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An Empirical Analysis for Technical Efficiency of Bioenergy Industry in EU28 Region Based on Data Envelopment Analysis Method

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ABSTRACT

Over the last few years concerns have enhanced about the bioenergy industry as main source for renewable and sustainable energy in many countries. These concerns have been major magnitude for countries with joint green energy legislation such as European Union (EU) member states. A significant aspect to be considered when selecting a provided bioenergy is the efficiency involved in its production. In this context, the current study analyzes the technical efficiency (TE) components in bioenergy industry in EU28 region between 1990 and 2013. To this end, parametric and non-parametric frontier models are applied, where both are particularly appropriate in this special context due to their treatment of undesirable outputs. Results are presenting higher means for TE and pure TE in developing countries in compare with developed countries. In the other hand, scale efficiency mean presenting high value in developed countries in compare with developing ones.

Keywords: Bioenergy Industry, Technical Efficiency, EU28 Region
JEL Classifications: Q4, D61

1. INTRODUCTION

The world economy is on the edge of one of the biggest model transfer since the beginning of the industrial revolution worldwide. Wide convert from utilizing fossil fuel energy to renewable and sustainable energy, due to many serious reasons such as: Producing and consuming fossil fuels energy is enhancing relentlessly and along with the emission of climate killer CO_2. Moreover, traditional fossil fuel energy supplies can barely meet the world requirement for energy. Furthermore, as per the International Energy Agency report, by 2012 oil production will reach the peak and will not be able to meet the world demand (Geheeb, 2007). In addition, the price of energy imports has been increased significantly affecting the international market economies. Nevertheless, climate change caused by CO_2 emission is threating the renewable energy sources through destroying the natural resource and environment. The world society requires serious changes in energy systems, away from fossil fuel energy sources to a renewable and sustainable energy sources (Geheeb, 2007).

Bioenergy is one of the most sources of renewable and sustainable energy which can provide an essential contribution to supply future green energy in a sustainable approach. Bioenergy is the biggest world contributor of renewable and sustainable energy, and has an important role in different fields such as heating and cooling, electricity and power, and fuel for transportation. Biomass is the main source to produce bioenergy, presented by the organic raw materials and biological waste from different source (such as: Forestry, agriculture, food, fishery, municipality, etc.).

In 2010, National Renewable Energy Action Plan (NREAP) schedule gives detailed road maps of how the European Union (EU) countries can reach the 2020 targets, which can be summarized as follow: 20% mitigation of greenhouse gas emission in comparing with 1990 emission level, 20% increment of the portion of energy production from renewable energy sources, 20% reduction of energy consumption from conventional sources through increasing the efficiency. Scowcroft and Nies (2011) have indicated that bioenergy is a significant player to reach the 2020 (NREAP) targets. Also, Reddy and Assenza (2007) have pointed out that increasing energy efficiency can help to meet the gap between increased demand and shortage in supply without any change in the quality of produced energy. Based on Jossart and Calderon (2013), there is relation between the level of efficiency and the level of the country economic development, where developed EU countries have high level of efficiency presented in high production and export, less consumption and import, while developing countries have low level of efficiency presented in high consumption and import, less production and export (Burck et al., 2012).

The European Union (EU28) is an economic and political union of 28 countries or members. The EU countries manage a single and an internal market which authorize free transfer of goods, capital, services and citizens between EU member states. The latest statistics related to the Bioenergy balance in Europe in 2011 has showed that EU countries with high rate of efficiency in bioenergy production, such as: Bulgaria, Czech Republic, Estonia have registered high rate of efficiency in bioenergy production (electricity and heat sections in specific) with the average of (83.33%, 50.07%, 79.19%) respectively, have less import, more export, less final energy consumption and more primary energy production. On the other hand, countries with low rate of efficiency in bioenergy production for the same above fields, such as: Greece, Spain, Croatia have registered low rate of bioenergy efficiency in electricity and heat sections with the rate of (31.58%, 33.74%, 23.08%) respectively, have presented more import, less export, more final energy consumption and less primary energy production (Jossart and Calderon, 2013).

The need for efficiency in bioenergy industry has become a necessary requirement in the EU28 energy economic, due to the shortage in bioenergy production. For example the biofuel production in 2011 was (250.45 Thousand Barrels Per Day) which needs to be improved efficiently to meet the biofuel consumption (340.43 Thousand Barrels Per Day) in 2011. Moreover, the CO_2 emission increment from fossil fuel use has not decreased significantly since 1990 to meet the set (NREAPs) targets in 2020 (Scowcroft and Nies, 2011).

The inefficacy of bioenergy industry has affected EU28 countries economy negatively through; the over consumption of bioenergy and inability of bioenergy production to meet the required consumption. Moreover, failed to reach the (NREAP) 2020 targets as per the estimation of Scowcroft and Nies (2011) due to biomass supply gap, which is need to be imported from different regions for bioenergy production purpose. Furthermore, the mitigation of the CO_2 emission in EU28 region is unbalanced due to the over consumption and inefficient production of bioenergy (Scowcroft and Nies, 2011)

The main objective of this paper is to investigate the technical efficiency (TE) and analyze pertaining to the decomposition of bioenergy industry in the EU28 countries. While the output of this paper will identify which EU28 countries have high efficiency rate or low efficiency rate (inefficiency). Moreover, we will be able to recognize the factors behind the efficiency in bioenergy industry in some countries which will help to derive the required policies to improve the bioenergy industry process and obtain better efficiency in other inefficient countries. Furthermore, policy makers will be able to identify the needed policies and procedures in the bioenergy industry to develop and improve the bioenergy industry in EU28 region.

2. LITERATURE REVIEW

2.1. Empirical Review for Efficiency of Bioenergy Industry

In this part an empirical review for efficiency of bioenergy industry will be discussed in different regions/countries and sectors (electricity and power, heat and cooling, and transport) using different methods to measure the efficiency. In China, biomass is playing a main source for bioenergy production which presents the majority of renewable energy sources (Chang et al., 2013). However, bioenergy production could not meet the local demand in China for bioenergy due to the shortage of biomass. Therefore, China has transformed to become a net energy imported country (Chang et al., 2013). In South Africa, Winkler (2003) has granted with the other group of researchers regarding the importance of developing the renewable energy for electricity field to implement environmental, health and economical goals without losing sight of social development targets. Winkler (2003) has found that proper investment in renewable energy (bioenergy) and energy efficiency is significant to minimize the negative economic, social and environment effects from energy production. Scarlat et al. (2013) admits that bioenergy industry is a main player in the process to convert for renewable energy in electricity and power, heating and cooling, and transportations sectors in Italy and achieve the set targets to transform to green energy. In addition, biomass is anticipated to provide the largest source of renewable energy in Italy. Kythreotou et al. (2012) have analyzed the biomass potential for bioenergy production in Cyprus. However, the results indicated to that anaerobic digestion pertaining to bioenergy would give decentralization of bioenergy production in locations that are outlaying. Moreover, give the farms the opportunity to be energy self-governing and less impacted by the fuel prices variation. Balat and Balat (2009) have pointed that bioenergy (hydrogen energy) generated from biomass, organic and waste resources can provide an economical and environmental friendly energy output free of pollution, free of carbon, and can be utilized in household service, industry, and transports sectors. Shafie et al. (2012) has referred to that bioenergy is the highest potential energy source to meet the increasing demand for energy and provide a sustainable renewable energy security with proper environment protection in Malaysia. Berndes et al. (2009) has found that in 2nd generation of biofuel production output, there is an inverse relationship between the age of capital plant and the potential of bioenergy production. Evans et al. (2010) have found in their paper that the sustainable bioenergy production in Australia can be implemented through improving hardy crops on marginal or unutilized land. In Malaysia, Tye et al. (2011) has resulted that the second generation of bioethanol is considered significant, due to the potential as energy source for transportation sector and its long term strategies and development. Hu and Wang (2005) have analyzed in details the bioenergy efficiency for 29 regions in China for the period between 1995 and 2002. Empirically, there is an inverse relationship between the efficiency of energy production and used input (labor, capital stock, etc.) in the process of energy production.

2.2. Theoretical Review for Overall TE Approach

The study by Lee (2009) is among different studies which measured the operational efficiency of (173) medium- sized audit firms in 2005 by employing frontier efficiency approach. Lee (2009) has employed different parametric and non-parametric tests to a panel analysis for the studied sample. Lee (2009) has indicated that there are (24) audit firms with the overall TE value of (1 = fully efficient). In terms of overall TE, pure TE (PTE) and scale efficiency (SE), the result shows that the average SE of all samples is higher than the average PTE. By using the DEA statistical mathematic, Yudistira (2004) examines the efficiency the performance of (18) Islamic banks during the period between 1997 and 2000. Yudistira (2004) has found that the Islamic banks suffered slight of inefficiencies during the world crisis for the period between 1998 and 1999 due to pure technical inefficiency rather than scale inefficiency. In another study, Sufian (2007) supposed that the TE of Malaysian Islamic banks reduced during the period between 2002 and 2004. Sufian (2007) has found that the local Islamic banks were more technical efficient compared to foreign Islamic bank in Malaysia. Sufian (2007) has pointed that the source of technical inefficiency of Malaysian Islamic banks is SE but not PTE. Another study, Sufian and Haron (2008) has examined the efficiency of Islamic banks in the MENA (Middle East and North African) and Asian countries. By applying the DEA statistical mathematic Sufian and Haron (2008) evaluated the TE, PTE and SE. Sufian and Haron (2008) has found that pure technical inefficiency override scale inefficiency since Islamic banks were found to have been operating at a relatively optimal SE of operations but they were managerially inefficient to utilize their resources to the fullest. Sufian and Habibullah (2011) have examined the effect of economic freedom on bank efficiency in a developing economy. Sufian and Habibullah (2011) employed data envelopment analysis (DEA) statistical method to measure the TE of the Chinese banking industry for the period between 2000 and 2008. Sufian and Habibullah (2011) have founds that the inefficiency of the Chinese banking sector was major in SE than PTE.

3. RESEARCH METHOD

The present study collects data on the bioenergy industry from European Union (EU28) countries which are listed in Table 1, for the period between 1990 and 2013. The main source of biomass and bioenergy data is the EUROSTAT database produced by the European Union Commission which provides all related data for biomass and bioenergy industry. We obtained data related to the used input and output variables from EUROSTAT databases. The final sample comprised (23) member/country operating in EU28 Region, can be divided into (15) developed countries and (13) developing countries in EU28 Region (Table 1). All input and output have been converted to Thousand TOE (tonnes of oil equivalent) for the purpose of comparability.

Table 1: List of EU28 region member countries

European Union (EU28) region			
Developed countries (15)		Developing countries (13)	
Member countries	Year of entry	Member countries	Year of entry
Austria	1995	Bulgaria	2007
Belgium	1958	Croatia	2013
Denmark	1973	Cyprus	2004
Finland	1995	Czech Republic	2004
France	1958	Estonia	2004
Germany	1958	Hungary	2004
Greece	1981	Latvia	2004
Ireland	1973	Lithuania	2004
Italy	1958	Malta	2004
Luxembourg	1958	Poland	2004
Netherlands	1958	Romania	2007
Portugal	1986	Slovakia	2004
Spain	1986	Slovenia	2004
Sweden	1995		
United Kingdom	1973		

Source: Official Website of European Union (www.Europa.eu)

3.1. The DEA First Stage

The level of TE is identified by using the DEA statistical approach. The DEA statistical method builds a frontier of the observation of input and output ratio through linear programming techniques. The linear programming substitution is acceptable between observed input groups on an isoquant (the same volume of output is generated while amending the volume of two or more inputs) that was assumed by the DEA statistical method. Charnes et al. (1978) were the first to version for the method of DEA to scale the efficiency of each decision making unit (DMU), obtained as a maximum of a ratio of weighted outputs to weighted inputs. The more the output generated from provided inputs, the more efficient is the generation of the (DMU). This study applies efficiency assessment under the variable returns to measure (VRS) hypothesis. The VRS hypothesis was given by Banker et al. (1984). The Banker, Charnes, and Cooper (BCC) structured model (VRS) expanded the Charnes, Cooper, and Rhodes model which was first suggested by Charnes et al. (1978) by relieve the constant return to measure hypothesis. The found BCC model was applied to evaluate the efficiency of DMUs specified by VRS hypothesis. The VRS hypothesis gives the degree of PTE. PTE measure the efficiency of DMUs without getting infectious by scale effects.

Moreover, outcomes concluded from the VRS hypothesis gives extra trustworthy information on DMUs' efficiency compared to the constant return to scale (CRS) hypothesis (Coelli et al., 1998). The TE model is given in equation (1). As resulted, the technical, pure technical and SE scores are limited between the values (0) and (1) range. To choose optimum weights we selected the below mathematical programming problem:

$$\min_{u,y}\left(\frac{u^{'}y_i}{v^{'}x_i}\right), \quad \frac{u^{'}y_i}{v^{'}x_i}\leq 1, \quad j=1,2,...,n, \quad u,v\geq 0 \tag{1}$$

The above Equation1 has an issue to infinite solution and therefore we impose the constraint (v' xi = 1), which drives to:

$$\min_{u,\varphi}(u^{'}y_{1})\varphi^{'}x_{i,} = 1,\ \ u^{'}y_{1} - \varphi^{'}k_{i} \leq 0,\ \ j=1,2,...,N,\ \ \varphi,\mu \geq \quad (2)$$

In Equation 2 we have adjusted the notations to reverberate the conversion from (u) and (v) to the (μ) and (φ) respectively, employing the duality in linear programming, an equivalent envelopment method of this issue can be derived as follow:

$$\min_{\theta,\lambda}\theta,\ \ y_{i} + Y\lambda \geq 0,\ \ \theta x_{i} - X\lambda \geq 0,\ \ \lambda \geq 0 \quad (3)$$

Where (θ) is a scalar illustrating the value of the efficiency score for the (i^{th}) country will score between the values (0) and (1) (λ) is the vector of (N*1) constants. The linear programming has to be computed (N) times, once for each country in the EU region. Due to compute the TE under the hypothesis of VRS, the convexity constraint identify the how nearly the production function envelop the observed input and output integrations and is not required in the CRS situation (Sufian, 2009).

By computing the three efficiency measures (e.g., technical, pure technical, scale), we will be capable to observe a more robust result for the bioenergy industry developed and developing countries in EU28 region over the period under study between 1990 and 2013. However, the present study point's greater emphasis on the TE measure compared to the other decomposition efficiency measures (e.g., pure technical and scale).

3.2. The Input and Output Variables in DEA

Based on Cooper et al. (2002), there is a standard requirement to be met in order to choose the number of inputs and outputs. The basic rule formula which can give instruction can be presented as:

$$n \geq \max\{m * s, 3(m + s)\} \quad (4)$$

Where, (N) refer to the number of DMUs; (M) point to the number of inputs; and (S) indicate to the number of outputs. Given the underdevelopment of bioenergy industry in EU28, the importance of efficiency of bioenergy production is critical as a significant source of renewable and sustainable energy. Therefore, it is reasonable to suppose that the efficiency of bioenergy industry in terms of their intermediation function is crucial as an effective channel to provide energy for different sectors (power, electricity, heat, cold, and fuel) from renewable and sustainable sources. In this vein Chang et al. (2013) has pointed out that bioenergy industry play an important economic role in providing renewable and sustainable source of energy by converting biomass into energy and contribute to develop the economic sector.

Winkler (2003) has granted that the efficiency of renewable energy industry has also been shown to perform a critical role electricity field to implement environmental, health and economical goals without losing sight of social development targets. As confirmed by different scholars to the significant role of efficiency in bioenergy industry in the economic (Kythreotou et al., 2012; Scarlat et al., 2013; Balat and Balat, 2009; Shafie et al., 2012; Evans et al., 2010). Following Sufian (2008), Sufian and Habibullah (2013), Sufian and Kamurdin (2015), and Coelli (1996) among others, the present study uses the TE approach which views TE as the solution to develop the bioenergy industry in EU28 countries. Accordingly, three inputs and one output variables were chosen. The three input vector variables consist of x1: Raw material, x2: Labor and x3 physical capital, the output vector is y1: Production.

4. EMPIRICAL RESULTS AND DISCUSSION

Following many studies related to the same statistical approach such as Sufian and Kamurdin (2015), Gilani (2015), Omar and Jones (2015), Md and Kashfia (2015), and Sufian (2008). Table 2 shows the means of TE (0.77), and the decomposition of TE into SE (0.91) exceeded PTE (0.85) of EU28 zone of bioenergy industry for the period between 2000 and 2013, which can reflect the EU28 zone inefficiency for the same study period resulted as technical inefficiency (0.23), and the decomposition into pure technical inefficiency (0.15) overrides scale inefficiency (0.09). Table 2 shows the mean technical, pure technical and scale efficiencies of developing and developed countries in bioenergy for the period between 2000 and 2013 (for further details refer Appendix A and Appendix B).

The empirical findings seem to indicate that the developing countries have exhibited higher means in TE and PTE in compare with developed countries as follow and respectively: TE (0.80 vs. 0.75), PTE (0.89 vs. 0.80), but not SE where mean of developed countries is higher than developing countries as showed (0.90 vs. 0.91). Despite the fact that the empirical findings clearly highlight that both the developing and developed countries in bioenergy industry have not been fully efficient in producing outputs by using the available input resulted technical inefficiency, pure technical inefficiency, and scale inefficiency. In essence, the empirical findings seem to indicate that developing and developed countries have not fully utilized the inputs efficiently to produce the same outputs (technical inefficiency). Moreover, empirical results trend to indicate that developing and developed countries have not took the proper decision pertaining to both raw material and human resources properly (pure technical inefficiency). Also, empirical findings seem to indicate that developing and developed countries have not fully utilized the capital inputs efficiently to generate the same outputs (scale inefficiency). The empirical findings given in Table 2 clearly indicate that in developing and developed countries the level of technical inefficiencies are (0.20 vs. 0.25), pure technical inefficiencies are (0.11 vs. 0.20), scale inefficiencies are (0.10 vs. 0.09) respectively.

As for TE, the average developing and developed countries could only generate (0.80 vs. 0.75) of output, less than what it was initially expected to generate. Hence, TE is lost by (0.20 vs. 0.25) indicating that the average developing and developed countries loses an opportunity to receive (0.20 vs. 0.25) more output given the same amount of resources, or it could have produced (0.20 vs. 0.25) of its outputs given the same level of inputs. This result shows that the developing countries are generating more output and experiences less loses of input compared to the developed countries for the period between 2000 and 2013, as the level of the TE in the developing countries is higher than that of developed countries.

Table 2: Average of technical efficiency of bioenergy industry in EU28 over 2000-2013

Year	Efficiency	Average of developing countries by year	Average of developed countries by year	Average of EU28 by year
2000	TE	0.80	0.74	0.77
	PTE	0.90	0.82	0.86
	SE	0.90	0.87	0.89
2001	TE	0.83	0.75	0.79
	PTE	0.91	0.79	0.85
	SE	0.92	0.92	0.92
2002	TE	0.86	0.76	0.81
	PTE	0.93	0.80	0.86
	SE	0.93	0.92	0.93
2003	TE	0.82	0.72	0.77
	PTE	0.92	0.78	0.85
	SE	0.90	0.90	0.90
2004	TE	0.82	0.73	0.77
	PTE	0.90	0.81	0.86
	SE	0.91	0.88	0.89
2005	TE	0.81	0.72	0.77
	PTE	0.90	0.83	0.87
	SE	0.91	0.85	0.88
2006	TE	0.82	0.75	0.79
	PTE	0.90	0.79	0.84
	SE	0.92	0.93	0.93
2007	TE	0.80	0.74	0.77
	PTE	0.89	0.81	0.85
	SE	0.90	0.89	0.90
2008	TE	0.79	0.75	0.77
	PTE	0.88	0.81	0.84
	SE	0.90	0.92	0.91
2009	TE	0.77	0.75	0.76
	PTE	0.88	0.80	0.84
	SE	0.88	0.93	0.91
2010	TE	0.77	0.75	0.76
	PTE	0.88	0.80	0.84
	SE	0.88	0.93	0.91
2011	TE	0.74	0.73	0.74
	PTE	0.85	0.78	0.81
	SE	0.88	0.94	0.91
2012	TE	0.78	0.75	0.76
	PTE	0.87	0.81	0.84
	SE	0.91	0.93	0.92
2013	TE	0.81	0.81	0.81
	PTE	0.90	0.83	0.86
	SE	0.91	0.97	0.94
Average by group type	TE	0.80	0.75	0.77
	PTE	0.89	0.80	0.85
	SE	0.90	0.91	0.91

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Regarding PTE, the results indicate that, on average, developing and developed countries have utilized only (0.89 vs. 0.80) of the resources or inputs to produce the same level of outputs. In other words, on average, both of developing and developed countries have wasted (0.11 vs. 0.20) of its inputs, or it could have saved (0.11 vs. 0.20) of its inputs to produce the same level of outputs. Noticeably, the level of the PTE is higher in developing countries rather than developed countries.

This indicates that the developing countries are capable to utilize the minimum resources and involve with lower wastage of inputs. While, developed countries shows that they are utilizing a large volume of resources to produce outputs that lead to the higher wastage inputs for the study period between 2000 and 2013. For the SE, the results seem to suggest that the average developing and developed countries could only utilize (0.90 vs. 0.91) of what was available. Therefore, both developing and developed countries lost the opportunity to generate (0.10 vs. 0.09) more optimal outputs from the minimum level of inputs that may lead to higher SE. The results state that the level of SE is higher in the developed countries compared to that in the developing countries. This implies that developed countries are capable of producing more outputs by utilizing less input to generate higher SE. Meanwhile, developing countries are utilizing more inputs and produce fewer outputs that may lead to the lower SE (Table 2).

For the period between 1990 and 1999, the results present the means of TE (0.71), and the decomposition into SE (0.91) exceeded PTE (0.78) of EU28 zone of bioenergy industry for the period between 1990 and 1999, which can reflect the EU28 zone inefficiency for the same study period resulted as technical inefficiency (0.29), and the decomposition into pure technical inefficiency (0.22) overrides scale inefficiency (0.09). In the period between 1990 and 1999, the empirical findings seem to indicate that the developing countries have exhibited higher means in TE and PTE in compare with developed countries as follow and respectively: TE (0.75 vs. 0.67), PTE (0.84 vs. 0.72), but not SE where mean of developed countries is equal to the one in developing countries as showed (0.91 vs. 0.91) (Appendix E).

Despite the fact that the empirical findings clearly highlight that both the developing and developed countries in bioenergy industry have not been fully efficient in producing outputs by using the available input resulted technical inefficiency, pure technical inefficiency, and scale inefficiency. The empirical findings are clearly indicates that in developing and developed countries the level of technical inefficiency is (0.25 vs. 0.33), pure technical inefficiency is (0.16 vs. 0.28), scale inefficiency is (0.09 vs. 0.09) respectively for the period between 1990 and 1999 (Appendix C and D).

5. RUBOSTNESS TESTS

After examining the results derived from the DEA method, the issue of interest now is whether the difference in the TE, PTE, and SE of developing and developed countries is statistically significant. Mann–Whitney Wilcoxon test is a relevant test for two independent samples coming from populations having the same distribution. The most relevant reason is that the data violate the stringent assumptions of the independent group’s t-test. In what follows, we perform the non-parametric Mann–Whitney Wilcoxon test along with a series of other parametric (t-test) and non-parametric Kruskall–Wallis tests to obtain more robust results. Table 3 shows detailed robustness tests for developing and developed countries in bioenergy industry between the period 2000 and 2013. Based on Table 4, the results from the parametric t-test for the period between 2000 and 2013 suggest that the developing countries have exhibited a higher mean TE level compared to the developed countries (0.804 > 0.745). which statically insignificant because P value is greater than the significant level at 10%

Table 3: Details of parametric and non-parametric mean tests during 2000-2013

Year	Group	Summary of parametric and non–parametric tests																	
		Parametric test						Non-paramentric test											
		t–test						Mann–Whitney Wilcoxon test						Kruskal–Wallis					
		TE	t	PTE	t	SE	t	TE	Z	PTE	Z	SE	Z	TE	Chi-square	PTE	Chi-square	SE	Chi-square
2000	Developing	0.807	0.250	0.902	0.062	0.899	0.428	14.810	–0.303	15.380	–0.744	13.230	–0.785	14.810	0.035	15.380	0.312	13.230	0.617
	Developed	0.738		0.815		0.872		14.230		13.730		15.600		14.230		13.730		15.600	
2001	Developing	0.829	0.163	0.912	0.021	0.916	0.719	15.000	–0.326	15.690	–0.413	13.540	–0.222	15.000	0.092	15.690	0.553	13.540	0.379
	Developed	0.748		0.791		0.921		14.070		13.470		15.330		14.070		13.470		15.330	
2002	Developing	0.858	0.319	0.925	0.030	0.932	0.683	16.120	–0.998	16.420	–1.252	14.850	–0.242	16.120	0.996	16.420	1.567	14.850	0.059
	Developed	0.761		0.803		0.922		13.100		12.830		14.200		13.100		12.830		14.200	
2003	Developing	0.822	0.187	0.922	0.023*	0.899	0.845	16.310	–1.101	16.920	–1.551	14.880	–0.243	16.310	1.212	16.920	2.407	14.880	0.059
	Developed	0.721		0.785		0.896		12.930		12.400		14.170		12.930		12.400		14.170	
2004	Developing	0.817	0.230	0.903	0.090	0.912	0.551	15.960	–0.890	16.500	–1.282	15.650	–0.720	15.960	0.793	16.500	1.644	15.650	0.518
	Developed	0.727		0.808		0.876		13.230		12.770		13.500		13.230		12.770		13.500	
2005	Developing	0.815	0.481	0.903	0.162	0.909	0.464	15.920	–0.867	15.580	–0.690	15.580	–0.672	15.920	0.752	15.580	0.476	15.580	0.452
	Developed	0.725		0.832		0.852		13.270		13.570		13.570		13.270		13.570		13.570	
2006	Developing	0.813	0.379	0.898	0.170	0.912	0.500	15.420	–0.562	15.920	–0.911	14.540	–0.026	15.420	0.316	15.920	0.830	14.540	0.001
	Developed	0.760		0.799		0.933		13.700		13.270		14.470		13.700		13.270		14.470	
2007	Developing	0.801	0.458	0.895	0.046	0.903	0.886	15.420	–0.562	15.690	–0.763	15.350	–0.516	15.420	0.316	15.690	0.583	15.350	0.266
	Developed	0.736		0.807		0.892		13.700		13.470		13.770		13.700		13.470		13.770	
2008	Developing	0.805	0.644	0.838	0.870	0.962	0.057*	15.120	–0.377	15.770	–0.812	14.270	–0.146	15.120	0.142	15.770	0.660	14.270	0.021
	Developed	0.699		0.804		0.864		13.970		13.400		14.700		13.970		13.400		14.700	
2009	Developing	0.775	0.833	0.881	0.199	0.886	0.322	14.810	–0.187	16.040	–0.985	12.650	–1.152	14.810	0.035	16.040	0.971	12.650	1.328
	Developed	0.749		0.800		0.934		14.230		13.170		16.100		14.230		13.170		16.100	
2010	Developing	0.773	0.591	0.868	0.220	0.899	0.220	13.960	–0.326	15.190	–0.432	12.730	–1.117	13.960	0.107	15.190	0.187	12.730	1.248
	Developed	0.783		0.807		0.964		14.970		13.900		16.030		14.970		13.900		16.030	
2011	Developing	0.743	0.593	0.852	0.157	0.884	0.073	14.540	–0.023	15.540	–0.642	11.650	–1.798*	14.540	0.001	15.540	0.412	11.650	3.231*
	Developed	0.733		0.779		0.946		14.470		13.600		16.970		14.470		13.600		16.970	
2012	Developing	0.779	0.291	0.867	0.051	0.907	0.231	15.080	–0.349	15.380	–0.566	14.190	–0.192	15.080	0.122	15.380	0.321	14.190	0.037
	Developed	0.745		0.809		0.928		14.000		13.730		14.770		14.000		13.730		14.770	
2013	Developing	0.815	0.434	0.815	0.105	0.913	0.001	14.230	–0.165	15.460	–0.607	13.920	–0.383	14.230	0.027	15.460	0.368	13.920	0.147
	Developed	0.810		0.810		0.974		14.730		13.670		15.000		14.730		13.670		15.000	
2012	Developing	0.779	0.636	0.867	0.451	0.907	0.619	15.080	0.727	15.380	0.571	14.190	0.848	15.080	0.727	15.380	0.571	14.190	0.848
	Developed	0.745		0.809		0.928		14.000		13.730		14.770		14.000		13.730		14.770	
2013	Developing	0.815	0.945	0.815	0.342	0.913	0.137	14.230	0.869	15.460	0.544	13.920	0.702	14.230	0.869	15.460	0.544	13.920	0.702
	Developed	0.810		0.810		0.974		14.730		13.670		15.000		14.730		13.670		15.000	

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency, ***,** and*: indicate significance at the 1%, 5%, and 10% levels respectively

Table 4: Summary of parametric and non-parametric mean tests during 2000-2013

Test groups (2000-2013)	Parametric test		Non-parametric test			
Individual test	t-test		Mann–Whitney [Wilcoxon] test		Kruskall–Wallis test	
Hypothesis test	t-test		Median developed and developing		Equality of populations test	
Test statistics	**t (P>t)**		**z (P>z)**		**χ^2 (P>χ^2)**	
	Mean	**t**	**Mean rank**	**z**	**Mean rank**	**χ^2 (P>χ^2)**
TE						
Developing countries	0.804	0.418	15.193	–0.503	15.193	0.353
Developed countries	0.745		13.900		13.900	
PTE						
Developing countries	0.884	0.158*	15.820	–0.832	15.820	0.807
Developed countries	0.804		13.356		13.356	
SE						
Developing countries	0.909	0.427*	14.470	–0.587*	14.074	0.597*
Developed countries	0.912		14.870		14.870	

Note: ***, ** and * indicate significance at the 1%, 5%, and 10% levels respectively, TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Likewise, the developing countries have also exhibited a higher mean PTE level compared to the developed countries (0.884 > 0.804), which statically insignificant because P value is greater than the significant level at 10% statistically significant at the 10% level. In the other hand, the developing countries have exhibited lower mean SE level compared to the developed countries (0.909 > 0.912) which statically insignificant because P value is greater than the significant level at 10%.

As per Table 4, the results from the non-parametric test Mann–Whitney Wilcoxon test for the period between 2000 and 2013 suggest that the developing countries have exhibited a higher mean TE level compared to the developed countries (15.193 > 13.900) which statically insignificant because P value is greater than the significant level at 10%. Likewise, the developing countries have also exhibited a higher mean PTE level compared to the developed countries (15.820 > 13.356) which statically insignificant because P value is greater than the significant level at 10%. In the other hand, the developing countries have exhibited lower mean SE level Compared to the developed countries (14.470 > 14.480) which statically insignificant because P value is greater than the significant level at 10%, statistically significant at the 10% level. As per Table 4, the results from the non-parametric test Kruskall–Wallis test for the period between 2000 and 2013 suggest that the developing countries have exhibited a higher mean TE level compared to the developed countries (15.193 > 13.900) which statically insignificant because P value is greater than the significant level at 10%. Likewise, the developing countries have also exhibited a higher mean PTE level compared to the developed countries (15.820 > 13.356) which statically insignificant because P value is greater than the significant level at 10%. In the other hand, the developing countries have exhibited lower mean SE level compared to the developed countries (14.470 > 14.074) which statically insignificant because P value is greater than the significant level at 10%, statistically significant at the 10% level.

Regarding the period between 1990 and 1999, the results from t-test parametric test, non-parametric Mann–Whitney Wilcoxon test, and Kruskall–Wallis test suggests that the developing countries have exhibited a higher means TE and PTE level compared to the developed countries, statistically significant at the 5%, 10% and 10% levels respectively. On the other hand, the results from t-test parametric test, non-parametric Mann–Whitney Wilcoxon test, and Kruskall–Wallis test suggests that the developing countries have exhibited a lower means SE level compared to the developed countries for the period between 1990 and 1999 (Appendix F and G).

In t-test for the year 2000, the mean of TE is statistically insignificance, because p-value is greater than the significant level at 10% as follow 0.514 > 0.1, where PTE is statistically insignificance because P value is greater than the significant level at 10% as follow 0.262 > 0.1, while SE is statistically insignificance, because P value is greater than the significant level at 10% as follow 0.761 > 0.10. Moreover, in Mann–Whitney test for the same year 2000, the mean of TE is statistically insignificance, because P value is greater than statistical level at 10% as follow 0.864 > 0.1, where PTE is statistically insignificance because P value is lesser than the significant level at 10% as follow 0.577 > 0.1, while SE is statistically insignificant because P value is greater than the significant level at 10% as follow 0.432 > 0.10. Furthermore, in Kruskal–Wallis test for the same year 2000, the mean of TE is statistically insignificance because P value is greater than the statistical level at the level 10% as follow 0.854 > 0.1, where PTE is statistically insignificance because P value is greater than the statistical level at 10% as follow 0.577 > 0.1, while SE is statistically insignificant because P value is greater than the significant level at 10% as follow 0.432 > 0.10.

In 2006, t-test results have presented that means of TE, PTE and SE are statistically insignificance because of P values are greater than the statistical level at 10% as follow 0.554 > 0.10, 0.227 > 0.10 and 0.734 > 0.10 respectively. Moreover, in Mann Whitney test for the same year 2006, the results have indicated to TE, PTE and SE are statistically insignificance because of P values are greater than the statistical level at 10% as follow 0.574 > 0.10, 0.362 > 0.10 and 0.980 > 0.10 respectively. Furthermore, in Kruskal–Wallis test for the same year 2006, the results have indicated to TE, PTE and SE are statistically insignificance because of P values are greater than the statistical level at 10% as follow 0.574 > 0.10, 0.362 > 0.10 and 0.980 > 0.1) respectively.

In t-test for the year 2013, TE is statistically insignificance because of P value is greater than the statistical level at 10% as follow

0.945 > 0.10, where PTE is statistically insignificance because of P value is greater than the statistical level at 10% as follow 0.342 > 0.1, while (SE) is statistically insignificance because of P value is greater than the statistical level at 10% as follow 0.137 > 0.10. Moreover, in Mann–Whitney test and Kruskal–Wallis test for the year 2013 the results have referred to that TE, PTE and SE are statistically insignificance because the P values are greater that the statistical level at 10% as follow 0.869 > 0.10, 0.544 > 0.10 and 0.702 > 0.10 respectively.

6. CONCLUSION AND POLICY IMPLICATIONS

The paper has attempted to investigate the efficiency of EU28 bioenergy industry during the period between 1990 and 2013. The employed non-parametric DEA method has gave us the chance to distinguish between three distinction kinds of efficiency which are technical, pure technical and scale efficiencies. Moreover, we have applied a series of parametric and non-parametric tests to examine whether the developing and developed countries were drawn from the same population. Finally, we have employed non parametric tests (Mann–Whitney U and Kruskal–Wallis tests) and parametric test (t-test). For the period between 2000 and 2013, we have resulted that the mean of TE in developing countries is higher than the one in developed countries in EU28 Region, suggesting minimal waste of inputs by developing countries lower than the one in developed countries. Overall, our results suggest that the mean of SE dominates PTE effects in determining EU28 developing countries in TE. Moreover, our results suggest that SE dominates the PTE effects in determining EU28 developed countries in TE. In EU28 and for the same study period between 2000 and 2013, bioenergy industry has exhibited relatively higher efficient in developing countries than developed countries during the same study period.

Our findings through robustness test have indicated to that in TE from the parametric and non-parametric tests in Table 4 rejected the null hypothesis and accepted the alternative hypothesis due to that the average means of TE in developing and developed countries are different and statistically insignificant because P value is greater than the statistical level at 10%. Moreover, the results for PTE from the parametric and non-parametric tests in Table 4 have rejected the null hypothesis and accepted the alternative hypothesis due to that the average means of PTE in developing and developed countries are different and statistically insignificant because P value is greater than the statistical level at 10% in the different employed t-test, Mann–Whitney U test and Kruskal–Wallis test respectively. Nevertheless, the results for SE from the parametric and non-parametric tests in Table 4 have rejected the null hypothesis and accepted the alternative hypothesis due to that the average means of SE in developing and developed countries are different and statistically insignificant because P value is greater than the statistical level at 10%.

The finding shows that in developing and developed countries SE is dominating PTE. Moreover, the contributing of pure technical inefficiency is outweighs scale inefficiency in EU28 bioenergy industry. Therefore, our results do not support further increasing in the size of the plants, because in further enhance in size will only result smaller enhance in output for every proportionate enhance in inputs, giving from the fact that EU28 bioenergy industry has been producing at decreasing returns to scale between the period 2000 and 2013, but our results recommend more efforts to be given to the top management and decision makers with regard to attaining optimal utilization of capacity, improvement in managerial and skills expertise, efficiency allocation of available resources and most productive scale in production of bioenergy industry in EU28, which may facilitate directions for sustainable competitiveness on bioenergy industry in the future. Furthermore, our results from the parametric and non-parametric tests could reject relatively the null hypothesis (6 results) that the means of TE in developing and developed countries are not the same (different) and were drawn from the different population.

Due to the study limitations, the current study may be expanded in different of ways. First, if information on input prices is available, further analysis could be performed to investigate the overall cost efficiency decomposition TE and allocative efficiency. Second, interested researchers may employ the malmquist productivity index method to examine the sources of total factor productivity changes of bioenergy industry in EU28 countries. Third, to obtain more robust results, empirical findings from the current study could be compared to the results derived from improved statistical methods, i.e., Bootstrap DEA.

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APPENDICES

Appendix A: Technical efficiency of bioenergy industry in developing countries during 2000-2013

Year	2000			2001			2002			2003			2004		
Country	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
Bulgaria	0.50	0.51	0.98	0.52	0.52	1.00	0.53	0.53	1.00	0.53	0.54	1.00	0.52	0.52	0.99
Czech	0.73	0.78	0.93	0.77	0.83	0.92	0.78	0.87	0.90	0.77	1.00	0.77	0.82	1.00	0.82
Estonia	0.78	0.87	0.89	0.77	0.87	0.89	0.77	0.87	0.89	0.72	0.83	0.87	0.73	0.83	0.88
Croatia	0.94	0.94	0.99	0.98	0.98	1.00	0.94	0.95	1.00	0.88	0.96	0.92	0.93	0.97	0.96
Cyprus	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lithuania	1.00	1.00	1.00	0.97	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hungary	0.69	0.70	0.99	0.76	0.76	1.00	0.81	0.81	1.00	0.81	0.81	1.00	0.81	0.81	1.00
Malta	0.88	0.95	0.93	0.93	0.97	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Poland	0.98	1.00	0.98	0.93	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Romania	0.92	0.98	0.93	0.89	0.99	0.90	1.00	1.00	1.00	0.76	0.84	0.91	0.61	0.61	1.00
Slovenia	0.14	1.00	0.14	0.41	1.00	0.41	0.39	1.00	0.39	0.39	1.00	0.39	0.38	1.00	0.38
Slovakia	0.93	1.00	0.93	0.85	1.00	0.85	0.93	1.00	0.93	0.83	1.00	0.83	0.82	1.00	0.83
Average by year	0.80	0.90	0.90	0.83	0.91	0.92	0.86	0.93	0.93	0.82	0.92	0.90	0.82	0.90	0.91
Year	**2005**			**2006**			**2007**			**2008**			**2009**		
Country	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**
Bulgaria	0.52	0.53	0.98	0.52	0.52	1.00	0.51	0.51	0.99	0.52	0.52	0.99	0.52	0.52	0.99
Czech	0.82	1.00	0.82	0.84	1.00	0.84	0.81	1.00	0.81	0.76	1.00	0.76	0.79	1.00	0.79
Estonia	0.70	0.84	0.84	0.75	0.88	0.85	0.77	0.89	0.87	0.74	0.85	0.87	0.74	0.96	0.77
Croatia	0.94	0.99	0.96	0.78	0.82	0.95	0.79	0.82	0.97	0.78	0.80	0.97	0.71	0.76	0.94
Cyprus	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lithuania	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	1.00	0.90
Hungary	0.91	0.92	0.99	0.92	0.93	1.00	0.93	0.96	0.97	0.85	0.88	0.96	0.73	0.78	0.93
Malta	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Poland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Romania	0.56	0.56	1.00	0.62	0.62	1.00	0.58	0.59	0.99	0.63	0.63	1.00	0.63	0.66	0.96
Slovenia	0.37	1.00	0.37	0.50	1.00	0.50	0.34	1.00	0.34	0.36	1.00	0.36	0.46	1.00	0.46
Slovakia	0.77	0.90	0.85	0.71	0.91	0.78	0.68	0.86	0.80	0.64	0.79	0.81	0.60	0.77	0.78
Average by year	0.81	0.90	0.91	0.82	0.90	0.92	0.80	0.89	0.90	0.79	0.88	0.90	0.77	0.88	0.88
Year	**2010**			**2011**			**2012**			**2013**			**Average by country**		
Country	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**
Bulgaria	0.52	0.52	0.99	0.45	0.45	1.00	0.45	0.45	1.00	0.45	0.45	1.00	0.50	0.51	0.99
Czech	0.79	1.00	0.79	0.75	1.00	0.75	0.77	1.00	0.77	0.79	1.00	0.79	0.78	0.96	0.82
Estonia	0.74	0.96	0.77	0.72	0.93	0.77	0.76	0.91	0.84	0.92	0.99	0.93	0.76	0.89	0.85
Croatia	0.71	0.76	0.94	0.72	0.78	0.92	0.72	0.75	0.95	0.85	0.85	1.00	0.83	0.87	0.96
Cyprus	1.00	1.00	1.00	0.95	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lithuania	0.90	1.00	0.90	0.88	1.00	0.88	0.83	1.00	0.83	0.69	0.91	0.76	0.94	0.99	0.94
Hungary	0.73	0.78	0.93	0.72	0.73	0.99	0.76	0.76	1.00	0.86	0.86	1.00	0.81	0.82	0.98
Malta	1.00	1.00	1.00	0.82	0.84	0.98	0.85	0.87	0.98	1.00	1.00	1.00	0.96	0.97	0.99
Poland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00
Romania	0.63	0.66	0.96	0.59	0.60	0.99	0.72	0.72	1.00	0.78	0.79	1.00	0.71	0.73	0.97
Slovenia	0.46	1.00	0.46	0.51	1.00	0.51	0.63	1.00	0.63	0.61	1.00	0.61	0.42	1.00	0.42
Slovakia	0.60	0.77	0.78	0.55	0.78	0.71	0.64	0.81	0.79	0.65	0.84	0.78	0.73	0.89	0.82
Average by year	0.77	0.88	0.88	0.74	0.85	0.88	0.78	0.87	0.91	0.81	0.90	0.91	0.80	0.89	0.90

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Appendix B: Technical efficiency of bioenergy industry in developed countries over 2000-2013

Year	2002			2003			2004			2005			2006		
Country	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
Belgium	0.69	0.69	0.99	0.67	0.68	0.99	0.60	0.61	0.98	0.58	0.60	0.97	0.52	0.52	1.00
Denmark	0.63	0.63	1.00	0.52	0.53	0.97	0.52	0.61	0.85	0.52	0.68	0.76	0.60	0.60	1.00
Germany	0.80	0.81	0.98	0.77	0.84	0.93	0.76	0.78	0.98	0.84	0.84	1.00	0.82	0.85	0.96
Ireland	1.00	1.00	1.00	0.88	1.00	0.88	1.00	1.00	1.00	0.91	1.00	0.91	0.83	1.00	0.83
Greece	0.38	0.41	0.93	0.36	0.41	0.88	0.43	0.49	0.88	0.41	0.49	0.83	0.42	0.45	0.93
Spain	0.61	1.00	0.61	0.58	0.96	0.60	0.47	1.00	0.47	0.56	1.00	0.56	0.87	1.00	0.87
France	0.77	0.77	1.00	0.75	0.75	1.00	0.74	0.74	1.00	0.69	0.69	1.00	0.65	0.65	1.00
Italy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luxembourg	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Netherlands	0.90	0.90	1.00	0.99	1.00	0.99	0.88	0.92	0.95	0.77	0.93	0.83	1.00	1.00	1.00
Austria	0.08	0.23	0.36	0.11	0.27	0.39	0.07	0.37	0.19	0.04	0.56	0.07	0.12	0.24	0.51
Portugal	0.60	0.60	1.00	0.56	0.56	1.00	0.60	0.61	0.99	0.66	0.69	0.96	0.68	0.68	1.00
Finland	0.95	1.00	0.95	0.62	0.77	0.81	0.92	1.00	0.92	1.00	1.00	1.00	0.93	1.00	0.93
Year	2007			2008			2009			2010			2011		
Country	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
Belgium	0.55	0.56	0.98	0.62	0.62	0.99	0.66	0.66	1.00	0.66	0.66	1.00	0.68	0.68	1.00
Denmark	0.54	0.65	0.83	0.57	0.63	0.90	0.66	0.66	1.00	0.66	0.66	1.00	0.53	0.53	1.00
Germany	0.82	0.86	0.95	0.86	0.86	0.99	0.66	0.67	0.99	0.66	0.67	0.99	0.70	0.70	1.00
Ireland	0.87	1.00	0.87	0.88	1.00	0.88	0.80	1.00	0.80	0.80	1.00	0.80	0.74	1.00	0.74
Greece	0.38	0.43	0.89	0.46	0.57	0.82	0.48	0.65	0.74	0.48	0.65	0.74	0.45	0.51	0.89
Spain	0.66	1.00	0.66	0.65	1.00	0.65	0.73	1.00	0.73	0.73	1.00	0.73	0.73	1.00	0.73
France	0.62	0.63	0.99	0.68	0.68	1.00	0.68	0.71	0.96	0.68	0.71	0.96	0.73	0.80	0.92
Italy	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	0.96	0.96	1.00	0.96	1.00	1.00	1.00
Luxembourg	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Netherlands	0.95	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.95	1.00
Austria	0.13	0.37	0.35	0.19	0.35	0.54	0.23	0.27	0.83	0.23	0.27	0.83	0.22	0.24	0.91
Portugal	0.68	0.68	0.99	0.70	0.70	1.00	0.62	0.63	1.00	0.62	0.63	1.00	0.68	0.68	1.00
Finland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Year	2012			2013			Average								
Country	TE	PTE	SE	TE	PTE	SE									
Belgium	0.67	0.67	1.00	0.74	0.74	1.00	0.76								
Denmark	0.59	0.59	0.99	0.54	0.54	0.99	0.71								
Germany	0.65	0.67	0.97	0.70	0.71	0.98	0.83								
Ireland	0.79	1.00	0.79	1.00	1.00	1.00	0.92								
Greece	0.53	0.62	0.86	0.58	0.60	0.97	0.61								
Spain	0.72	1.00	0.72	0.83	1.00	0.83	0.78								
France	0.88	1.00	0.88	0.96	0.99	0.97	0.82								
Italy	1.00	1.00	1.00	1.00	1.00	1.00	0.99								
Luxembourg	1.00	1.00	1.00	1.00	1.00	1.00	1.00								
Netherlands	1.00	1.00	1.00	1.00	1.00	1.00	0.97								
Austria	0.25	0.28	0.92	0.20	0.22	0.89	0.34								
Portugal	0.65	0.65	1.00	0.76	0.76	1.00	0.77								
Finland	0.80	1.00	0.80	1.00	1.00	1.00	0.96								

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Appendix C: Technical efficiency of bioenergy industry in developing countries over 1990-1999

Year	1990			1991			1992			1993		
Country	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
Bulgaria	0.53	0.53	1.00	0.54	0.54	1.00	0.54	0.54	1.00	0.50	0.50	1.00
Czech	0.54	0.54	1.00	0.53	0.53	1.00	0.56	0.57	0.98	0.52	0.59	0.88
Estonia	1.00	1.00	1.00	1.00	1.00	1.00	0.82	1.00	0.82	1.00	1.00	1.00
Croatia	0.88	0.90	0.98	0.81	0.81	1.00	0.88	0.88	1.00	0.82	0.83	1.00
Cyprus	0.83	0.83	1.00	0.78	0.78	1.00	0.88	0.88	1.00	0.98	0.98	1.00
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lithuania	0.52	0.52	1.00	0.54	0.54	1.00	0.70	0.70	1.00	0.55	0.69	0.80
Hungary	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.79	0.94	0.84
Malta	0.28	0.29	1.00	0.28	0.28	1.00	0.53	0.53	1.00	0.54	0.55	0.98
Poland	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.90	0.99	0.85	0.85	0.99
Romania	0.89	0.90	0.99	0.57	0.57	1.00	0.52	0.52	1.00	0.71	0.71	1.00
Slovenia	0.42	1.00	0.42	0.47	1.00	0.47	0.50	1.00	0.50	0.09	1.00	0.09
Slovakia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.44	0.65	0.69
Average by year	0.76	0.81	0.95	0.73	0.77	0.96	0.75	0.81	0.94	0.68	0.79	0.87
Year	**1994**			**1995**			**1996**			**1997**		
Country	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**
Bulgaria	0.53	0.53	1.00	0.52	0.52	1.00	0.54	0.54	1.00	0.55	0.55	1.00
Czech	0.56	0.61	0.91	0.58	0.60	0.96	0.60	0.62	0.97	0.62	0.70	0.88
Estonia	1.00	1.00	1.00	0.84	1.00	0.84	0.87	1.00	0.87	0.85	1.00	0.85
Croatia	0.75	0.75	1.00	0.75	0.75	1.00	0.76	0.76	1.00	0.83	0.83	1.00
Cyprus	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lithuania	0.79	0.92	0.86	0.91	0.96	0.94	0.95	1.00	0.95	1.00	1.00	1.00
Hungary	0.81	0.87	0.93	0.73	0.75	0.98	0.76	0.77	0.98	0.75	0.75	1.00
Malta	0.52	0.53	0.99	0.80	0.82	0.98	0.98	1.00	0.98	0.92	0.93	0.99
Poland	1.00	1.00	1.00	0.90	0.91	0.99	0.86	0.87	0.99	0.79	0.79	1.00
Romania	0.74	0.76	0.98	0.76	0.80	0.95	0.72	0.79	0.90	0.75	0.78	0.96
Slovenia	0.12	1.00	0.12	0.24	1.00	0.24	0.27	1.00	0.27	0.24	1.00	0.24
Slovakia	0.48	0.65	0.74	0.85	1.00	0.85	0.86	1.00	0.86	0.83	1.00	0.83
Average by year	0.71	0.82	0.89	0.76	0.85	0.90	0.78	0.87	0.90	0.78	0.87	0.90
Year	**1998**			**1999**			**Average by country**					
Country	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**			
Bulgaria	0.57	0.57	1.00	0.57	0.57	1.00	0.54	0.54	1.00			
Czech	0.65	0.71	0.92	0.65	0.74	0.88	0.58	0.62	0.94			
Estonia	0.89	1.00	0.89	0.79	0.88	0.89	0.91	0.99	0.92			
Croatia	0.81	0.81	1.00	0.89	0.89	0.99	0.82	0.82	1.00			
Cyprus	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.95	1.00			
Latvia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
Lithuania	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.83	0.95			
Hungary	0.73	0.73	1.00	0.69	0.69	0.99	0.83	0.85	0.97			
Malta	0.80	0.82	0.98	0.79	0.85	0.93	0.65	0.66	0.98			
Poland	0.97	0.97	0.99	1.00	1.00	1.00	0.93	0.93	1.00			
Romania	0.84	0.87	0.96	0.80	0.81	0.99	0.73	0.75	0.97			
Slovenia	0.25	1.00	0.25	0.19	1.00	0.19	0.28	1.00	0.28			
Slovakia	0.81	1.00	0.81	0.89	1.00	0.89	0.81	0.93	0.86			
Average by year	0.79	0.88	0.91	0.79	0.88	0.90	0.75	0.84	0.91			

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Appendix D: Technical efficiency of bioenergy industry in developed countries over 1990-1999

Year	1990			1991			1992			1993		
Country	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE	TE	PTE	SE
Belgium	0.68	0.68	1.00	0.69	0.69	1.00	0.71	0.71	1.00	0.45	0.45	0.99
Denmark	0.34	0.34	1.00	0.35	0.36	1.00	0.36	0.36	1.00	0.25	0.26	0.97
Germany	0.77	0.77	1.00	0.81	0.81	1.00	1.00	1.00	1.00	0.91	1.00	0.91
Ireland	0.96	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greece	0.49	0.49	1.00	0.51	0.51	1.00	0.50	0.50	1.00	0.30	0.49	0.62
Spain	0.14	0.58	0.25	0.14	0.61	0.24	0.49	0.50	0.97	0.48	0.71	0.68
France	0.55	0.55	1.00	0.54	0.54	1.00	0.53	0.53	1.00	0.47	0.47	1.00
Italy	0.88	0.88	1.00	0.90	0.90	1.00	0.94	1.00	0.94	1.00	1.00	1.00
Luxembourg	0.50	0.50	1.00	0.52	0.52	1.00	0.56	0.57	1.00	0.16	0.16	0.99
Netherlands	1.00	1.00	1.00	1.00	1.00	1.00	0.72	0.76	0.96	0.55	0.57	0.96
Austria	0.07	0.09	0.75	0.07	0.10	0.72	0.08	0.10	0.82	0.06	0.11	0.56
Portugal	0.55	0.55	1.00	0.56	0.56	1.00	0.52	0.52	1.00	0.72	0.73	0.99
Finland	0.77	0.77	1.00	0.91	0.91	1.00	0.53	0.53	1.00	0.20	0.60	0.34
Sweden	0.94	0.95	0.99	1.00	1.00	1.00	0.68	0.71	0.96	1.00	1.00	1.00
UK	0.92	0.92	1.00	0.79	0.79	1.00	0.62	0.62	0.99	1.00	1.00	1.00
Average by year	0.64	0.67	0.93	0.65	0.69	0.93	0.62	0.63	0.98	0.57	0.64	0.87
Year	**1994**			**1995**			**1996**			**1997**		
Country	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**
Belgium	0.45	0.45	0.99	0.63	0.64	1.00	0.55	0.55	0.99	0.58	0.58	1.00
Denmark	0.29	0.29	0.98	0.34	0.34	0.99	0.52	0.56	0.94	0.47	0.48	0.99
Germany	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.71	0.80	0.89
Ireland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Greece	0.38	0.49	0.78	0.46	0.51	0.90	0.46	0.51	0.92	0.45	0.48	0.93
Spain	0.51	0.72	0.71	0.51	0.60	0.86	0.51	0.76	0.68	0.54	0.88	0.61
France	0.49	0.49	1.00	0.52	0.52	1.00	0.63	0.63	1.00	0.67	0.67	1.00
Italy	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luxembourg	0.21	0.21	1.00	0.40	0.48	0.83	0.44	0.54	0.82	0.97	1.00	0.97
Netherlands	0.81	0.82	0.98	0.78	0.78	1.00	0.92	0.96	0.95	1.00	1.00	1.00
Austria	0.11	0.14	0.83	0.07	0.11	0.64	0.07	0.16	0.43	0.07	0.16	0.40
Portugal	0.77	0.79	0.98	0.90	1.00	0.90	0.84	0.94	0.89	0.84	0.86	0.98
Finland	0.28	0.62	0.45	0.46	0.72	0.64	0.65	0.88	0.74	0.75	1.00	0.75
Sweden	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UK	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Average by year	0.62	0.67	0.91	0.67	0.71	0.92	0.71	0.77	0.89	0.74	0.79	0.90
Year	**1998**			**1999**			**Average by country**					
Country	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**	**TE**	**PTE**	**SE**			
Belgium	0.62	0.62	0.99	0.61	0.64	0.96	0.60	0.60	0.99			
Denmark	0.50	0.51	0.97	0.47	0.55	0.85	0.39	0.40	0.97			
Germany	1.00	1.00	1.00	0.84	0.88	0.95	0.90	0.93	0.97			
Ireland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
Greece	0.47	0.50	0.94	0.49	0.52	0.95	0.45	0.50	0.90			
Spain	0.52	0.74	0.70	0.39	0.95	0.41	0.42	0.70	0.61			
France	0.68	0.68	1.00	0.74	0.75	1.00	0.58	0.58	1.00			
Italy	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.98	0.99			
Luxembourg	0.93	0.97	0.95	0.84	0.86	0.98	0.55	0.58	0.95			
Netherlands	0.98	1.00	0.98	0.80	0.83	0.97	0.86	0.87	0.98			
Austria	0.06	0.16	0.38	0.06	0.32	0.18	0.07	0.14	0.57			
Portugal	0.77	0.82	0.93	1.00	1.00	1.00	0.75	0.78	0.97			
Finland	0.77	1.00	0.77	0.92	1.00	0.92	0.62	0.80	0.76			
Sweden	1.00	1.00	1.00	0.69	0.83	0.82	0.93	0.95	0.98			
UK	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.93	1.00			
Average by year	0.75	0.80	0.91	0.72	0.81	0.87	0.67	0.72	0.91			

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Appendix E: Average of technical efficiency of bioenergy industry in EU Region over 1990-1999

Year	Efficiency	Average of developing countries by year	Average of developed countries by year	Average of EU28 by year
1990	TE	0.76	0.64	0.70
	PTE	0.81	0.67	0.74
	SE	0.95	0.93	0.94
1991	TE	0.73	0.65	0.69
	PTE	0.77	0.69	0.73
	SE	0.96	0.93	0.94
1992	TE	0.75	0.62	0.69
	PTE	0.81	0.63	0.72
	SE	0.94	0.98	0.96
1993	TE	0.68	0.57	0.62
	PTE	0.79	0.64	0.71
	SE	0.87	0.87	0.87
1994	TE	0.71	0.62	0.67
	PTE	0.82	0.67	0.74
	SE	0.89	0.91	0.90
1995	TE	0.76	0.67	0.71
	PTE	0.85	0.71	0.78
	SE	0.90	0.92	0.91
1996	TE	0.78	0.71	0.74
	PTE	0.87	0.77	0.82
	SE	0.90	0.89	0.90
1997	TE	0.78	0.74	0.76
	PTE	0.87	0.79	0.83
	SE	0.90	0.90	0.90
1998	TE	0.79	0.75	0.77
	PTE	0.88	0.80	0.84
	SE	0.91	0.91	0.91
1999	TE	0.79	0.72	0.76
	PTE	0.88	0.81	0.84
	SE	0.90	0.87	0.88
Average by group type	TE	0.75	0.67	0.71
	PTE	0.84	0.72	0.78
	SE	0.91	0.91	0.91

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency

Appendix F: Details of parametric and non-parametric mean tests during 1990-1999

Year	Group	Summary of parametric and non-parametric tests																	
		Parametric test						Non-parametric test											
		t-test						Mann–Whitney Wilcoxon test						Kruskal-Wallis					
		TE	t	PTE	t	SE	t	TE	Z	PTE	Z	SE	Z	TE	Chi-square	PTE	Chi-square	SE	Chi-square
1990	Developing	0.761	0.844	0.809	0.568	0.953	0.922	16.540	−1.227	16.920	−1.469	14.880	−0.303	16.540	1.506	16.920	2.157	14.880	0.092
	Developed	0.637		0.671		0.930		12.730		12.400		14.170		12.730		12.400		14.170	
1991	Developing	0.732	0.623	0.773	0.968	0.959	0.424	15.690	−0.723	16.120	−0.984	14.920	−0.472	15.690	0.523	16.120	0.969	14.920	0.223
	Developed	0.653		0.687		0.931		13.470		13.100		14.130		13.470		13.100		14.130	
1992	Developing	0.755	0.986	0.809	0.894**	0.945	0.067	16.880	−1.434	17.580	−1.867*	15.120	−0.430	16.880	2.055	17.580	3.484*	15.120	0.185
	Developed	0.616		0.627		0.976		12.430		11.830		13.970		12.430		11.830		13.970	
1993	Developing	0.676	0.190	0.792	0.047	0.867	0.892	15.810	−0.787	16.310	−1.095	15.190	−0.428	15.810	0.619	16.310	1.200	15.190	0.183
	Developed	0.570		0.637		0.867		13.370		12.930		13.900		13.370		12.930		13.900	
1994	Developing	0.715	0.099	0.817	0.033	0.887	0.638	15.880	−0.843	16.500	−1.226	14.380	−0.073	15.880	0.711	16.500	1.503	14.380	0.005
	Developed	0.620		0.668		0.913		13.300		12.770		14.600		13.300		12.770		14.600	
1995	Developing	0.760	0.037	0.855	0.033	0.902	0.651	15.460	−0.581	16.380	−1.165	13.650	−0.528	15.460	0.337	16.380	1.357	13.650	0.279
	Developed	0.671		0.713		0.917		13.670		12.870		15.230		13.670		12.870		15.230	
1996	Developing	0.782	0.118	0.873	0.048	0.905	0.874	15.310	−0.488	16.420	−1.200	14.770	−0.165	15.310	0.238	16.420	1.440	14.770	0.027
	Developed	0.706		0.766		0.891		13.800		12.830		14.270		13.800		12.830		14.270	
1997	Developing	0.779	0.226	0.872	0.059	0.904	0.972	15.040	−0.326	15.150	−0.413	14.850	−0.222	15.040	0.107	15.150	0.170	14.850	0.049
	Developed	0.737		0.794		0.901		14.030		13.930		14.200		14.030		13.930		14.200	
1998	Developing	0.794	0.216	0.883	0.043	0.908	0.961	14.880	−0.233	15.380	−0.558	14.920	−0.264	14.880	0.054	15.380	0.312	14.920	0.070
	Developed	0.753		0.880		0.907		14.170		13.730		14.130		14.170		13.730		14.130	
1999	Developing	0.789	0.367	0.879	0.175	0.904	0.534	15.380	−0.536	15.880	−0.856	15.500	−0.264	15.380	0.288	15.880	0.732	15.500	0.376
	Developed	0.723		0.809		0.866		13.730		13.300		13.630		13.730		13.300		13.630	

TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency, ***, ** and * indicate significance at the 1%, 5%, and 10% levels respectively

Appendix G: Summary for developing and developed countries over 1990-1999

Test groups (1990-1999)	Parametric test		Non-parametric test			
Individual test	t-test		Mann–Whitney [Wilcoxon] test		Kruskall–Wallis test	
Hypothesis test	t-test		Median developed and developing		Equality of populations test	
Test statistics	**t (P>t)**		**z (P>z)**		**χ^2 (P>χ^2)**	
	Mean	**t**	**Mean rank**	**z**	**Mean rank**	**χ^2**
TE						
Developing countries	0.754	0.371	15.687	–0.718	15.687	0.644
Developed countries	0.669		13.470		13.470	
PTE						
Developing countries	0.836	0.287**	16.264	–1.083*	16.264	1.332*
Developed countries	0.725		12.969		12.969	
SE						
Developing countries	0.913	0.694	14.818	–0.350	14.181	0.149
Developed countries	0.910		14.223		14.223	

Note: ***,** and * indicate significance at the 1%, 5%, and 10% levels respectively, TE: Technical efficiency, PTE: Pure technical efficiency, SE: Scale efficiency