax credits on the purchase and installation of renewable equipment to facilitate the penetration of renewable energy deployment into the market. For example, a draft bill was introduced in Poland for a renewable heat obligation in private and public buildings and to provide a tax credit for private customers for solar thermal energy (Martinot and Sawin, 2012). Tax policy is also used as a useful instrument to reduce fossil fuel consumption. A carbon tax imposed by a government imposes a higher cost burden for burning fossil fuels and increases investment in renewable energy sources. Demand for energy could be influenced by carbon tax through the relative cost of using different fuels. Following the Fukushima Daiichi accident, Japan set a target to triple power generation from renewable energy by 2030 over the generated in 2010. In this regard, Japan released a new FIT system to support renewable energy and employ other subsidy mechanisms, such as tax credits, investment grants, and loans (IEA, 2012e).

Using tax credits as a supportive policy in some countries, such as Germany, could be applied in other countries, especially because the lack of competitiveness in conventional sources of energy is a typical barrier for most countries (Gutermuth, 1998). Exemption of fuels produced by renewable energy sources (RES), such as biomasses, from other taxes was applied by Germany, which made it competitive with the highly taxed conventional diesel fuel. Consequently, sales rose from 40,000 t in 1996 to 100,000 t in 1997. A similar policy was applied to electrical vehicles, exempting EVs from motor vehicle tax for five years. The main reason that this instrument is attractive is that it makes cash available. Therefore, it could be an important financial incentive for private investors and an opportunity to make small investments because it directly increases investor liquidity. Many economists believe that employing a carbon emission tax or emission trading mechanism is considered a good policy to mitigate emissions at the lowest cost (Kalkuhl et al., 2013).

Kahn and Goldman (1987) analyzed the sensitivity of renewable energy and cogeneration project's internal rate of return (IRR) based on tax changes created by the US federal tax code according to PURPA. The electricity market was stimulated by tax incentives under PUPRA. Kahn an Goldman investigated six different technologies to evaluate the effects of tax reform on the financial viability of projects. Based on their calculations, capital intensive projects, such as wind turbine, small hydro, geothermal and wood-fired electricity, were not financially viable because of the expiration of energy tax credits (ETS). The results showed that gas-fired cogeneration technology is the most beneficial under the tax reform. Walsh (1989) applied a two-period utility maximization model of household behavior to investigate the relationship between federal and state tax credits and energy saving improvement in the US. The federal government reduced income tax liability by 15 percent of expenditure for conservation facilities from 1977 to 1986. The results indicated that tax credits are not an effective solution to subsidizing energy conservation activities. This could be because of the small discount rate applied by the tax reform, the inconvenience of claiming the credit, or lack of knowledge about the effects of price reduction.

Alfsen et al. (1995) simulated a model to assess the possible effects of carbon tax in Western Europe and the partial deregulation of power generation industry on CO_2, SO_2 and NO_x emissions. They assumed two regimes, plan-efficient and cost-efficient, in order to examine the effectiveness of carbon tax. They found that emissions were reduced by European Community (EC) tax by 6 to 10 percent under both regimes compared to a scenario without the tax. The regime change from plan-efficient to cost-efficient caused a reduction by 3 percent in CO_2 and NO_x emissions, while SO_2 was reduced by 13 percent. The results showed that an economic instrument for carbon emission reduction is able to influence the emissions of SO_2 and NO_x. Hassett and Metcalf (1995) estimated a panel data model of individual tax returns and variations in state tax policy in order to evaluate the impact of tax policies on investment in residential energy conservation in the US. They concluded that a point change of 10 percent in the rate of tax incentives for energy investment could increase the probability of investment by 24 percent. Kahn (1996) examined the impact of tax credits set by the US government based on Energy Policy Act (EPAct) of 1992 to enhance renewable energy technologies. The results showed that production tax credit was ineffective in providing incentive to invest in wind turbine power plants because it raised the financing cost. Therefore, the tax credit might not be able to reduce unit cost of electricity generated by wind turbine compared to the non-incentive plan. Consequently, the effect of the production tax credit could be minimal.

Brännlund and Nordström (2004) formulated an econometric model of nondurable consumer demand in Sweden to analyze consumer response and welfare effects of changing energy or environmental policy. The results showed that households living in populated areas were more influenced by CO_2 tax, indicating that carbon tax has a regional distribution effect. In terms of environmental effects, petrol demand was decreased almost 11 percent, which affects carbon emissions. The findings showed that the distribution of tax burden and welfare loss was uneven because the tax revenue was not returned at an even rate. Barradale (2010) examined the impact of repeated expiration and a short-term renewal federal production tax credit (PTC) on wind power investment. The federal tax revision created an on-off pattern, which led to a boom-bust cycle in wind power plant investment in the US, leading to a severe down trend for investment because of the high cost of ramp-up and ramp-down. The results implied that wind power is not feasible in the absence of PTC. However, Barradale found that it was formed because of the negotiation dynamics in the power purchase agreement in the face of PTC uncertainty. Therefore, an incentive instrument applied for enhancing renewable energy production may be changed to a disincentive form if it causes uncertainty.

Galinato and Yodar (2010) introduced an integrated tax-subsidy policy for carbon emission reduction, which is considered a compromise between standard Pigovian tax and a traditional indirect subsidy. They argued that environmental taxes on energy are not popular politically, because the taxes imposed on fossil fuels could lead to higher energy prices. Moreover, subsidies paid for renewable energy fuels are funded mainly by labor or income taxes. Galinato and Yodar suggested that revenues from carbon taxes could be used to fund subsidies for the production of low-emitter fuels. Therefore, the carbon tax and subsidy mechanism are revenue neutral within the energy industry. Levin et al. (2011) developed an energy optimization model and applied it to investigate the effects of the Renewable Energy Standard (RES) and carbon tax in the state of Georgia in the US. The results showed that power generated from biomass co-generation at coal plants could be considered a low-cost option, but the potential was limited. The findings indicated that constant carbon tax to 2030 would lead to the replacement coal with natural gas, instead of generating electricity from renewable energy sources. Based on the calculation, the low-cost biomass had the lowest levelized costs of electricity in all scenarios. The importance of a properly designed policy in order to achieve targets was emphasized in this research.

Pablo-Romero et al. (2013) investigated a variety of instruments, such as tax incentives applied in Spain, to enhance solar thermal energy deployment. They argued that tax incentives have not had a sufficient impact on solar thermal energy deployment because of regulatory changes at the national level, which complicated the system. It has also been stated that tax incentives would be more effective if they were associated with a proper financing mechanism. In this regard, Lehmann (2013) employed an analytical partial-equilibrium model of the electricity sector to show that an optimal policy to mitigate climate change could be designed efficiently by applying an emission tax along with a subsidy for renewable energy sources. Lehmann analyzed the performance of revenue-neutral fixed tariff and relevant differences compared to a governmental-funded premium tariff. He argued that a premium tariff policy may seen better than a non-continuous adoption, but some important parameters, such as increasing investment uncertainty and transaction cost, concerns associated with funding tariffs from public budgets, and breaking EU completion law (because they are classified as national subsidies), should be taken into account. It has been indicated that an optimal tax rate should be less than the Pigovian level, differentiated across the fossil fuels, and modified continuously, based on technological change. This paper implies that in the presence of learning-by-doing for renewable energy technologies, a combination of emission tax and a subsidy that is modified continuously could be considered as an optimal strategy.

Table (5-2): Some empirical studies regarding tax incentive policies

Author	Subject	Result
Kahn & Goldman (1987)	Impact of tax reform on renewable and cogeneration project	Capital intensive projects such as wind turbine, small hydro, geothermal and wood-fired electricity were not financially viable with the expiration of energy tax credits. The avoided cost price is important to develop projects.
Walsh(1989)	Energy tax credit and housing improvement	Tax credits are not considered as an effective solution to subsidize energy conservation activities. It could be due to small discount rate, uncomfortable procedure to claim the credit or lack of knowledge about price impact.
Alfsen et al. (1995)	Impacts of EC carbon tax and deregulating power supply on emissions	Emissions are reduced by European Community (EC) tax by 6-10 percent under both regimes (plan- and cost-efficient) compared to the scenario without tax.

Author	Subject	Result
Hassett and Metcalf (1995)	Energy tax credits and residential conservation	They found that a 10 percentage point change in the rate of tax incentive for energy investment could increase probability of investment by 24 percent.
Kahn (1996)	Production tax credit for wind turbine power plants	Production tax credit is considered as an ineffective incentive for wind turbine power plants, because it raises financing cost.
Brännlund & Nordström (2004)	Carbon tax simulation using a household model	Households living in populated areas are influenced more by CO_2 tax. Petrol demand will be decreased almost 11 percent which effects carbon emissions.
Barradale (2010)	Wind power and the production tax credit	Wind power is not feasible in the lack of production tax credit. An incentive instrument applied for enhancing renewable energy production may be changed to a disincentive form if it comes with uncertainty.
Galinato &Yodar (2010)	An integrated tax-subsidy policy for carbon emission reduction	Revenues made by carbon taxes could be used to fund subsidies for low-emitter fuels. Therefore, carbon tax and subsidy mechanism is revenue neutral within the energy industry.
Levin et al. (2011)	The role of renewable electricity credits and carbon taxes	Low-cost biomass has the lowest levelized costs of electricity in all scenarios. The importance of properly designing policy in order to achieve targets has been emphasized.
Pablo-Romero et al. (2013)	Incentives to promote solar thermal energy in Spain	Tax incentives have not had sufficient impact on solar thermal energy deployment due to regulatory change at national level which caused the system to be confused.
Lehmann (2013)	Supplementing and emission tax by a FIT for renewable electricity	Optimal tax rate should be less than Pigouvian level, differentiated across the fossil fuels, and modified continuously based on technological change.

5.4 Renewable portfolio standard

As previously mentioned, governments use a variety of policies to promote renewable energy. The renewable portfolio standard (RPS) is one of the most common policies used with FITs. In contrast to the FIT policy, which is price-based (fixed-price and premium-price), the RPS policy is quantity-based. This instrument requires companies to increase the amount of power generated by renewable energy sources. The RPS mechanism obligates utility companies to generate a specified share of their electricity by renewable energy. By doing so, they receive tradable certificates for every unit (for example, 1 MWh) of power generated; these are called tradable green certificates (TGCs). Unlike the FIT mechanism, in which the government guarantees the purchase of generated electricity, the RPS mechanism relies on the private market for its implementation. Therefore, there is more price competition across different types of renewable energy technologies. By early 2010, RPS were in place in 56 states, provinces, and countries, including more than half of US states (Martinot and Sawin, 2012). RPS policy is usually associated with the certificate trading mechanism. In the US, a credit multiplier is applied to promote specific types of renewable energy technology. For instance, a wind multiplier means that one MWh of power generated by wind technology could equal three certificates for the generator (M.J. Beck Consulting, 2009). Therefore, governments could use the credit multiplier as an instrument to direct revenue, investment, and job creation to a particular type of renewable energy technology.

The EU has experience with both FIT and RPS mechanisms. However, the former has led to the rapid expansion of the capacity of renewable and thus has been employed more than the latter has. Experience with FIT is limited in the US, which has focused more on RPS (Rickerson and Grace, 2007). Although RPS policies have diffused rapidly across the US, FIT policy is gaining in attractiveness to policy makers because of its success in the EU, particularly Germany. As of June 2010, the RPS mechanism had been applied by 29 states in the US. Another seven states had established nonbinding renewable energy goals. Almost 65 percent of the total wind capacity additions from 2001 to 2007 in the US were motivated by state RPS policies (Wiser, 2008). Some states have experienced rapid renewable energy expansion by these policies, and Texas achieved its 2015 RPS target of 5 GW installed capacity six years earlier than scheduled (Edenhofer et al., 2011). According to *GSR 2012 report*, by 2010, quotas or RPS were used in 69 states, provinces, and countries. Two additional countries applied this policy, making total of 71 countries in 2011, compared to the 92 indicated by FITs policies (Martinot and Sawin, 2012). In South Korea, a FIT policy that was operational through 2011 was changed to a RPS policy in 2012. Considering that RPS policies are usually associated with trading certificates, in 2011 India launched a new Renewable Energy Certificate (REC) mechanism linked to the current quota system.

Espey (2001) discussed a main support mechanism that was introduced to promote renewable energy deployment and examined the possible effects of applying RPS based on theoretical concepts and practical evidences. Espey argued that the RPS could not be considered a stand-alone solution that would enhance renewable energy sources. However, the advantages of the RPS make it a good starting point in the transition to an international trading system (as proposed in the Kyoto Protocol) if a well-designed mechanism is employed. Berry and Jaccard (2001) analyzed the implementation of RPS in three European countries (Netherland, Denmark, and Italy), nine US states, and Australia. They concluded that the RPS is generally applied to generators instead of end users. Moreover, the RPS system is managed by the government in Europe, but it is administered by a delegation of government and independent utility regulators in the US and Australia. Lauber (2004) compared FIT and RPS mechanisms as two options for a harmonized community framework. Lauber argued that these systems could not be measured by a common standard because they have different purposes. The FIT mechanism is appropriate to support renewable technology development and equipment industry, whereas the RPS system is more suitable in the phase of near-market competitiveness than in the early stage of technology development.

Wiser et al. (2005) examined experiences with RPS design, application, and effects in 13 US states. The results showed that the RPS was performed successfully in Texas, Iowa, and Minnesota. However, it was not effective because the policies were poorly designed. Some critical design pitfalls were experienced by states, such as the following: "*narrow applicability, poorly balanced supply-demand conditions, insufficient duration and stability of targets, insufficient enforcement, and poorly defined or non-existent* *contracting standards and cost recovery mechanisms for regulated utilities and providers of last resort*."

Nishio and Asano (2006) applied a quantitative analysis to evaluate the supply amount and marginal prices of electricity generated by renewable energy sources under the RPS mechanism in Japan. The results showed that the majority of power supplied under RPS was generated by wind and biomass energy. In addition, the purchase of certificates from generators in other regions and trading among retailers enabled the RPS system to be implemented effectively. Based on the analysis of the dynamic supply curve of certificates, the marginal price would increase according to the amount of electricity supplied. Kydes (2007) analyzed the effects of applying a federal 20 percent non-hydropower RPS on US energy markets by 2020. The calculation showed that this policy would be effective in enhancing renewable energy technologies and reducing emissions of NO_x by 6 percent, mercury by 4 percent and CO_2 by 16.5 percent. It was estimated that the total electricity cost for customers would increase by almost 3 percent, making a significant cost increase of 35 to 60 billion dollars for the power generation industry by 2020.

Carley (2009) examined the causal effects of RPS policies in states in the US on the percentage of renewable energy (RE) deployment. They applied a standard fixed model to evaluate the effectiveness of state energy programs from 1998 to 2006. The results showed significant potential for RPS policies and an increase in the number of states that implemented this policy could lead to an increase in RE deployment. The results indicated that the percentages of RE generation were lower in deregulated states than in regulated states, implying that competitive markets stimulate RE investment. Yin and Powers (2010) applied a panel data model to determine the impact of state-level RPS policies in the US and introduced an index to measure RPS stringency. Their findings showed that RPS policies significantly affected in-state renewable energy development. The results also showed that allowing out-of-state certificate trading had a negative impact on the effectiveness of RPS deployment. Moon et al. (2011) performed an economic analysis of biomass power generated by two technologies under an RPS scheme in order to compare the impact of the biomass on combined heat and power (CHP) system capacity. The Korean government introduced a FIT program in 2006 but changed it to RPS because it failed to achieve targets in recent years. The results showed that considering current infrastructure and technological levels, biomass gasification in CHP ranging from 0.5 to 5 MW_e could be considered a good starting point for initiating RPS mechanism.

Buckman (2011) investigated the effectiveness of banding and carve-outs as two modifications of the RPS mechanism used to support high-cost types of renewable energy technologies. UK and Italy used these modifications as particular examples of analysis banding. The US is selected for carve-out device. The results showed that both methods have strengths and weakness and could enable markets to enhance renewable energy deployment. They concluded that banding might be better than carve-outs to support high-cost renewable energy technologies. Dong (2012) examined the effectiveness of FIT and RPS to enhance wind power generation by applying a panel data analysis of 53 countries for five years from 2005 to 2009. The results showed that FIT policies increased power capacity by 1800 MW more than RPS mechanisms did. This capacity would increase to 2000 MW when the timing of policy was taken into account because the FIT system was started earlier than the RPS mechanism. There was no significant difference between FIT and RPS in terms of annual capacity. Fagiani et al. (2013) simulated a model for the period 2012 to 2050 in order to analyze the effects of investors' risk aversion driven by profit maximization on FIT and the certificate market system. The results showed that although FIT policy could achieve better economic efficiency better than RPS could, it strongly depended on regulators' decisions. In contrast, RPSs showed better performance compared to FITs in terms of cost-efficiency when the degree of risk aversion was moderate.

The comparison of FIT and RPS policies showed that the former was good when a good policy to develop renewable energy sources with a low level of risk for investors is required. However, the RPS is an appropriate when a market view policy is supposed to be applied by the government. Europe intends to organize a single harmonized FIT system, while it is impossible because of different policies across the countries in the EU. The RPS system has not been developed in Europe because most European countries use the FIT system. Hence, it seems that FIT polices are suitable to encourage developing renewable energy sources. However, RPS system should be applied after the implementation of renewable energy sources at a certain level.

Table (5-3): Some empirical results regarding RPS policies

Author	Subject	Result
Espey (2001)	RPS for trade with electricity from renewable energy sources	It cannot be considered as a stand-alone solution for enhancing renewable energy sources, but it is a good starting point for a transition to international trading system.
Berry & Jaccard (2001)	Design consideration and implementation of RPS	RPS system is managed by the government in Europe, but it is administered by a delegation of government and independent utility regulators in US and Australia. It is applied alongside with other support mechanism.
Lauber (2004)	FIT and RPS options for a harmonized community framework	FIT mechanism is an appropriate policy to support renewable technology development and equipment industry, while RPS system is more suitable to the phase of near-market competitiveness.
Wiser et al. (2005)	Evaluating experience with renewable RPS in US	Some critical design pitfalls are as follows: narrow applicability, poorly balanced supply-demand conditions, insufficient duration and stability of targets, insufficient enforcement, and poorly defined contracting standards and cost recovery mechanisms.
Nishio & Asano (2006)	Supply amount and marginal price of renewable electricity under the RPS in Japan	Majority of power supplied under RPS are generated by wind and biomass power. Purchase of certificates from generators in other regions and trading among retailers enables RPS system to be implemented more effectively.
Kydes (2007)	Impacts of renewable RPS on US energy markets	It will be effective to enhance renewable energy technologies alongside with an emission reduction of NO_x by 6 percent, mercury by 4 percent and CO_2 by 16.5 percent.
Carley (2009)	State renewable energy electricity policy in US	There is a significant potential for RPS policies and an increase in the percentage of sates performed this policy could lead to an increase in RE deployment. Percentages of RE generation are lower in deregulated states than regulated states.

Author	Subject	Result
Yin & Powers (2010)	State RPS promote in-state renewable generation	RPS policies have affected in-state renewable energy development significantly. Also, allowing out-of-state certificate trading has a negative impact on RPSs deployment effectiveness.
Moon et al. (2011)	Economic analysis of biomass power with RPS in Korea	Considering current infrastructure and technological level, biomass gasification CHP ranging from 0.5 to 5 MW_e could be considered as a good starting point to initiate RPS mechanism.
Buckman (2011)	The effectiveness of RPS banding and carve-outs in supporting renewable	Both methods have different strengths and weakness, but they could enable markets to enhance renewable energy deployment. Banding may be better than carve-outs to support high-cost renewable energy technologies.
Dong (2012)	FIT vs. RPS: An empirical test of their relative effectiveness	The FIT policy made power capacity by 1800 MW more than the RPS mechanism. This capacity will be increased to 2000 MW when the timing of policy is taking into account due to the fact that FIT system has been started earlier than the RPS mechanism.
Fagiani et al. (2013)	Cost efficiency and affectivity of renewable energy support scheme	FIT could achieve economic efficiency better than RPS, but it depends on regulators' decisions. RPS has a better performance compared to FIT in terms of cost-efficiency when the degree of risk aversion is moderate.

5.5 Cross-national incentive policies

Cross-national incentive policies could be studied from different points of view, including the transfer of climate change mitigation technologies, emission trading schemes, and the clean development mechanism (CDM) derived from the Kyoto Protocol. Given the considerable scale of effort required to reduce greenhouse gas emissions (GHG), it is almost impossible for all countries to produce environmentally friendly technologies by themselves. The OECD and the World Bank have shown that climate-mitigation technology trading could be affected by non-tariff measures, which would also help them to promote technologies (Tébar Less and McMillan, 2005). Trade barriers are not the only barriers to commodity movement. Total technology is constituted by the knowledge, skills, and services associated with installation and operation. Steenblik and Kim (2009) investigated the effects of tariff and non-tariff barriers on trading a selection of carbon-change-mitigation technologies (CCMTs) identified by the Intergovernmental Panel on Climate Change (IPCC) and IEA. These included combined heat and power, district heating and cooling, solar heating and cooling, and energy efficiency motor systems. They concluded that is necessary for technology importers to review their policies in order to facilitate the diffusion of CCMT technologies made and developed in OECD countries. Adequate environmental regulations, removal or reduction of trade barriers, adequate intellectual property rights regimes, and appropriate financing mechanism were considered incentives to transfer renewable energy technology across countries (Tébar Less and McMillan, 2005).

The Kyoto Protocol introduced three mechanisms to mitigate GHG emissions: emission trading, CDM, and joint implementation (JI). Emission trading is based on an allowance transition that enables a country (listed in Annex B) to trade emission permits. In contrast, CDM and JI are classified as project-based. The European Union Emission Trading Scheme (EU ETS) is an essential part of EU climate change policy. The allowance mechanism in ETS is based on three methods: grandfathering, benchmarking and auctioning (Koh, 2010). In this system, which was applied from 2005 to 2012, nearly all permits were grandfathered (Bernard and Vielle, 2009). Based on the mechanism applied to mitigate emissions, incentives could be different. In case of emission trading, the renewable energy certificate mechanism derived from RPS has gained importance. As previously, the EU aims to harmonize support mechanisms in order to facilitate market creation for trading certificates across member nations. A CDM or JI is similar to an investment project because it is able to earn both financial returns and carbon credits. Carbon credits have monetary value, and net financial returns will be affected by this value.

Carbon credit transactions enable the host countries to receive significant amounts of foreign investment. CDM is specifically designed as a mechanism to channel foreign investment into non-Annex I countries (Koh, 2010) Therefore, the incentives for using CDM facilities across countries are similar to incentives to attract foreign direct investment (FDI). For example, it is important to consider any regulation that may create a limitation to the inflow of FDI, such as restrictions on the profit repatriation of investors. Some countries may offer investment incentives and tax concessions to promote CDM projects. Krey (2004) examined 15 unilateral potential CDM projects in India and found that average transaction costs were estimated at 0.06-0.47 $/tCO_2$ equivalent, which corresponds to approximately 76 to 88 percent of the total transaction cost of the projects. Chaurey and Kandpal (2009) analyzed the carbon abatement potential of solar home systems (SHS) in India and estimated that a bundled project of 20,000 SHS could return almost Rs 1.9 million annually at 10 \$/tCO_2 after expenses of 20 percent for pre-implementation transaction costs. Of course, the balance between demand and supply should be taken into account. The Total demand in the Kyoto Protocol from 2008 to 2012 was estimated at 1222 MtCO_2, whereas the supply was over 3000 MtCO_2. Additionally, the Green Investment Scheme developed by Russia and East European countries would bring a return of more than 1800 MtCO_2 (Bhattacharyya, 2011). On the other hand, these numbers demonstrate the potential capacity of carbon emission reduction in several countries. By other means, there would be a large capacity available to reduce emissions if a well-designed support mechanism were in place.

Chapter 6: Market Design for Trading Commoditized Renewable Energy

6.1 Introduction

In the future, energy efficiency will be one of the most important approaches to reducing electricity consumption. Information and communication technology (ICT) play important roles in achieving this target. In particular, smart grids can achieve energy efficiency by integrating information technology and the interactions between suppliers and customers. Smart grids have been used since 2005, when Amin and Wollenberg (2005) introduced the concept of smart systems in electricity networks. Smart grids help in avoiding the problems of traditional systems, such as transmission loss, inefficiency, unbalanced supply and demand in peak time, and interdependency among the components of the network.

The improved flexibility of the smart grid network helps to develop different kinds of renewable energy sources, such as solar and wind power. The smart grid enables households to have their own devices to produce renewable energy and trade their surpluses of electricity. Furthermore, households can manage energy consumption by using intelligent control systems. Households that generate electricity using their own resources may enter surplus electricity into the network and take it back another time. However, the power exchange between the Distributed Generation (DG) owner and the network requires appropriate management (Mashhour and Tafreshi, 2009).

Regarding the outlook of the renewable energy market, a marketplace for energy trading in small volumes is required. The world will use DG because of environmental issues and limited availability of fossil fuels in the future. By 2030, U.S. Department of Energy (DOE), through the implementation of its Research and Development Plan, will produce 20 percent of U.S. electricity generation, an estimated 200 GW, from distributed and renewable energy sources (DOE, 2010). Because of the high penetration of DG in the future, the power industry should be restructured. In order to facilitate the use of renewable energy sources, it would be better for power distribution systems at the retail level to change to market-based operations. The market is based on two-way interactions between stakeholders by internet telecommunication (IT). Some customers may be worry about data privacy issues and the remote monitoring of their devices.

The remainder of this chapter is organized as follows. In the second section, we explain the state-of-the art distributed generation. In the third section, we consider the components required to build a smart network. We also described a smart grid market place where energy is traded. In the fourth section, we explain the market structure. The smart grid market place requirements are discussed in the fifth chapter and finally, model of a renewable energy market is provided.

6.2 State of the art

The idea for using a market place and the market mechanism is not new. It has been employed in wholesale electricity markets and computing resources. In recent years, the idea of distributed resources spilled over from computer grids to power grids. Therefore, we devote this section to discussing marketplaces for trading electricity, distributed electricity generation, emission trading and computing resources.

6.2.1 Marketplaces for trading electricity

Three fundamental markets are available for trading electricity: the spot market, the physical forward market, and the financial futures market. Nord Pool Spot is considered the largest market for electricity worldwide in terms of volume traded (TWh) and market share. It provides the leading marketplace for buying and selling power in the Nordic and Baltic regions, as well as in Germany and Great Britain. Nord Pool operates two kinds of markets for trading electricity: Elspot and Eltermin. In the Elspot, buyers and sellers trade in the day-ahead market. The Eltermin market is divided into two markets: future and forwards (Kristiansen, 2007). The Elbas market bridges the gap between Elspot and the national Nordic real time markets and is a physical market for trading in hourly contracts (Benth et al., 2008). The European Energy Exchange (EEX), based in Leipzig, is a leading trading market for energy and energy-related products. EEX operates trading platforms for electricity, natural gas and carbon dioxide emission, and coal.

The base-load financial contracts traded in this market are similar to the Nord Pool contracts (Benth et al., 2008).

6.2.2 Marketplaces for distributed electricity generation

Wang et al. (2011) summarized the current state of research on the communication networks of smart grids. Buchholz and Schluecking (2006) showed different experiences with distributed generation and energy management system in distribution grids in representative European pilot installations. Block et al. (2008) introduced a market mechanism that facilitates the efficient matching of electricity and heating demand and supply in Micro Energy Grid environments.

Molderink et al. (2009) defined and developed a simulator to analyze the impact of different combinations of micro-generators, energy buffers, appliances, and control algorithms on energy efficiency, both within house and on a larger scale. Albadi and El-Saadani (2008) presented a summary of demand responses in deregulated electricity markets. They emphasized the effect of demand response on electricity prices by using a simulated case study. Lund et al. (2012) illustrated the reasons that electricity smart grids should be part of overall smart energy systems, and the emphasized that the inclusion of flexible CHP production in electricity balancing and grid stabilization.

Friedman (2002) focused on the technologies required to interconnect DER systems with the grid. Recent increases in electric grid prices, coupled with shortages in electricity generation capacity, have prompted some industrial and commercial customers to evaluate DER solutions for their energy needs.

Shi You et al. (2009) proposed a virtual power plant model which provides individual DER units with accesse to current electricity markets. They applied this model to a micro Combined Heat and Power (µCHP) systems.

6.2.3. Marketplace for emission trading

The SO_2 trading system in the U.S. could be considered an early example of an emission trading system created to reduce the effects of emissions from power plants. The US has two major emission trading programs: The SO_2 program began in the early 1990s, and the NO_x program began in the late 1990s (Kruger and Pizer, 2004). The European Union emission trading system (EU ETS), which started in 2005, is the world's largest emission trading market to date and covers around 50 percent of Europe's total CO_2 emissions (Hintermann, 2010). As we discussed in chapter five, the Kyoto Protocol introduced three mechanisms to reduce GHGs emissions: international emissions trading, Joint Implementation, and a clean development mechanism. The EU ETS is considered an essential part of EU climate change policy in meeting its obligations under the Kyoto Protocol. Hintermann (2010) examined the drivers of allowance prices in the first phase of the EU ETS and found that it was necessary to set an appropriate price to avoid start-up problems. Soleille (2006) argued that ETS itself does not abate emissions; its efficiency depends on political will, proper design, and implementation. The results obtained by the previous markets in the US and the EU could be employed in the new market in order to take advantage of lessons learned from existing trading programs.

6.2.4 Marketplace for computing resources

Buyya et al. (2001) deployed economic models of resource allocation and regulating supply and demand in a grid computing environment. They demonstrated the use of economic models in resource brokering for two different optimization strategies on the World Wide Grid test bed, which contains peer-to-peer resources located on five continents: Asia, Australia, Europe, North America, and South Asia. Preist (1999) described a new agent-based market mechanism for commodity trading via the internet. This institution combines the best properties of the continuous double auction and the call auction. It consists of a marketplace and a set of agents that represent participants.

Wolski et al. (2003) described the use of economic principles for grid resource allocation policies and mechanisms. They found that a computational economy, in which users "buy" resources from their owners, is an attractive method of controlling grid resource allocation for several reasons. In other study, Wolski et al. (2001) investigated G-commerce computational economies for controlling resource allocation in a computational grid setting. Their results indicated that commodity markets are a better choice for controlling grid resources than previously defined auction strategies. Altmann et al. (2008) presented the design and implementation of the GridEcon Market place for trading commoditized computing resources.

6.3 Stakeholders

First, we need to recognize the components of the smart network for trading renewable energy resources. Our network includes producers, energy providers, energy service providers, consumers, operation, and electricity market participants. Intelligent management is a critical part of the smart network. All components should have the capability of being managed by an automatic system. We should keep in mind that new technology for deploying smart control and management is required. Innovative technologies, including advanced power equipment, intelligent home appliances, smart meters, and communication facilities have not yet improved sufficiently, or they are not available commercially.

6.3.1 Bulk generation companies

Power is produced by using fossil fuels, such as coal, natural gas, and non-fossil fuels, such as nuclear fusion, water, and sunlight. This component is connected to the transmission line and thus to the transmission control center. There should be interactive communication between bulk generation and the control center regarding crucial parameters, such as capacity, production and consumption monitoring, peak-load time, off-load time, and related unit cost.

Bulk generation includes nuclear, hydro-electric, or Coal power plants. In addition, some number of DERs with different technologies, such as wind turbines, solar panels and CHP units could be combined and connected to the electricity network as a virtual power plant (VPP). All these power sources are connected by ICT. (Bühler, 2010)

6.3.2 Transmission entities

The generated power is transmitted to the distribution network through the transmission line and substations. Large and medium size plants that producte power that is transmitted to the network. Because of the importance of the transmission line in the case of possible black outs, our system should be self-healing, in order to recover automatically. Furthermore, substations are remote controlled and will be managed by the control center.

6.3.3 Operators

Operators are responsible for the optimal and efficient operation of the transmission and distribution of power. Information about all activities, including monitoring, control, and maintenance is transferred by smart system. This component has subsidiaries, such as energy providers and energy service providers. Energy provider companies supply a bundle of different energy sources (both fossil and non-fossil based) to end users. Energy Service Provider Companies (ESCO) provide consultancy services to customers. These companies may be affiliates of the energy provider companies.

Considering that the development of DG has a wide effect on the network, the role of operators in this system is gaining importance. Technical parameters of the network, such as node voltages, strongly depend on the operation of DG. For example, the high penetration of DG may cause serious problems in the network. Furthermore, some households may inject their surplus power into the network during some hours and compensate their shortage at other times. Therefore, the power flow current in the network may be altered during the day at times of high penetration of DG (Mashhour and Tafreshi, 2009).

6.3.4 Customers

This domain consumes, generates, and stores electricity power. Customers may be household, commercial building or an industrial factory. This domain is one of the most important parts of network because they play a key role in demand response programs. These components should be considered when we are talking about customers: smart energy efficient devices, smart distributed energy resources, smart control system and IT architecture. The customers also participate in demand response program. In order to have efficient participation of customers, an advanced IT infrastructure and a symmetric information system are required. In addition, there should be some methods and incentives to encourage end users and overcome barriers to customers' acceptance.

6.4 Market structure

The global importance of renewable energy deployment is increasing continuously. It is usually difficult for new players to enter energy markets, but the latter are need to stimulate the development of renewable energy. Without such markets, support policies, and reliable mechanisms, there is no incentive for suppliers or consumers to use electricity generated by renewable energy sources. Renewable energy sources cannot penetrate a market that is not developed. Without market development, it is limited to cover individual demand. However, if renewable energy usage is connected to a commercial market, its progress is endless (similar to the wholesale electricity market). On the other hand, market development depends on transaction liquidity and the availability of commodities in the market. Therefore, the main challenges to this market are facilitating transmission electricity through households and the intermittent characteristics of renewable energy sources. Moreover, another market that is related to this new market would be a strong support instrument. Our proposed market provides a place to trade the electricity produced by households. In fact, there should be a balance between supply and demand in order to prevent power blockages. Currently, no market place exists for trading small amounts of electricity. Furthermore, it is difficult to send small amounts of electricity to the transmission network. The proposed market place is able to prepare an environment to deal with this problem. Because of the increasing penetration of DG, the power industry around the world should be restructured rapidly, and the power system operation at the retail level should be changed to a market-based system that is the same as the wholesale level. In building the new structure, DG units should be merged according to entity and controlled by an energy management system (EMS), which is a crucial part of the distributed control (Mashhour and Tafreshi, 2009).

This section considers the micro-grid concept. A large number of households is able to connect as micro generators, which then have the capability to reduce energy consumption at peak time periods and justify demand at other times. Therefore, through market development and increasing the number of households in the market, they could reduce the demand for building new power generation capacity to cover electricity consumption. In this view, the costs (i.e., financial and non-financial) required to build power plants could be compared with the cost of our proposed market establishment. We should keep in mind that any type of power plant has a limited capacity, and it is necessary to build a new plant when demand increases. However, the proposed market is flexible, and it has the capability to develop if the required infrastructure (e.g., IT facilities, intelligent devices, etc.) is available.

By analyzing the incentives of customers to participate in a smart network and by studying the structure of distributed energy resources in order to establish a market, one can identify five major restrictions in using renewable energy widely:

- The risk of accessibility to external resources;
- It is costly to replace old devices to new one for integrating them into the existing IT infrastructure;
- Different pricing mechanisms cause uncertainty about the actual cost

of a resource;

- Reliable models for distributed energy resources that are applicable in the real world do not exist;
- The penetration and liquidity of energy sources is limited.

The analysis of these objectives showed that a solution could be a market for trading renewable energy. This market would also have the capacity to provide support and consultancy services in order to help customers integrate a demand-response program into their existing IT infrastructure. Of course, they might change their home appliances to smart devices, but the support services would help take advantage of the current IT network. A number of information-related objectives are important in encouraging customers to use energy efficient devices.

In recent years, concerns about the effects of greenhouse gases have increased. The awareness of this issue and rising energy prices has stimulated end users to improve energy efficiency. This stimulus includes micro-generation, energy storage, and efficient home devices. It will affect electricity infrastructure in the future; consequently, the structure of electricity market will change. Currently, trading in electricity markets is one-sided. In other words, suppliers sell electricity to end users. In the future, end users will be able to produce electricity in order to use it at home or trade it. Because price setting is a crucial part of any market, it is important to provide a mechanism to customers for trading their energy resources. This trading mechanism will be made possible by using a smart network. Accordingly, these customers need to use new devices in order to take advantage of the smart grid system;

however, this procedure is costly because smart meters must be installed. According to Ahmad Faruqui et al. (2010) estimation, this cost for the EU would be 51 billion Euros, and operational saving would be worth between 26 and 41 billion Euros, showing a gap of 10-25 billion Euros between benefits and costs. They argued that smart meters are able to fill this gap because they enable provisions of dynamic pricing, which reduces electricity consumption at peak times and lowers the demand for building and operating costly power plants.

In recent years, many market mechanisms have been proposed for trading computing resources, aiming at economically efficient resource allocation (Altman et al., 2008). In a real market, commodities are traded in a certain location. The main index of such a market is that the same goods are offered by different suppliers, whether their identity is known or not. In addition, price is determined by unit cost, margin, and the supply and demand of power. All market participants decide the amount of payment to buy or sell commodities. Because the main objective of a smart grid market is to provide end users with electricity regardless of the particular energy provider, we can apply the concept of a natural commodity market to the proposed market mechanism.

6.5 Requirements for establishing market

In this section, the fundamental requirements of designing market place for smart grid and the details of its market mechanism are explained. In general, a market for trading renewable energy will work if the following conditions are achieved:

- Pattern of individual demand for renewable resources is bold;
- Individual storage is possible for owners of renewable energy; and
- Adequate technology for implementing this market is available.

In addition to the above three conditions, three principal prerequisites must be fulfilled. First, a friendly user platform should be designed to enable the market participants to trade and communicate. Second, technology for commoditizing energy resources must be easily used by all people, even those who are not highly educated. Many people in urban areas, especially in suburban areas, are not familiar with smart technology. Hence, it may be difficult for them to use new devices controlled by smart meters. Third, sufficient information should be available to all customers. In making decisions to buy an intelligent appliance and participate in smart energy market, consumers need to have all available information regarding electricity price, electricity consumption, and initial cost.

6.5.1 Infrastructure

The main infrastructures required to establish this market are listed as follows:

1. Communication: ICT infrastructure is a key component in this market, including internet based technologies and services, internet protocol based services through broadband availability, virtual private network, wireless technology, etc. (You, 2010).

2. Science-technology infrastructure: The required technology should be available to control micro grids, coordinate distributed generation, and aggregate resources, smart meters are needed to record data properly, and applied scientific knowledge and skills are needed for knowledge transfer, education, etc.
3. Storage facilities: Because of the intermittent character of wind and solar generators, storage facility is required. Furthermore, to allow an islanded operation in the micro grid network, which is based mainly on distribution energy sources, storage facilities should be available. Four main tasks addressed by storages: dispatch ability, interruptibility, efficiency, and regulatory-driven needs (Tester, 2005).
4. Device provisioning: This connects a newly installed smart meter with the customer's account, and it connects an increasing number of home appliances in each household to the correct smart meter (Sioshansi, 2011).

Market participants need a reliable infrastructure (power grid, IT, etc.) for doing business. IT communication infrastructure should be provided by the government before market creation. Considering that the micro-gird market is internet-based, managing a large-scale of wide communication network is required. Therefore, IT infrastructure should include both accurate data recording and the integration of diverse applications (i.e., software, micro generators, and home appliances).

In chapter three, we discussed alternative technologies for power generation by renewable energy sources. As Oliver and Jackson (1999) pointed out, satellites, remote industries, remote communities, solar home systems, remote houses, and consumer products could be considered a niche market for solar PV. Unit cost of competitors' technologies must be determined in order to select a feasible technology for application in the market. The growth of market sales affects the scale of innovation in the US, Germany, and Japan. In the future, feasibility of the solar PV system will increase as it extends geographically (Huo et al., 2011). Of course, a reliable political framework is required to ensure both return on investment and continuous research on cost effective materials, device designing, and improved efficiency (Waldau, 2006). The importance of distributed generation in the electricity network was discussed in chapter three. An appropriate science-technology infrastructure, such as VPP, is required to control and manage the power generated by individual units. It is possible to employ a VPP constituted by a large number of customers with controlled home appliances in order to ameliorate network congestion (Ruiz et al., 2008). Therefore, ICT infrastructure is considered a key component in this market. We cannot apply smart metering if appropriate ICT facilities are absent.

6.5.2 Regulation

In order to improve energy efficiency and power generation by renewable energy sources, high-level management is required for the development and implementation of policies and programs (Gellings, 2009). There are different kinds of barriers regarding market (e.g., information transparency, fossil fuel subsidizing, financing, etc.), technical issues (e.g., lack of skilled workers, knowledge transfer, intellectual property rights, etc.), and public acceptance (e.g., lack of knowledge, lack of interest, avoidance of comfortable decreases, etc.), compatibility between current operating systems and new technology implemented in the renewable energy market (e.g., data recording system). These barriers should be removed in order to facilitate the environment for market creation.

No single regulation in the world works well. Depending on conditions and player interest, different policies are required to achieve this goal. According to Gunningham et al. (1998) argument, a range of available policies is available to use for environmental protection: command and control regulation, self-regulation, voluntarism, education and information instruments, economic instruments, and free market environmentalism. Education and information is categorized into education and training, corporate environmental reports, community right-to-know, and pollution inventories, product certification, and award schemes. He also categorized economic instruments as property rights, market creation, fiscal instruments, charge systems, financial instruments, liability instruments, performance bonds, deposit refund systems, and the removal of perverse incentives.

Because our proposed market includes different players, such as major power generators (including fossil fuel and non-fossil fuel generators), distributors, consumers, service companies, consumers (including industries, commercial building and households), interactions between parties are also important. Therefore, we should pay attention to this issue when we discuss regulation.

Furthermore, external factors should be considered in order to maintain the stability of our policy and avoid causing uncertainty among the market players regarding policies and regulations.

In order to establish a market-based micro-grid successfully, we use a combination of the above-mentioned instruments as a regulatory framework. Governmental regulations are set to control and manage the market.

1. Command and control: These regulations apply specific standards to energy consumption in industries, public sectors, commercial buildings, and households. This regulation could be used in combination with awards and penalty regulations.
2. Self-regulation: Government sets a specific standard for industries, and every industry self-regulates to achieve this standard. This kind of regulation is also seen at the international level. For example, the OECD sets a target for members to reduce carbon emissions, and each member self-regulates to achieve organizational targets.
3. Education and information: Education and information form a crucial parameter in developing the capacity of renewable energy usage in industry and the community. Public acceptance is one of the most important components of market development. Environmental information and training programs presented by the government could be considered a supplementary instrument to other forms of regulation (Gunningham et al., 1998).
4. Economic instruments: A wide range of economics instruments exists

to encourage private companies and consumers to use renewable energy sources. These include feed-in tariffs, reduction of fossil fuel subsidies, CO_2 emission trading, renewable fuel standards or targets, green certificate trading, emission and energy taxes, residential and commercial tax credits for renewable energy usage, the Kyoto Protocol, etc. (Hofman and Huisman, 2012). It's recommended to stimulate market creation by feed-in-tariff and support market direction to tradable green certificate in order to be relied on market mechanism instead of governmental decision making. Feed-in-tariff policy is related to governmental budget, and it may be not stable in case of some difficulties like financial crisis. Decreasing or cutting financial support by feed-in-tariff has a negative effect on the market, while continuing and sustainability in a policy is the most important factor to be successful.

The planned target plays a crucial role in the selection of market instruments. For example, as discussed chapter five, using a harmonized FIT is almost impossible at the European level because of the intention to promote green certificates instead of FITs to meet the up-coming market demand for emission certificates (Ringel, 2006). However, when no target has been set for creating market oriented renewable energy sources, the FIT policy is able to compensate the negative impacts of low electricity prices on the feasibility of solar PV. These costs could decrease rapidly over the time because of innovation and technology development (Rigter and Vidican, 2010).

Stability is an important issue that should be considered regarding policy making. Any regulation set by policy makers should be stable. In chapter four, we discussed that in addition to grid modernization efforts to enhance energy efficiency and adapting current policy, a regulatory framework and market environment are crucial in supporting new technology investment. Suppliers and consumer will not be attracted if they cannot trust the policies because of uncertainty. For example, the financial crisis has forced some European governments using feed-in tariff to cut their subsidies (Hofman and Huisman, 2012). Public views and investor decision making are affected by this kind of issue. Environmental policies and all related supportive instruments, especially economic ones, should be selected properly and considered high priority in governmental planning. Foxon et al. (2008) gave three reasons regarding sustainability in current policy-making procedure: low priority compared with immediate policy pressure; interaction between problems in addition to uncertainties about future costs; and, every plan to achieve targets is inevitably contested.

6.6 Model of a renewable energy market

In order for customers and suppliers to accept a market, it is crucial that the market place is able to meet the following objectives:

- In order to prevent power outages, supply and demand must be balanced all times. Energy resource offers should be monitored.

Therefore, it is assumed that there is no fluctuation in the power network for the market place;

- In order to guarantee security, energy providers are not allowed to give the customer's information to third parties;
- In order to gain acceptance of the market place by customers, the market place should provide access to energy resources in a transparent and simple way. Furthermore, incentives should encourage customers to use market place services;
- There should be no barrier to entering or exiting the market. The number of participants in the market should be sufficiently large; and
- The information system connecting market participants should be symmetrical.

Offers to sell excess energy resources are matched with orders that have already been placed. The task of the market place is allocating time and facilitating financial transactions of private resources.

6.6.1 Market mechanism

Different market mechanisms are used for trading commodities. Continuous double auction (CDA) is the main market institution and is used widely in markets, such as stock exchanges and commodity markets. The CDA mechanism matches buyers and sellers of a particular good, and it determines the prices at which trades are executed. The specifications of electricity differ from other commodities, because of the small unit of trade and extra cost of using batteries to store electricity; we use future contracts to trade electricity in our designed market place. This type of contracts is designed for use in the wholesale electricity market, but it can also be used in the retail market and smart grid netwoek.

Because power companies use blocks for end users, future contracts can adopt this system. Of course, these contracts could also be used in dynamic pricing. Electricity prices are volatile because demand changes continuously, depending on the time day and weather conditions. The unit of trade and bid-ask procedure is defined as follows:

1. *Unit of trade*

The most important factor in this market is the unit of trade because it is small and is not available in any other market. Therefore, we should organize our market based on this unique capability. The format of the specification of the unit of trade is defined by the following three parameters:

- Start time: It is the time at which the resource is available for the buyer or the time that the resource is required by the buyer.
- Unit duration: This is the standard length of time that the resource will be available to the buyer or the shortest period that the resource will be required by the buyer. The unit duration is set according to the acceptance of users within the marketplace. The unit of trade is one hour in the power market. However, because of the size of the proposed market, we can use a smaller division, such as five minutes.
- Unit volume: This is calculated based on kWh, but the total volume should be defined in the contract.

2. Bids and Asks

Based on the unit of trade, we define bids and asks. Ask is submitted by a customer who owns extra electricity and wants to supply it to the market. The bid is submitted by a customer who needs extra electricity at a low price. These customers may be households, commercial buildings, or industrial sectors. The unit of trade, bids, and asks comprise the following parameters:

- Price: This parameter defines the minimum price that a seller is willing to accept or the maximum price a buyer is willing to pay for a unit of trade. We should consider additional items that are usually added to the unit price. Additional charges regarding option contracts or settlement operations (in some cases) which should be included in the requested price.
- Volume of resources: This parameter defines the number of units of trade. Because of the small size of the unit of trade, each buyer may purchase the required electricity from the pull of several sellers.
- Duration: This is based on the dynamic pricing period, which is used by power companies to set the price of electricity consumption. The minimum duration is one hour because the kilowatt hour is used as a billing unit for energy delivered to consumers by power companies.

6.6.2 Performance evaluation

Performance evaluation is a crucial part of market creation. An essential goal in establishing this market is energy efficiency. Although the investments in many projects involving energy-efficient technology show good economic results, the percentage of their successful implementation is less than expected because of barriers that discourage decision makers, such as households and firms (IEA, 2012). The lack of a measurement of energy efficiency has led to the effect that opportunities are not visible. Hence, no decisions are made to take advantage of them. We have to define some indices to show households, firms, and policy-makers the economic and environmental benefits of the micro-grid market.

A different type of index could be calculated to evaluate market performance. Some indices are used in current markets. For example, Energy Exchange Austria (EXAA) is a European energy exchange headquartered in Vienna which covers energy trading in Austria and Germany. Table (6-1) shows some selected indices in EXAA, which are applicable to the micro-grid market.

Table (6-1): Key Performance Ratios for EXAA

Key Performance ratios	**2010**	**2011**
Sales revenues (in Euro)	2,030,159	2,324,493
Spot market electric power		
Trading volume in GWh	6,410	7,558
Clearing volume in Euro	292,146,570	390,236,567
Number of trading members	90	71
Spot market CO_2 allowance		
Trading volume in t	88,401	19,179
Trading volume in Euro	1,260,481	269,072
In % of Austrian consumption		
Market share	10.7	13.1

Source: Annual Report 2011, EXAA

In addition to the numbers used for the energy exchange center, other indices, such as storage capacity, storage inflow, storage outflow, generation capacity, installed generators, and load shift numbers, could be calculated to analyze market performance. Of course, because of the small amount of electricity traded in the micro-grid market, unit volume is in MWh instead of GWh. In addition, the CO_2 saving number could be calculated as an index, which could represent the share of market participants in attributed CO_2 saving.

Another approach to evaluating market performance is the decomposition method. By calculating renewable energy intensity and performing a cross-national analysis, we can compare market performance in countries that have planned to mitigate the effects of energy consumption and carbon emission on climate change. For example, this kind of analysis could be used by the OECD in order to compare members' achievements. In addition, economic side effects of funding the micro-grid market could be evaluated by economic indices. For example, producers' companies will be affected by market development and this effect could be measured according to rate of production, employment, payroll, number of patents, R&D investment, number of skilled laborers, education investment, etc., all of which are considered as economic effect of market creation.

Chapter 7: Impact of Renewable Energy Development on Carbon Emission Reduction

7.1 Introduction

During the last three decades, two different approaches have been applied in the research of natural resources. First is the viewpoint that considers the effect of natural resources on economic growth. As previously discussed chapter two, many researchers have studied the relationship between energy consumption and economic growth. Early studies were published in the 1970s, including Allen et al. (1976), Hitch (1978), and Kraft and Kraft (1978). This relationship has been studied in both individual and groups of countries. Akarca and Long (1980), Yu and Hwang (1984), Cheng (1995), and Stern (2000) applied this methodology in the US. Wold-Rufael (2005) employed the causal relationship methodology in a study of 19 African countries. Lee and Chang (2007) tested causality in 16 Asian countries, and Huang et al. (2008) tested causality in 82 countries. The effect of energy consumption on economic growth could differ substantially in developed countries. Narayan and Prasad (2007) found different causality effects in 30 OECD countries. This means that conservative energy policy could affect individual countries differently.

The second approach takes into account the environmental effects of economic growth. Following the empirical study of Grossman and Kruger

(1991), many scholars analyzed the relation between economic growth and environmental pollution. Coondoo and Dinda(2002) studied the relationship of income-CO_2 emissions based on a Granger causality test of cross-country panel data. Zhang and Cheng (2009) investigated Granger causality among economic growth, energy consumption, and carbon emissions in China. Soytas and Sari (2009) examined causality relationships between these variables in Turkey. In the most recent study, Choi et al. (2011) used the environmental Kuznets curve (EKC) to examine the relationship of carbon dioxide emissions to economic growth and openness.

In the present study, we investigate EKC according to a number of variables, as follows: the share of renewable energy sources in total power generated; number of patents per million inhabitants for energy applications adopted to mitigate climate change; ICT as a proxy variable for technological innovation; environmental tax per capita as a proxy variable for market regulation; and trends. We examine the effects of these variables on carbon emission per capita.

Our contribution is to investigate the effectiveness of power generated by renewable energy sources, technological innovation, and market regulations on the mitigation of climate change. We also calculate the elasticity of carbon emissions per capita for each parameter. The results obtained by our model could be used by policy makers to evaluate effectiveness of different policy tools and the effects of interactions between these policies.

7.2 Methodology and analytical framework

In this section, we explain the methodology used to build the model, we define the model specifications, and we state the hypothesis of our model.

7.2.1 Methodology

A cross-country panel data model has been applied to EU-15 countries. Hsiao (2003) and Klevmarken (1989) mentioned various advantages for using panel data, such as controlling for individual heterogeneity, more variability, less co-linearity among the variables, more degrees of freedom, and more efficiency (Baltagi, 2008). The countries differ in terms of economic structure, technology, and policy. If this heterogeneity is not included in the model, serious misspecification could result. Moreover, the probability of co-linearity is high in time-series studies, but it is less likely with a panel across the countries, because the cross-country dimension adds variability. Additionally, informative data could lead to the increased reliability of estimators. Several different linear models can be applied to panel data. The individual-specific-effects model for the scalar dependent variable, y_{it}, specifies that

$$y_{it} = X_{it}\beta + \alpha_i + \gamma_t + v_{it} \qquad (7\text{-}1)$$

where α_i and γ_t are error components (or random effects) specific to units i and time periods t. The composite error term $u_{it} = \alpha_i + \gamma_t + v_{it}$ is generally not independent and identically distributed (iid), but its variance-covariance matrix (Ω) could be estimated. y_{it} is the n-by-1 matrix of a dependent variable, X_{it} is the n-by-k matrix of an independent variable, β is the k-by-1 matrix of a coefficient that is estimated. Two different assumptions may be applied for α_i in a large proportion of empirical applications: fixed-effect and random-effect models (Johnston and DiNardo, 2007). In the fixed-effect (FE) model, α_i and γ_t can be correlated with the independent variables, but it is assumed that X_{it} is uncorrelated with the error term v_{it}. The attraction of the FE model is that it follows a consistent estimator (convergence in probability) (Cameron and Trivedi, 2009). The random-effect (RE) model assumes that α_i and γ_t is random, and it is not correlated with the independent variables.

Based on the Gauss-Markov theorem, if the errors have expectation zero, are uncorrelated, and have equal variance, the least-square estimators (OLS) has minimum variance in the class of linear unbiased estimators. It is called the best linear unbiased estimator, or BLUE (Johnston and DiNardo, 2007). Therefore, if we have these assumptions:

$$E\,(u|X) = 0 \qquad (7\text{-}2)$$

$$E\,(uu'|X) = \sigma^2\Omega \qquad (7\text{-}3)$$

In Eq. (7-2), the disturbances have conditional zero mean. In Eq. (7-3), $\Omega = I_n$ is an n-by-n identity matrix. It means that conditional on the X, the disturbances are independent and identically distributed with conditional variance σ^2 (Jackman, 2004) Then the ordinary least estimator $\hat{\beta}_{ols}$ = $(X'X)X'y$ with variance-covariance matrix $V(\hat{\beta}_{ols}) = \sigma^2(X'X)^{-1}$ is the best linear unbiased estimator (BLUE). If the assumption in Eq. (7-3) fails hold, the mentioned estimator for the parameters is unbiased, but it is not BLUE. According to Johnston and DiNardo (2007), Eq. (7-3) states that disturbances have homoscedasticity and are pair-wise uncorrelated. However, this condition is rarely satisfied in practice, so it is important to develop feasible generalized least square (FGLS) estimators, where unknown parameters are substituted by consistent estimates (Johnston and DiNardo, 2007).

It should be noted that when Eq. (7-3) holds, $\Omega = I_n$ and $\hat{\beta}_{GLS} = \hat{\beta}_{OLS}$. Considering that we usually do not have knowledge oft Ω, $\hat{\beta}_{GLS}$ is non-operational, and we have to utilize an FGLS estimator. FGLS estimators are calculated in three steps (Jackman, 2004):

1) OLS analysis to yield estimated residuals $\hat{u}$
2) Analysis of the $\hat{u}$ to form an estimate of Ω
3) Calculation of the FGLS estimator as $\hat{\beta}_{FGLS}=(X'\hat{\Omega}^{-1}X)^{-1}X'\hat{\Omega}^{-1}y$

FGLS is most commonly used estimator in dealing with residual autocorrelation and heteroscedasticity. Cochrane-Orcutt (1949) and Paris-Winsten (1954) established procedures for AR (1) disturbances yielding FGLS estimators. Applying FGLS to deal with heteroscedasticity has been mentioned in different econometric texts. For example, Judge et al. (1980, 128-145) and Amemiya (1985, 198-207) provided different rigorous treatments of FGLS estimators in this regard (Jackman, 2004).

7.2.2 Model specification

We specify and estimate our model based on Environmental Kuznets Curve (EKC). The Kuznets Curve was introduced for the first time by Simon Kuznets in 1955 in order to show the relationship between inequality in the distribution of income and levels of income (Kuznets, 1955). However, in the 1990s, the curve became an engine for studying the relationship between emissions and economic growth. The standard form of this function is defined as follows (Grossman and Krueger, 1991):

$$\ln (E/P)_{it} = \alpha_i + \beta_1 \ln (GDP/P)_{it} + \beta_2 (\ln(GDP/P))_{it}^2 + \varepsilon_{it} \qquad (7\text{-}4)$$

where E is urban air pollution, P is population, GDP is gross domestic product, and ln indicates natural logarithms. Several basic models have been estimated without additional independent variables (Grossman and Krueger, 1991; Shafik, 1992; Selden and Song, 1994). Many researchers have studied this model, using additional explanatory variables to evaluate the environmental effects of different factors. Panayotou (1993) examined the hypothesis of deforestation as a function of income per capita and population density as follows:

$$\ln (DEF) = \alpha_1 \ln INC + \alpha_2 \ln POP + \tfrac{1}{2} \alpha_{11} (\ln INC)^2 + \alpha_{12} (\ln INC)(\ln POP) + \tfrac{1}{2}\alpha_{22}(\ln POP)^2 \qquad (7\text{-}5)$$

Panayotou applied a translog formulation to allow for the effects of interaction between explanatory variables and the evaluation of elasticities.

Some researchers investigated the effects on environmental quality of literacy, political rights, and civil liberties (Torras and Boyce, 1998), output structure (Panayotou, 1997), and trade (Suri and Chapman, 1998). Choi et al. (2010) employed trade dependence, fossil consumption per capita, share of renewable energy, and time trend in an attempt to broaden the concept of EKC and evaluate the impact of these parameters on CO_2 emissions. Magnani (2000) used R&D expenditure as a proxy to measure the impact of environmental protection on pollution emissions and to analyze the EKC.

In this study, we evaluate the impact of renewable energy deployment, technological innovation and market regulation on carbon emission reduction. Similar to Panayotou (1993), our model is formulated in a translog function in order to investigate the interaction effects between variables and calculate elasticities. Our model also permits us to check the shape of the relationship between dependent variables and explanatory variables.

$$\ln Y_{it} = \alpha_0 + \Sigma_j\beta_j \ln X_{jit} + \Sigma_j\beta_{jj}\ln X^2_{jit} + \Sigma_i\Sigma_j\beta_{jk}\ln X_{jit}\ln X_{kit} + \alpha_t t + \alpha_{tt} t^2 + \Sigma_j\beta_{jt}\ln X_{jit} t + \varepsilon_{it} \quad (7\text{-}6)$$

where the variable Y represents the dependent variables defined as carbon emission per capita (CO_2/P), vector X represents independent variables, including gross domestic product per capita (GDP/P), share of electricity generated by renewable energy sources in total power generation (Ren/TPG), number of energy-related patents per million inhabitants (Pateng/P), number of ICT patents per inhabitant (Patict/P), environmental tax per capita (Evt/P), and t is a trend (Trd) representing the rate of technical change or shift in the CO2 function over time.

7.2.3 Analytical framework for variable selection

Considering the long lifetime of CO_2 in the atmosphere, stabilizing the concentration of greenhouse gases (GHGs) at any level depends on large reductions of worldwide CO_2 emissions from current levels (IEA, 2012a). Therefore, CO_2 emission reduction could be used as an index to evaluate climate change mitigation. In our model, CO_2 emission is considered a dependent variable, and it is defined as total carbon dioxide emissions caused by the consumption of energy. The explanatory variables are defined as follows:

1. ***Gross domestic product (GDP)***: As we discussed in chapter two, there is extensive literature about the relationship between economic growth in energy consumption. Consistent with the literature about the relationship between GDP and environmental pollution described in section 7.2.2, we considered GDP an explanatory variable in our model.

2. ***Renewable energy sources*****:** we used share of electricity produced by renewable energy sources (variable Ren) in total power generation (variable TPG) in our model which is in line with the literature on the effectiveness of

renewable energy sources in climate change mitigation (Sinha, 1995; Frankl et al., 1997; Schleisner, 2000; Lehner et al., 2005; Benitez et al., 2008; Saner et al., 2010) and the contribution of renewable energy in power generation as an effective parameter on carbon emission in (Choi et al., 2010). According to the U.S. Energy Information Administration, renewable energy sources include biomasses, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action (EIA, 2013).

3. ***Energy patent applications*****:** Innovation has responded to emission abatement expenditure over time (Lanjouw and Mody, 1996; Popp, 2003). Innovation could be done through building energy efficiency (Li and Colombier, 2009) or technological change in renewable energy capacity (Popp et al., 2011). Therefore, considering that technological innovation plays an important role in mitigating the effects of environmental problems, we added the number of energy technologies patents (variable Pateng) to our model. These are energy technology patent applications to the European Patent Office (EPO) for mitigation or adaption to climate change, including capture, storage, sequestration, or disposal GHGs, and the reduction of GHGs emissions related to energy generation, transmission, or distribution.

4. ***ICT patent applications*****:** Energy efficiency is a solution used to reduce carbon emissions. As we discussed in chapter three, different technologies could be used for this purpose, such as electric vehicles (Ford, 1995; Kempton and Letendre, 1997; Kempton and Tomic, 2005), virtual power plants (Pudjianto et al., 2007; Ruiz et al., 2008; Jansen et al., 2010), and smart meters (Hartway et al., 1999; Faruqui, 2007; Depuru et al., 2011).

Considering that patent applications for information and communication technology (ICT) play a crucial role in facilitating these technologies, we employed ICT patent (variable Patict) applications to the European Patent Office (EPO) as another kind of technological innovation in our model.

5. ***Environmental tax*****:** Environmental tax (Evt) is used in our model as a proxy for market regulation in order to evaluate its impact on carbon emission reduction. Nordic countries, such as Finland and Sweden, are in the forefront of taxing fuels because of environmental damage (Bhattacharyya, 2011). In line with the literature and based on the findings (Alfsen et al., 1995; Brännlund and Nordström, 2004; Galinato and Yodar, 2010) regarding the effectiveness of carbon tax policy on CO_2 emission reduction, we used environmental tax as an explanatory variable in our model. Total environmental taxes are for energy products (including fuel for transport), transport (excluding fuel for transport), pollution, and natural resources (excluding oil and gas). Based on Eurostat, CO_2 taxes are included under energy taxes instead of pollution taxes. The reason is that in many cases, CO_2 taxes are levied on the same tax base as energy is. Therefore, considering CO_2 taxes as a pollution tax instead of an energy tax would distort international comparisons.

6. ***Trend:*** Time trend represents the possibility that technological change causes effects or shifts in the environment function over time (Shafik and Bandyopadhyay, 1992; Cole et al., 1997; Luzzati and Orsini, 2009). It is expected that the CO2 function shifts downwards suggesting progress or reduction in CO_2 over time for given energy use and GDP production. Trend is included in the specifications of the model to allow for the possibility of technological change or shift in the CO_2 model over time. The time trend is generally taken into account as a proxy for technological effects (Shafik and Bandyopadhyay, 1992). The inclusion of trend squared allows testing for the nonlinearity of the shift or changes in CO_2 function, which is more realistic considering the amount of production and energy use. The coefficient shows the changes in the dependent variable holding constant the influence of the other variables. The coefficient could also reflect some unmeasured factors in trend, such as increasing productivity and efficiency, which may affect carbon dioxide emissions over time.

Fossil fuel energy is a major source of CO_2 emissions. However, this variable is not used to avoid the co-linearity problem. Considering that we have employed GDP in our model, the related effects could be captured through this variable. Fossil fuel is the major source of primary energy consumption in EU-15. According to British Petroleum Statistical Review of World Energy, more than 90 percent of the primary energy used in the EU-15 comes from non-renewable energy sources (BP, 2012). If fossil fuel consumption is used as an independent variable in our model, we may have co-linearity between GDP and fossil fuel consumption.

By applying the translog formulation, we can examine the interactions among these variables and their potential effects on policy making. For example, an increase in environmental compliance cost could lead to increases in the patenting of new environmental technologies (Jaffe and Palmer, 1997). Therefore, they could have an interaction effect on carbon emission reduction.

According to Stern (1998), the use of resources implies the production of waste. Therefore, the regressions that consider indicators that are allowed to become zero or negative are not estimated appropriately. We applied restriction by using a logarithmic dependent variable in order to comply with Stern's comment.

7.2.4 Hypotheses

We examined the effect of renewable energy development (chapter two), technological innovation (chapter three) and market regulation applied by governments (chapter five). We therefore define the following three hypotheses:

1) The power generated by renewable energy sources in the EU-15 has been able to affect carbon emission by displacing traditional capacity fueled by fossil fuels. We also expect negative elasticity for renewable energy sources regarding carbon emission.
2) Technological advances are able to decrease the costs of renewable energy technologies and energy efficiencies, thereby saving energy and reducing carbon emissions. Therefore, we expect a negative relation between technological innovation and carbon emission. Furthermore, we expect negative elasticity for technological innovation.
3) Environmental tax applied by governments has a direct negative relation to carbon emissions. The size of this parameter could

indicate its importance, compared with renewable energy development and technological innovation. We also expect a negative elasticity for environmental tax.

Elasticity is the measurement of how changing one variable affects carbon emissions per capita. This measurement enables policy makers to know the effectiveness of each policy, which helps them to make appropriate decisions to achieve targets set for carbon emission reduction.

7.2.5 Top-down vs. bottom-up approach

Technology-oriented studies use bottom-up engineering models, which are based on integration of data on the cost and performance of technology. Economic studies employ top-down models to analyze aggregate behavior according to economic indices and elasticities, and they focus on applying carbon tax to limit emissions (Grubb, 1993). As we discussed in chapter three, most researchers have used the bottom-up approach to show the potential of carbon saving obtained by different renewable energy technologies. These studies concluded that carbon emission reduction could be achieved by carbon saving. Previous research noted that differences between top-down versus bottom-up are less theoretical and relate to the level of aggregation to assumptions (Böhringer, 1998).

The bottom-up approach is applied by researchers to show the lower cost of carbon emission reduction compared with top-down estimates. Williges et al. (2010) examined the cost of a European fee-in tariff for the large-scale development of concentrated solar power. Their results were significantly lower than most current top-down estimates of achieving GHG- stabilizing scenarios. However, the bottom-up approach is applied in pure engineering, and it is not an appropriate model for policy making and market behavior. Some important parameters such as hidden cost, the cost of implementation measures, market imperfection and other economic barriers, and macro-economic relationships, are not included in these models (Grubb et al., 1993).

Because this study evaluates the effects of renewable energy development, technological innovation, and market regulation on carbon emission reduction in addition to the effects of their interactions, the top-down approach is appropriate. It should noted that the bottom-up approach could be applied in the selection of competitive renewable energy technology when a proper policy has been made. In other word, a combination of the top-down and the bottom-up approach is required to achieve targets for carbon emission reduction. Governmental commitment to fostering renewable energy sources, with a combination of bottom-up and top-down approaches, was the key of initial success in Denmark (Lipp, 2007).

7.3 Model estimation

In this section, we compare our proposed model with two other forms of function formulation and evaluate it by testing the functional form, model specification, and share of significance of the parameters. We then analyze the results and parameters. Finally, we present the conclusion and policy recommendations.

7.3.1 Data

In this research, we investigate the effects of renewable energy development, technological innovation, and market regulation on carbon emission reduction in the EU-15 countries, which include Austria, Belgium, Germany, Denmark, Spain, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Sweden, and the UK. We selected these countries because they are at the forefront of renewable energy development and applied market regulation to mitigate climate change. In 1990, Finland was the first country to apply a carbon tax, followed by Norway, Sweden and Denmark in 1992 (Bhattacharyya, 2011).· Germany's renewable sector is considered the most innovative and successful in the world. Since starting negotiations about climate change in 1991, the EU has provided leadership in global climate policy (Oberthür and Kelly, 2008).

These countries are studied during the period from 1995 to 2011. Because the impact of the financial crisis began in 2008, it has been included in the model. We used different sources to obtain information for our model. The data on carbon emission, total power generation, and electricity produced by renewable energy sources was obtained from the US Energy Information Administration (EIA, 2013) database. The information related to environmental tax and the number of patent applications in energy technology and ICT was derived from the European Commission database (Eurostat).

Population sizes were extracted from the World Bank database. Table (7-1) shows the summary, definition and source of data for all variables, including: CO_2/P (cdecap), GDP/P (gdpcap), Ren/TPG (regenp), Pateng/P (ptgcap), Patict/P (pticap), Evt/P (evtcap), and trend.

Because the variables are measured in different units, the continuous variables are transformed to logarithmic form. Therefore, the coefficients are interpreted based on the percentage of change. Regarding the unit measured for the variables, the same unit was been used for the explanatory variables. GDP per capita and environmental tax per capita were measured by a constant US dollar (2005). They were normalized by the deflator index. The measurement of the energy patents and ICT technologies are based on the number of patents per million inhabitants.

Table (7-1): Variable summary, definition and source

Variable	Definition	Source
CDECAP	Carbon dioxide emissions per capita made by fossil fuels burning and the cement manufacturers. Carbon dioxide made by consumption of solid, liquid, and gas fuels and gas flaring are included (metric ton per capita).	WB
REGENP	Share of electricity produced by renewable energy sources (include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action) in total power generation (percent).	EIA
GDPCAP	Gross Domestic Product per capita based on 2005 constant dollar (1000 USD per capita).	WB
PTGCAP	Number of patents in energy technologies or applications for mitigation or adaptation against climate change per million inhabitants	Eurostat
PTICAP	Number of patents in information and communication technology (ICT) per million inhabitants	Eurostat
EVTCAP	Total environmental tax per capita based on 2005 constant dollar, including: energy products, transport and pollution (1000 USD per capita).	Eurostat
TREND	Time trend	

Table (7-2) displays the correlation matrix or covariance matrix for the variables presented in table (7-1). We constructed this table in order to check the existence of correlations between variables. If a variable shows a high correlation and is significant for other variable, it should be omitted in order to avoid co-linearity. As the covariance matrix shows, no significant correlation was found between variables.

Table (7-2): Correlation matrix between variables

	CDECAP	GDPCAP	REGENP	PTGCAP	PTICAP	EVTCAP	TREND
CDECAP	1.0000						
GDPCAP	0.7085 (0.0000)	1.0000					
REGENP	0.0.640 (0.3233)	0.1642 (0.0109)	1.0000				
PTGCAP	0.1441 (0.0256)	0.4685 (0.0000)	0.0715 (0.2699)	1.0000			
PTICAP	0.0516 (0.4260)	0.0843 (0.1933)	-0.1138 (0.0785)	0.1087 (0.0931)	1.0000		
EVTCAP	0.1798 (0.0052)	0.2749 (0.0000)	-0.0876 (0.1763)	0.3829 (0.0000)	0.0934 (0.1492)	1.0000	
TREND	0.0017 (0.9796)	0.3479 (0.0000)	-0.0661 (0.3079)	0.3472 (0.0000)	0.0283 (0.6623)	0.1517 (0.0187)	1.0000

The second line of each variable presents the p-values of correlation coefficients and significant coefficients at the level of 5 percent. The coefficient for some correlations is not significant. The sign for some coefficients such as CO_2 emission per capita-gross domestic production per capita (cde-gdpcap), environmental tax per capita-number of energy patent per million inhabitants (evtcap-ptgcap), trend-gdpcap, and environmental tax per capita-gross domestic production per capita (evtcap-gdpcap), are as expected. However, others, such as carbon dioxide emission-energy patent (cde-ptg) and CO_2 emission per capita-environmental tax per capita (cdecap-evtcap), are not as expected. We should consider that correlation matrix presents the unconditional relation between variables. This means that the sign and significance situation could change when they are studied with the other variables (conditional). Moreover, the covariance matrix examines the correlation between general trends of every pair of variables. If they show an increasing trend simultaneously, the result will be a positive correlation coefficient.

A Fisher-type test was applied to check the stationarity of all variables. In the context of panel data, the Fisher-type test performs a unit root test for each panel individually and then combines the p-values from these tests to obtain an overall test to identify whether the panel series contains a unit root. The null hypothesis tested by the Fisher-type test is that all panels contain a unit root. For a finite number of panels, the alternative hypothesis is that at least one panel has stationarity.

Table (7-3) shows the results for Fisher-type unit root test for all panels, based on augmented Dickey-Fuller tests. All tests rejected the null hypothesis and it is detected that all panels are stationary.

Table (7-3): Fisher-type unit-root test result

Variable	Inverse chi-squared	Inverse normal	Inverse logit t(79)	Modified inv. Chi-squared
LCDECAP	102.4375	-6.9248	-7.1988	9.3516
LGDPCAP	121.3020	-7.2424	-8.4251	11.7870
LPTGCAP	154.5430	-9.4482	-11.0220	16.0784
LPTICAP	108.2611	-6.3102	-7.1981	10.1035
LEVTCAP	101.8071	-6.5370	-7.0435	9.2703
LREGENP	79.0775	-5.0988	-5.2345	6.3359
LGDPCAP2	116.7426	-7.0275	-8.0665	11.1984

Variable	Inverse chi-squared	Inverse normal	Inverse logit t(79)	Modified inv. Chi-squared
LREGENP2	60.1541	-3.3450	-3.3837	3.8929
LPTGCAP2	130.8208	-8.4524	-9.3066	13.0159
LPTICAP2	103.8467	-5.6432	-6.5478	9.5336
LEVTCAP2	63.0009	-4.0403	-4.0083	4.2604
GDPRENP	87.7950	-5.7567	-5.9721	7.4613
GDPPTIP	109.2815	-6.1472	-7.0694	10.2352
GDPENGP	154.4527	-9.4641	-11.0214	16.0668
GDPEVTP	93.2944	-5.7185	-6.2946	8.1713
RENPTGP	152.1289	-9.3607	-10.8274	15.7668
RENPTIP	63.3171	-3.4676	-3.5652	4.3012
RENEVTP	74.5212	-4.5670	-4.8312	5.7477
PTGPTIP	147.9147	-9.2704	-10.5574	15.2227
PTGEVTP	93.9943	-6.4550	-6.5826	8.2616

7.3.2 Model specification and testing functional form

As previously mentioned, the standard form of Environmental Kuznets Curve is defined as Eq. (7-4). In order to evaluate the impact of renewable energy deployment, technological innovation in energy applications adopted with climate change mitigation and ICTs, we include the additional variables related to these parameters and test the functional form by comparing it with two quadratic equations in the form of the log-linear function as follows:

Model one:

$$\ln (CO_2/P)_{it} = \alpha_i + \beta_1 \ln(GDP/P)_{it} + \beta_2 (\ln(GDP/P))_{it}^2 + \varepsilon_{it} \qquad (7\text{-}4)$$

Model two:

$$\ln Y_{it} = \alpha_0 + \Sigma_j \beta_j \ln X_{jit} + \Sigma_j \beta_{jj} \ln X^2_{jit} + \alpha_t t + \alpha_{tt} t^2 + \varepsilon_{it} \quad (7\text{-}7)$$

These functions are frequently used by researchers. The translog function has become more popular because it provides more flexibility (Corbo and Meller, 1979).

We employed the Likelihood Ratio (LR) test to select the best functional form. The likelihood ratio is defined as follows (Johnston and DiNardo, 2007):

$$\lambda = \frac{L(\beta\tilde{},\sigma\tilde{}2)}{L(\beta\hat{},\sigma\hat{}2)}$$

where the result value of $L(\beta\hat{},\ \sigma\hat{}2)$ is the unrestricted maximum likelihood, and $L(\beta\tilde{},\ \sigma\tilde{}2)$ is related to restricted function. We estimated these models and derived the log-likelihood value in order to calculate the LR test for each functional form. It was expected that the null hypothesis would be rejected if λ were small. The LR test could be calculated as follows:

$$LR = -2 \ln \lambda = 2\ [\ln L(\beta\hat{},\sigma^{\hat{}2}) - \ln L(\beta\tilde{},\sigma^{\tilde{}2})] \sim \chi^2_{(q)} \quad (7\text{-}8)$$

The results of the LR test for all three functions are presented in table (7-4), which shows that the translog functional form (Model 3) is an appropriate equation to estimate among the different forms of functions.

Table (7-4): LR test for functional form

Function	LR test	Critical value	Result
Model 3 vs. Model 1	340.00976	14.611	Model 3 accepted
Model 2 vs. Model 1	221.13196	3.94	Model 2 accepted
Model 3 vs. Model 2	118.8778	1.145	Model 3 accepted

We employed the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) to compare the functions for model specification. The AIC and BIC are two popular statistical measures to compare models. They are defined as follows:

$$AIC = -2 * \ln(likelihood) + 2 * k \quad (7\text{-}9)$$

$$BIC = -2 * \ln(likelihood) + \ln(N) * k \quad (7\text{-}10)$$

where k is the number of parameters estimated and N is the number of observations. AIC and BIC are measures that combine fit and complexity. Fit is measured negatively by -2 * ln(likelihood); the larger the value, the worse the fit. Complexity is measured positively, either by 2 * k for AIC or ln(N) * k for BIC. Because the two models fit on the same data, the model with the smaller value of information criterion is considered better (Stata Base Reference Manual, 2012). The results of AIC and BIC for comparing models are presented in table (7-5).

Table (7-5): Model specification test

Model	Obs.	LL(model)	df	AIC	BIC
Model 1	240	45.30512	18	-54.61025	8.041252
Model 2	240	155.8711	28	-255.7423	-158.2844
Model 3 (TL)	240	215.31	43	-344.62**	-194.9525**

Based on the results, the model specified by the translog function (model 3) is selected because it has the smallest value in both AIC and BIC measurements.

7.3.3 Estimation method, testing and selection of final method

This model is usually estimated using panel data. Most studies have estimated both fixed effects and random effect models. As previously mentioned Eq. (7-1), the fixed effects model assumes that α_i and γ_t are correlated with explanatory variables but they are considered error components in the random effects model. The least-squares dummy variable (LSDV) is then applied to estimate the fixed model. In the case of the random effects model, the residuals form and the OLS are used to construct a variance-covariance matrix in order to estimate the model by the generalized least squares (GLS) technique. If a correlation is found between α_i, γ_t and the explanatory variables, the random effects model is inconsistent, and only the fixed effects model can estimate the regression consistently (Mundlak, 1978; Hsiao, 2003). A Hausman (1978) test was used to compare the fixed effects and random effects models to measure consistency. With the assumption that no other statistical problem exists, the fixed effect model is estimated consistently.

Our estimation method differs from most studies because it uses Feasible Generalized Least Squares (FGLS) to correct for heteroscedasticity and autocorrelation. Although sources of serious problems are heteroscedasticity and autocorrelation in residuals, no of early studies presented diagnostic tests of models. Stern et al. (1996) identified that the heteroscedasticity problem is important when we concerned with cross-sectionals of grouped data. Many researchers (Cropper and Griffiths, 1994; Shafik, 1994; Westbrook, 1995; Horvath, 1997; Moomaw and Unruh, 1997; Suri and Chapman, 1997) estimated fixed effect models without presenting regression diagnostic tests. Stern (2002) estimated a decomposition EKC using a FGLS model. Suri and Chapman (1998), Aldy (2005), and Luzzati and Orsini (2005) obtained results employing the FGLS approach in order to correct cross-sectional heteroscedasticity and serial correlation.

Based on the literature, correlation and heteroscedasticity in panel-data models will cause the results achieved by the models to be biased and less efficient. We therefore need to check these problems in our model. Stata (Stata Quick Reference and Index, 2012) implements a test for serial correlation in the idiosyncratic errors of a linear panel-data model discussed by Wooldridge (2002). Drukker (2003) presented simulation evidence that this test has good size and power properties in a reasonable sample size. When we applied the Wooldridge test for serial correlation, the null hypothesis of no first-order autocorrelation was rejected. The result is presented in table (7-6). As the table shows, the computed value for the F test (33.107) exceeds the critical F value obtained from the F table at the chosen level of significance (or the probability value).

Table (7-6): Serial correlation test result

Wooldridge test for autocorrelation in panel data
H0: no first-order autocorrelation
F(1,14) = 33.107
Prob > F = 0.0000

This test provides an important alternative to Wald testing for models by maximum likelihood. Because Wald testing requires fitting only one model (the unrestricted model), it is computationally more attractive than likelihood-ratio testing. Hence, it is used whenever feasible because the null-distribution of the LR test statistics is often more closely chi-squared distributed than the Wald test statistics are (Stata Quick Reference and Index, 2012).

Since iterated GLS with only heteroscedasticity generates the maximum likelihood parameter, we are able to calculate an LR test by comparing the estimation of a model fitted with panel-level heteroscedasticity and a model without heteroscedasticity. Based on the result, the null hypothesis is rejected. Therefore, the presence of heteroscedasticity is detected, as shown in table (7-7). The computed value for LR test (152.13) exceeds the critical chi-square value obtained from the F-table at the chosen level of significance (or the probability value).

Table (7-7): Heteroscedasticity test result

Likelihood-ratio test
Assumption: homosc nested in hetero
LR chi2 (14) = 152.13
Prob > F = 0.0000

Thus, in the presence of heteroscedasticity and serial autocorrelation, we applied FGLS to estimate our model. It is asymptotically more efficient than OLS and other estimators (Wooldridge, 2002).

7.3.4 Estimation result

The results of our estimation are as follows. The share of coefficients, which were estimated with a high significance percentage ($p < 0.001$), is greater than 60 percent. If we consider a general significance of 0.05, it will be more than 70 percent. The variables are as follows: carbon dioxide per capita (cdecap), GDP per capita (gdpcap), and contribution of renewable energy sources in total power generation (regenp), number of energy patents per million inhabitants (ptgcap), number of ICT patents per million inhabitants (pticap), environmental tax per capita (evtcap), and trend. All variables have been considered logarithmic values. The signs related to renewable energy generation, energy patents, and environmental tax are negative, as we expected. The sign for the linear and square of energy patents is negative, but the second one is not significant.

Considering the negative sign for the first order of GDP and positive sign for the second order, the relation between CO_2 emissions and GDP shows a convex curve for the EU-15 countries (Figure 7-1). Regarding GDP, our result contrasts with early studies focused on the Environmental Kuznets Curve, which argued for the inverted U-shaped curve relationship between emission per capita and GDP per capita in developed countries. According to the literature, the relationship between environmental quality, level of income, and other variables was tested and analyzed by several researchers (Shafik, 1992; Panayotou, 1993,1997; Selden and Song, 1994; Torras and Boyce, 1998; Suri and Chapman, 1998). Based on their findings, there may be willingness to accept a weak level of environmental quality in the early stage of development, but a turning point will be achieved as the level of income increases.

Table (7-8): Generalized least squares estimation result

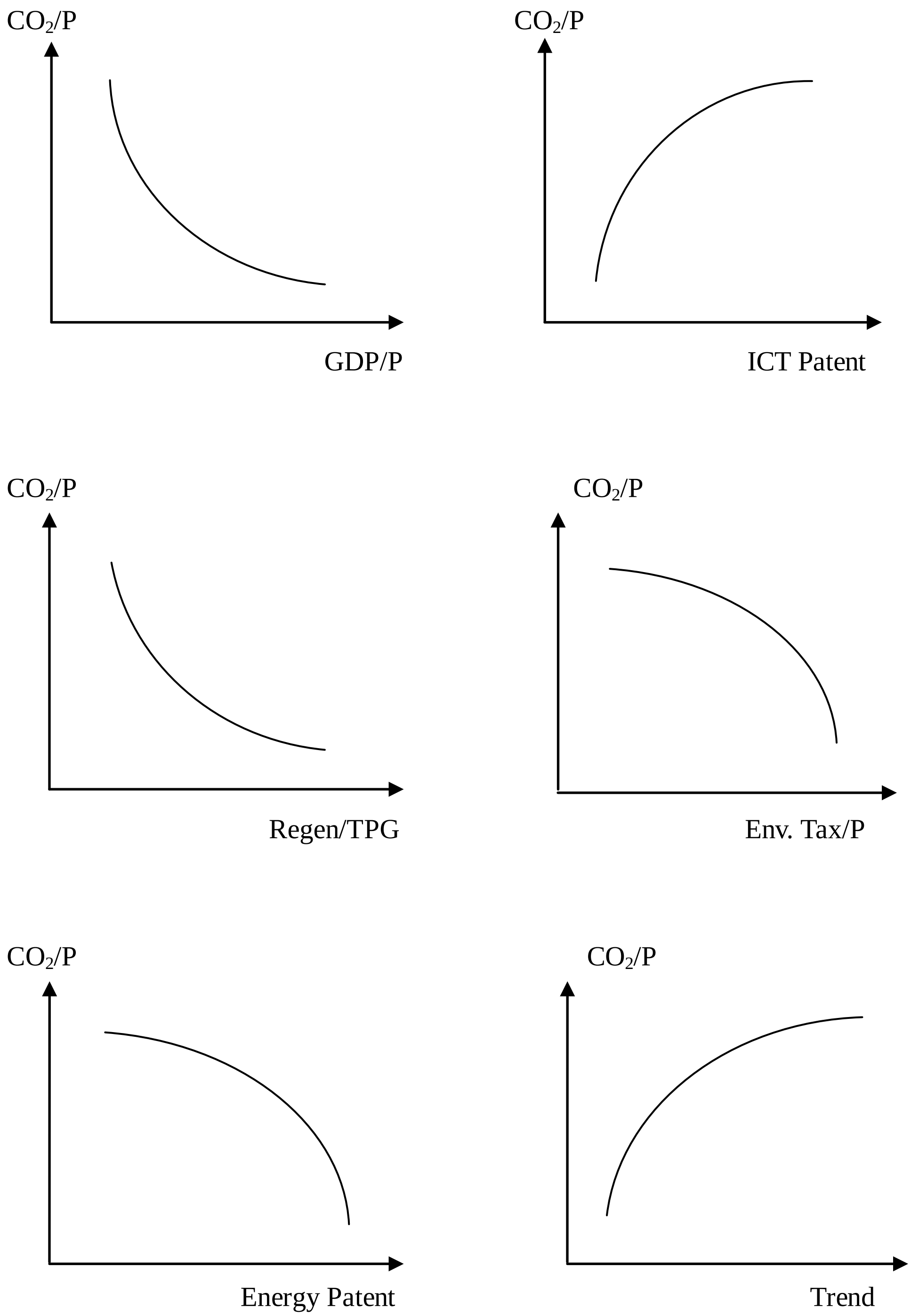
Variables	Model 1		Model 2		Model 3	
	Coeff.	P>|z|	Coeff.	P>|z|	Coeff.	P>|z|
LnGDP/P	-1.14808	0.000	-2.01421	0.000	-0.32725	0.328
(LnGDP/P)^2	0.20777	0.000	0.32874	0.000	0.28970	0.000
LnRen/TPG			-0.02128	0.102	-0.26618	0.001
(LnRen/TPG)^2			0.02103	0.000	0.04580	0.000
LnPateng/P			-0.01032	0.000	-0.40697	0.000
(LnPateng/P)^2			-0.00307	0.003	-0.00321	0.191
LnPatict/P			0.02531	0.000	1.03926	0.000
(LnPatict/P)^2			-0.00542	0.000	-0.00114	0.409
LnEvt/P			0.12302	0.000	-1.83548	0.000
(LnEvt/P)^2			-0.04155	0.000	-0.17791	0.000
Trend			0.03569	0.000	0.18498	0.000
Trend^2			-0.00248	0.000	-0.00192	0.000
(LnGDP/P)(LnRen/TPG)					0.09861	0.000
(LnGDP/P)(LnPateng/P)					0.10013	0.000
(LnGDP/P)(LnPatict/P)					-0.28603	0.000
(LnGDP/P)(LnEvt/P)					0.37623	0.000
(LnGDP/P)Trend					-0.04738	0.000
(LnRen/TPG)(LnPateng/P)					-0.00773	0.039
(LnRen/TPG)(LnPatict/P)					0.00437	0.262
(LnRen/TPG)(LnEvt/P)					-0.01784	0.389
(LnRen/TPG)Trend					-0.00917	0.000
(LnPateng/P)(LnPatict/P)					0.00372	0.255
(LnPateng/P)(LnEvt/P)					-0.09005	0.000
(LnPateng/P)Trend					0.00089	0.231
(LnPatict/P)(LnEvt/P)					0.19941	0.000
(LnPatict/P)Trend					-0.00236	0.002
(LnEvt/P)Trend					0.02046	0.000
Const.	3.67216	0.000	5.05640	0.000	-0.30706	0.625
Number of obs	240		240		240	
Number of groups	15		15		15	
Time periods	16		16		16	
Wald chi2	516.71		1389.29		2549.14	
Prob > chi2	0.0000		0.0000		0.0000	

Considering the negative sign for the first order of GDP and positive sign for the second order, the relation between CO2 emissions and GDP shows a convex curve for the EU-15 countries (Figure 7-1). Regarding GDP, our result contrasts with early studies focused on the Environmental Kuznets Curve, which argued for the inverted U-shaped curve relationship between emission per capita and GDP per capita in developed countries. According to the literature, the relationship between environmental quality, level of income, and other variables was tested and analyzed by several researchers (Shafik, 1992; Panayotou, 1993,1997; Selden and Song, 1994; Torras and Boyce, 1998; Suri and Chapman, 1998). Based on their findings, there may be willingness to accept a weak level of environmental quality in the early stage of development, but a turning point will be achieved as the level of income increases.

However, this concept was challenged recently by researchers, such as Harbaugh et al. (2002) and Millimet et al. (2003). Wagner (2008) claimed that the evidence of an inverted U-shaped relationship between carbon emission and GDP obtained with commonly used methods is entirely spurious because of several major econometric problems. In line with this approach, we cast doubt on the results achieved by previous researchers because they cannot be confirmed based on our findings. As Dasgupta et al. (2004) pointed out, the less robust relationship between GDP and CO_2 emissions caused some econometric critiques; therefore, this relationship is not rigid as found by previous researchers. Moreover, the role of GDP growth in CO_2 emission reduction could be affected by the governance related explanatory variables.

Figure (7-1), shows an increase in decreasing rate of CO_2 emissions in relation to the variables of energy patents and environmental tax. Furthermore, considering that we estimated our model from 1995 to 2010, and the financial crisis occurred within this period, the EU countries had to reduce expenditures for renewable energy, and coal-fueled power plants restarted operations because of the lower unit cost compared with imported crude oil and natural gas. In addition, the recession in the early 2000s should be taken into account. It was a downtrend in economic activity, which mainly happened in developed countries. The EU was affected by this recession from 2000 to 2002. Therefore, all indicators, including GDP, number of patents, taxes, and CO_2 emissions could be affected by the recession in the early 2000s and the financial crisis from 2008 to 2009.

Figure (7-1): The relationship between explanatory variables and CO_2 emission



The relationship between variables and CO_2 emissions per capita is presented in Figure (7-1). The figure shows a concave formation between carbon emissions per capita (CDECAP) with GDP per capita (GDPCAP) and the share of renewable energy sources in total power generation (REGENP). It defines a decrease in the decreasing rate of carbon emissions regarding GDP and renewable energy in the EU-15. The results also showed a convex formation between carbon emissions per capita (CDECAP), the number of ICT patents per million inhabitants (PTICAP), and technological change over time (TREND). Therefore, the results showed a decrease in the increasing rate of carbon emissions in relation to ICT patents and technological change over time. Furthermore, there is a convex formation between carbon emission per capita (CDECAP), energy patent applications per million inhabitants (PTGCAP), and environmental tax per capita (EVTCAP). The results showed an increase in the decreasing rate of carbon emissions in relation to the variables of energy patents and environmental tax.

ICT patents showed relevant positive and negative effects on CO_2 emissions in different ways: the positive effects were increased electronic wastes, and the negative effects were improved energy efficiency. The impact of ICT on emissions was closely related to energy consumption (Hilty et al., 2006). The main increase in effects was caused by freight transport and ICT's demand for electricity in manufacturing and the disposal of hardware. Energy saving is made by virtual goods, whereas ICT-supported management and ICT-supported the control of the production process. Regarding the relationship between ICT patents and CO_2 emissions, the results showed higher ICT growth with lower emission increases over time. Our findings are consistent with Romm et al. (2002), which argued that recent reductions in energy intensity were related to IT growth because they were less energy intensive and increased efficiency in every other sectors of the economy.

The results showed that carbon emission is reduced through power generated by renewable energy sources. The impact of renewable energy deployment on carbon emission reduction was discussed in chapter three. As previously mentioned, there is extensive literature regarding the potential of carbon saving using renewable energy technologies. However, the reductions made by renewable energy enhancement have been decreased from 1995 to 2010 in the EU-15. The employment trend in renewable energy has been affected worldwide by global recession, policy changes, and overcapacities in the wind and solar supply chains (Martinot and Sawin, 2012). Therefore, the decreasing rates in the effectiveness of renewable energy could be explained by the reduction in the growth rate of renewable energy deployment.

Based on our findings, the impact of environmental tax on carbon emission has increased over time. This is consistent with the results obtained by Alfsen et al. (1995) regarding the sizable effects of carbon tax on emissions in Western Europe. They indicated that external benefits, such as reduction in health damage, damage to nature, and road traffic, are associated with carbon and energy taxes. Our findings are also consistent with Brännlund and Nordström (2004), who studied the effects of CO_2 tax in Sweden. They found that demand for all fossil fuel-related goods was decreasing because of the CO_2 tax.

As shown in figure (7-1), the number of patents of energy technology for mitigation or adaptation to climate change had a similar impact on carbon emission compared with environmental tax. This is consistent with Popp (2001, 2005), who argued that it is important to consider the role of technological innovation in considering solutions to long-term environmental problems, such as energy consumption and climate change. Furthermore, according to Nordhaus (2002), it is expected that induced innovation would lead to a reduction in carbon intensity, and the cumulative effect might be larger in the long term.

Time trend showed a decreasing in increasing rate of carbon emission per capita. It indicated that the growth rate of carbon emission is reduced over time. The amount of CO_2 is increasing; because the amount of production and consumption is increasing. However, the rate is decreasing because of the effects of technological change, productivity, and efficiency. This finding is consistent with Popp (2005) regarding the gradual process of the diffusion and adoption of new technologies. It is also consistent with the implications of energy efficiency technologies for climate policy, as discussed by Jaffe et al. (2001, 2003).

An alternative model was estimated, using environmental tax divided by fossil fuel consumption as a proxy for tax rate. The results showed that the coefficients for ICT patents were positive, which is not acceptable because it indicates that the impact of ICT technologies on CO_2 emissions is positive and it is increasing. Furthermore, the results of the environmental tax rate based on fossil fuel consumption showed that its marginal effectiveness is decreasing with increases in the ratio of environmental tax to fossil fuel consumption, which is not reasonable because this is considered an inelastic parameter. Energy consumption will be more sensitive to environmental tax when it passes a certain level. The result is shown in table B-1 in the Appendix.

A normalized model with the mean of variables was also tested. The results showing impact of renewable energy generation and environmental tax were not acceptable. Based on the estimation, there is an increasing rate of carbon emission when the power generated by renewable energy sources increases. Carbon emissions increases at a decreasing rate when environmental tax increases. This result is presented in table A-1 in the Appendix.

7.3.5 Elasticities

Although the parameters in the translog function do not have an interpretation, they show the formation of a relationship between dependent variables and explanatory variables. Considering that our model was estimated in logarithmic form, we can calculate the elasticity of carbon emission to GDP, renewable energy generation and environmental tax. These elasticities measure the percentage change in emissions caused by a percent change in each variable. Based on Eq. (7-6), the formula used to calculate elasticities is as follows:

$$E_j = \delta \ln Y_{it}/\delta \ln X_{jit} = \beta_j + \sum \beta_{jk} X_{kit} + \beta_{jt} t \qquad (7\text{-}11)$$

Based on the results, the elasticity of carbon emission for EU-15 countries over the period of 1995-2010 is calculated as 0.238, -0.165, and 0.267 for GDP, renewable energy generation, and environmental tax, respectively.

The results showed that the elasticity for each variable is affected by the other variables because of the interactive relationship between parameters. Therefore, elasticity is positive for environmental tax, whereas its coefficient is negative and strongly significant in our model. Generally, we face this situation when the translog function is applied. If model one is employed to estimate the model, we could have expected a sign for the variables. However, this did not occurred in the translog function because of the interaction relationship between the explanatory variables. The advantage of the translog function, compared with the other models, is its ability to evaluate these interactions.

In addition to interaction effects, the positive sign of environmental tax could be explained by the level of tax and its impact on consumer revenue. The EU-15 countries are considered developed countries, and their GDP per capita is relatively high. Therefore, the tax rate should be high enough to cause a sensitive reduction in energy consumption. This finding is consistent with Pearce (1991), who showed that a reduction in carbon emission may not be achieved unless the related elasticities are known with acceptable certainty. Moreover, Howarth (2006) pointed out that private consumption generates negative externality by increasing the standard of living. Hence, we can argue that environmental tax has a negative effect on carbon emission indirectly by making an incentive to enhance renewable energy development or create technological innovation, Tax revenues could cause an increase in household energy consumption through the revenue recycling effect, in which revenues are used to reduce the tax rate on income or provide increased transfer payments to households. .

7.3.6 Technological change

Regarding the elasticity of CO_2 emissions in relation to energy patent applications, the results showed that ICT patents and trends were -0.0249, 0.005, and -0.002 respectively. Our findings are consistent with the literature regarding the links between environmental regulation, innovation and technological change (Lanjouw and Mody 1996; Buonanno et al., 2003; Popp, 2006). The elasticities showed that energy patent applications that adopted climate change mitigation caused a reduction of 0.02 percent in carbon emissions per capita for an increase of 1.0 percent in the number of patents per one million inhabitants. Elasticity for trend, assumed as technological change, implies a negative, small impact on carbon emissions. The elasticity of ICT patents was positive and small, around 0.01, which can be considered an effective parameter in climate change mitigation. This result is consistent with Fuchs (2008), and confirms that ICT sector emits less CO_2 than the total economy. Fuchs indicated that the ICT sector constitutes a small portion of total value added and the most dominant economic activity in modern industrialized economies is fossil fuel combustion. The elasticities, as we will see in next section, confirm this viewpoint, and the numbers vary across the countries in the EU-15.

7.3.7 Variations in elasticities over time

The variation in elasticities of CO_2 emissions per capita in the EU-15 countries over time are presented in table (7-9). The time trend shows that effectiveness of renewable energy generation, innovation, and technological change on carbon emission reduction has improved steadily. There is a negative elasticity for GDP from 2001 to 2002, which could be explained by the recessions in Europe in the early 2000s.

The results showed that the elasticity of carbon emission per capita for tax has an upward trend, which is consistent with previous comments about the effects of environmental tax, interaction, and revenue recycling. The general trend of elasticities for renewable energy, energy patents, ICT patents, and trend steadily shows increased effectiveness in climate change mitigation. The elasticities of two alternative models were calculated, and the results are presented in the Appendix. In both models, the sign of environmental tax elasticity is negative. However, the sign of renewable energy is positive in the normalized model.

Table (7-9): CO_2 elasticities in the EU-15 countries over 1995-2010

	GDP	Regenp	Ptgcap	Pticap	Evtcap	Trend
1995	0.6171	-0.1133	-0.0173	0.0010	0.0740	0.0284
1996	0.5471	-0.1220	-0.0204	0.0077	0.1045	0.0251
1997	0.3783	-0.1300	-0.0226	0.0160	0.1530	0.0225
1998	0.3058	-0.1301	-0.0241	0.0190	0.1997	0.0178
1999	0.1929	-0.1443	-0.0244	0.0214	0.2539	0.0146
2000	0.0436	-0.1569	-0.0234	0.0219	0.2779	0.0122
2001	-0.0370	-0.1697	-0.0243	0.0241	0.3014	0.0092
2002	-0.0195	-0.1920	-0.0237	0.0214	0.3074	0.0062
2003	0.1044	-0.1845	-0.0235	0.0083	0.3322	-0.0025
2004	0.2021	-0.1784	-0.0258	0.0025	0.3301	-0.0095
2005	0.1798	-0.1850	-0.0269	0.0010	0.3396	-0.0139
2006	0.2031	-0.1854	-0.0281	-0.0043	0.3320	-0.0195
2007	0.3039	-0.1830	-0.0272	-0.0165	0.3267	-0.0265
2008	0.3250	-0.1794	-0.0274	-0.0224	0.3337	-0.0325
2009	0.2090	-0.1906	-0.0303	-0.0107	0.3233	-0.0335
2010	0.2558	-0.1920	-0.0286	-0.0063	0.2792	-0.0356
Mean	0.2382	-0.1648	-0.0249	0.0053	0.2668	-0.0023
Std dev	0.1793	0.0277	0.0033	0.0147	0.0869	0.0223

7.3.8 Variation by country

Table (7-10) presents the elasticities of CO_2 emission per capita to GDP per capita, share of electricity generated by renewable energy, energy patents application per one million inhabitants, ICT patents per one million inhabitants, environmental tax per capita, and trend in the EU-15 from 1995 to 2010 by country. The elasticities vary across countries, which can be explained by different demography, geography, economic structure, and policies of the member countries.

Table (7-10): CO_2 elasticities in the EU-15 by country

	GDP	Regenp	Ptgcap	Pticap	Evtcap	Trend
Austria	0.3186	-0.0187	-0.0178	-0.0373	0.3358	-0.0228
Belgium	-0.1164	-0.3010	0.0187	-0.0697	0.4787	0.0042
Germany	0.8316	-0.2425	-0.2009	0.3898	-0.3302	0.0389
Denmark	0.7046	-0.1485	-0.0666	0.0620	0.0807	-0.0032
Spain	0.1419	-0.1556	0.0161	-0.0659	0.1926	-0.0033
Finland	-0.0791	-0.0948	-0.0275	0.0048	0.5251	-0.0127
France	-0.0662	-0.1719	0.0119	-0.0721	0.4778	-0.0092
Greece	0.2423	-0.2387	-0.0001	-0.0090	-0.0552	0.0150
Ireland	0.2294	-0.2107	0.0123	-0.0728	0.4247	-0.0066
Italy	0.2449	-0.1474	-0.0217	0.0054	0.1975	-0.0014
Luxembourg	1.0530	-0.0381	-0.0156	-0.0822	0.2663	-0.0322
Netherlands	0.0437	-0.2401	-0.0327	0.0270	0.4054	0.0041
Portugal	0.4437	-0.1417	-0.0286	0.0463	-0.2309	0.0122
Sweden	0.1644	-0.0433	-0.0281	-0.0128	0.4528	-0.0205
UK	-0.5830	-0.2787	0.0075	-0.0346	0.7806	0.0023
Mean	0.2382	-0.1648	-0.0249	0.0053	0.2668	-0.0023
Std dev	0.4078	0.0883	0.0541	0.1158	0.2996	0.0172

7.4 Policy implication for developing countries

Our findings could be used by countries that attempt to develop eco-cities, such as Dongtan City in China and Masdar City in the UAE. Masdar City is supposed to rely entirely on solar energy and other renewable energy sources.

Because of the wide range of strategies in different countries, which we have already analyzed, there is a good opportunity for the UAE government to take advantage of our findings to formulate policies to promote renewable energy in Masdar City. It is possible for the government to apply efficient energy policies at the starting point. The buildings of Masdar City are going to utilize energy-efficient construction material (Premalatha et al., 2013). Targets must be set and policies should be formulated to achieve these targets. For example, although European countries applied FIT policies to develop renewable energy sources, they are now trying to build a harmonized market for renewable energy. However, FIT is not an appropriate policy for this purpose.

Al-Amir and Abu-Hijleh (2013) investigated the strategies used in different countries in order to determinate the best practical policy to apply in the UAE. As we pointed out, it is necessary to consider the effects of different variables on carbon emission reduction and the effects of their interactions. In other words, we should use a top-down approach to design a policy for climate change mitigation. We can then apply a bottom-up approach to select competitive technology in order to achieve the target. According to Al-Amir and Abu-Hijleh, a combination of FIT, RPS, and tax incentive policies should be applied by the government. Based on our findings, all elasticities should be known and reliable in order to formulate an effective policy. As already analyzed, a tax policy will be not effective if it does not set taxes high enough to provide incentives to eliminate fossil-fuels products.

Masdar City has an advantage that differentiates from other eco-cities. It has the potential to establish the first market for trading renewable energy, which we discussed in chapter six. Partial trading has been applied already in Dubai, and traders are familiar with this mechanism. Therefore, a similar mechanism could be applied to trading commoditized renewable energy in small amounts. In addition, the micro-certificate could be applied as a type of partial trading for the RPS mechanism in this market. Considering that ICT infrastructure and advanced technologies are supposed to be used in the building of Masdar City, the basis for creating a new energy market is available.

7.5 Summary, conclusion and policy recommendation

In this chapter, we evaluated the impact of renewable energy development on carbon emission reduction. We also investigated the effectiveness of innovation in energy technologies adopted to reduce carbon emissions, ICT technologies, and environmental taxes applied to encourage renewable energy development. Environmental tax was considered in the model in order to evaluate the effects of market regulation. Several scholars have applied different methodologies to examine the relationship between energy consumption and economic growth in individual countries and in groups of countries in order to analyze the effects of governmental energy policies. The relationship between carbon emissions and economic growth has been studied by many researchers using the Environmental Kuznets Curve (EKC). These studies analyzed variables, such as population, inequality, trade, and openness. Most results showed that environmental quality would be promoted after a certain level of economic growth was achieved. Therefore, developed countries with a high level of GDP per capita would promote environmental quality.

Recently, this idea has been challenged by theoretical and econometric critiques. Recent studies have shown that the methodology used by previous researchers was not appropriate to estimate this relationship. Moreover, the important role of governance-related variables was neglected. Our contribution to the literature is to add electricity generated by renewable energy sources, technological innovation in energy technology patent, ICT, and environmental tax to the model. All these variables are considered governance related, either directly or indirectly. Environmental tax applied by governments is an example of the direct effect of governance. On the other hand, carbon emission is indirectly affected by governmental policy through technological innovation and renewable energy generation. Furthermore, we applied the FGLS method to estimate the model in order to avoid major econometric problems.

In contrast with previous research, we found that economic growth might not lead to promoting environmental quality. The results showed a positive relation between carbon emission per capita and GDP per capita in the EU-15, which is considered developed countries. Previous research found a negative relation between these variables. In popular myths about the effects of ICT technological innovation and environmental tax, both factors negatively affect carbon emission. However, our results showed that the impact of ICT differs across countries based on their structure. Environmental tax had a negative and strong effect on carbon emission by itself but the positive elasticity showed that its negative effect becomes positive because of high income and revenue recycling effects of tax policy.

In summary, we consider that the role of governmental policymaking is more important than economic growth. Renewable energy sources have been promoted in the EU-15 because of governmental supporting mechanisms and subsidies. Environmental tax policy and tightened standards could lead to more patents. Therefore, carbon emission will be more affected by governmental-related parameters than by achieving a certain level of economic development. This result could be important for the climate change policies of developing countries. In other words, it is not necessary to obtain a high level of economic growth in order to enhance a country's environmental quality. Developing countries are able to achieve this target through appropriate policy making by their governments. Hence, developing countries could achieve high levels of environmental quality before achieving high levels of GDP per capita.

Chapter 8: Summary and Conclusion

Ongoing concerns about climate change have made renewable energy sources an important component of the world energy consumption portfolio. Renewable energy technologies could reduce carbon dioxide emissions by replacing fossil fuels in the power generation industry and the transportation sector. Because of some negative and irreversible externalities in conventional energy production, it is necessary to develop and promote renewable energy supply technologies. Power generation using renewable energy sources should be increased in order to decrease unit cost and make them compatible with the conventional energy sources. Energy consumption depends on several factors: economic progress, population, energy prices, weather, technology, etc. Although renewable energy (RE) was used as a major source of energy for centuries, it currently constitutes only a small percentage of the world's total primary energy supply. Based on an IEA report, renewable energy subsidies sharply increased to 88 billion dollars in 2011, which shows a growth rate of 24 percent from 2010. According to GSR 2012 (Martinot and Sawin, 2012), new investment in renewable energy sources worldwide increased to 257 billion dollars in 2011, which is twice the amount of investment in 2007 and six times higher than in 2004. Wind and solar energy are the main sources of renewable energy in many countries.

The level of economic activities plays a key role in energy consumption, which is considered a key driver of energy markets. The relation between energy consumption and economic growth has been studied by many scholars.

Generally, four hypotheses are defined in this regard. If there is no causality, called the neutral hypothesis, energy consumption is not related to GDP. Therefore, neither conservative nor expansive policies affect economic growth. Uni-directional causality may be from economic growth to energy consumption (conservation hypothesis) or energy consumption to economic growth (growth hypothesis). The feedback hypothesis is applicable when there is bi-directional causality. Depending on the hypothesis; energy policies have different effects on economic growth. Early research on this topic was published in the 1970s and an extensive body of literature has evolved since then. Many researchers have studied the causality relationship between energy consumption and economic growth, using different variables. Using various approaches and methodologies, previous research studied individual countries and groups of countries to investigate the effect of governmental energy policy on economic growth.

As table (2-4) shows, some countries showed different results within the same period, regardless of the methodology used. It also should be noted that this analysis considers individual relationships between two variables (here, energy consumption and economic growth). Therefore, the results are not reliable as a basis for making decisions regarding energy policy. Other parameters, such as technological innovation and governmental taxes may affect this relationship. The effects of energy policies depend on conditions in the country, the methodology used, and the effects of time in the data sample. The effects of interactions with other variables should also be considered.

Although many researchers have studied the relationship between energy consumption and economic growth, they have rarely focused on causal relationships in renewable energy consumption. Renewable energy technologies could enable countries with good solar or wind resources to deploy these energy sources to meet their domestic demand. Two main solutions may be implemented to reduce CO_2 emissions and overcome the problem of climate change: 1) replacing fossil fuels with renewable energy sources as much as possible; 2) enhancing energy efficiency. Energy efficiency in an electricity network could be considered in different stages, including power generation (here the focus is on small amounts), transmission, distribution, and consumption. Different technologies are available for this purpose, such as electric vehicles (EV), combined heat and power (CHP), virtual power plants (VPP), and smart metering. The improved flexibility of the smart grid network will help in developing different renewable energy sources, such as solar and wind power. The smart grid enables household to have their own devices to produce renewable energy and trade surpluses of electricity. Furthermore, households could manage energy consumption using intelligent control systems. Households that generate electricity using their own resources may enter their surplus electricity in the network and withdraw it at other times. This power exchange between the distributed generation (DG) owner and the network requires appropriate management (Mashhour and Tafreshi, 2009).

Considering the outlook of the renewable energy market, a marketplace where small volumes can be traded is needed. Without market development, renewable energy usage is limited to covering individual demand. However, if it is connected to a commercial market, its progress could be limitless (similar to the wholesale electricity market). Our proposed market is a place to trade electricity power that is produced by households. In fact, there should be a balance between supply and demand in order to prevent power blockages. The micro-grid concept could be considered here. Many households could be connected to each other as micro generators and then they would be able to reduce energy consumption at peak periods and justify demand at other times. Therefore, through market development and an increasing number of households in the market, they could reduce the demand for increasing the capacity of new power generation to cover electricity consumption. The infrastructures required to establish this market includes the following: communication, science-technology infrastructure, storage facilities, and device provisioning.

Our proposed market consist of several players, such as major power generators (including fossil fuel and non-fossil fuel generators), distributors, service companies, consumers (including industries, commercial building and households). Therefore interaction between these parties is an important factor. This interaction should be considered in discussion of regulation. Furthermore, external factors should be taken into account in order to maintain stability in our policy and avoid causing uncertainty in market players regarding policies and regulations. In order to establish a successful market-based micro-grid, we should use a combination of instruments, including command-control, self-regulation, education and information, and economic instruments as a regulatory framework. Governmental regulations should be set to control and manage the market.

Environmental regulations could affect the commercial policies and strategic decisions made by companies. The interactions between players and organizations (state and non-state) in markets and their reciprocal influence are important in making an effective policy. Regarding renewable energies, in addition to parameters, such as decreasing technology costs because of advancement and economies of scale, the rapid growth of renewable energy was achieved mainly by support policies. Because some sources of energy, such as natural gas and coal, are available in the market at low prices, renewable energy would not be economical without government support. As our findings indicated, market regulation, technological innovation, and environmental tax play significant roles in meeting targets.

Alternative policies for environmental protection are applied in the form of economics (incentive) or regulations (non-incentive). Economic policies could be an incentive for using renewable energy or charging taxes imposed on emission generation or fossil-fuel consumption. Three types of support mechanisms are widely used, including feed-in-tariff, tax incentives, and tradable green certificates. A governmental carbon tax creates a higher burden of cost in burning fossil fuels and increases investment in renewable energy sources. Employing a carbon emission tax or emission trading mechanism could be considered a good policy to mitigate emissions at the lowest cost. The comparison of FIT and RPS policies showed the former is good when a policy to develop renewable energy sources with a low level of risk for investors is required. However, the latter is an appropriate policy when a market view policy is applied by the government. Although Europe has attempted to organize a single harmonized FIT system, it is impossible because of different policies across the member countries. The RPS system has not been developed in Europe because most European countries use the FIT system. In this regard, it seems that FIT polices are suitable to encourage the development of renewable energy sources. However, the RPS system should be applied after implementation of renewable energy sources at a certain level.

During the last three decades, two different approaches have been applied in the context of natural resources. The first approach considers the effects of natural resources on economic growth and the second approach explains the effects of economic growth on pollution, such as carbon emissions. The relationship between energy consumption and economic growth has been studied by many researchers. The second approach takes into account the environmental effects of economic growth. Following an empirical study by Grossman and Kruger (1991), many scholars analyzed the relation between economic growth and environmental pollution. The environmental consequences of economic development are crucial in discussion about sustainable economic growth.

We evaluated the impact of alternative energy production, technological innovation for mitigation or adaptation to climate change, and market regulation of carbon emission reduction. Our model estimated the effectiveness of these parameters for a panel of 15 countries in Europe (EU-15) from 1995 to 2011. We selected these countries because they are in the forefront of renewable energy development and applied market regulation to mitigate climate change. The earliest EKC function was made as a simple quadratic function of the levels of income. We employed additional explanatory variables in order to evaluate environmental-related effects. The number of patents of energy technologies and ICT per million inhabitants was applied in the model instead of R&D expenditure in order to measure the effects of technological innovation on carbon emission reduction. In addition, environmental tax per capita was considered to show that market regulation influences carbon emissions.

Usually, this model has usually been estimated using panel data. Most studies estimated both fixed effects and random effect models. Our estimation method differed from most studies because it used Feasible Generalized Least Squares (FGLS) to correct heteroscedasticity and autocorrelation. Although heteroscedasticity and autocorrelation in residuals are serious problems, none of the early studies reported diagnostic tests of models. Consistent with Harbaugh et al. (2002), Millimet et al. (2002), Stern (2004), and Wagner (2008), our findings confirmed that an inverted U-shaped relationship between carbon emission and GDP obtained with commonly used methods is entirely spurious because of several major econometric problems. The relation between CO2 emissions and GDP showed a concave curve for the EU-15 countries, which contrasts many studies that focused on the Environmental Kuznets Curve and claimed the inverted U-shaped curve relationship between emissions per capita and GDP per capita in developed countries. In addition, the results showed a convex formation between carbon emissions per capita

(CDECAP) with the number of ICT patents per million inhabitants (PTICAP) and technological change over time (TREND). Therefore, we found a decrease in the increasing rate of carbon emissions regarding ICT patents and technological change over time. Furthermore, there was a convex formation between carbon emission per capita (CDECAP) in relation to energy patent applications per million inhabitants (PTGCAP) and environmental tax per capita (EVTCAP). The results showed an increase in the decreasing rate of carbon emissions in relation to energy patents and environmental tax. Based on our findings, the policies developed for environmental tax, energy patent applications, and renewable energy generation could mitigate carbon emissions.

The effects of interactions between policies play a key role in reducing carbon emissions. Appropriate market instruments should be selected properly in order to mitigate carbon emissions. These instruments could be complementary or sequential. We recommend avoiding policies that affect each other negatively. We cannot assume that increasing GDP per capita means that more will be spent on environment quality because the latter is based on consumer behavior. Our results showed that environmental tax per capita has a negative impact on carbon emission, but the elasticity of environmental tax in relation to carbon emission is positive. Tax rates should be high enough to make a sensitive reduction in carbon emission. A reduction in carbon emission may not be achieved unless the related elasticities are known with acceptable certainty.

The results of this research could be important even in developing countries.

They are able to achieve the same level of environmental quality before achieving high levels of GDP per capita if appropriate policies are developed by their government. Our findings may be used by countries which attempting to develop eco-cities, such as Dongtan City in China and Masdar City in the UAE. We have analyzed a wide range of strategies used in different countries, which has indicated opportunities for the UAE government to formulate policies to promote renewable energy in Masdar City. An advantage of Masdar City distinguishes it from other eco-cities. Masdar City has the potential to establish the first market for trading renewable energy, which we discussed in chapter six. The micro certificate, a type of partial trading in the RPS mechanism, could be applied in this market.

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Appendix A

Table (A-1): Generalized least squares estimation result for alternative models with normalized variables

Variables	Model 1A		Model 2A		Model 3A	
	Coeff.	P>|z|	Coeff.	P>|z|	Coeff.	P>|z|
LnGDP/P	-1.756	0.000	-3.080	0.000	-0.500	0.328
(LnGDP/P)^2	1.101	0.000	1.742	0.000	1.535	0.000
LnRen/TPG			0.018	0.102	0.222	0.001
(LnRen/TPG)^2			0.033	0.000	0.072	0.000
LnPateng/P			-0.002	0.000	-0.071	0.000
(LnPateng/P)^2			0.000	0.003	0.000	0.191
LnPatict/P			0.034	0.000	1.404	0.000
(LnPatict/P)^2			-0.022	0.000	-0.005	0.409
LnEvt/P			-0.002	0.000	0.037	0.000
(LnEvt/P)^2			0.000	0.000	0.000	0.000
Trend			0.134	0.000	0.694	0.000
Trend^2			-0.079	0.000	-0.061	0.000
(LnGDP/P)(LnRen/TPG)					-0.286	0.000
(LnGDP/P)(LnPateng/P)					0.061	0.000
(LnGDP/P)(LnPatict/P)					-1.339	0.000
(LnGDP/P)(LnEvt/P)					-0.026	0.000
(LnGDP/P)Trend					-0.616	0.000
(LnRen/TPG)(LnPateng/P)					0.003	0.039
(LnRen/TPG)(LnPatict/P)					-0.011	0.262
(LnRen/TPG)(LnEvt/P)					-0.001	0.389
(LnRen/TPG)Trend					0.065	0.000
(LnPateng/P)(LnPatict/P)					0.002	0.255
(LnPateng/P)(LnEvt/P)					0.001	0.000
(LnPateng/P)Trend					0.001	0.231
(LnPatict/P)(LnEvt/P)					-0.012	0.000
(LnPatict/P)Trend					-0.027	0.002
(LnEvt/P)Trend					-0.003	0.000
Const.	1.620	0.000	2.231	0.000	-0.135	0.625
Number of obs	240		240		240	
Number of groups	15		15		15	
Time periods	16		16		16	
Wald chi2	516.71		1389.32		2549.09	
Prob > chi2	0.0000		0.0000		0.0000	

Table (A-2): CO_2 elasticities in EU-15 countries over 1995-2010

	GDP	Regenp	Ptgcap	Pticap	Evtcap	Trend
1995	0.9436	0.0947	-0.0030	0.0013	-0.0015	0.1066
1996	0.8367	0.1020	-0.0036	0.0104	-0.0021	0.0941
1997	0.5785	0.1086	-0.0040	0.0216	-0.0030	0.0843
1998	0.4677	0.1087	-0.0042	0.0256	-0.0040	0.0669
1999	0.2950	0.1206	-0.0043	0.0290	-0.0051	0.0549
2000	0.0667	0.1311	-0.0041	0.0296	-0.0055	0.0458
2001	-0.0566	0.1418	-0.0042	0.0326	-0.0060	0.0344
2002	-0.0298	0.1604	-0.0041	0.0289	-0.0061	0.0232
2003	0.1597	0.1542	-0.0041	0.0113	-0.0066	-0.0092
2004	0.3091	0.1491	-0.0045	0.0034	-0.0066	-0.0357
2005	0.2750	0.1546	-0.0047	0.0014	-0.0068	-0.0521
2006	0.3106	0.1549	-0.0049	-0.0059	-0.0066	-0.0731
2007	0.4647	0.1529	-0.0048	-0.0224	-0.0065	-0.0995
2008	0.4970	0.1499	-0.0048	-0.0302	-0.0066	-0.1221
2009	0.3197	0.1593	-0.0053	-0.0145	-0.0064	-0.1256
2010	0.3912	0.1605	-0.0050	-0.0086	-0.0056	-0.1335
Mean	0.3643	0.1377	-0.0044	0.0071	-0.0053	-0.0088
Std dev	0.2741	0.0231	0.0006	0.0199	0.0017	0.0838

Table (A-3): CO_2 elasticities in EU-15 by country

	GDP	Regenp	Ptgcap	Pticap	Evtcap	Trend
Austria	0.4872	0.0156	-0.0031	-0.0504	-0.0067	-0.0855
Belgium	-0.1780	0.2515	0.0033	-0.0941	-0.0095	0.0158
Germany	1.2717	0.2027	-0.0352	0.5266	0.0066	0.1459
Denmark	1.0774	0.1241	-0.0117	0.0838	-0.0016	-0.0119
Spain	0.2170	0.1300	0.0028	-0.0890	-0.0038	-0.0123
Finland	-0.1210	0.0792	-0.0048	0.0065	-0.0104	-0.0477
France	-0.1013	0.1436	0.0021	-0.0974	-0.0095	-0.0347
Greece	0.3705	0.1995	0.0000	-0.0122	0.0011	0.0561
Ireland	0.3509	0.1761	0.0022	-0.0983	-0.0085	-0.0247
Italy	0.3745	0.1232	-0.0038	0.0073	-0.0039	-0.0053
Luxembourg	1.6103	0.0319	-0.0027	-0.1111	-0.0053	-0.1208
Netherlands	0.0669	0.2007	-0.0057	0.0365	-0.0081	0.0155
Portugal	0.6785	0.1185	-0.0050	0.0625	0.0046	0.0459
Sweden	0.2514	0.0362	-0.0049	-0.0174	-0.0090	-0.0769
UK	-0.8916	0.2329	0.0013	-0.0468	-0.0155	0.0087
Mean	0.3643	0.1377	-0.0044	0.0071	-0.0053	-0.0088
Std dev	0.6236	0.0738	0.0095	0.1564	0.0060	0.0645

Appendix B

Table (B-1): Generalized least squares estimation result for alternative model with Environmental Tax / Fossil Fuel Consumption

Variables	Model 1B		Model 2B		Model 3B	
	Coeff.	P>|z|	Coeff.	P>|z|	Coeff.	P>|z|
LnGDP/P	-1.148	0.000	-1.356	0.000	-1.389	0.000
(LnGDP/P)^2	0.208	0.000	0.285	0.000	0.573	0.000
LnRen/TPG			-0.002	0.455	-0.123	0.084
(LnRen/TPG)^2			0.028	0.000	0.027	0.000
LnPateng/P			-0.004	0.000	-0.094	0.004
(LnPateng/P)^2			-0.004	0.000	-0.001	0.495
LnPatict/P			0.007	0.000	0.212	0.000
(LnPatict/P)^2			-0.004	0.000	0.001	0.482
LnEvt/egp			-0.911	0.000	-0.175	0.022
(LnEvt/egp)^2			0.709	0.000	0.076	0.000
Trend			0.033	0.000	0.052	0.000
Trend^2			-0.002	0.000	-0.002	0.000
(LnGDP/P)(LnRen/TPG)					0.124	0.000
(LnGDP/P)(LnPateng/P)					0.000	0.967
(LnGDP/P)(LnPatict/P)					-0.045	0.000
(LnGDP/P)(LnEvt/egp)					-0.273	0.000
(LnGDP/P)Trend					-0.019	0.000
(LnRen/TPG)(LnPateng/P)					-0.018	0.000
(LnRen/TPG)(LnPatict/P)					0.011	0.001
(LnRen/TPG)(LnEvt/egp)					-0.065	0.000
(LnRen/TPG)Trend					-0.005	0.000
(LnPateng/P)(LnPatict/P)					0.001	0.750
(LnPateng/P)(LnEvt/egp)					0.012	0.033
(LnPateng/P)Trend					-0.001	0.190
(LnPatict/P)(LnEvt/egp)					-0.009	0.306
(LnPatict/P)Trend					-0.001	0.048
(LnEvt/egp)Trend					0.007	0.000
Const.	3.672	0.000	6.145	0.000	3.704	0.000
Number of obs	240		240		240	
Number of groups	15		15		15	
Time periods	16		16		16	
Wald chi2	516.71		56653.30		8904.97	
Prob > chi2	0.0000		0.0000		0.0000	

Table (B-2): CO_2 elasticities in EU-15 countries over 1995-2010

	GDP	Regenp	Ptgcap	Pticap	Evtegp	Trend
1995	0.6735	-0.1331	0.0081	-0.0077	-0.1692	0.0306
1996	0.6453	-0.1377	0.0073	-0.0083	-0.1619	0.0263
1997	0.5490	-0.1443	0.0041	-0.0036	-0.1482	0.0224
1998	0.5368	-0.1424	0.0025	-0.0041	-0.1476	0.0178
1999	0.4885	-0.1504	0.0028	-0.0049	-0.1348	0.0139
2000	0.3971	-0.1594	-0.0011	0.0007	-0.1235	0.0101
2001	0.3559	-0.1672	-0.0022	0.0011	-0.1140	0.0060
2002	0.3621	-0.1806	0.0017	-0.0057	-0.0976	0.0026
2003	0.5013	-0.1742	0.0027	-0.0163	-0.1132	-0.0039
2004	0.5900	-0.1720	0.0018	-0.0227	-0.1210	-0.0098
2005	0.5811	-0.1791	0.0005	-0.0241	-0.1132	-0.0144
2006	0.6034	-0.1839	-0.0022	-0.0256	-0.1121	-0.0198
2007	0.6895	-0.1840	-0.0024	-0.0325	-0.1174	-0.0253
2008	0.7206	-0.1841	-0.0046	-0.0348	-0.1191	-0.0306
2009	0.5946	-0.1974	-0.0076	-0.0293	-0.0918	-0.0331
2010	0.5906	-0.1898	-0.0083	-0.0301	-0.0919	-0.0356
Mean	0.5550	-0.1675	0.0002	-0.0155	-0.1235	-0.0027
Std dev	0.1108	0.0203	0.0047	0.0127	0.0232	0.0221

Table (B-3): CO_2 elasticities in EU-15 by country

	GDP	Regenp	Ptgcap	Pticap	Evtegp	Trend
Austria	0.8248	-0.0763	-0.0290	0.0008	-0.2518	-0.0133
Belgium	0.5390	-0.2054	0.0208	-0.0277	-0.1259	0.0005
Germany	-0.0152	-0.3248	0.0314	-0.0388	0.1999	0.0108
Denmark	0.6725	-0.2001	0.0050	-0.0324	-0.0759	-0.0051
Spain	0.4338	-0.1578	-0.0101	0.0030	-0.1308	0.0011
Finland	0.7189	-0.0883	-0.0180	-0.0011	-0.2535	-0.0122
France	0.6031	-0.1479	-0.0036	-0.0099	-0.1779	-0.0053
Greece	0.1263	-0.2330	0.0046	0.0003	-0.0021	0.0114
Ireland	0.6817	-0.1781	0.0172	-0.0361	-0.1221	-0.0010
Italy	0.4322	-0.1737	-0.0031	-0.0085	-0.0891	0.0003
Luxembourg	1.5487	-0.0399	-0.0150	-0.0412	-0.3839	-0.0223
Netherlands	0.4844	-0.2082	0.0171	-0.0289	-0.0796	-0.0010
Portugal	0.1175	-0.1941	-0.0146	0.0164	-0.0217	0.0093
Sweden	0.8623	-0.0703	-0.0253	-0.0024	-0.2781	-0.0154
UK	0.2947	-0.2141	0.0254	-0.0260	-0.0606	0.0020
Mean	0.5550	-0.1675	0.0002	-0.0155	-0.1235	-0.0027
Std dev	0.3795	0.0742	0.0190	0.0183	0.1381	0.0098

탄소 배출 절감에 대해 재생 에너지 개발이 미치는 영향

초 록

기후 변화에 대한 우려가 지속되면서 재생 에너지원에 대한 연구는 세계 에너지 소비에 관한 연구에서 중요한 주제 중 하나로 자리잡고 있다. 몇몇 학자들은 에너지 소비와 각 나라별 경제 성장률 그리고 에너지 정책 효과를 분석하기 위한 군집 나라의 경제 성장률의 관계에 대한 연구를 위해 각각 다른 방법론을 적용하였다. 그리고 이전 연구들은 생애 주기 분석 방법론을 적용하여 기존 에너지원과의 결합 (예) 하이브리드 발전) 혹은 재생 에너지 각각을 이용한 탄소 배출 절감에 대해 분석하였다.

기존 문헌을 살펴보면 일정 기간이 지난 이후에 경제 성장은 환경의 질 향상을 이끌었다. 하지만 계량 경제 비판론은 이러한 연구 결과에 대해 반대한다. 게다가, 이러한 연구들은 정부 관련 변수들의 효과는 무시되었다. 따라서 본 연구에서는 탄소 배출 절감에 대한 재생 에너지 개발의 영향에 대해 분석하였다.

이러한 관점에서 본 논문은 재생 에너지 개발을 촉진하기 위해 재생 에너지원에 의해 생산되는 전력의 거래를 위한 시장 설계에 대

해 논의하였다. 재생 에너지 생산의 기반인 분산 전력 발전은 재생 가능 에너지 자원으로부터의 전력 생산을 고무시키고, 전송 손실을 감소시키며, 이에 따라 에너지를 절약할 수 있으며, 에너지 효율성을 향상시킨다. 그러므로 분산 재생 에너지원들과 작은 단위의 재생 에너지 거래할 수 있는 지역 시장에서의 스마트 그리드는 미래 에너지를 위한 유망한 결합이다. 본 논문은 재생 에너지 자원들을 위한 시장을 제안하고, 이 시장에서 거래를 위한 시장 메커니즘을 고안하였으며, 이 시장이 제 역할을 하기 위한 필요 요소들을 보여준다.

그리고 본 연구에서는 탄소 배출 절감에 대한 시장규제, 재생 에너지 개발, 기술 혁신의 효과를 평가하기 위한 모델을 추정하였다. 이 관계를 파악하기 위해 1995년부터 2010년까지 유럽의 15개 나라들의 패널 데이터 모델을 적용하였다. 더불어, 각 변수들의 효과를 측정하기 위해 이산화탄소 배출의 탄력성을 계산하였다. 본 연구 결과는 경제 개발 대신에 정부 관련 변수들에 의해 기후 변화의 영향들을 완화시킬 수 있다는 것을 보여준다.

키워드: 재생 에너지, 기술 혁신, 환경세, 탄소 배출, 경제 성장, 시장 메커니즘