sustainability

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Input-Output Analysis for Sustainability by Using DEA Method: A Comparison Study between European and Asian Countries

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Academic Editor: Marc A. Rosen

Received: 16 September 2016; Accepted: 11 November 2016; Published: 28 November 2016

Abstract: Policymakers around the world are confronted with the challenge of balancing between economic development and environmental friendliness, which entails a robust set of measures in energy efficiency and environmental protection. The increasing complexity of these issues has imposed pressure on the Asian countries that have been acting as global factories. This paper proposes a meta-frontier slacks-based measure (SBM) data envelopment analysis (DEA) model, with the hope that policymakers clarify the relationship between labor force, energy consumption, government expenditures, GDP, and CO_2 emissions. Clarification of the causal relationship can serve as a template for policy decisions and ease concerns regarding the potential adverse effects of carbon reduction and energy efficiency on the economy. The results show: (1) Developing countries should establish their own climate change governance and policy frameworks; (2) Developed economies should seek to lower carbon emissions; (3) Energy policies play a pivotal role in energy efficiency improvement; (4) Top-down efforts are critical for the success of carbon reduction policies; (5) Learning from the success of developed countries helps to improve the effectiveness of energy policies; (6) Environmental policies should be formulated, and new production technologies, pollution prevention measures, and treatment methods should be introduced; (7) Governments are suggested to build long-term independent management institutions to promote energy cooperation and exchange.

Keywords: meta-frontier; economic growth; energy policy; undesirable output; sustainability; input-output analysis

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1. Introduction

The human race has fought with nature for survival and a better life, and as a consequence, the human factor has become one of the causes of environmental changes. Continued industrialization has also resulted in the exacerbation of global climate change [1]. Hurricanes, tsunamis, floods, and other natural disasters have become increasingly frequent as nature fights back against the human-caused destruction. It goes without saying that greenhouse gas reductions should be at the top of the agenda for all governments around the world. As carbon dioxide is the main constituent of the greenhouse gases, the monitoring of carbon emissions has become an important issue for governments [2]. Regarding the current strategies of economic development, in order to fulfill the ideal of sustainable development [3,4], all countries must stop giving a leading role to capitalism, and consider the correlation among the Three Es—Environment, Energy, and Economy. The human race uses a large quantity of fossil fuels to boost productivity and capacity, which results in greenhouse gas emissions [5]. Thus, it is necessary for all countries to steer away from a capitalism-centric approach to a holistic approach, which encompasses environmental concerns, energy needs, and economic growth, in order to ensure sustainable development.

In the United Nations Climate Change Conference in December 2015, all 195 attending countries agreed to replace the Kyoto Protocol with the Paris Agreement, and to control the global average temperature increase to 1.5 degrees Celsius (no more than 2 degrees) by 2100. It was also decided that efforts should be made to enhance climate resilience and reduce greenhouse gas emissions, but not at the expense of food production, in order to mitigate the impact of climate change.

At present, the problem confronting the policymakers of all countries is how to formulate a set of effective policies regarding environmental protection and energy conservation in the pursuit of economic development. However, this involves a wide range of decision-making factors, such as energy consumption and environmental issues, which significantly increases the complexity of policymaking [6]. There are both differences and similarities in the environments of energy development between European and Asian countries. The problem of energy environment has gradually become a global issue, causing a great threat to sustainable economic development.

Asia is responsible for most of the increased global demand for energy and fuel over the past three decades. As the majority of Asian countries are still developing economies, their rapid industrialization and development requires high energy consumption, which causes environmental destruction. Most developing countries seek development at the cost of energy and environment, meaning they put development before the environment and focus on automation to enhance productivity. All such challenges have imposed substantial pressure on the policymakers of Asian countries, which serve as the world's factories.

Economic development enhances the income flexibility of people's demands for environmental quality. To avoid the impacts of energy price on the overall economy and prevent the consequences of inflation, Asia has gradually eliminated the energy-dependent economic system featuring high carbon emissions through technological advancement, industrial transformation, and the formulation of supervisory regulations. Asia society gradually moves up the wealth ladder, the public sets higher standards for the environment, meaning that increasing income levels impose pressure on environmental supervision [7]. It is essential to enhance productive efficiency and mitigate environmental pollution, via technological effects, in order to enhance the standard of living and boost the scale of economy [8,9]. Waste gas emissions affect neighboring countries. Has it occurred to developed countries that they are the ones who relocated high-polluting and high labor-cost factories to Asia? Should they be enjoying the benefits of Asian industrialization, while accusing Asian countries of causing pollution? As Asia's contribution to greenhouse emissions continues to rise, and some Asian countries are considered the most polluted in the world, efforts from Asia are critical to combat against climate change.

While globalization may lead to transnational integration, it would also impact domestic industries, especially the energy industry, which is highly related to national economic development and people's lives, and affects governments when setting energy policies [10]. Therefore, a thorough understanding of the specifics and characteristics of different countries is critical to the formation of suitable and effective energy policies. Once it is confirmed that globalization will increase energy efficiency and dependence on imported energies, it will change the current direction through supporting policies, such as levying energy and carbon taxes to internalize external cost, improving energy efficiency, rationalizing energy price, encouraging private enterprises to improve production equipment through fiscal, tax, and financial incentives, and establishing other systems, such as carbon footprint, all of which will be dominated by governments and their ideologies; therefore, government's attitude plays an essential role.

As developed European countries impose stricter regulations on environmental control, on the basis of comparative advantages, multinational companies tend to relocate production from developed economies to developing countries in Asia, where costs are low and regulations are relaxed. These scale and structural effects have deteriorated the environments of developing economies [11–14]. As European countries are able to integrate climate change policies in energy, environment, agriculture, R&D, internal markets, and external affairs, their climate change measures are holistic, efficient, and effective [15]. Energy management and policymaking are both subject to the influence of the governmental ideologies and global trends of the international community. In addition, energy needs and environmental issues are highly related, as environmental issues are mostly initiated from energy production and consumption. In fact, environmental policies are gradually becoming regional and global concerns, rather than single-country decisions. This cross-border policy diffusion and convergence resulted from globalization [16], which achieved the social integration process via visits, information sharing, and communication. Developed countries in Europe have a high awareness of environmental protection and strict regulations of environmental supervision, which facilitates the implementation of policies; however, as their incomes increase, people begin to have higher requirements for the environment.

According to the above arguments, in the initial stage of national economic development, people do not have high requirements for the quality of the environment; as a result, the loose regulations of environment supervision facilitate the existence and development of high-pollution industries, which result in deteriorating environments. When incomes reach a certain level, people begin to have higher requirements for the environment; meanwhile, technologies become more innovative, which drive governmental institutions to formulate stricter regulations for environmental supervision. Moreover, the transformation of the consumption pattern in the market promotes the gradual conversion of the industrial structure from high-pollution intensive industries into efficient, less-polluting service-intensive industries or knowledge- and technology-intensive industries.

Most academic papers have neglected the policymaking role of "government" in topics concerning the world and energy. As underlined by scholars, various institutions, such as cabinets and congress, would always play a key role in the formulation and planning of energy policies; when it is confirmed that globalization would increase energy efficiency, that dependency on imported energy would change the current direction of development, and that a supporting policy system would be established, all such policy tools will be controlled by governments and their ideologies [17].

Policy makers around the world are confronted with the challenges of balancing between economic development and environmental friendliness, which entail a robust set of energy efficient and environmental protection measures. The increasing complexity of these issues has imposed pressure on Asian countries, which have been serving as the world's factories.

Empirical results can lead to an overall and scientific understanding of globalization, as well as the formulation and development of energy policies; moreover, they can bring relevant disputes back to scientific and rational discussion. In Europe, environmental awareness has been well-established [18]. Asian countries, such as China and India, where productivity is high and pollution is serious, will need to invest more in remedial measures. This paper compares these two regions because they are at the opposite ends of the spectrum in terms of economic development stages. It is intended that the research findings can serve as a template for the policymaking of other countries and regions, and set a tone for objective and scientific discussions of economic developments and energy policies.

The difference between this study and the abovementioned academic papers is that this study compares European countries with Asian countries. Without any changes to consumption patterns, this study assumes that developed countries professionalize their less-polluting, service-intensive industries; whereas, developing countries underline highly-polluting, raw material-intensive industries [19]. While previous studies focused on only one area or country, this study considers Europe and Asia, as the developments of different nations in the two regions can be compared for analysis, and papers regarding the variables related to the nations can be summarized for comprehensive study. The results of this study can be taken as objective and scientific economic arguments, and provide strategic suggestions for the development of nations with energy policies. In addition, they can serve as important references for the decision-makers of different governments in their formulation of policies.

2. Literature Review

The requirements for labor force and energy inputs increase with improved standards of living and economic growth. Apergis and Payne [20], and Wolde-Rufael [21] examined labor force and capital diversity in order to prove the causal relationship between energy, capital, labor force, and economic development. Yang et al. [22] argued that the labor force has an impact on carbon emissions. Given the limited number of relevant studies, this paper incorporates labor force as one of the input variables.

As energy drives the development of industries and economies, governments must balance between economic growth and energy consumption. The worsening global environment renders the issues associated with energy consumption an international concern. While energy efficiency and carbon reductions have been on political agendas all over the world, relevant academic studies only appeared in the late 1970s. Since then, the relationship between energy consumption and GDP has become a new research topic. In fact, energy consumption, GDP, and CO_2 emissions are closely related, and there is a difficult balancing act between reducing carbon emissions and energy consumption for the environment, while promoting energy consumption for the economy. For instance, in the past, China focused on economic growth and paid little attention to the environment [23,24]. As the causal relationship between energy consumption and economic development has important policy implications, there has been extensive literature attempting to clarify the nature of this relationship. Continued economic growth has been at the top of the political agenda, as it eliminates poverty. As economic activities are highly related to fossil fuels, energy is considered one of the production inputs; however, energy consumption may also constrain economic development. Thus, this study seeks to examine the correlation between energy consumption and CO_2 emissions.

As carbon emissions have caused extreme climate on a global scale, a large number of research works have addressed the relationship between economic development and carbon emissions. Many studies have indicated a single-direction causal relationship between GDP and CO_2 [25–27]. Dinda [28] indicated that there is a two-directional relationship between economic development and environmental pollution. The economic shift from being agriculture-centric to an industrial focus causes serious environmental impact. However, environmental pollution is controlled when the public demands higher quality environments and the economy evolves from industrialization to service-oriented. At this juncture, environmental pollution starts to improve [29].

Governments around the world have set up specific guidelines, timeframes, and targets regarding carbon emissions and energy efficiency. The environment provides resources for economic development, and such economic growth drives technological advancements and product innovations. Environmental pollution rapidly deteriorates air quality in the industrialization stage, as public demands for incomes and jobs outweigh the focus on air quality and clean water. Meanwhile, relaxed environmental regulations and a lack of financial resources to address pollution will lead to the rapid deterioration of environmental quality. However, rising incomes and cleaner, more efficient production technologies will reduce environmental pollution. Dasgupta et al. [30], and Lozano and Gutierrez [31] applied the DEA method to examine the relationship among energy consumption, GDP, and CO_2 emissions, and the empirical results suggested that GDP growth and greenhouse gas reductions can be simultaneously achieved with high energy efficiency.

There is extensive literature discussing the relationship between government expenditures and economic growth. Barro [32] indicated that government spending is an important engine for continued economic development. While increased government expenditures will initially enhance economic growth and increase savings, this impact will gradually taper off and eventually reverse. Since the 1990s, many studies have explored how government spending affects the nature of economic growth [33–36].

Ram [37] posited that the sale of government expenditures has positive influence over economic growth, particularly in the developing world, as based on the data regarding 115 countries.

The empirical study by Cooray [38] suggested that government spending is critical to economic development, regardless of government size or institutional quality [39,40]. Rehman et al. [41] indicated that Pakistan's increased domestic production value boosted government spending and economic growth. Some scholars contend that the degree of openness has significant impact on energy efficiency [42], which is why a number of countries prefer a more lenient policy regarding climate change, namely, the so-called regulatory chill. For instance, if a developed country adopts stringent environmental standards, domestic industries may lose market shares or move overseas, which is a consequence of the pollution haven effect [43]. Hence, while it is possible to achieve economic growth and pollution reduction in such countries, technological shifts remain a prerequisite for decreasing the undesirable outputs of other countries. Compared to the standardized data envelopment analysis (DEA) approach, the method developed by Arcelus and Arocena [44] can accurately estimate the operating efficiency of different countries by analyzing various groups and meta-efficiency values.

In summary of the above literature, there is no consistent conclusion regarding the relationship between government expenditures, labor force, and energy consumption as inputs, or GDP and CO_2 emissions as outputs. There are two sides to the arguments in some instances, which are possibly due to different statistical techniques, sampled countries, research period, variables, and data sources [45]. As global warming and climate change have become global issues, the correlation between energy security and energy efficiency (or carbon emissions) is a topic worthy of attention in the context of globalization. This paper explores the variances between groups and meta-efficiency values; differing from existing literature, this paper refers to European and Asian countries as the benchmarks, employs the DEA method to examine the efficiency of the inputs required for GDP growth, and takes the level of CO_2 emissions as undesirable outputs.

3. Methodology

The standardized DEA (see Appendix A) model does not consider country-specifics, applies the production function without pre-determinants, and calculates efficiency values with linear programming and a non-parametric frontier method. This paper seeks to establish a meta-frontier slacks-based method (SBM) DEA model, as follows:

DEA is a widely accepted application of Pareto optimality, as described by Pareto, an Italian economist, which considers the estimates of the relative efficiencies of a group of decision-making units (DMUs). The calculated efficiency values are the optimal outcomes for DMUs in an objective environment. The term DEA was coined by Charnes et al. [46] in the expansion of the efficiency measurement model, as developed by Farrell [47], for a single output into the CCR model for multiple outputs in the discussion of fixed returns to scale. Banker et al. [48] removed the constraints of fixed returns to scale in the CCR model, and developed the BCC model, which is capable of calculating efficiency values with non-fixed production and variable returns to scale. Essentially, it is the application of linear programming techniques to production functions in order to derive efficiency benchmarks. The greatest advantage of this approach is the removal of the requirement for predetermined function formats and model specifications, meaning DEA can handle the efficiency estimates of multiple inputs and outputs, without any judgment of the relative importance of the different inputs or outputs. This avoids the issue of subjectivity in the determination of weights and aggregations.

Generally speaking, an input-oriented model or an output-oriented model may be used to estimate the relative efficiencies in the DEA model. Input orientation refers to calculation of the possible and simultaneous reductions of percentages for each output at a given output level, while output orientation refers to calculation of the possible and simultaneous increased percentages for each output at a given input level. Fare et al. [49] was the first scholar to suggest the incorporation of undesirable outputs. Seiford and Zhu [50] improved the standardized DEA model, and designed the output-oriented BCC model by considering undesirable outputs. Hence, the presumption of higher inputs for higher outputs and higher efficiency is not supported.

Tone and Tsutsui [51] developed the modified SBM DEA model by incorporating desirable outputs, and there are two approaches: (1) the bad output model, which separates outputs into good (desirable) and bad (undesirable) without assuming the correlation between them; (2) the non-separable model, which posits the inseparability of good (desirable) outputs and bad (undesirable) outputs. In other words, a reduction in undesirable outputs will inevitably require a cut in desirable outputs.

$$X = [x_1 \ldots\ldots\ldots x_n] \in R^{m\times n}, Y^g = [Y_1^g, \ldots.. Y_n^g] \in R^{S1\times n}, Y^b = [y_1^b \ldots\ldots y_n^b] \in R^{S2\times n}] \quad (1)$$

It is assumed that $X > 0$, $Y^g > 0$, $Y^b > 0$, and the possible set of production is defined, as follows:

$$\rho^{***} = \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i}{x_{io}}}{1 + \frac{1}{s_1+s_2}\left(\left(\sum_{r=1}^{S_1}\frac{s_r^g}{y_{ro}^g}\right)+\left(\sum_{r=1}^{S_2}\frac{s_r^b}{y_{ro}^b}\right)\right)} \quad (2)$$

S.T.

$$x_0 = X\lambda + s^- \quad (3)$$

$$y_0^g = y^g\lambda - s^g \quad (4)$$

$$y_0^b = y^b\lambda - s^g \quad (5)$$

$$\lambda, s^-, s^g, s^b \geq 0 \quad (6)$$

The symbol s^- denotes excess inputs, while s^b denotes excess undesirable outputs, and both should be reduced. The $0 < \rho^{***} \leq 1$ symbol s^g denotes ashortage of desirable outputs, which should be increased. If the optimal value of the above linear programming is defined as $(\lambda^*, s^{-*}, s^{b*}, s^{g*})$, when $s^{-*} = 0$, $s^{b*} = 0$ and $s^* = 0$, $\rho^{***} = 1$, it indicates the efficiency of the DMU in the bad output model.

If $\rho^{***} < 1$, it indicates the DMU is inefficient in the bad output model. To achieve efficiency, it is necessary to scale back inputs, reduce excessive undesirable outputs, and increase the shortfall of desirable outputs. The bad output model is expressed by the following equations, and the adjustment for inefficient DMUs is the projection point of an efficient frontier, as represented $b(x_0, y_0^g, y_0^b)$.

$$x_0 = x_0 - s^- \quad (7)$$

$$y_0^g = y_0^g + s^{g*} \quad (8)$$

$$y_0^b = y_0^b - s^{b*} \quad (9)$$

According to O'Donnell et al. [52], the application of the meta-frontier model to DMUs with varying levels of production efficiency can accurately estimate technical efficiency. This can be modified into a weighted meta-frontier SBM DEA model by identifying the group frontier each country belongs to, and then inducing a meta-frontier—i.e., an envelopment curve that dominates all the groups, as based on the complete sample. It is hence possible to derive the efficiency of the different groups and the meta-frontier, and then the meta-technology ratios (MTRs). This model combines the modifications proposed by Tone and Tsutsui [51], and O'Donnell et al. [52], as follows:

$$X = [x_1 \ldots\ldots x_n] \in R^{m\times n}, Y^g = [Y_1^g, \ldots.. Y_n^g] \in R^{S1\times n}, Y^b = [y_1^b \ldots\ldots y_n^b] \in R^{S2\times n}]. \quad (10)$$

It is assumed that $X > 0$, $Y^g > 0$, $Y^b > 0$, and the possible set of production is defined, as follows:

Different countries have different cultures, economic developments, and regulatory regimes. The symbol N denotes the collection of all the DMUs within the g number of groups ($N = N_1 + N_2 + \ldots + N_G$), X_{ij} and y_{rj} the i-th input ($i = 1, \ldots, m$) and the r-th output ($r = 1, \ldots, S$) of the j-th DMU ($j = 1, \ldots, N$), respectively. Under the meta-frontier, DMU k can select the weight for optimal outputs u_r^g

(r = 1, ..., s), in order to maximize the efficiency value. The efficiency of DMU k under the meta-frontier can be derived with the following linear programming:

$$\rho** = \text{Min}\frac{1-\frac{1}{m}\sum_{j=1}^{J}\sum_{i=1}^{m}\frac{s_{ijo}^{-}}{x_{ijo}}}{1+\frac{1}{s}(\sum_{j=1}^{J}\sum_{r=1}^{s_1}\frac{s_{rj}^{g}}{y_{rjo}^{g}})+(\sum_{j=1}^{J}\sum_{r=1}^{s_2}\frac{s_{rj}^{b}}{y_{rj}^{b}})} \quad (11)$$

If the sampled European and Asian countries are divided into a g group of DMUs, the DMUs dominated by respective group frontiers may select the optimal weights of the final outputs. Therefore, the efficiency of the DMUs dominated by respective group frontiers can be derived by the following equation:

$$\rho* = \text{Min}\frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}}{\text{x}_{\text{io}}}}{1+\frac{1}{s}(\sum_{r=1}^{s_1}\frac{s_{r}^{g}}{y_{ro}^{g}})+(\sum_{r=1}^{s_2}\frac{s_{r}^{b}}{y_{ro}^{b}})} \quad (12)$$

Subject to:

$$x_0 = x\lambda + s^- \quad (13)$$

$$y_0^g = y\lambda - s^g \quad (14)$$

$$y_0^b = y\lambda - s^g \quad (15)$$

$$L \leq e\lambda \leq u \quad (16)$$

$$\lambda,\ s^-,\ s^g,\ s^b \geq 0 \quad (17)$$

$$\lambda \geq 0 \quad (18)$$

Battese et al. [53] estimated the technology gap ratio (TGR) by referring to the distance from the group frontier to the meta-frontier, which is also the ratio of the optimal group frontier to the optimal meta-frontier for the DMU in question. The closer the ratio is to 1, the closer the optimal group frontier is to the optimal meta-frontier for the DMU concerned. O'Donnell et al. [52] believed that a higher TGR implied that the gap between the group frontier and the meta-frontier was shrinking. However, as the name TGR sounds counter-intuitive, this paper replaces it with MTR to avoid confusion.

$$\text{MTR} = \rho^{**}\ /\ \rho^{*} \quad (19)$$

4. Empirical Analysis

This paper intends to explore the influence of undesirable outputs on the efficiency values of individual countries in Europe and Asia in the context of environmental protection. The sampling of the countries is based on the availability and consistency of the data concerning income distribution, as well as the integrity of variable data. This paper selects a total of 37 European countries and 36 Asian countries from the member countries of the United Nations. Variable data is sourced from the United Nations Statistics Division (UNSD), the World Bank, and the Energy Information Administration (EIA). This paper uses the bad output, meta-frontier, and non-oriented SMB model for undesirable outputs, which considers all the input variables and output variables of the sample, analyzes the efficiency values using DEA-SOLVER 6.0 (a research and analytical software, SAITECH, Holmdel, NJ, USA), and the research period is 2006–2010.

Based on the literature review of Section 2, this paper summarizes the inputs and outputs in relation to the operating performances of countries in Europe and Asia. The three inputs are labor force, energy consumption, and government expenditures, while the two outputs are gross domestic product (GDP) and CO_2 emissions. The definitions of input and output variables are offered, as follows.

- Input Variables

(1) Labor Force
Labor force is an essential input to economy. Fare, Grosskopf, Norris, and Zhongyang [49], and Hu and Kao [54] used labor force as one of the input variables. Labor force is defined by the International Labor Organization as people capable and willing to work.

(2) Energy Consumption
Marklund and Samakovlis [55] indicated that energy consumption as an input factor refers to the aggregation of the energy consumed by all residents and economic activities within a certain period of time. Energy is narrowly defined as the primary energy obtained from nature or processed into usable resources, such as coal, crude oil, and natural gas.

(3) Government Expenditures
This paper samples the data regarding general governmental final consumption expenditures as government expenditures. Government expenditures are a fiscal tool for governments to achieve economic goals, which are often related to the degree of urbanization and highly relevant to economic growth.

- Output Variables

(1) GDP (Gross Domestic Product)
GDP—a macroeconomic indicator of overall economic activities—is measured in US dollars, and based on the official exchange rate of the year. Domestic incomes of different countries or regions are often compared against each other.

(2) CO_2 Emissions
Carbon dioxide emissions, which are measured in units of 1000 metric tones, are caused by the burning of fossil fuels and the production of cement. Energy consumption and acquisitions are a necessary cost for economic growth.

This paper applies the DEA method to examine the efficiency of energy consumption in European and Asian countries. To understand the correlation between energy consumption as inputs and outputs, this paper conducts Pearson testing on the sampled European and Asian countries from 2006–2010. The bad output model is applied by assuming the relative importance is 1:1, regarding GDP as a desirable output, and CO_2 emissions as an undesirable output.

Input data for the DEA model must meet the isotonicity criteria, i.e., the level of outputs is at least the same, and do not fall when inputs increase. All the Pearson correlation coefficients are estimated to be positive, indicating the explanatory power of the inputs and outputs in the model (Table 1).

Table 1. Correlation coefficients of inputs and outputs.

Variable	Labor Force	Energy Consumption	Government Expenditure	CO_2 Emissions	GDP
Labor Force	1	0.9102	0.3676	0.9207	0.5259
Energy Consumption	0.9102	1	0.5925	0.9923	0.7281
Government Expenditure	0.3676	0.5925	1	0.5248	0.9761
CO_2 Emission	0.9207	0.9923	0.5248	1	0.6715
Gross Domestic Product	0.5259	0.7281	0.9761	0.6715	1

By considering the different economic developments and industrial structures in Europe and Asia, Table 2 summarizes the estimated efficiency values of European and Asian countries in 2006–2010.

The European countries with the highest average efficiency values among the group frontier are Albania, France, Germany, Iceland, Ireland, Italy, Luxembourg, Malta, Montenegro, Norway, Romania, and Sweden. While Bulgaria, Bosnia, Belarus, and the Ukraine report the lowest values. The mean efficiency value in Europe was 0.6758 in 2010, which was slightly higher than 0.6731 in 2006, which was mainly due to cuts in government expenditures in response to the sovereign debt crisis. The deployment of renewable development in Europe continued to increase in 2008–2010, but started to decline when the government reduced or cancelled incentives. The private sector decided to take a wait-and-see attitude or slowed their pace of emission reduction.

Table 2. Regional meta-technology ratios (MTRs).

	Euro Area		
Year	**Group-Frontier Score**	**Meta-Frontier Score**	**Meta-Technology Ratio**
Average–2006	0.6731	0.6325	0.9511
Average–2007	0.6277	0.6223	0.9829
Average–2008	0.6498	0.6449	0.9873
Average–2009	0.6561	0.6496	0.9796
Average–2010	0.6758	0.6381	0.9462
	Asia Area		
Year	**Group-Frontier Score**	**Meta-Frontier Score**	**Meta-Technology Ratio**
Average–2006	0.7521	0.6531	0.8741
Average–2007	0.7451	0.6236	0.8413
Average–2008	0.7939	0.6986	0.8732
Average–2009	0.7433	0.6463	0.8659
Average–2010	0.7307	0.6288	0.8662

The Asian countries with the highest average efficiency values among the group frontier are Armenia, Bangladesh, Brunei Darussalam, Cambodia, China, Cyprus, India, Indonesia, Japan, Mongolia, Qatar, Singapore, Tajikistan, Turkey, Vietnam, and Bahrain, while Pakistan, Iraq, and Uzbekistan are the worst performers. The group efficiency value in Asia decreased from 0.7521 in 2006 to 0.7307 in 2010, which was mainly due to a difficult balancing act between the pursuit of economic growth and a requirement for robust environmental/energy policies. Policymakers are confronted with a daunting challenge in association with the diversity of alternative energies and the complexity of the policy formation process. In fact, policy effectiveness was not consistent throughout the research period.

The countries with the highest meta-frontier efficiency are Albania, France, Germany, Iceland, Ireland, Italy, Luxembourg, Malta, Montenegro, Norway, and Romania in Europe, and Armenia, Bangladesh, Cambodia, China, India, Indonesia, Japan, Mongolia, Singapore, Tajikistan, Turkey, and Vietnam in Asia.

Table 2 shows the annual MTRs of European countries during the research period. As a group, the European countries reported the highest mean MTR of 0.9873 in 2008 and the lowest mean MTR of 0.9462 in 2010. The mean MTR in 2006–2010 was 0.9694. The countries posting the highest MTRs are Albania, France, Germany, Iceland, Ireland, Luxembourg, Malta, Montenegro, Norway, and Romania. Europe originally spearheaded the global initiatives in carbon reductions and climate change policies. As public demand for environmental quality increases with economic development, European countries have been upgrading technologies, transforming industrial structures, and formulating regulations to control energy prices and inflation, in order to gradually mitigate energy dependency, lower carbon emissions, and establish long-term energy supply. The top priority of European policymakers is to advocate the importance of environmental protection and enhance public awareness of sustainability, which facilitates the implementation of energy efficiency and carbon reduction measures. Meanwhile, the continued improvement of energy efficiency and deployment of renewables will help companies to reduce costs, lower carbon emissions per output unit, and boost the international competitiveness of their products.

Data from Eurostat indicated that Germany was one of the highest emitters in Europe. However, Germany's six environmental-friendly and green technology industries have evolved from utilities, machinery, and automated companies into a global powerhouse of cross-disciplinary applications. The development of renewables has created thousands of jobs, connected energy policies with a green economy, and enhanced Germany's competitiveness through sustainability. The German government's focus on energy efficiency and carbon reductions per output unit shows that economic growth does not always jeopardize the environment. In fact, the growth of anew economy will become more efficient by exporting technologies with production efficiency.

The French government provides subsidies and incentives to low-carbon products, technologies, and industries, and promotes carbon footprint certification in order to encourage consumption of products with low environmental impact. Russia has been taking the bold steps of relaxing laws and regulations to privatize its energy industries. Although energy is highly relevant to national security, a degree of privatization can mitigate the bureaucracy typically seen in state-owned enterprises, and enhance the efficiency of market competition through transmission and distribution; moreover, privatization attracts foreign investment and introduces state-of-the-art technologies in energy efficiency. Italy is expected to phase out subsidies and incentives to high energy-consuming industries, and its government encourages the development of carbon emission technologies and improved energy efficiency [25].

Table 2 also summarizes the MTRs in Asia during the research period. The number peaked in 2006 at 0.8741, and dropped to its slowest point in 2007 at 0.8413. The five-year mean was 0.8641. The countries with the highest group-frontier efficiency values are Armenia, Bangladesh, Brunei Darussalam, Cambodia, China, India, Indonesia, Japan, Mongolia, Singapore, Tajikistan, Turkey, Vietnam, and Bahrain. However, China and India are the major carbon emitting countries in Asia, and their carbon emissions have caused the global levels to increase. The rapid economic development in China has resulted in increased energy consumption, and the coal-centric energy mix used in the country has caused high-pollution and deteriorating air quality [56].

China is one of the largest greenhouse emitters in the world; however, pressured by the international community as a member of the global village, China has been incorporating climate change policies and energy efficient initiatives since the 115 Plan in 2006–2010. These measures include economic, social, and industrial aspects, and focus on energy conservation, efficiency, and alternative energy. The phasing-out of tired, inefficient, and uncompetitive steel, cement, paper, electrolytic coloring of aluminum, and thermal power plants helps to achieve energy efficiency targets. China is one of the efficient countries in this study, due to the government's efforts to promote industries in relation to energy efficiency and the certification system. Japan relies on exports to meet most of its energy needs, thus, the country has invested heavily in production technologies and innovations in energy efficiency, and encourages the development of eco-tourism and environmental sustainability.

It is expected that the carbon emissions of developing countries will surpass those by developed countries, as developing economies continue to grow at a rapid pace. In fact, going forward, the developing world must be committed to carbon reduction in global negotiations, in order that no developed country will be tempted to withdraw from the crusade against climate change by refusing to contribute climate funds or transfer technologies. The participation of developing countries is critical for effective solutions to climate change. It also presents an opportunity to step up environmental protection and social welfare. For governments, there are significant ex-post costs and expenses associated with climate change and pollution, as environmental damage to human life and the ecosystem are chronic and often irreversible. If relevant laws and regulations are less than robust or specific, policy efforts in energy efficiency and carbon reduction, via the closure of high emitting and high-energy-consumption capacities, will not achieve the desired outcome. In general, costs in relation to carbon reduction and energy efficiency exceed expectations in Asia. Policymakers must juggle between economic development and energy mix, as based on the conditions and specifics of each country. Governments should maximize the benefits of traditional energy sources, while gradually shifting to alternatives.

As mentioned by the European Union, the transition to a low-carbon economy is a global challenge, and signals the beginning of a new industrial revolution. The European Union extended great support to China's 115 Plan and its goal to reduce energy intensity by 20% in 2006–2010. The success of Europe's energy and environmental policies prove that it is possible to continue growth with social and economic benefits, as created by energy efficiency and renewable development. European lessons can serve as a template for Asia, and facilitate the establishment of a long-term institution of energy cooperation between Europe and Asia.

To understand whether the sampled European and Asian countries share the same group-frontier, this paper conducts non-parametric tests to examine the variances between operating performances and meta-technology ratios. Brocket and Golany [57] were the first scholars to apply non-parametric testing on the efficiency rankings produced by the DEA model. To examine the variances in energy policy effectiveness in Europe and Asia, this paper conducts Mann-Whitney testing. The null hypothesis (Ho) is described, as follows:

Ho: European and Asian countries, as two groups, share the same effectiveness in energy policy (measured with means and medians).

Test results are as shown in Table 3. The *p*-values of the tests on meta-technology ratios in 2006–2010 are markedly higher than the 0.05 criterion, indicating significant variances between Europe and Asia. Europe reports better MTEs than Asia in 2006–2008, although the mean values were lower than Asia in 2009–2010. In addition, Europe posted better MTRs than Asia throughout the research period. Non-parametric Mann-Whitney testing suggests that the variances in MTRs were meaningful in 2006–2010, and statistically significant.

Table 3. Test statistics.

Result	Euro/Asia [a]	2006	2007	2008	2009	2010
MTE	Mann-Whitney *U*	639.000	666.000	606.000	647.000	665.000
	Wilcoxon *W*	1342.000	1332.000	1309.000	1313.000	1368.000
	Z Test	–0.306	0.000	–0.689	–0.216	–0.011
	Significance (two-tailed)	0.760	1.000	0.491	0.829	0.991
MTR	Mann-Whitney *U*	423.500	373.000	419.000	353.000	465.000
	Wilcoxon *W*	1089.500	1039.000	1085.000	1019.000	1131.000
	Z Test	–3.027	–3.564	–3.114	–3.872	–2.378
	Significance (two-tailed)	0.002 **	0.000 ***	0.002 **	0.000 ***	0.017 *

[a] Group variable: Area; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Throughout the research period, the mean meta-efficiency ratios in Europe were all higher than those in Asia, which indicates that the production efficiency in Europe, as compared to Asia, is better and closer to the level of the meta-frontier. The maximum MTR for both Europe and Asia is 1, suggesting that the production frontier is tangential to the meta-frontier for both two groups. The lower MTRs in Europe (vs. Asia) imply that the production frontier of Asian countries is steeper.

This paper conducts slack variable analysis to examine the desired improvements and required adjustments to inputs and outputs in Europe and Asia. It is intended that the findings can serve as reference for policy making and goal setting. Table 4 details the room for improvement and possible changes for the inputs and outputs of inefficient countries. DEA Solver, a professional software program, can estimate the slack variable values required. For European countries, the room for improvement in energy consumption was 42.26% in 2006, which is equivalent to a reduction of 39,233 kg. Government expenditures could have been improved by 14.23%, or $79,928,246,271. The room for improvement in carbon emissions was 45.89%, which is approximately equal to 81,521 kt. The GDP could have been raised by 0.02%, or approximately $439,964,605,733. In general, economic activities in Asia are efficient, and there is no need to adjust inputs for GDP as an output. However, the reduction of carbon emissions decreased from 57.05% in 2006 to 49.92% in 2010, indicating inefficiency in environmental protection.

Table 4. Slack variable.

Area	Year	Labor Force	Energy Consumption	Government Expenditure	CO_2 Emission	GDP
Euro	2006	−59.05%	−42.26%	−14.23%	−45.89%	0.02%
	2007	−52.99%	−35.71%	−10.97%	−39.15%	0.00%
	2008	−50.62%	−33.49%	−9.35%	−35.58%	0.36%
	2009	−59.10%	−37.02%	−17.01%	−38.17%	0.00%
	2010	−59.23%	−37.84%	−15.09%	−39.30%	0.20%
Asia	2006	−53.24%	−48.44%	−7.56%	−57.05%	0.38%
	2007	−47.96%	−44.29%	−8.33%	−52.91%	0.00%
	2008	−46.84%	−36.85%	−6.87%	−45.34%	0.00%
	2009	−61.49%	−47.94%	−11.01%	−56.80%	0.00%
	2010	−52.88%	−41.03%	−8.73%	−49.92%	0.00%

5. Conclusions

A common concern for governments is that energy efficiency and carbon reduction may hinder economic growth. Hence, it is essential for policymakers to understand the relationship between labor force, energy consumption, and government expenditures as inputs, GDP as the desirable output, and CO_2 emissions as the undesirable output. Clarification of the causal relationship can serve as a template for policy decisions and ease concerns regarding the potential adverse effects of carbon reduction and energy efficiency on the economy. On the basis of the empirical results, this paper reaches the following conclusions and policy implications:

(1) Developing countries should establish their own climate change governance and policy frameworks

While Asian countries have been actively formulating their own climate change policies and governance frameworks over recent years, these efforts are largely passive in nature, and are in response to international negotiations. Thus, policy targets and implementations only meet the basic requirements of international covenants. This paper argues that developing countries should take on the challenge of designing their own climate change governance at a standard comparable to developed countries.

(2) Developed economies seek to lower carbon emissions

It is necessary for European countries to upgrade technologies, transform industrial structures, and formulate regulations to control energy prices and inflation, as well as to gradually mitigate energy dependency and lower carbon emissions. This means the regulations governing environmental protection and emissions must be robust and stringent. The downside is that energy consumption may be a limiting factor to economic growth.

(3) Energy policies play a pivotal role in energy efficiency improvement

The effective implementation of energy policies and efficiency programs underpins the public's responsibility, actions, and values. In both Europe and Asia, the pursuit of carbon reduction, via energy efficiency and renewable development, has been at the top of political agendas. Through concrete implementation of energy transformation policies, European countries must establish the reasons for their innovation and successful economic development. The transformation of energy systems will benefit the fight against climate change, accelerate a green economy, and guide other countries to make progress in green technological industries and economy. The success of Europe in climate change initiatives has important implications for the strategic development of Asian countries.

(4) Top-down efforts are critical to the success of carbon reduction policies

European countries should set a specific timetable and objective for carbon reduction, and distribute carbon reduction duties through top-down effects, which will help to monitor and facilitate achieving the objective. In recent years, it has been demonstrated that the technological advancements of energy, architecture, transportation, agriculture, fisheries, and manufacturing, which are driven by climate policies, are closely related to and promote the transformation of the current fossil fuels and black economy (high-pollution) into a green economy. If fiscal tax is taken as an incentive or punishment, it will involve an overall economic transformation. Thus, a combination of high-level decision-making and coordination among the different parts will facilitate change. Taking a top-down approach regarding the allocation of carbon reduction responsibilities, timeframes and targets in Europe is essential to the supervision and achievement of goals. The empirical findings of this paper suggest a high and sustained level of carbon emissions in Asia, particularly in China. The 115 Plan was the first time that the Chinese government put climate change policies at the top of its social and economic roadmap. The higher the government support and relevant expenditures, the better the efficiency of carbon emissions, and the greater the success of sustainable development.

(5) Learning from the success of developed countries helps to improve the effectiveness of energy policies

The high awareness of environmental protection and the robustness of the regulatory framework facilitate the effective implementation of policies in Europe, as industries must comply with relevant laws and meet market demands by constantly improving production technology and efficiency. Promoting economic development will reduce the effects of CO_2 emissions on the environment and improve energy consumption. As international energy prices fluctuate, increasing enterprises' use of efficient energy will bring indirect benefits and have significant effect on execution effectiveness. Most countries in Asia are still in the developing stage, and thus, have long prioritized economic growth; in fact, their commitment to environmental protection remains relatively weak. Nonetheless, the empirical findings of this paper suggest that it is possible to achieve a balance between economic growth and environmental protection. The experience of Europe can serve as a success story.

(6) Environmental policies should be formulated, and new production technologies, pollution prevention measures, and treatment methods should be introduced

Economic development has the greatest effects on environmental pollution. With the liberalization of international trade and the change to national industrial structures and trade policies, the increasingly rigorous economic development of different countries and frequent transnational trades must be led to gradually increase the demand for and use of energy, which will result in the scale back effect for deteriorating environments. Finally, the formulation of environmental policies and the introduction of new production technologies, pollution prevention measures, and treatment methods will reduce the technological effect of environmental pollution. When the structural and technological effects, which help alleviate environmental pollution, are stronger than the scale effect, environmental pollution will be reduced. In consideration of national sustainable development, economies should not be developed at the expense of the environment. The policymakers of different countries should establish definite mechanisms as early as possible to safeguard the environments of all regions and nations of the world.

(7) Governments are suggested to build long-term independent management institutions to promote energy cooperation and exchange

For the policymakers of different countries, the real challenge is how to achieve the macroscopic development of national economy, become acquainted with the subjective and objective conditions of different countries, and seek the best combination of traditional and alternative fuels. With the continuous global energy consumption and worsening greenhouse effects, it is predictable that all countries will pay special attention to energy development. To date, as Europe has formulated its energy environment policies, European and Asian countries should be encouraged to establish long-term independent management mechanisms regarding energy cooperation and exchange among different countries, thus, Europe will be able to share its experience with developing countries in Asia.

European governments have been expanding their energy mix, and the energy policies of 2006 articulated the goals of competitiveness, security, and sustainability. This paper suggests Asian countries could learn from the forward-looking approach of Europe in energy policies, economic development, and carbon and pollution reduction.

Acknowledgments: The authors are extremely grateful to the Sustainability journal editorial team and reviewers who provided valuable comments for improving the quality of this article. The authors also would like to thank the Ministry of Science and Technology of Taiwan for partially financial support of this research under Grant No: MOST105-2410-H-008-039.

Author Contributions: Wen-Hsien Tsai and Hsiu-Li Lee provided the research idea and the research purpose and designed the research; Hsiu-Li Lee, Chih-Hao Yang and Chung Chen Huang collected the data, analyzed the data and wrote the paper; Wen-Hsien Tsai provided the research method and supervised, corrected, and revised this paper. All authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. CCR Model

Charnes et al. [46] proposed a model assumed on constant return to scale (CRS), named the CCR model, which is only appropriate when all DMUs are operating at an optimal scale.

Banker et al. [48] assumes there are DMU_j (j = 1, 2, . . . , n) with m inputs X_{ij} (i = 1, 2, . . . , m) to produce s outputs Y_{rj} (r = 1, 2, . . . , s), and the relative efficiency score of the DMU_k is:

Min

$$h_k = \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)$$

S.T.

$$\sum_{j=1}^{n} \lambda_j X_{ij} - \theta X_{ik} + s_i^- = 0, i = 1, ..., m$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} - s_r^+ = Y_{rk}, r = 1, ..., s$$

$$\lambda_j, s_i^-, s_r^+ \geq 0, j = 1, ..., n, i = 1, ..., m, r = 1, ..., s$$

Y_{rj}: The r-th output of DMU_j

X_{ij}: The i-th input of DMU_j

u_r: The weight of the r-th output

V_i: The weight of the i-th input

θ: can be either positive or negative

s_i^-: slack

s_r^+: surplus

λ: the weights of efficient DMUs

Banker et al. [48] assume there is DMU_j (j = 1, 2, . . . , n) with m inputs X_{ij} (i = 1, 2, . . . , m) to produce s outputs Y_{rj} (r = 1, 2, . . . , s), and the input-oriented relative efficiency of DMU_k under the BCC model is:

Min

$$h_k = \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)$$

S.T.

$$\sum_{j=1}^{n} \lambda_j X_{ij} - \theta X_{ik} + s_i^- = 0, i = 1, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} - s_r^+ = Y_{rk}, r = 1, \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

Y_{rj}: The r-th output of DMU_j
X_{ij}: The i-th input of DMU_j
u_r: The weight of the r-th output
V_i: The weight of the i-th input
θ: can be either positive or negative
s_i^-: slack
s_r^+: surplus
$\lambda_j, s_i^-, s_r^+ \geq 0, j = 1, \ldots, n, i = 1, \ldots, m, r = 1, \ldots, s$
where the convexity constraint: $\sum_{j=1}^{n} \lambda_j = 1$ changes the CRS linear programming problem into VRS.

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