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Environmental Assessment of European Union Countries

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Abstract: This study utilizes the dynamic data envelopment analysis (DEA) model by considering time to measure the energy environmental efficiency of 28 countries in the European Union (EU) during the period 2006–2013. There are three kinds of variables: input, output, and carry-over. The inputs are labor, capital, and energy consumption (EC). The undesirable outputs are greenhouse gas emissions (GHE) and sulfur oxide (SOx) emissions, and the desirable output variable is gross domestic product (GDP). The carry-over variable is gross capital formation (GCF). The empirical results show that first the dynamic DEA model can measure environment efficiency and provide optimum improvement for inefficient countries, as more than half of the EU countries should improve their environmental efficiency. Second, the average overall scores of the EU countries point out that the better period of performance is from 2009 to 2012. Third, the output variables of GHE, SOx, and GDP exhibit a significant impact on environmental efficiency. Finally, the average value of others is significantly better than high renewable energy utilization (HRE) with the Wilcoxon test. Thus, the EU's strategy for environmental energy improvement should be to pay attention to the benefits of renewable energy (RE) utilization, reducing greenhouse gas emissions (GHE), and enhancing the development of RE utilization to help achieve the goal of lower GHE.

Keywords: dynamic DEA; environmental efficiency; undesirable output; gross capital formation; greenhouse gas emissions

1. Introduction

The International Energy Agency (IEA) [1] reported that the amount of global energy consumption continues to grow. In particular, the proportion of petrochemical energy usage has increased by over 60% from the year 2005 to 2013. When petrochemical energy reserves drop, the technology to find new reserves and mining locations becomes harder and production costs rise. The decline of oil prices has led to a slowdown in new oil development and infrastructure investment and to greater capacity risk in 2017, which may lead to an unstable relationship between energy supply and demand. IEA estimated, that under the current population and capital income growth, energy demand will continue to rise over the next 20–25 years. The global population is expected to hit 8.7 billion by 2035, with the energy using population rising by 1.6 billion. IEA forecasted that global gross domestic product (GDP) will more than double, global economic growth will rise by 88%, and carbon dioxide emissions will increase by 8% from 2013 to 2030 (reaching 34.8 billion tons) within the business policy as usual. In a low oil price scenario analysis by IEA, the energy consumption of the global transportation industry will push up demand of petrochemical fuels from 2020 to 2030 and may inhibit the development of biofuels, such as electric vehicles, fuel cell vehicles, other high-efficiency carriers, etc. One important strategy to improve energy efficiency is to improve the efficiency of energy supply and increase end-use efficiency.

The European Union (EU) is currently the largest global energy importer, relying on imports for about 53% of their energy needs. This leads to an average annual cost of about 400 billion EUR. Spending about 1 billion EU a day on imported energy, the bloc's energy security is an important restricting factor for its economic development.

All of the EU countries signed a common strategical objective in 2008 which announced that the bloc's energy efficiency would increase by 20% in 2020. The EU executive committee set a goal of reducing energy consumption to 1842 million tons by 2020; and the 28 countries of the EU had been cut primary energy consumption by about 400 million tons from 2007 to 2014. The EU proposed an energy policy with three principles: supply security, sustainability, and competitiveness. The ultimate goal is to develop a common framework for the energy markets, policies, and transmission and distribution systems of the 28 members and to develop a diversified energy supply model, to reduce the demand for specific energy, to prevent energy security problems due to inadequate energy supply sources, and to solve the problems of energy inefficiency and high electricity prices due to aging infrastructure. The response to climate change will be achieved through the goal of increasing energy efficiency by 27% and cutting greenhouse gas emissions (GHE) by 40% by 2030 (versus 1990 levels), as shown in Figure 1. Eurostat Statistics Explained [2] showed respectively the continuous statistics as 80.4, 77.4, 78 and 77.6 within 2013–2016. In order to achieve this carbon reduction target, the EU has become more active in renewable energy (RE) development—RE rose to 15% of the proportion of total power generation in 2013—in order to reach the goal of a 20% energy ratio by 2020. The EU RE industry has an annual turnover of 129 billion EUR, employing more than one million people. Thus, its energy-saving and carbon reduction targets not only can stimulate economic demand, promote energy-saving industrial growth, and enhance competitiveness, but also create a large number of employment opportunities.

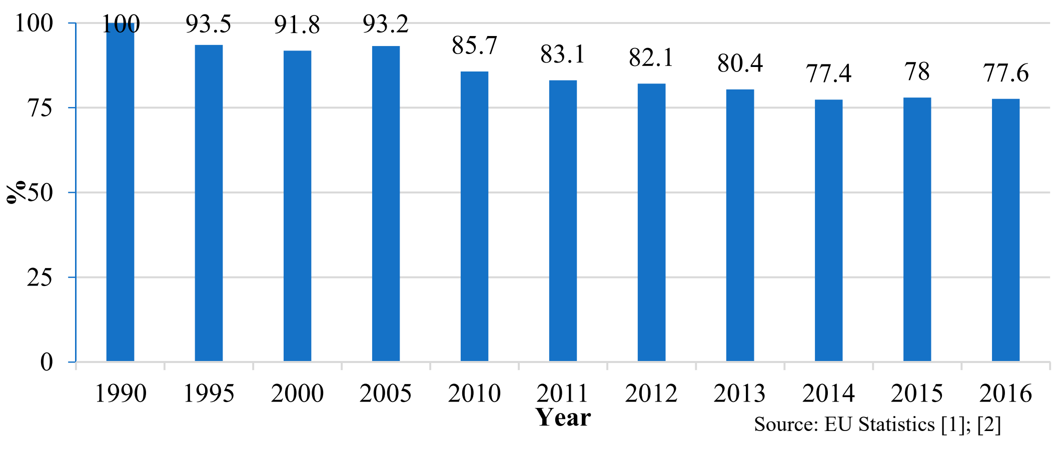

Figure 1. Greenhouse gas emissions (GHE) of the European Union (EU) countries relative to 1990.

The global climate has continued to warm in recent years, causing a greater number of natural disasters. The United Nations Intergovernmental Panel on Climate Change (IPCC) assessed that climate change will continue to intensify, with the main reason being carbon emissions from mankind's extensive use of oil, coal, natural gas, etc. leading to heavy GHE of carbon dioxide, nitrous oxide, methane, and other pollution, as shown in Table 1 for 1995–2016 [1,3], the total global carbon dioxide emissions is continuing to maintain an increasing trend from 22,552 to 33,018 million tons. In particular, China's growth rate is the most amazing, with almost three times the growth, these data show. These results indicate that it has caused serious environmental deterioration. These greenhouse gases form a greenhouse effect, and had resulted in average global temperatures increasing 0.74 Celsius from 1906 to 2005, economic growth drops by 3% when the global temperature increases by 2 Celsius. Therefore, the key issue is how to reduce GHE, how to control carbon emissions, and how to slow down the impact of global warming.

Table 1. Global carbon dioxide emissions. Unit: million tons.

Area \ Year	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016
EU-28	4063	4100	4276	4407	4311	4253	4159	3966	4028	4061
China	3085	3382	5503	8105	8792	8966	9204	9207	9163	9114
U.S.	5275	5844	5923	5508	5375	5169	5309	5160	5214	5130
Asia	1793	2257	2789	5843	6056	6321	6428	6565	6707	6899
Middle East	835	970	1247	1746	1791	1859	1928	1980	2031	2058
Russia	1573	1510	1527	1490	1556	1571	1524	1533	1496	1511
Africa	637	725	871	1079	1072	1108	1133	1170	1168	1185
Others	5291	5807	6343	2896	7325	3071	3117	3306	3045	3060
Total	22,552	24,595	28,479	31,074	31,971	32,318	32,802	32,887	32,852	33,018

Source: International Energy Agency (IEA) [1,3].

Reviewing the literature of environmental and energy efficiency, some studies are focused on using structural equation models to explore energy intensity, energy efficiency, industrial divisions' energy efficiency, and environmental efficiency [4,5]. Many scholars use data envelopment analysis (DEA) as the method to assess performance [6–8] because the DEA method can handle multiple input and output items at the same time and can discover the reasons for efficiency and inefficiency. The literature of environmental performance includes not only the assessment of energy efficiency, but also examines agriculture, water resource, ecology, and building energy efficiencies, as well as the energy conservation of transportation. Thus, it must be considered that the effects of undesirable outputs for regional environmental, such as carbon dioxide emissions. However, most studies using the DEA method employ decision-making units (DMU) in the same period, but this does not account for period extension and does not consider the phenomena of capital output process delay and the input–output process across multiple periods when assessing national energy environmental efficiency.

These research methods of environmental and energy are four main directions in the field: (1) using structural equation models to explore energy intensity or energy efficiency of industrial/overall and environmental efficiency [4,5]; (2) using traditional DEA to explore energy and environmental efficiency assessments for different countries and industries in single period [6–8]; (3) analyzing the relationship between GDP growth, energy and environmental [9,10]; and (4) energy and environmental efficiency analysis with bad output, such as CO_2, SO_2, etc. [11–14]. The above research lacks analysis of considering the inputs and outputs of mutual influence, and environmental efficiency is affected by dynamic changes over multiple periods. Environmental performance is a complex issue; it may concern positive economic growth, energy policy and negative environmental degradation, etc. This study refers to the aforementioned literature to consider the mutual influence relationship between variables of input and output. GDP, gross capital formation (GCF), labor, capital and energy consumption (EC) belong to economics and energy policy, EC, GHE and SO_2 belong to the environmental level. This study utilizes these variables and a dynamic SBM-DEA approach to find the relationship between environmental efficiency, economic growth and energy policy. These results will provide an important reference for the EU countries in formulating environmental policy.

The purpose of this paper is therefore to investigate the performance of energy environmental efficiency in the EU countries through dynamic DEA, to observe the effects of input and output variables and multiple carryover periods in EU energy consumption, and to consider undesirable output in order to explore the negative impacts on EU energy and environmental efficiencies and productivity differences. Because economic development and environmental efficiency have a close relationship between overall input variables and good or bad output, previous studies have investigated the overall relevance less. Thus, we used EC, GHE and SO_2 as input and output items etc.;

these are very important variables in affecting environmental performance, and then utilize dynamic DEA to find the effect of cross multiple periods. This study also used the Wilcoxon test to identify regional differences in environmental performance, and to find the differences between the area of high GHE and SO_2 emissions and other regions, and then also to understand the effect of the performance using renewable energy. These results will provide an important reference for these countries as energy policies. The issues are explored the energy environmental efficiencies of the EU countries in this study as the following: (1) the energy environmental efficiency value; (2) the effects of the carryover period; (3) the effects of the relationship between energy consumption and productivity; (4) the effects of undesirable output; and (5) the strategy of improving energy efficiency.

This study assesses the energy environmental efficiency of 28 countries in the EU over the period 2006–2013. The DMUs are Austria, Belgium, Czech, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Poland, Portugal, Latvia, Lithuania, Malta, Cyprus, Bulgaria, Romania, Croatia, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. There are many factors that affect energy environmental efficiency, such as electricity consumption, coal consumption, carbon monoxide, sulfur oxides, nitrogen oxides, industrial dust, etc. Some statistical data are incomplete, and so we use quantifiable external public data on energy consumption, capital, labor, greenhouse gases, and sulfur oxides.

The remainder of this paper is organized as follows: Section 2 is Literature Review, Section 3 is Research Methods, Section 4 is Empirical Results, and Section 5 provides the Conclusions.

2. Literature Review

Energy has always been one of the main elements of the development of human civilization, industrial construction, and economic development. Fossil energy has dominated human energy activities over the past 100 years, but the world is facing a gradual decline of reserves, and their excessive use has led to rapid changes in global climate. Developed countries have put forth great efforts into research and development (R&D) to improve energy efficiency and to reduce carbon emissions, such as the EU, the United States (US), and Japan (JP). US Energy Information Administration (EIA) proposed CO_2 emission of the US declined by a cumulative 3855 million metric tons (MMmt) within 2005–2017, the policy is used shifting in fossil fuels to natural gas and increasing in non-carbon generation sources [15]. Renewable energy technologies have even recently progressed, such as wind power, solar energy, and biomass energy. Thus, these developed countries are formulating various energy policies to ensure their energy security, thereby enhancing their industrial competitiveness

The relevant journal articles used undesirable outputs to assess energy environmental efficiency as follows. Sueyoshi and Goto [11] used the DEA method to measure unified (operational and environmental) and scale efficiencies among inputs and outputs of desirable and undesirable, and assessed the performances of coal-fired power plants in the northeast region of the U.S., finding significant differences in bituminous coal and sub-bituminous coal power plants' efficiencies. Woo et al. [9] used DEA to assess the dynamic environmental efficiency of renewable energy in the Organization for Economic Cooperation and Development (OECD). The input items were labor, capital, and renewable energy supply, while GDP was the desirable output, and carbon emissions were the undesirable output. The Malmquist productivity index (MPI) was applied to estimate the average efficiency change over the 2004–2011 period. The results demonstrated geographical differences in environmental efficiency across the OECD. Shabani et al. [12] proposed that the outputs contained desirable and undesirable outputs, combined the previous DEA techniques in a flexible model to select the optimum eco-efficient technology in the presence of undesirable outputs. Kuo et al. [13] examined farming environmental efficiency in Taiwan; the output contained undesirable output, and found that the DEA analysis showed that reducing pollution was the most important issue. Dritsaki and Dritsaki [4] used fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) to estimate the long-run relationships between energy consumption (EC), economic growth

(GDP), and CO_2 emissions for the panel unit root test, panel cointegration test, and panel causality test in three countries of southern Europe (Greece, Spain, and Portugal) in the period 1960–2009, and found that energy is a force for economic growth both in the short and long run, as it is driven by economic growth. Goto et al. [14] also separated outputs into desirable and undesirable categories to assess three efficiencies of various organizations with the DEA method, and found that the DEA method has an analytical capability to quantify the importance of investment on capital assets for technology innovation in the manufacturing and non-manufacturing industries in 47 prefectures of Japan and confirmed the validity of the Porter hypothesis in Japan's manufacturing industries. Thus, using undesirable outputs that assess environmental performance is an important issue. Zhao [10] examined the effects of conventional regulations on CO_2 emissions to sensitive productivity over the period 1995–2007 and found that the eastern region had the highest total factor productivity (TFP) growth rate, and the western region had the lowest under CO_2 emission restrictions; these variables had different effects on the regulation of CO_2 emissions, with sensitive measures toward productivity, such as GDP per capita, technical efficiency, capital labor ratio, energy intensity, and openness. Sueyoshi and Goto [16] discussed the outputs were not only desirable outputs (e.g., electricity), but also undesirable outputs (e.g., CO_2) to measure the unified efficiency of Japan's fossil fuel power generation for the period 2004–2008. Tsolas [17] used the DEA and bootstrapping model to explore the performance of Greece's fossil fuel-fired power stations, the outputs are net power (intended) and the non-intended output items were sulfur dioxide (SO_2), nitrogen oxide (NO_x), and carbon dioxide (CO_2). The results suggested that the power stations were considerably more inefficient than revealed by the initial point estimates of inefficiency.

There are also some studies used such as slacks-based measure (SBM), super SBM approach to evaluate the environmental performance, such as Dogan and Tugcu [18] estimated the technical and super efficiency scores of G20 countries in terms of electricity production for the years 1990, 1995, 2000, 2005, and 2011. The results revealed that China and Russia appeared at the top of energy efficiency rankings, France and the EU are inefficient in four of the five periods, and the US appeared inefficient for recent electricity production. Li and Lin [19] combined the super-efficiency and sequential DEA models to avoid the discriminating power problem and technical regress. The results showed that China's energy intensity fluctuate around 21%, 7.5%, and 12% for eastern, central, and western China, respectively, and eastern China has the highest level of energy technology. Thus, China must reduce the gap for improvement in energy intensity across regions. Yang et al. [20] investigated the environmental efficiency of China based on super-efficiency DEA model with DMUs from 30 provinces during the period 2000–2010, and found that the environmental efficiencies showed regional disparities, whereby Beijing and Shanghai had more efficiency, and Qinghai showed worse performance, suggesting that policies should be established to further promote production efficiency. Chang et al. [21] used the non-radial DEA SBM to explore the environmental efficiency of China's transportation sector, and proposed that China must reduce a great deal of carbon emissions—at least 1.6 million tons of oil equivalent (TOE) in Qinghai and 33 million TOE in Guangdong and Shanghai. Zhou et al. [22] used the non-radial DEA and the Malmquist approach to see the change in environmental performance over time, and found that the environmental performance of OECD countries as a whole improved from 1995 to 1997.

Some research used two-stage, dynamic DEA and also combined life cycle assessment (LCA) and analysis hierarchy process (AHP) to evaluate the environmental performance. Halkos et al. [23] applied a two-stage DEA model to evaluate sustainability efficiency indices (SEI) for European regions and the results revealed inequalities among the examined regions for the eco-efficiency stage. Wang and Feng [24] assessed the performance of China's energy, environmental, and economic efficiencies in period 2002–2011, and proposed that China perform well on the economic front, while its energy and environmental performances were not optimistic. Meng et al. [25] also proposed the two-stage DEA approach to examine the inefficiency and congestion in 16 Asia-Pacific Economic Cooperation (APEC) countries in the period 1996–2011. The results showed that energy is congested due to the fossil energy in 16 APEC countries, and that the APEC countries also should take some useful measures to control the congestion coming from non-fossil energy. Vlontzos et al. [26] employed the dynamic DEA model to evaluate the energy and environmental efficiencies of the primary sectors of the EU member state countries for the period 2001–2008, and found that the countries of Germany, Sweden and Austria, compared to the countries of Denmark, Belgium, Spain, France, and Ireland, had strong environmental protection standards, but appeared to be less energy and environmentally efficient, the eastern EU countries achieved low efficiency scores, which can be characterized as expectable, due to low technology levels being implemented in their primary production process. Wang et al. [27] measured the energy and environmental efficiencies of 29 administrative regions in China for 2000–2008. The empirical results showed that the east region of China had the highest energy and environmental efficiencies, and the west region was the worst. Moreover, the energy and environmental efficiencies slightly showed in the east regions having a more balanced development than the central and west regions. Geymueller [28] used dynamic DEA to assess the performance of 50 of the largest U.S. electric transmission system operators in the period 2000–2006. Yago et al. [29] combined the life cycle assessment (LCA) and DEA method to analyze the eco-efficiency of a group of 113 wastewater treatment plants (WWTPs) located in regions across Spain, and found that the effects of the plants' efficiency are contained in the size of the facility, the climatic influence, the influent load, and the over- or under-use of the plant. Zhang and Tao [30] used the methods of analytic hierarchy process (AHP) and DEA in assessing environmental performance, and found that wind power and solar power are more suitable for the country's economic, technical, environmental, and social requirements, followed by biomass, hydropower, ocean energy, and geothermal energy. Sun et al. [31] combined the DEA and fuzzy integral assessment methods to analyze eight typical western regions in China; the results can help local governments take corresponding measures to improve their environmental performance level. Lacko and Hajduova [32] used a two-stage DEA approach to assess environmental efficiency of the EU countries, and found that the climate change and socio-economic factors are the most relevant and significant. Moutinho et al. [33] utilize DEA and Malmquist productivity index to evaluate the eco-efficiencies of German and French cities, and found that high GDP over CO_2 emissions does not imply high eco-efficiency scores. This research shows that mutual influence issues between environmental and economic development are important; it is concerned with the sustainable development strategy of coexisting economic and environmental development.

More scholars used DEA as a measurement and analysis method to evaluate energy and environmental efficiencies in the above literature. DEA can deal with multiple inputs and outputs at the same time and can find the reasons for efficiency and inefficiency and hit efficiency goals of input and output items. Energy performance mostly explores power, power plant, fuel energy, hybrid energy, transportation energy, industrial energy consumption, and technology efficiency, in order to consider the effects of undesirable output pollutants such as CO_2 and to explore the relationship of carbon dioxide (CO_2) emissions between regions and countries. The inputs and outputs of the above literature are more focused in the same period, as they lack carry-over periods. The input items of labor, capital, and energy consumption and the output items of GDP and carbon dioxide emissions may go across multiple periods when evaluating energy environmental efficiency. Thus, each DMU input or the corresponding output does not necessarily appear in the same period. The across multi-period production process of the dynamic DEA model is used to evaluate energy environment efficiency in this study, in order to observe the impact of the overall environment on energy efficiency over time and to explore the effects of non-intended outputs to environment efficiency. Thus, EC, GHE and SO_2 as input and output items, etc. in this study; these are very important variables in affecting environmental performance, and then utilize dynamic DEA to find the effect of cross multiple periods. They also used the Wilcoxon test to identify regional differences in environmental performance, and to find the differences between the area of high GHE and SO_2 emissions and other regions, and then also to understand the effect of the performance using renewable energy. These results will provide an important reference for these countries as energy policies.

3. Research Method

DEA was developed from Charnes et al. to utilize constant returns-to-scale (CRS), called the CCR model, and the BCC model of variable returns-to-scale (VRS) for Banker et al. [34,35]. Though CCR and BCC mainly focus on desirable output or input, in real life, the production process or the content of output may not be a desirable output. In the actual production process, unwanted by-products may appear during input and output conversions, such as wastewater, exhaust gas, and carbon dioxide. In the traditional DEA model, if the relative inefficient DMUs have desirable and undesirable inputs/outputs to adjust, then they will be increased or decreased simultaneously because they cannot just increase the desirable output yet also decrease the undesirable output. To address this problem, Seiford and Zhu [36] applied their undesirable DEA model, which integrates weak disposal and strong disposal concepts, in order to measure a DMU's relative efficiency in a non-radial way. Hence, this situation can be improved.

Dynamic DEA was derived by Kloop [37] to use dynamic analysis for window analysis, followed by Färe et al. [38] who proposed the Malmquist index (MPI), but neither of them analyzed the interaction effect for two carry-over periods. Färe and Grosskopf [39] placed internal linkages into the dynamics, and the studies of dynamic analysis were followed by some research [40–43].

Tone and Tsutsui [44] proposed the weighted Slack-Based Measures (SBM) Dynamic DEA model, with carry-over as the dynamic period link. They classified them into four types: desirable (good), undesirable (bad), discretionary (free), and non-discretionary (fixed). The dynamic DEA model contained input-oriented, output-oriented, and non-oriented factors.

This study uses the non-oriented SBM dynamic DEA to find the optimal solution of overall efficiency (OE) and term efficiency. Each DMU has independent input and output in period t. Through the carry-over link of period t to the next period t+1, we can understand the changes across two periods. The structure of dynamic DEA of this study is shown in Figure 2.

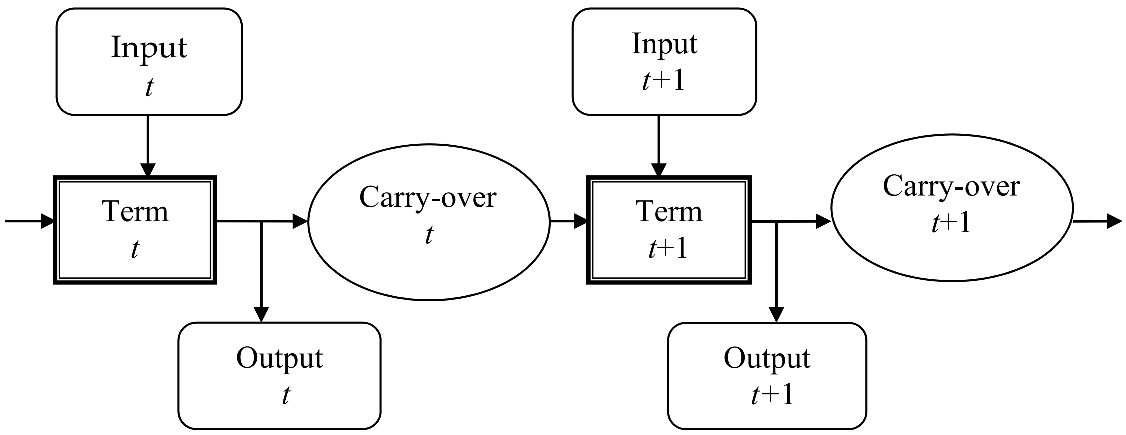

Figure 2. The structure of dynamic data envelopment analysis (DEA).

This model sets up n DMUs (j = 1, . . . ,n) over T periods (t = 1, . . . ,T). The DMUs have m inputs and s outputs in each period, and four category links, zgood, zbad, zfree, and zfix, carry over from period t to period t+1. The carry-over can be guaranteed by the following equation:

$$\sum_{j=1}^{n} z_{ijt}^{\alpha}\lambda_j^t = \sum_{j=1}^{n} z_{ijt}^{\alpha}\lambda_j^{t+1} \quad \left(\forall; t = 1, \ldots, T-1\right) \tag{1}$$

Here, the symbol α shows good, bad, free, or fix, and the non-oriented overall efficiency (θ*) is calculated by Equation (2), where ω^t and ω_i are weights to period t and the input:

$$\theta^* = \frac{\frac{1}{T}\sum_{t=1}^{T}\omega^t\left[1-\frac{1}{m+nbad}\left(\sum_{i=1}^{m}\frac{\omega_i^- s_{ij}^-}{x_{iot}}+\sum_{i=1}^{nbad}\frac{s_{it}^{bad}}{z_{iot}^{bad}}\right)\right]}{\frac{1}{T}\sum_{t=1}^{T}\omega^t\left[1-\frac{1}{s+ngood}\left(\sum_{i=1}^{s}\frac{\omega_i^+ s_{ij}^+}{y_{iot}}+\sum_{i=1}^{ngood}\frac{s_{it}^{good}}{z_{iot}^{good}}\right)\right]} \quad (2)$$

The non-oriented term efficiency (σ*) is shown in Equation (3):

$$\sigma^* = \frac{1-\frac{1}{m+nbad}\left(\sum_{i=1}^{m}\frac{\omega_i^- s_{iot}^{-*}}{x_{iot}}+\sum_{i=1}^{nbad}\frac{s_{iot}^{bad*}}{z_{iot}^{bad}}\right)}{1-\frac{1}{s+ngood}\left(\sum_{i=1}^{s}\frac{\omega_i^+ s_{iot}^+}{y_{iot}}+\sum_{i=1}^{ngood}\frac{s_{iot}^{good*}}{z_{iot}^{good}}\right)} \quad (3)$$

4. Empirical Result and Discussion

The research of energy efficiency has focused on the optimal production boundary of the production process, in order to create the most efficient combination of input and output. These studies simply considered the input of energy as energy density, ignoring the effects of other inputs to create desired outputs. Therefore, energy efficiency not only considers the inputs of energy consumption, net labor, and fixed capital, but also considers the production of polluting emissions, resulting in a cost burden upon the social environment and reducing the overall welfare of society. In this study, the input items are labor, capital, and energy consumption (EC), the variables of output are the intended outputs of GDP and the undesirable outputs of GHE (such as six kinds of legal GHE: carbon dioxide, methane, nitrous oxide, fluorinated hydrocarbon, perfluorocarbon and sulfur hexafluoride) and sulfur oxide (SOx) emissions, and use gross capital formation (GCF) as carry-over variable, in order to obtain a more accurate description of the output boundary and to expand analysis of energy environmental efficiency. Thus, this study's variables are economic variables, energy variables, environmental variables, and time factors. Table 2 show the variables' definitions of inputs, outputs, and carry-over.

Table 2. Variables' definitions.

Variable		Unit	Definition
Inputs	Labor	Thousand people	People 15–64 years of age for labor in the EU countries' statistics, in line with the definition of Internal Labor Organization (ILO).
	Capital	Million EUR	Income, savings, and net lending or borrowing; current prices of EU countries' statistics.
	EC	Thousand TOE	The gross inland energy consumption of EU countries' statistics.
Outputs	GHE	Thousand TOE	Use EU countries' statistics to contain six kinds of greenhouse gases: carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), fluorinated hydrocarbon (HFCs), perfluorocarbon (PFCs), and sulfur hexafluoride (SF6).
	SO_X	TOE	The emissions of sulfur oxides (SO_x) of EU countries statistics values.
	GDP	million EUR	The market value of EU countries' statistics using the factors of production to produce all final products (products and services) in a period.
Carry-over	GCF	Million EUR	The total value of gross fixed capital formation, changes in inventories and acquisitions less disposals of valuables for a unit, an institutional sector, or the whole economy in national accounts.

Source: Eurostat Statistics explained [2].

The descriptive statistics of the input and output variable data results are shown in Tables 3 and 4 as follows: (A) Labor: The average (AVE) value for labor is 7,634,000 people from 2006 to 2013. Germany had the most (MAX) people in labors in 2013 at 38,640,000; on the other hand, Malta had the least (MIN) people in labor in 2006 at 150,000 people. The standard deviation (STDEV) value was 9,773,000 people; (B) Capital: The AVE value was 444.997 billion EUR in 2006–2013. Germany had the MAX value in 2013 at 2.737 trillion EUR, and Malta had the MIN value in 2006 at 5.206 billion EUR. The STDEV value was 670.893 billion EUR; (C) EC: The AVE value was 62.365 million TOE in 2006–2013. Germany had the MAX value in 2013 at 351.703 million TOE, and Malta had the MIN value in 2009 at 870,400 TOE. The STDEV value was 83.693 million TOE; (D) GHE: This study adopts the Seiford and Zhu [36] DEA undesirable model to evaluate every country's fossil-fuel CO2 emissions in 2006–2013, such that the fossil-fuel CO_2 emissions increased during 2006–2013. The AVE value of each year increased 160.545 million TOE, the MAX value was Germany at 987.631 million TOE in 2006, and the MIN value was 2.785 million TOE from Malta. The STDEV value was 222.301 million TOE; and (E) SO_X: The AVE value increased 184,491 TOE every year from 2006 to 2013, the MAX value was Poland at 1,292,374 TOE in 2006, and the MIN value was Luxembourg at 1,279 TOE in 2011. The STDEV value was 255,172 TOE. (F) GDP: The AVE value increased 461.199 billion EUR every year from 2006 to 2013, the MAX value was Germany at 2.820 trillion EUR in 2013, and the MIN value was Malta at 5.386 billion EUR in 2006. The STDEV value was 695.620 billion EUR.

Table 3. Descriptive statistics of input and output variables.

Variable		STDEV	AVE	MAX	MIN
Input Variables	Labor	9773.39	7633.94	38,640	150.20
	Capital	670,893	444,997	2,737,600	5206
	EC	83,693.60	62,365.69	351,703.70	870.40
Output Variables	GHE	222,301	160,545.62	987,631.99	2785.47
	SO_X	255,172	184,491.11	1,292,374	1279
	GDP	695,620	461,199.67	2,820,820	5368.10

Source: Authors' collection.

Table 4. AVE value of input and output variables per year for 2006–2013.

Year \ Variables	EC	Capital	Labor	GHE	SOx	GDP
2006	65,713	420,162	7592	173,607	268,608	435,095
2007	64,660	445,488	7734	173,366	255,983	461,264
2008	64,486	448,163	7819	168,007	198,433	464,134
2009	60,766	421,991	7678	155,253	169,666	437,699
2010	62,982	440,618	7601	159,712	160,166	456,954
2011	60,638	453,971	7573	154,091	158,103	470,746
2012	60,159	462,839	7548	151,799	142,478	479,756
2013	59,521	466,741	7527	148,529	122,492	483,949

Source: Authors' collection.

There were significant impact relationships between the input and output variables as the Pearson correlation coefficients show in Table 5, and find that EC has a very significant positive correlation with Capital, Labor, GHE, SOx, and GDP; Capital has a very significant positive correlation with Labor, GHE, SOx, and GDP; and Labor has a very significant positive correlation with GHE, SOx, and GDP. This shows that these countries in the EU must improve their environmental conditions by promoting GDP growth, which has a significant impact on the relationship from 2006 to 2013.

Table 5. Pearson correlation coefficients of input and output variables for 2006–2013.

Variables	EC	Capital	Labor	GHE	SOx	GDP
EC	1					
Capital	0.982 **	1				
Labor	0.979 **	0.966 **	1			
GHE	0.966 **	0.948 **	0.981 **	1		
Sox	0.494 **	0.402 **	0.581 **	0.577 **	1	
GDP	0.982 **	0.999 **	0.966 **	0.947 **	0.400 **	1

** $p < 0.01$. Source: Authors' collection.

In this study, we use the Dynamic DEA-SBM method to evaluate the energy environmental efficiency of 28 countries of the EU in 2006–2013, with results in Table 6. This shows the polarization distribution of the overall efficiency (OE) of energy environmental efficiency; the efficient countries are Denmark, Ireland, Cyprus, Luxembourg, Malta, and Latvia (efficiency value is 1 or above 0.9). The countries that need to improve efficiency (efficiency value is below 0.1) are United Kingdom, Germany, Italy, France, Spain, Poland, Portugal and Greece. Some countries such as Denmark, Ireland, Cyprus, Luxembourg, Malta, Latvia, Estonia, Sweden, Slovenia and the Netherlands have a TOE value larger than the AVE value (0.4044) but smaller than AVE value. It shows that, among the 28 countries of the EU, more than half still need to improve their environmental efficiency. The results show that larger countries have poor energy environmental efficiency, and smaller countries have good efficiency value, indicating that the effects of economic and environmental variables are more complex in larger countries.

Table 6. Energy environmental efficiency of EU countries for 2006–2013.

Countries	Overall Efficiency (OE)	Rank	Term Efficiency (TE)							
			2006	2007	2008	2009	2010	2011	2012	2013
Belgium	**0.2187**	18	0.0928	0.1054	0.1246	0.2368	1	1	1	0.4791
Bulgaria	0.3589	11	0.1742	0.1937	1	1	1	0.2813	0.2031	0.2707
Czech	0.266	16	0.0963	0.1134	0.1257	1	1	1	1	1
Denmark	1	1	1	1	1	1	1	1	1	1
Germany	0.0141	27	0.0162	0.018	0.0139	0.0112	0.0125	0.0149	0.014	0.014
Estonia	0.885	7	1	1	1	0.7195	0.4836	1	1	1
Ireland	1	1	1	1	1	1	1	1	1	1
Greece	0.0823	21	0.0772	0.0817	0.0748	0.063	0.1833	0.0696	0.0803	0.1054
Spain	0.0255	24	0.007	0.0101	1	1	1	1	0.0318	0.0263
France	0.0192	25	0.012	0.0134	0.0117	0.0181	0.0265	0.0309	0.0418	0.0406
Croatia	0.3446	13	0.3034	0.3489	0.3674	0.4688	0.7702	0.2328	0.2756	0.3092
Italy	0.0177	26	0.0145	0.0151	0.0148	0.0135	0.0216	0.0227	0.1372	0.0127
Cyprus	1	1	1	1	1	1	1	1	1	1
Latvia	0.9009	6	1	1	1	1	0.5023	0.8636	1	1
Lithuania	0.3369	14	0.3635	0.3572	0.3345	0.4138	0.2613	0.3876	0.3505	0.2759
Luxembourg	1	1	1	1	1	1	1	1	1	1
Hungary	0.1079	20	0.1	0.1005	0.0986	0.1247	0.0889	0.1048	0.1281	0.1294
Malta	1	1	1	1	1	1	1	1	1	1
The Netherlands	0.4492	10	1	1	1	1	1	1	1	0.0867
Austria	0.2888	15	0.1171	0.1324	0.151	1	1	1	1	1
Poland	0.0395	23	0.0391	0.0347	0.0329	0.042	0.029	0.052	0.0482	0.0472
Portugal	0.0813	22	0.0668	0.0723	0.0827	0.0802	0.0974	0.0717	0.1371	0.0752
Romania	0.1972	19	0.068	0.061	0.1411	1	0.5156	1	0.6937	0.466
Slovenia	0.5377	9	0.4536	0.7011	1	0.6355	0.5586	0.3854	0.5084	0.4247
Slovakia	0.2225	17	0.2039	0.1808	0.2077	0.176	0.1475	0.4118	0.4444	0.2286
Finland	0.3531	12	0.2004	0.2179	0.2173	0.3502	0.4215	0.5311	1	1
Sweden	0.5658	8	0.5376	0.4555	0.3233	0.3156	1	1	1	1
The United Kingdom	0.0107	28	0.015	0.0169	0.0085	0.0098	0.0091	0.0093	0.0135	0.0088
AVE	0.4044	NA	0.3914	0.4011	0.4761	0.56	0.576	0.5887	0.5753	0.5
MAX	1	NA	1	1	1	1	1	1	1	1
MIN	0.0107	NA	0.007	0.0101	0.0085	0.0098	0.0091	0.0093	0.0135	0.0088
STDEV	0.3667	NA	0.4128	0.4142	0.4386	0.4247	0.4167	0.4294	0.4293	0.429

Source: Authors' collection.

The AVE value of term efficiency (TE) had the largest value (0.5887) in 2011, indicating that the overall energy environmental efficiency of EU countries was at an optimum during that year; it had the lowest value (0.3914) in 2006, meaning that the overall energy environmental efficiency of EU countries was the worst that year. The AVE of term efficiency shows a better interval in the period 2009–2012. The term efficiency values of Denmark, Ireland, Cyprus, Luxembourg and Malta became smaller from 2006 to 2013; the value of term efficiency equals 1, indicating stable energy environmental efficiency in these countries. The term efficiency values of Belgium, Bulgaria, Czech, Spain, the Netherlands, Austria, Romania, Slovenia, Finland and Sweden became larger; the value equals 1 or less than 0.1 for the period 2006–2013, showing unstable energy environmental efficiency in these countries, and so they must have more specific energy policies to make energy efficiency turn more stable. The term efficiencies of Germany, Greece, France, Italy, Lithuania, Hungary, Poland, Portugal, Slovakia and the United Kingdom changed very little, but the values were relatively lower than other countries. The values were less than 0.1, indicating that these countries must improve their strategies of energy environmental efficiency. The geographical distribution of these countries was split up between Western Europe and Eastern Europe. These results are consistent with cross multiple periods have a significant impact on environmental efficiency in Sueyoshi and Goto [16]. The traditional DEA of constant returns to scale (CRS) considers individual DMUs to find the set of virtual multipliers with the highest efficiency value under the same constraints, but it may cause multiple efficient DMUs with different virtual multipliers, its efficiency value is overall technical efficiency. The dynamic DEA approach is contained inputs and outputs of over multiple periods, and can utilize good or bad carry-over to find the effect of carry-over activities between two consecutive terms; it is a radial approach and can obtain non-uniform inputs and outputs' factor efficiencies; it is a good approach to evaluate energy and environmental efficiency that may have a cross-year continuity impact, so this study uses this approach.

The main factors leading to poor energy environmental efficiency were EC or GHE and SOx emissions in the EU countries. There are higher scores of emissions of GHE and SOx in countries like the United Kingdom and Germany. From the adjusted values of input items, output items, and carry-over, the United Kingdom, Germany, Italy, France and Portugal were less likely to have excess investment of input items, but, in order to improve environmental performance, they must reduce the undesirable outputs of GHE and SOx and increase carry-over of GCF during the period 2006–2013. However, Poland, Greece, Hungary, Slovakia, Lithuania and Croatia had excess input of EC and labor and thus must adjust the values of input items to the two, while reducing the undesirable outputs of GHE and SOx and increasing the desirable output of GDP.

The carry-over variable is GCF in this study, which can help us understand whether there will be good results into the next year. Thus, this value indicates the effect of efficiency across periods. Germany, Greece, Croatia, Italy, Lithuania, Poland, Portugal and the United Kingdom have to adjust the percentage makeup of more than four terms, shown in Table 7, which may lead to inefficiency in these periods for these countries. Although some previous research focused on dynamic DEA and using CO_2 emission in evaluating environmental performance [10–13], this study is also combined with a dynamic model and used bad outputs to assess environmental performance, and the dynamic SBM-DEA can find the effects of cross multiple periods of some variables. Therefore, this study is different from this research to use GCF as the carry-over. This may be affected by good output (GDP) and bad output (GHE and SO_x), and find that the United Kingdom and Germany are relatively poor environmental efficiency, their carry-over adjustment percentages are relatively bigger, and GHE adjustment percentages are also relatively bigger. This indicates that these DMUs must work on environmental strategies to reduce bad output, these variables of input/output and carry-over can really find the mutual influence relationship in environmental performance within the period 2006–2013 in this study, these results will provide an important reference for the EU countries in formulating environmental strategies.

Table 7. The carry-over adjustment percentage of all EU countries. Unit: %.

DMU	2006	2007	2008	2009	2010	2011	2012	2013
Belgium	3.82	0	0	0	0	0	0	1.98
Bulgaria	0	0	0	0	0	0	0	0.37
Czech	0	3.4	0	0	0	0	0	0
Denmark	0	0	0	0	0	0	0	0
Germany	16.12	11.67	9.68	9.65	8.12	0	7.96	4.34
Estonia	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0
Greece	6.91	0	0	9.43	10.85	24.46	55.77	85.42
Spain	0	0	0	0	0	0	7.9	15.12
France	3.94	0	0	0	0	0	1.12	0
Croatia	0	17.33	0	0	9.27	0	7.53	13.09
Italy	22.19	17.38	9.6	2.74	0	0	2.47	7.81
Cyprus	0	0	0	0	0	0	0	0
Latvia	0	0	0	0	33.5	0	0	0
Lithuania	15.56	0	0	61.02	30.98	0	1.31	0
Luxembourg	0	0	0	0	0	0	0	0
Hungary	0	0	0	0	14.2	0	4.88	0
Malta	0	0	0	0	0	0	0	0
The Netherlands	0	0	0	0	0	0	0	2.7
Austria	6.95	0.33	0	0	0	0	0	0
Poland	17.53	0	0	9.86	10.76	0	2.38	15.33
Portugal	1.28	0	0	0	4.29	3.53	14.55	25.1
Romania	18.64	0	0	0	0	0	0.68	0
Slovenia	0	0	0	0	8.31	0	11.87	11.62
Slovakia	1.72	0	0	0.78	0	0	7.2	8.69
Finland	11.7	0	0	0	0	0	0	0
Sweden	8.83	0	0	0	0	0	0	0
The United Kingdom	33.64	26.75	33.52	41.06	22.69	18.81	12.05	6.64

Source: Authors' collection.

The larger values of adjustment variables are 85.42% and 55.77% for Greece in 2012 and 2013. Greece and the United Kingdom have to adjust the GCF value over a multi-period, which also causes poor long-term energy environmental efficiency values. These countries must propose a better policy to increase GCF strategies, such as emphasizing changes of inventories and acquisitions in the measures of energy use and environmental protection.

In order to understand whether the effect of energy environmental efficiency exhibits geography differences between the east and west of the EU, we use the Wilcoxon test. We divide the geography into 14 east EU countries of Bulgaria, Czech, Estonia, Greece, Croatia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Romania, Slovenia and Slovakia (AVE of OE was 0.4485) and 14 west EU countries of Belgium, Denmark, Germany, Ireland, Spain, France, Italy, the Netherlands, Luxembourg, Austria, Portugal, Finland, Sweden and the United Kingdom. (AVE of OE was 0.3603). The Wilcoxon test p-value was 0.3533, showing that energy environmental efficiency values are not affected by the geographical location of the countries. The results are in Table 8.

We want to understand the effects of energy environmental efficiency in the different GDP values of EU countries, by using the GDP of predicted percentage (adjusted) values. We divide the group into higher growth GDP (HGDP) countries when they contain an AVE value larger than the total AVE value (0.97) in the period 2006–2013. This group includes Estonia, Spain, Cyprus, Latvia, Hungary, the Netherlands, Austria, Poland, Romania and Slovenia. The lower growth GDP countries (others) are Belgium and Bulgaria, etc. as shown in Table 9. This study use Imports/GDP as a verification variable to understand the relationship between external variables and environmental efficiency. These imports data come from Eurostat Statistics Explained [2], the largest value is 14,481 million EUR of Germany, the least value is 12 million EUR of Latvia in 2013, this study divides groups into larger than average (is Imports/GDP larger than average value 0.3811% of these variables, and others are less than average, it shows in Table 8, and finds that there is no significant relationship between external variables and environmental efficiency.

Table 8. The Wilcoxon test on AVE of OE.

Test Variable	Classification	Number	AVE of OE	Wilcoxon Test (p-Value)
Geographical	East area West area	14 14	0.4485 0.3603	0.3533
GDP	HGDP countries Others	10 18	0.4432 0.3829	0.065
GHG	HGHG countries others	7 21	0.0823 0.5118	0.0031 **
SOx	High SOx emissions others	10 18	0.0850 0.5557	0.0013 **
RE	HRE others	10 18	0.1532 0.5440	0.0064 **
Imports/GDP	Larger than average	9	0.4815	0.8830
	others	19	0.5088	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Source: Authors' collection.

Table 9. Adjusted GDP value of EU countries. Unit: %.

DMU \ Year	2006	2007	2008	2009	2010	2011	2012	2013	AVE
Belgium	0	0	0	0	0	0	0	0	0.00
Bulgaria	0	0	0	0	0	0	0	0	0.00
Czech	0	0	0	0	0	0	0	0	0.00
Denmark	0	0	0	0	0	0	0	0	0.00
Germany	0	0	0	0	0	0	0	0	0.00
Estonia	0	0	0	0	9.11	3.09	0	0	1.53
Ireland	0	0	0	0.56	0.24	0	0	0	0.10
Greece	0	0	0	0	0	0	0	0	0.00
Spain	3	2.53	0	4.74	4.03	1.47	4.19	2.44	2.80
France	0	0	0	0	0	0	0	0	0.00
Croatia	2.48	0	0	0	0	0	0	0	0.31
Italy	0	0	0.25	0	0	0.21	0	0	0.06
Cyprus	3.81	4.51	4.33	8.24	3.41	1.98	3.59	3.53	4.18
Latvia	5.51	4.25	3.15	0	1.02	1.63	4.81	4.25	3.08
Lithuania	0	0	0.55	0	0	0	0	0	0.07
Luxembourg	0	0	3.09	0	0	0	0	0	0.39
Hungary	3.1	2.32	4.82	0.79	0.94	0.98	4.85	1.46	2.41
Malta	0	0	2.33	1.17	0	0	0	0.39	0.49
The Netherlands	4.99	4.56	6.43	0	2.99	0	3.3	0.67	2.87
Austria	2.36	1.39	2.05	0	0.29	1.41	2.8	1.11	1.43
Poland	0	0	0.45	0	2.86	0	5.73	5.38	1.80
Portugal	0.29	0	0.05	0	0	0	4.84	2.59	0.97
Romania	3.68	3.02	3.99	3.14	0	0.3	2.64	2.96	2.47
Slovenia	1.45	1.67	0	0	0	0	3.89	3.08	1.26
Slovakia	0	0	0.33	0.86	0.74	1.83	0.63	0.39	0.60
Finland	0	0	0	0	0	0	0.04	0.65	0.09
Sweden	0	0	0	0	0	0	0	0.57	0.07
The United Kingdom	0	0	0	1.21	0	0	0	0	0.15
AVE of year	1.1	0.87	1.14	0.74	0.92	0.47	1.48	1.05	0.97
MAX	5.51	4.56	6.43	8.24	9.11	3.09	5.73	5.38	4.18
MIN	0	0	0	0	0	0	0	0	0

Source: Authors' collection.

The results of the Wilcoxon test of GDP are in Table 8. The p-value of 0.065 indicates no overall significant difference in the EU countries. The most significant relationship is in 2013, where the *p*-value is 0.0011**. The energy environmental efficiency of the HGDP countries (0.5180) was higher than others (0.4600), followed by 2012 with a *p*-value of 0.0123*, and 2006 and 2007 which are at 0.0129*. These results are consistent with GDP and bad outputs have a significant impact on environmental efficiency in Dritsaki and Dritsaki [4].

The higher GHE (HGHE) countries have an adjustment percentage larger than 20%. They include Portugal, Poland, Spain, France, Italy, Germany and the United Kingdom. The other countries (adjustment percentage lower than 20%) are also in Table 10. The results of the Wilcoxon test are in Table 8, where the *p*-value is 0.0031**, confirming that the energy environmental efficiency of the other EU countries (0.5118) is significantly better than that of HGHG countries (0.0823). The most significant relationship is in 2013, where the *p*-value is 0.0005***, followed by 2012 with a *p*-value of 0.0048**, and 2006 and 2007 at 0.0060**.

Table 10. Adjustment percentage of GHG in EU countries. Unit: %.

DMU \ Year	2006	2007	2008	2009	2010	2011	2012	2013	AVE
Belgium	0	0	0	0	0	0	0	0	0.00
Bulgaria	0	0	0	0	0	0	0	0	0.00
Czech	0	0	0	0	0	0	0	0	0.00
Denmark	0	0	0	0	0	0	0	0	0.00
Germany	0	0	0	0	0	0	0	0	0.00
Estonia	0	0	0	0	0.58	0.13	0	0	0.09
Ireland	0	0	0	0.31	0.42	0	0	0	0.09
Greece	1.37	2.13	3.88	3.88	0	0	0	0	1.41
Spain	2	0.64	0	1.04	1.32	2.93	1.77	2.6	1.54
France	0	0	0	0	0	0	0	21.33	2.67
Croatia	2.38	1.43	0	0	0	1.16	3.06	2.26	1.29
Italy	6.4	5.85	6.05	2.91	2.13	1.44	0	0	3.10
Cyprus	4.21	3.35	3.14	1.61	0.5	4.99	4.15	3.86	3.23
Latvia	2.29	2.43	2.83	1.63	3.32	1.99	2.48	3.65	2.58
Lithuania	15.55	13.61	11.68	0	0	0	0	0	5.11
Luxembourg	15.89	13.46	11.32	0	0	0	0	0	5.08
Hungary	5.56	6.79	5.21	7.55	8.22	2.6	2	6.24	5.52
Malta	17.93	15.58	13.2	5.92	0	0	0	1.83	6.81
The Netherlands	12.95	16.63	6.92	0	0.95	0	0.23	1.64	4.92
Austria	14.89	12.94	14.86	11.57	14.72	12.51	10.5	10.9	12.86
Poland	18.48	17.11	18.84	21.83	6.21	22.2	19.64	14.96	17.41
Portugal	26.33	23.77	20.45	22.2	16.77	25.4	11.65	23.19	21.22
Romania	70.88	81.44	85.44	62.91	91.72	57.79	62.05	66.42	72.33
Slovenia	83.18	47.38	0	0	0	0	54.56	71.31	32.05
Slovakia	183.65	162.7	185.8	121.32	84.77	73.71	53.63	52.36	114.74
Finland	165.02	161.55	162.76	177.67	110.85	106.37	15.36	184.66	135.53
Sweden	100	100	100	100	100	100	100	100	100.00
The United Kingdom	161.26	148.07	280.58	252.16	268.36	254.11	166.41	253.53	223.06
AVE of year	32.51	29.89	33.32	28.38	25.39	23.83	18.12	29.31	27.59

Note: 1. In this study, the GHE and SOx of unintended outputs are used as the largest annual changes of emissions of the DMU as the base and to calculate the relative emissions value, i.e., the GHE adjustment value equals the MAX value of GHE emissions of the DMU—original emissions value of each DMU + 1. 2. The largest value of GHE emissions is Germany for 2006–2013, and we let the Germany adjustment percentage be 100%. The relative adjustment value of each DMU is in this table. Source: Authors' collection.

As with the same method with GHE, the SOx emissions were divided into high SOx emission countries (predicted to reduce emissions by more than 10%), are the Netherlands, Hungary, Greece, Portugal, Poland, Spain, France, Italy, Germany and the United Kingdom, and there are 18 countries remaining. The results of the Wilcoxon test are in Table 8. The *p*-value is 0.0013**, confirming that the energy environmental efficiency of the other EU countries is significantly better than that of high SOx emissions' countries. The most significant relationships are in 2006, 2007, and 2012, where the *p*-values are 0.0006***, followed by 2013 with a *p*-value of 0.0011**, and 2011 at 0.0079**.

As shown in Table 10, the GHG emissions of Denmark, Ireland, Cyprus, Luxembourg and Malta are not adjusted for the whole period of 2006–2013. The larger values of reducing GHE emissions are for the United Kingdom, France, Germany and Italy during this time. The largest value of reducing GHE emissions is 280.58% for the United Kingdom in 2008, and the largest AVE value of reducing GHE emissions is also 223.03% for the United Kingdom over the period 2006–2013. The MAX of AVE value of overall countries is 33.32% in 2008, and the MIN value is 18.12% in 2012.

The study of renewable energy (RE) and how it affects energy environmental efficiency is an important issue. To further understand the energy environmental efficiency of RE use in the EU countries, we divide them into a higher RE (HRE) group if the AVE value is larger than the AVE of all countries; and the others group has an AVE value lower than the AVE of all countries in the same period. According to the EU statistics, the AVE value was 128.334 million TOE, and, for 2007–2013, the order is 138.351, 148.695, 156.808, 173.748, 170.919, 187.271, and 197.884 million. The HRE group contains Germany, the United Kingdom, France, Italy, Spain, Finland, Sweden, Austria, Poland and Romania; the others contain Belgium, Czech, Denmark, Estonia, Greece, Hungary, Ireland, Luxembourg, the Netherlands, Portugal, Latvia, Lithuania, Malta, Cyprus, Bulgaria, Croatia, Slovakia and Slovenia. For the strategy of RE utilization in EU, the countries must pay attention to the benefits of RE utilization and reducing GHE, promote the development of effective EC patterns, and improve the development of RE utilization to achieve the goal of reducing GHE. Through the data / sample period ends in 2013 of this study, but the European Environment Agency (EEA) [45] proposed that the emissions of undesirable gas still have no significant reduction trend during 2013–2016, the results show in Appendix A that the undesirable gas is contained SOx, COx, NH3, non-methane volatile organic compounds (NMVOC) and fine particle (PM2.5). The GDP of economic index that continues to maintain stable development in 2010–2016 is about 17 trillion US$; therefore, the issues of economic development and environmental protection must continue to be concerned. These results are still significantly linked to the period set 2006–2013 in this study.

5. Conclusions and Policy Implications

This research uses the dynamic DEA model to measure the energy environmental efficiency of 28 countries in the EU from 2006 to 2013. The results provide a reference for them develop an energy policy. When countries exhibit inefficiency for the overall period or in certain years, then they can think of how to improve and adjust the input variables (EC, capital, and labor) and the carry-over variable of GCF, so that they can achieve high efficiency. The EU can also consider how to reduce GHE and Sox emissions of undesirable outputs and to raise GDP through an increase of desirable outputs. The energy environmental efficiencies of the 28 countries present a polarized distribution, in which more than half need to improve their efficiency. Denmark, Ireland, Cyprus, Luxembourg and Malta are the best energy environmental efficiency, these values of efficiency are equal to 1. The worst inefficiency is United Kingdom, Germany, Italy, France and Spain, the overall values of environmental efficiency are 0.0107, 0.0141, 0.0177, 0.0192 and 0.0255 in periods 2006–2013. Moreover, Latvia, Spain, Sweden, Bulgaria, Austria, Czech, Belgium, the Netherlands, Finland and Austria show larger changes in efficiency value during the period 2006–2013. The overall efficiency from 2009 to 2012 turns better, but the global financial crisis and its after-effects occurred during most of this time. Thus, the economic downturn led to relatively good energy and environmental efficiency.

We use the Wilcoxon test method to analyze the effects of geography on energy environmental efficiency for eastern and western Europe. The results showed that the effect is not significant (p-value = 0.3533) for the EU countries over the whole time. The overall efficiency less than average value 0.4044, had Belgium and Bulgaria, etc. 18 countries, the reasons for inefficiency were due to excessive EC, the projection difference (%) in order 50.89, 50.54, 32.77, 41.27, 35.11, 35.29, 33.90 and 53.50 in periods 2006–2013, indicating that energy consumption is a main factor in environmental inefficiency, so we suggest the EU countries should promote the strategy of energy conservation and reducing GHE emissions. These countries can focus on industries and countries with higher discharges of carbon dioxide, in order to improve their efficiency in energy use, to reduce carbon emissions, and thus to control GHE emissions. The EU countries must propose an effective constraints policy that reduces internal resistance and cohesion consensus of all countries and effectively enhances energy and environmental efficiency.

The major economic countries of EU, such as United Kingdom, Germany, Italy and France, have a low efficiency score due to higher emissions of GHE and Sox, and the adjustment difference (%) is 148.07, 100, 165.02 and 183.65. However, decreasing the pollutants of GHE and Sox is required to achieve a certain economic level, which can slightly improve energy environmental efficiency. It could be found that Sox emissions may be related to industry, metal manufacturing, mining, etc., such as Poland being the country with the greatest Sox emissions in the 28 EU countries. Therefore, it may be a good way for the EU to formulate policies of reducing emissions that target these sectors and focus on controlling Sox and other pollutant emissions. The AVE value of the others group was significantly better than the HRE group in RE utilization. Hence, a strategy of energy environmental efficiency in EU must pay attention to the benefits of RE utilization and reducing GHE, promote the development of effective EC patterns, and improve the development of RE utilization to achieve the goal of reducing GHE. The shortcomings of this study are that it can't deal with the largest efficiency being equal to 1 and statistical interval problems. To solve these problems, future researchers can choose to use a resampling super DEA approach, but these methods have significant differences in the direction of the discussion.

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Appendix A

Table A1. The emissions of air pollutants index of European Union Countries.

Variables	1990	2010	2011	2012	2013	2014	2015	2016
Sox	100	17	16	15	13	12	11	9
Nox	100	53	50	49	46	45	44	42
NH3	100	76	76	75	75	75	77	77
NMVOC	100	45	43	42	41	39	39	38
PM2.5	100	85	79	80	78	73	73	72
GDP (trillion US$)	7.57	16.99	18.35	17.29	17.03	18.64	16.42	17.29

Source: European environment agency (EEA)

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