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Doctor of Philosophy (PhD)

TWO ESSAYS ON THE DYNAMICS OF ENVIRONMENTAL TECHNICAL EFFICIENCY IN EU MEMBER AND CANDIDATE COUNTRIES

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DECLARATION

I hereby declare that this doctoral thesis titled as “Two Essays on the Dynamics of Environmental Technical Efficiency in EU Member and Candidate Countries” has been written by myself in accordance with the academic rules and ethical conduct. I also declare that all materials benefited in this thesis consist of the mentioned resources in the reference list. I verify all these with my honour.

…/…/…….

Yavuz Selman DUMAN

ÖZET

Doktora Tezi

Avrupa Birliği ve Aday Ülkelerde Çevresel Teknik Verimlilik Dinamikleri Üzerine İki Makale

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İktisat Anabilim Dalı

İktisat Doktora Programı

Son yıllarda küresel ilgi, yüksek karbon emisyonlarının çevre ve ekonomi üzerindeki yıkıcı etkileri üzerine yoğunlaştı. Aralık 2015'te 190'dan fazla ülke tarafından kabul edilen Paris Anlaşması, iklim değişikliğine karşı savaşta yeni bir dönemin başlamasını işaret ediyor. Küresel bir olguya yönelik böylesine ortak bir eylemin yapılmasının nedeni gelecek nesiller için daha temiz bir çevre ve sürdürülebilir ekonomi sağlamaktır. Çevresel etkinliği anlamak bu çabanın en önemli yönlerinden biridir. Bu çalışma, 1990-2011 döneminde Avrupa Birliği (AB) üyesi ve aday ülkelerden oluşan bir panel için çevresel teknik verimlilik konusuna ilişkin birbirine bağlı iki makaleden oluşmaktadır.

İlk makale, parametrik hiperbolik mesafe fonksiyonu kullanarak AB üyesi ve aday ülkeler için çevresel teknik verimi hesaplar. Ayrıca, örneklenen ülkeler arasındaki çevresel teknik verimlilik yakınsamasını da incelemektedir. Temel sonuçlar, çevresel teknik verimlilik puanlarının AB üye ve aday ülkeler arasında farklılık gösterdiğini ortaya koymaktadır. Yeni üyeler ve aday ülkelerin aksine, AB-15 ülkeleri, CO_2 emisyonlarını ve enerji kullanımını azaltırken eş zamanlı olarak GSYİH'yi artırma noktasında daha büyük bir potansiyele sahiptir. Sonuçlar AB üye ve aday ülkelerinde çevresel teknik verimlilik yakınsamasının varlığına da işaret ediyor.

İkinci makale, birinci makalede parametrik hiperbolik mesafe fonksiyonu aracılığıyla tahmin edilen çevresel verimlilik puanlarını kullanarak, kişi başı gelir, sanayinin GSYİH içindeki payı, dış ticarete açıklık ve kentleşmeyle olan ilişkisini, Tobit modeli kullanarak araştırmaktadır. Sonuçlar, tüm değişkenlerin çevresel teknik verimliliğin önemli belirleyicileri olduğuna işaret etmektedir. Çevresel teknik verimlilik ile ekonomik kalkınma arasındaki ilişki U şeklinde bir eğri olarak tespit edilmişken, sanayinin GSYİH içindeki payı, ters U şeklinde bir eğri yapısını izlemektedir. Çevresel teknik verimlilik ile dış ticarete açıklık arasında ters yönlü bir ilişki varken, kentleşme ile pozitif bir ilişki vardır.

Anahtar Kelimeler: Parametrik Hiperbolik Mesafe Fonksiyonu, Çevresel Teknik Verimlilik, Avrupa Birliği, Verimlilik Yakınsaması. Verimlilik Belirleyicileri, Çevresel Kuznets Eğrisi.

ABSTRACT

Doctoral Thesis

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Two Essays on the Dynamics of Environmental Technical Efficiency in EU Member and Candidate Countries

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In recent years, global attention has been devoted towards the devastating effects of high carbon emissions on the environment and economy. The Paris Agreement which was accepted by over 190 countries in December 2015 marks the beginning of a new era towards the battle against climate change. The reason for such a collective action towards a renown global phenomenon is to provide a cleaner environment and sustainable economy for the future generations. Understanding environmental efficiency is one of the most significant aspects of this endeavor. This study consists of two interconnected essays on the topic of environmental technical efficiency for a panel of European Union (EU) member and candidate countries for the period 1990-2011.

First essay calculates environmental technical efficiency for the EU member and candidate countries using parametric hyperbolic distance function. Furthermore, the essay also examines the environmental technical efficiency convergence among the sampled countries. The main results suggest that environmental technical efficiency scores vary among EU member and candidate countries. The EU-15 countries in contrast to the new members and the candidate

countries have a greater potential for reducing CO_2 emissions while increasing GDP and reducing energy use simultaneously. The results also indicate the existence of environmental technical efficiency convergence among EU member and candidate countries.

Second essay uses environmental efficiency scores estimated through a parametric hyperbolic distance function in the first essay and investigates its relationship with per capita income, industrial share of GDP, openness to trade, and urbanization by using a Tobit model. The results suggest that all the variables are significant determinants of environmental technical efficiency. The relation between environmental technical efficiency and economic development shows a U-shaped curve, whereas industrial share of GDP follows an inverse U- shaped curve. There is an inverse relationship between environmental technical efficiency and openness to trade, and a positive relationship with urbanization.

Keywords: Parametric Hyperbolic Distance Function, Environmental Technical Efficiency, European Union, Efficiency Convergence. Determinants of Efficiency, Environmental Kuznets Curve.

TWO ESSAYS ON THE DYNAMICS OF ENVIRONMENTAL TECHNICAL EFFICIENCY IN EU MEMBER AND CANDIDATE COUNTRIES

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ABBREVIATIONS

BAU	Business as Usual
BP	British Petrol
CEE	Central Eastern European
CO_2	Carbon Dioxide
COP	Conference of Parties
DDF	Directional Distance Function
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EE	Energy Efficiency
EEA	European Environment Agency
EHDF	Enhanced Hyperbolic Distance Function
EKC	Environmental Kuznets Curve
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gas
GNP	Gross National Product
HDF	Hyperbolic Distance Function
IEA	International Energy Agency
INDC	Intended National Determined Contribution
IT	Information Technologies
NASA	National Aeronautics and Space Administration
NO_x	Nitrogen Oxide
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares
PIM	Perpetual Inventory Method
PPP	Purchasing Power Parity

SFA	Stochastic Frontier Analysis
SO_2	Sulphur Dioxide
SO_x	Sulphur Oxide
THDF	Translog Hyperbolic Distance Function
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
WDI	World Development Indicators

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INTRODUCTION

Every year the rising global temperatures sets a new world record. According to NASA for the last 136 years, sixteen of the 17 years with the highest temperatures were observed since 2001. Increasing temperatures are effecting all aspects of our life and exacerbates the infamous phenomena climate change and global warming. Countries have formed coalitions and agreements such as the Kyoto Protocol and its successor Paris Agreement to tackle and battle climate change, to hold the global temperature increase below 2°C above pre-industrial levels. At first 2°C may seem like a trivial increment, however even such a small increase in global temperature could lead to catastrophic events throughout the globe with irreversible consequences.

The consensus among climate scientists indicate that increasing greenhouse gasses is the main cause and reason behind increasing temperatures. The basic explanation is that earth both reflects and absorbs some amount of the solar radiation it receives from the sun. Toxic gasses such as CO_2 (carbon dioxide) accumulated in the atmosphere deflects some amount of the solar radiation back to earth creating the "greenhouse effect", which causes surface temperature to increase. Because toxic gasses such as CO_2 causes the greenhouse effect they are called the greenhouse gasses. That is why countries seek to reduce CO_2 emissions thereby prevent global warming.

Energy consumption, primarily fossil fuel consumption, is the main cause of the rising CO_2. Following the industrial revolution energy consumption has become one of the vital factors of production. In the following years researchers studied its relationship with the overall production and the economy. The seminal article by Kraft & Kraft (1978) has proven that there is a significant relation between energy and the economy. Since there is irrefutable evidence to the energy/economy nexus, policy implications towards cutting energy consumption to reduce CO_2 came at a cost of lower production or economic growth rates. This led to diversification of energy resources towards renewable, nuclear and biofuels, in general clean energy resources that do not increase the atmospheric concentration of CO_2 when consumed.

Clean energy, however, might not be accessible or economically feasible for some developing countries and countries that lack in clean energy resources. Even for the

developed countries in some cases it is economically more beneficial to target the environmental aspect of consumption and production rather that the energy source. In these cases, countries seek to identify the best policy option that simultaneously reduce CO_2 emissions while maintaining or increasing the level of production and economic growth. Policy options that in general target efficiency. In the energy economics literature efficiency can be based on three pillars that are energy efficiency, environmental efficiency and technical efficiency. Energy and technical efficiency refers to improving production technologies, capital, and specialization of labor. These types of improvements will translate into more production with the same level of energy consumption, however despite economic growth, CO_2 emissions will remain the same. Environmental efficiency on the other hand deals directly with the undesirable outcome that is the GHG. A production process might be energy efficient but not environmentally efficient, however an environmentally efficient production can be both energy and technically efficient. Therefore, targeting environmental efficiency is relatively a more comprehensive approach.

Environmentally efficient production refers to a simultaneous increase in output with reducing CO_2 emissions. In that regard determining the environmental efficiency along with its determinants could provide sufficient evidence for countries towards determining policy options in battling climate change.

This research consists of two interconnected essays that deal specifically with environmental technical efficiency. The first essay estimates the environmental technical efficiency scores for EU member and candidate countries between the years 1990-2011. Using these scores, it also tests for efficiency convergence. We have used the general stochastic frontier approach with hyperbolic distance function to calculate environmental technical efficiency scores because, this methodology enables to treat inputs and outputs of the production function asymmetrically. The second essay investigates the relationship between environmental technical efficiency scores and its determinants, economic growth, trade openness, urbanization, and industrial share of GDP. Because the environmental technical efficiency scores calculated in the first essay range between 0 and

1, we have used Tobit (censored regression) methodology to test the relationship with its determinants.

The rest of the research is organized as follows. Part 1 consists of the first essay titled, “Environmental Technical Efficiency in EU Member and Candidate Countries: A Parametric Hyperbolic Distance Function Approach”. Part 2 consists of the second essay titled, “The Role of International Trade and Urbanization on Environmental Technical Efficiency in EU Member and Candidate Countries”. Overall concluding remarks for both essays are presented in the conclusion section.

PART I

ENVIRONMENTAL TECHNICAL EFFICIENCY IN EU MEMBER AND CANDIDATE COUNTRIES: A PARAMETRIC HYPERBOLIC DISTANCE FUNCTION APPROACH

1. Introduction

United Nations Climate Change Conference, also known as Conference of the Parties (COP) was held on December 2015 in Paris with the objective to reduce the greenhouse gas (GHG) emissions. The Paris Conference holds great significance in terms of establishing a legally binding and global agreement on climate change with the aim of keeping global warming below 2 °C above pre-industrial levels. In this regard, it is similar to its predecessor the Kyoto Protocol that required the parties to reduce their emissions 5% by 2012. The conference is expected to be a turning point against climate change towards motivating the business sector in transitioning to a low-carbon economy. Leaders of the world addressed their concerns and reiterated the significance of climate change during the 10 days. The main aim of the "Draft Agreement" is to enhance action, cooperation and support to limit the temperature increase (UNFCCC 2015).

Stabilizing the emissions rate and transitioning into a low-carbon economy is crucial to climate change because increasing CO_2 emissions, one of the GHG with the highest concentration, affects not only human health and agriculture but also the biodiversity, and the survival of certain species. In a much broader sense, a low-carbon economy is vital for sustainable growth of environmental quality and biodiversity.[1] Reducing emissions can be accomplished via clean energy and, energy is rendered clean if it does not increase the atmospheric CO_2 concentrations. In that sense, reducing emissions and making energy "clean", can be done by converting to renewable energy, adopting nuclear energy (focusing on nuclear fusion because it does not generate long lived radioactive waste), biofuels and finally, increasing environmental efficiency.

[1] Sustainable growth refers to promoting growth today without harming the future.

Converting or diversifying energy resources with renewable energy for developed countries might not have the same amount of economic burden as in the case of developing or poor countries, owing to the fact that renewable energy technologies require a great amount of investment. Apart from the economic cost of renewable energy, there is also the availability factor that plays an important role. Despite being able to handle the economic cost and having the adequate technologies some countries lack the natural resources to fully appreciate renewable energy. Countries without access to sea are not able to utilize waves as a source of energy, or those with no steady wind are unable to utilize wind turbines. Similar other scarcities of natural occurrences, due to a country's geographical location, prevent them from exploiting these resources.

Nuclear energy, on the other hand, requires a far more complicated infrastructure, technology, and know-how. The global energy profiles indicate that only some of the developed countries rely on nuclear power as a source of energy.[2] Nuclear fusion technology on the other hand is under extensive research, but it is yet to be developed to be an adequate energy source. Therefore, the only cost-effective option for countries that are unable to diversify their energy profiles with renewable or nuclear energy, or increase their energy consumption, is to increase their environmental performance. Increasing environmental technical efficiency can be accomplished by numerous ways, such as decreasing energy use, using modern high-tech devices that require less energy, designing energy efficient architectures or conserving energy.

It is valuable to carry out a study that investigates environmental technical efficiency for a sample of countries following the Paris conference, COP21, which introduced a new agreement on climate change. This study could also provide evidence on whether policies that addresses the increasing energy and environmental efficiency are successful. Hence, the main objective of this essay is to investigate environmental technical efficiency for a panel of European Union (EU) member and candidate countries for the period 1990-2011, employing recently developed parametric hyperbolic distance

[2] The International Atomic Energy Agency (IAEA) reports that there are 441 operable nuclear power reactors more than half of which are operating in the United States, Japan, France, China and Russia.

functions by Cuesta and Zofío (2005) and Cuesta et. al. (2009). In this study, data for capital stock, labor and energy are used to produce one desirable output GDP and one undesirable output CO_2 emissions. The main reason this essay has chosen to follow a hyperbolic form of the distance function is because of its flexible definition of production function. Unlike the conventional distance functions which partially define production functions from either input or output orientations, hyperbolic distance function relaxes this analytical framework and allows for simultaneous output and input characterization.

The other objective of the essay is to examine convergence in environmental efficiency among the sampled countries. To the authors' best knowledge, this is the first essay that investigates environmental technical efficiency and its convergence for the EU member and candidate countries. Efficiency convergence produces valuable information towards assessing the success of energy and environmental regulations, particularly for countries that have common goals and unified policy agendas towards increasing environmental efficiency.

By way of preview, our main empirical results suggest that environmental technical efficiency scores vary among EU member and candidate countries. EU-15 countries in contrast to the new members and the candidate countries have a greater potential for reducing CO_2 emissions while increasing GDP and reducing energy use simultaneously. The other main finding of our essay is the existence of environmental technical efficiency convergence among EU member and candidate countries.

The rest of the essay is organized as follows. Section 2 reviews the previous literature on energy and environment. Section 3 discusses the main model and econometric methodology. Section 4 discusses the data and the empirical results of the estimations. The essay's concluding remarks are provided in section 5.

2. Literature Review

One of the significant topics handled in the numerous directional distance function (DDF) and stochastic frontier analysis (SFA) studies is energy, and environmental efficiency. Since the use of energy in the production process results in multiple outputs, desirable and undesirable (emissions), DDF enables to measure producer performance with multiple outputs. However, the conventional distance function measure performance radially, that

is, it expands all outputs and contracts all inputs at the same rate without distinguishing between desirable and undesirable outputs. What is required to increase environmental efficiency is to be able to contract undesirable outputs and expand desirable outputs. Färe et al. (1985, 1989) introduced the hyperbolic distance function which was the first attempt to relax the restrictive assumptions on input and output, that treats desirable and undesirable outputs asymmetrically. The other study that treats outputs asymmetrically is Chambers et al. (1996) that explored the relationship between Shephard (1953) distance function and Luenberger (1992) benefit functions. They introduced an alternative production function in the context of the directional distance function. The DDF introduced in Chambers et al. (1996) is one of the two major DDF's, following Shephard (1953), in the study of energy and environment modeling. Chung et al. Chung et al. (1997) is the preliminary study to adapt Chambers' DDF to environmental efficiency measurement.

Following the preliminary studies and empirical applications on hyperbolic distance functions, studies that dwell on the same topic are, among the others, (Färe et al. 2001; Weber and Domazlicky 2001; Arocena and Waddams Price 2002; Boyd et al. 2002; Yörük and Zaim 2005; Mahlberg and Sahoo 2011). Mahlberg and Sahoo (2011) and Picazo-Tadeo et al. (2012) investigated eco-efficiency for EU-14 and for olive growing farms in Spain, respectively. Zhang and Choi (2013) and Zhang et al. (2013) investigated total factor carbon emission and pure CO_2 change for China and Mahlberg and Luptacik (2014) measured eco-efficiency and eco-productivity change for Austrian economy. Picazo-Tadeo et al. (2014) provided a new approach for measuring intertemporal environmental performance for the EU member countries.

Data Envelopment Analysis (DEA) rely on mathematical, non-parametric techniques to measure directional or hyperbolic distance functions. There is no need to specify a mathematical formulation for the production function. Some major limitations of DEA that motivate towards SFA are: (i) "efficiency estimates are serially correlated" Simar and Wilson (2007), (ii) inference is possible with bootstrapping, (iii) "except under constant returns to scale the program is non-linear" Cuesta et al. (2009) hence the efficiencies will be under-estimated, (iv) DEA does not account for standard noise

therefore on average efficiency estimates are lower than the true efficiencies compared to SFA which takes into account the standard noise.

Some of the recent DEA studies that deal with energy, and environmental efficiency use China as a sample country because of its high carbon emissions. Wu et al. (2012) and Wang and Wei (2014) measure industrial energy efficiency using DEA for China's different provinces. A further detailed review of energy, and environmental efficiency studies using DEA and non-parametric approaches are surveyed by Ang and Zhang (2000) and Zhou et al. (2008).

The major limitations of DEA motivated researchers to change course and they have recently devoted their attention on the parametric framework in estimating the distance functions. In contrast to DEA, there is a limited number of studies employing SFA to estimate distance functions in energy and environment. Färe et al. (2005) estimated a quadratic directional output distance function using linear programming techniques introduced by Aigner and Chu (1968) to measure technical efficiency, shadow price and elasticity of substitution, and used SO_2 (sulphur dioxide) as the pollutant. Vardanyan and Noh (2006) compared a variety of shadow pricing models and parameterization methodologies to show that the estimates are sensitive to the chosen functional form. Färe et al. (2012) estimated the distance function for a sample of coal-fired electric power plants in the US using the model developed by Färe et al. (2005) and further focused on the substitutability of pollutants, namely SO_2 and NO_x (nitrogen oxides).

Matsushita and Yamane (2012) derived the shadow price of CO_2, substitutability of pollutants similar to Färe et al. (2012) and technical efficiency, employing directional output distance functions. Zhang and Ye (2015) extended the parametric hyperbolic distance function introduced by Cuesta et al. (2009) to analyze energy and environmental efficiency for a panel of provinces in China and further analyzed the environmental total factor productivity in two components namely, environmental technical change and environmental efficiency change. Zhang and Choi (2014) provided a more recent and thorough review of directional distance functions in the field of energy and environment studies and compared the two different approaches, DEA and parametric methods.

3. The Model and Econometric Methodology

3.1. Production Technology

Production is a process of transformation of K input vectors, $x_i = (x_{1i}, \dots, x_{Ki}) \in \Re_K^+$ into the following good/desirable M output vectors, $y_i = (y_{1i}, \dots, y_{Mi}) \in \Re_M^+$ and bad/undesirable outputs $b \in \Re_J^+$ where $i = (1,2, \dots, N)$ representing the processes of firms, decision making units (DMU). Production possibility set representing the technology is specified as follows:

$$T = \{(x, y, b): x \in \Re_K^+, y \in \Re_M^+, x\ can\ produce\ (y, b)\} \quad (1)$$

which is assumed to satisfy the axioms listed in Färe and Primont (1995). The axioms state that; (i) any nonnegative input corresponds to at least zero output, (ii) T is a closed set which means that there are technically efficient input and output vectors, (iii) T is bounded, finite inputs can only produce finite outputs, (iv)$\forall\ (x, y) \in \Re_{\{K,M\}}^+, if\ y \in T(x)\ and\ 0 < \theta \leq 1\ then\ \theta y \in T(x)$ which is referred to as the weak disposability of outputs which allows the possibility of one output being bad. Bad output is only possible if the good output is also reduced, holding the input constant. Nevertheless, this axiom has been often replaced by another; (v) $(y, x) \in T \Longrightarrow (y', x') \in T\ \forall (y', -x') \leq (y, -x)$ which is referred to as strong (free) disposability. Following Cuesta and Zofío (2005) and Cuesta et al. (2009) the hyperbolic distance function $D_H: \Re_K^+ \times \Re_M^+ \times \Re_J^+ \rightarrow \Re^+ U\{+\infty\}$ is defined as;

$$D_H(x, y, b) = inf\ \{\theta > 0: (x, y/\theta, b\theta) \in T\} \quad (2)$$

The range of the distance function is, $0 < \mathrm{D_H(x, y, b)} \leq 1$. Equation (2) is called the hyperbolic distance function due to its hyperbolic path generated to the production frontier. The hyperbolic distance function has the feature of treating the desirable and undesirable outputs asymmetrically thus providing an inference on the environmental performance of the production process. The economic interpretation of $D_H(x, y, b) = 1$ is that the estimated observation is on the boundary of the production frontier and it will not be possible to reduce CO_2 or increase GDP at the same time which renders the production efficient. If $D_H(x, y, \mathrm{b}) < 1$ then the production is considered inefficient which leaves

room for enhancing efficiency for this economy by increasing GDP and reducing CO2 emissions.

The hyperbolic distance function satisfies the following axioms listed by Cuesta et al. (2009);

$$D_H(x, \mu y, \mu^{-1} b) = \mu D_H(x, y, b), \qquad \mu > 0 \tag{3}$$

$$D_H(x, \lambda y, b) \leq D_H(x, y, b), \qquad \lambda \in [0,1] \tag{4}$$

$$D_H(x, y, \lambda b) \leq D_H(x, y, b), \qquad \lambda \geq 1 \tag{5}$$

$$D_H(\lambda x, y, b) \leq D_H(x, y, b), \qquad \lambda \geq 1 \tag{6}$$

The axioms represent that the HDF satisfies almost homogeneity (3) it is non-decreasing in desirable outputs (4), non-increasing in undesirable outputs (5) and, non-increasing in inputs (6).

3.2. Translog Hyperbolic Distance Function (THDF)

We need to specify a translog functional form for the distance function in order to estimate environmental technical efficiency. The translog functional form provides easy calculation and flexibility to impose almost homogeneity restrictions. A traditional function $D_H(x, y, b)$ is almost homogenous of degrees k1, k2, k3 and k4 if, $D_H(\mu^{k_1} x, \mu^{k_2} y, \mu^{k_3} b) = \mu^{k_4} D_H(x, y, b), \forall \mu > 0$ From this definition the environmental hyperbolic distance function D_H (2) is homogenous of degrees 0,1,-1,1. Assuming our distance function $D_H(x, y, b)$ is continuously differentiable and satisfies the almost homogeneity condition, it takes the following functional form;

$$k_1 \sum_{\boldsymbol{p}=1}^{\boldsymbol{P}} \frac{\partial D}{\partial x_p} x_p + k_2 \sum_{\boldsymbol{q}=1}^{\boldsymbol{Q}} \frac{\partial D}{\partial y_{\boldsymbol{q}}} y_{\boldsymbol{q}} + k_3 \sum_{\boldsymbol{r}=1}^{\boldsymbol{R}} \frac{\partial D}{\partial b_r} b_r = k_4 D \tag{7}$$

Translog specification of $D_H(x, y, b)$ following Cuesta et al. (2009) takes the form

$$lnD = \alpha_0 + \sum_{p=1}^{P} \alpha_p lnx_{pi} + \frac{1}{2}\sum_{p=1}^{P}\sum_{l=1}^{P} \alpha_{pl} lnx_{pi} lnx_{li} + \sum_{q=1}^{Q} \beta_q lny_{qi} + \frac{1}{2}\sum_{q=1}^{Q}\sum_{m=1}^{Q} \beta_{qm} lny_{qi} lny_{mi} + \sum_{r=1}^{R} \theta_r lnb_{ri} + \frac{1}{2}\sum_{r=1}^{R}\sum_{n=1}^{R} \theta_{rn} lnb_{ri} lnb_{ni} + \sum_{p=1}^{P}\sum_{q=1}^{Q} \omega_{pq} lnx_{pi} lny_{qi} + \sum_{p=1}^{P}\sum_{r=1}^{R} \psi_{pr} lnx_{pi} lnb_{ri} + \sum_{q=1}^{Q}\sum_{r=1}^{R} \varphi_{qr} lny_{qi} lnb_{ri} \; (i = 1,2, \dots, N)$$

(8)

Panel data specification of the translog HDF, following (8), with inputs as capital, labor and energy and GDP as one desirable output and CO2 emissions as undesirable output will be

$$\begin{aligned} lnD_{it} = {} & \alpha_0 + \alpha_k lnK_{it} + \alpha_l lnL_{it} + \alpha_e lnE_{it} + \alpha_t t + 0.5\alpha_{kk}(lnK_{it})^2 + 0.5\alpha_{ll}(lnL_{it})^2 \\ & + 0.5\alpha_{ee}(lnE_{it})^2 + 0.5\alpha_{tt}t^2 + \alpha_{kl} lnK_{it} lnL_{it} + \alpha_{ke} lnK_{it} lnE_{it} \\ & + \alpha_{le} lnL_{it} lnE_{it} + \alpha_{kt} t * lnK_{it} + \alpha_{lt} t * lnL_{it} + \alpha_{et} t * lnE_{it} \\ & + \beta_{GDP} lnGDP_{it} + 0.5\beta_{GDP^2}(lnGDP_{it})^2 + \theta_{CO_2} lnCO_{2,it} \\ & + 0.5\theta_{CO_2^2}\left(lnCO_{2,it}\right)^2 + \omega_{kGDP} lnK_{it} lnGDP_{it} + \omega_{lGDP} lnL_{it} lnGDP_{it} \\ & + \omega_{eGDP} lnE_{it} lnGDP_{it} + \omega_{tGDP} t * lnGDP_{it} + \psi_{kCO_2} lnK_{it} lnCO_{2,it} \\ & + \psi_{lCO_2} lnL_{it} lnCO_{2,it} + \psi_{eCO_2} lnE_{it} lnCO_{2,it} + \psi_{tCO_2} t * lnCO_{2,it} \\ & + \varphi_{GDPCO_2} lnGDP_{it} lnCO_{2,it} + v_{it} \\ & i = 1,2, \dots, N\,, \;\; t = 1,2, \dots, T \end{aligned}$$

(9)

D_{it} is the distance function for country i at time t, besides t is also a time variable that captures the presence of technological change and v_{it} is the random error term distributed, $v_{it} \sim N(0, \sigma_v^2)$. Translog hyperbolic distance function must satisfy the homogeneity degrees of 0,1,-1,1 that corresponds to the environmental hyperbolic distance function, therefore we depart from (7)

$$\sum_{\boldsymbol{q=1}}^{\boldsymbol{Q}} \frac{\partial lnD}{\partial lny_{\boldsymbol{q}}} - \sum_{\boldsymbol{r=1}}^{\boldsymbol{R}} \frac{\partial lnD}{\partial lnb_r} = 1$$

(10)

And the relevant partial derivatives for the translog derived from (8) are (keeping in mind that $\frac{\partial D}{\partial x_{\boldsymbol{p}}} \frac{x_p}{D} = \frac{\partial lnD}{\partial lnx_p}$, $\frac{\partial D}{\partial y_{\boldsymbol{q}}} \frac{y_q}{D} = \frac{\partial lnD}{\partial lny_q}$, $\frac{\partial D}{\partial b_{\boldsymbol{r}}} \frac{b_r}{D} = \frac{\partial lnD}{\partial lnb_r}$)

$$\frac{\partial lnD}{\partial lnx_p} = \alpha_p + \sum_{l=1}^{P} \alpha_{pl} lnx_l + \sum_{q=1}^{Q} \omega_{pq} lny_q + \sum_{r=1}^{R} \psi_{pr} lnb_r \ \ (p = 1,2, \dots, P)$$

(11)

$$\frac{\partial lnD}{\partial lny_q} = \beta_q + \sum_{m=1}^{Q} \beta_{qm} lny_m + \sum_{p=1}^{P} \omega_{pq} lnx_p + \sum_{r=1}^{R} \varphi_{qr} lnb_r \ \ (q = 1,2, \dots, Q)$$

(12)

$$\frac{\partial lnD}{\partial lnb_r} = \theta_p + \sum_{n=1}^{R} \theta_{rn} lnb_n + \sum_{p=1}^{P} \psi_{pr} lnx_p + \sum_{q=1}^{Q} \varphi_{qr} lny_q \ \ (r = 1,2, \dots, R)$$

(13)

Substituting (12) and (13) to (10) we get

$$\sum_{\boldsymbol{q=1}}^{\boldsymbol{Q}} \left(\beta_q + \sum_{m=1}^{Q} \beta_{qm} lny_m + \sum_{p=1}^{P} \omega_{pq} lnx_p + \sum_{r=1}^{R} \varphi_{qr} lnb_r \right) - \sum_{\boldsymbol{r=1}}^{\boldsymbol{R}} \left(\theta_p + \sum_{n=1}^{R} \theta_{rn} lnb_n + \sum_{p=1}^{P} \psi_{pr} lnx_p + \sum_{q=1}^{Q} \varphi_{qr} lny_q \right) = 1$$

(14)

Departing from (14) the restrictions required to ensure almost homogeneity (0,1,-1,1), we have to modify (8) by choosing desirable output, GDP, as the normalizing variable and set $\mu = 1/y$. Hence, the distance function becomes;

$$D_{H,it}\left(x, \frac{y}{y}, b * y\right) = \frac{D_{H,it}(x, y, b)}{y}$$

(15)

and (8) becomes;

$$ln\left(\frac{D_{H,it}}{y_{Q,it}}\right) = \alpha_0 + \sum_{p=1}^{P} \alpha_p lnx_{pi} + \frac{1}{2}\sum_{p=1}^{P}\sum_{l=1}^{P} \alpha_{pl} lnx_{pi} lnx_{li} + \sum_{q=1}^{Q-1} \beta_q lny_{qi}^* + \frac{1}{2}\sum_{q=1}^{Q-1}\sum_{m=1}^{Q-1} \beta_{qm} lny_{qi}^* lny_{mi}^* + \sum_{r=1}^{R} \theta_r lnb_{ri}^* + \frac{1}{2}\sum_{r=1}^{R}\sum_{n=1}^{R} \theta_{rn} lnb_{ri}^* lnb_{ni}^* + \sum_{p=1}^{P}\sum_{q=1}^{Q-1} \omega_{pq} lnx_{pi} lny_{qi}^* + \sum_{p=1}^{P}\sum_{r=1}^{R} \psi_{pr} lnx_{pi} lnb_{ri}^* + \sum_{q=1}^{Q-1}\sum_{r=1}^{R} \varphi_{qr} lny_{qi}^* lnb_{ri}^* \ (i = 1,2, \dots, N)$$

(16)

Following (16) the environmental hyperbolic distance function is as follows;

$$-ln(GDP_{it}) = T\left(K_{it}, L_{it}, E_{it}, GDP_{it}^*, t_{it}, CO_{2,it}^*\right) + v_{it} - ln\left(D_{H,it}\right)$$

(17)

Since $y_{qi}^* = y_{qi}/y_{Qi} = 1$ variable involving y, GDP, is null and $\mathrm{CO}_{2,\mathrm{it}}^* = \mathrm{CO}_{2,\mathrm{it}} \times GDP_{it}$. $-ln\left(\mathrm{D}_{\mathrm{H,it}}\right)$ is the term representing the inefficiency in the composed error term structure of the stochastic frontier analysis, therefore we can note that $u_{it} = -ln\left(\mathrm{D}_{\mathrm{H,it}}\right)$ and redefine (17) as

$$-ln(GDP_{it}) = T\left(K_{it}, L_{it}, E_{it}, t_{it}, CO_{2,it}^*\right) + v_{it} + u_{it}$$

(18)

For u_{it}we follow Kumbhakar (1990) under a time-varying technical inefficiency framework and $u_{it} = u_i/[1 + \exp(b_t + c_t^2)] \sim iid\ N(0, \sigma_t^2)$ where b and c are the parameters that will be estimated. Following a similar methodology but for different almost homogeneity degrees of (-1,1,-1,1) and a slightly different definition for the distance function, Cuesta et al. (2009) introduces the enhanced hyperbolic distance function which enables further reductions in all of the inputs is formulated as follows

$$D_E(x, y, b) = inf\ \{\mu > 0 : (x\mu, y/\mu, b\mu) \in T\}$$

(19)

which additional to the axioms (4, 5, 6) listed for the HDF, enhanced HDF also satisfies a more inclusive almost homogeneity axiom defined as $\mathrm{D_H}(\mu^{-1}\mathrm{x}, \mu\mathrm{y}, \mu^{-1}\mathrm{b}) = \mu\mathrm{D_H}(\mathrm{x}, \mathrm{y}, \mathrm{b})$,

$\mu > 0$. The enhanced hyperbolic distance function, which we will be estimating in the following section, in the light of the previous formulation takes the form similar to (18) as

$$-ln(GDP_{it}) = T\left(K_{it}^{*}, L_{it}^{*}, E_{it}^{*}, t_{it}, CO_{2,it}^{*}\right) + v_{it} + u_{it} \tag{20}$$

where $\mathrm{CO}_{2,\mathrm{it}}^{*} = \mathrm{CO}_{2,\mathrm{it}} \times GDP_{it}$, $K_{\mathrm{it}}^{*} = \mathrm{K_{it}} \times GDP_{it}$, $L_{\mathrm{it}}^{*} = \mathrm{L_{it}} \times GDP_{it}$ and $E_{\mathrm{it}}^{*} = \mathrm{E_{it}} \times GDP_{it}$.

3.3. Efficiency Convergence (σ and β Convergence)

As stated before, another objective of this essay is to examine environmental technical efficiency convergence among the EU member and candidate countries. European Union has several prerequisites and policy adaptations regarding their candidates in their process of becoming a full member ranging from economy and health to infrastructure. One of the major topics new members must abide by is concerning energy and environmental issues, specifically the Energy Efficiency Directive. The Directive sets binding measures to EU members in reaching the 20% energy efficiency target by 2020. Under the directive, EU members are required to increase energy efficiency at all the stages of energy use from its generation to the production of the final product. Besides, data on energy efficiency are compiled by projects such as the Odyssee-Mure which aims to monitor energy efficiency trends and measures among EU members.

The literature on convergence is well established following the preliminary study of Barro and Sala-i-Martin (1991) in which they introduced two types of convergence; β (beta)-convergence and σ (sigma)-convergence. β-convergence implies that an economy will have a higher growth rate in contrast to another economy, given that the former has a lower initial starting point compared to the latter and, both will converge to the same steady state level in the long run. The test of β-convergence is performed using the following regression equation

$$lnF_{it} - lnF_{it-1} = \alpha + \beta lnF_{it-1} + \varepsilon_{it} \tag{21}$$

where F denotes the efficiency scores for country i at year t and $0 < \beta < 1$. α and β are the parameters to be estimated and the error term $\varepsilon_{\mathrm{it}}$ has mean zero, finite variance and

independent over t and i. The regression equation is estimated using the fixed effects model. β coefficient will be observed after the estimation is undertaken by fixed effects model and, negative β coefficient suggests the existence of convergence in technical efficiency scores.

It is common in efficiency studies to test for σ-convergence along with β-convergence. The reason as explained by Barro and Sala-i-Martin (1991) is that, β-convergence does not imply σ-convergence because even though the observed variables are converging, shocks to the economy can temporarily increase the dispersion. In these cases σ-convergence is the relevant concept because it indicates how the variables behaved in the past and are likely to behave in the future. The test of σ-convergence is performed using the following regression equation

$$\Delta D_{it} = \alpha + \beta D_{it-1} + \varepsilon_{it} \tag{22}$$

where $D = lnF_{it} - \overline{(lnF_{it})}$ and $\Delta \mathrm{D_{it}} = D_{it} - D_{it-1}$. Here, $\mathrm{F_{it}}$follows the same identification as it did in the β-convergence equation (21). $\overline{(\mathrm{lnF_{it}})}$ denotes the mean of $\mathrm{lnF_{it}}$. Equation (22) is also estimated following the fixed effect methodology as (21) and negative β coefficient suggests the existence of σ-convergence.

4. Data and Empirical Results

4.1. Data

Table 1. Data Sources

Variable	Source	Notes
GDP (constant 2005 US$)	World Bank national accounts data, and OECD National Accounts data files.	GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2005 U.S. dollars.
CO2 Emissions (metric tons per capita)	Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States.	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.
Net Capital Stock (current PPPs in mil. 2005US$)	Penn World Tables v8.1 (Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2015), "The Next Generation of the Penn World Table" forthcoming American Economic Review, available for download at www.ggdc.net/pwt)	Capital stocks are estimated based on cumulating and depreciation past investments using the perpetual inventory method (PIM).
Labor (total)	International Labour Organization, using World Bank population estimates.	Total labor force comprises people ages 15 and older who meet the International Labour Organization definition of the economically active population: all people who supply labor for the production of goods and services during a specified period. It includes both the employed and the unemployed. While national practices vary in the treatment of such groups as the armed forces and seasonal or part-time workers, in general the labor force includes the armed forces, the unemployed, and first-time job-seekers, but excludes homemakers and other unpaid caregivers and workers in the informal sector.
Energy (kg of oil equivalent per capita)	IEA Statistics © OECD/IEA 2012 (http://www.iea.org/stats/index.asp)	Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

To estimate the hyperbolic distance functions, this essay uses the panel of EU member and candidate countries from 1990 to 2011 including one desirable output GDP, one undesirable output CO2 and three inputs capital (K), labor (L) and energy (E). The data are compiled from different sources (see Table 1). GDP data in constant 2005 US dollars is obtained from the World Bank Development Indicators database, capital stock data calculated using perpetual inventory method (PIM) is obtained from the PENN World Tables v8.1. Summary statistics of the data is presented in Table 2.

Table 2. Descriptive statistics for outputs and inputs

	Outputs				Inputs					
	GDP (constant 2005 US$ x10^6)		CO_2 Emissions (per capita)		Capital (in mil. 2005 US$)		Labor ($x10^2$)		Energy (kgoe, per capita)	
EU-15										
Austria	286,325	(40,239)	8.003	(0.538)	886,841	(198,801)	3,948,8	(242,4)	3,690	(313.30)
Belgium	351,823	(46,360)	10.648	(0.728)	980,700	(282,787)	4,406,9	(285,9)	5,424	(261.32)
Denmark	238,826	(29,274)	10.079	(1.467)	553,523	(139,315)	2,890,4	(45,5)	3,615	(196.56)
Finland	177,022	(33,395)	11.086	(1.025)	563,444	(126,578)	2,609,4	(78,3)	6,331	(510.65)
France	2,002,569	(245,727)	6.016	(0.341)	5,481,056	(1,741,129)	27,660,8	(1,412,8)	4,084	(146.59)
Germany	2,757,932	(232,120)	10.109	(0.713)	7,867,179	(1,509,075)	40,735,1	(894,5)	4,096	(127.04)
Greece	210,731	(38,543)	8.051	(0.619)	771,618	(196,100)	4,774,5	(335,7)	2,418	(239.79)
Ireland	160,266	(53,715)	9.765	(0.964)	293,628	(144,106)	1,785,1	(321,4)	3,240	(314.40)
Italy	1,724,639	(137,719)	7.591	(0.445)	6,253,468	(1,524,916)	23,761,5	(702,0)	2,887	(193.75)
Luxembourg	31,187	(7,770)	22.359	(3.065)	74,192	(25,430)	193,2	(25,3)	8,391	(745.52)
Netherlands	611,755	(95,188)	10.634	(0.282)	1,543,284	(472,240)	8,068,2	(711,2)	4,671	(150.40)
Portugal	179,594	(22,693)	5.380	(0.663)	682,083	(251,853)	5,203,1	(333,9)	2,181	(273.28)
Spain	995,168	(189,330)	6.711	(0.879)	3,637,694	(1,823,363)	19,105,1	(2,800,5)	2,810	(319.70)
Sweden	343,041	(58,140)	5.811	(0.405)	659,323	(114,638)	4,664,8	(182,1)	5,554	(227.69)
United Kingdom	2,103,694	(335,784)	8.948	(0.687)	3,948,862	(1,111,599)	30,009,5	(1,239,7)	3,610	(240.12)
New Members										
Bulgaria	26,195	(5,112)	6.407	(0.795)	173,152	(45,943)	3,605,5	(225,2)	2,539	(209.26)
Croatia	41,322	(6,423)	4.780	(0.477)	213,209	(66,797)	1,986,2	(51,6)	1,870	(165.99)
Cyprus	15,626	(3,655)	6.995	(0.501)	60,394	(17,217)	451,2	(93,0)	2,147	(161.16)
Czech Republic	123,045	(22,501)	11.765	(0.779)	689,256	(165,528)	5,170,9	(50,8)	4,182	(189.11)
Estonia	11,880	(3,022)	12.325	(1.109)	50,799	(23,101)	684,1	(13,7)	3,821	(287.85)
Hungary	95,599	(15,917)	5.647	(0.368)	445,506	(166,335)	4,250,0	(123,2)	2,547	(89.18)
Latvia	14,442	(3,978)	3.371	(0.408)	80,389	(30,419)	1,122,1	(39,1)	1,925	(180.63)
Malta	5,335	(1,062)	6.204	(0.453)	22,527	(9,337)	156,9	(13,0)	1,998	(135.07)
Poland	267,808	(72,735)	8.481	(0.597)	1,259,746	(184,051)	17,552,6	(311,6)	2,520	(121.97)
Romania	89,953	(17,589)	4.812	(0.745)	681,373	(211,309)	10,677,5	(835,1)	1,903	(237.22)
Slovakia	56,349	(15,034)	7.280	(0.522)	245,345	(56,839)	2,606,4	(79,3)	3,351	(102.88)
Slovenia	33,756	(5,741)	7.738	(0.324)	144,462	(38,007)	994,8	(35,5)	3,434	(204.65)
Candidate Countries										
Albania	6,942	(2,342)	1.153	(0.453)	73,155	(27,466)	1,330,1	(57,9)	593	(136.78)
Macedonia	5,972,	(974)	5.242	(0.608)	38,458	(18,054)	873,0	(55,2)	1,357	(77.15)
Montenegro	2,678	(239)	3.801	(0.522)	22,083	(3,248)	253,7	(4,9)	1,859	(137.14)
Serbia	29,583	(1,134)	6.797	(0.414)	311,851	(22,010)	3,250,2	(94,1)	2,213	(91.29)
Turkey	407,470	(104,594)	3.350	(0.515)	1,416,545	(600,090)	22,000,8	(1,885,5)	1,189	(174.74)
Overall	***450,764***	***(719,968)***	***7.860***	***(3.863)***	***1,340,665***	***(2,091,622)***	***8,538,3***	***(10,499,7)***	***3,273***	***(1,646)***

Note: The figures in the parentheses are the standard deviations.

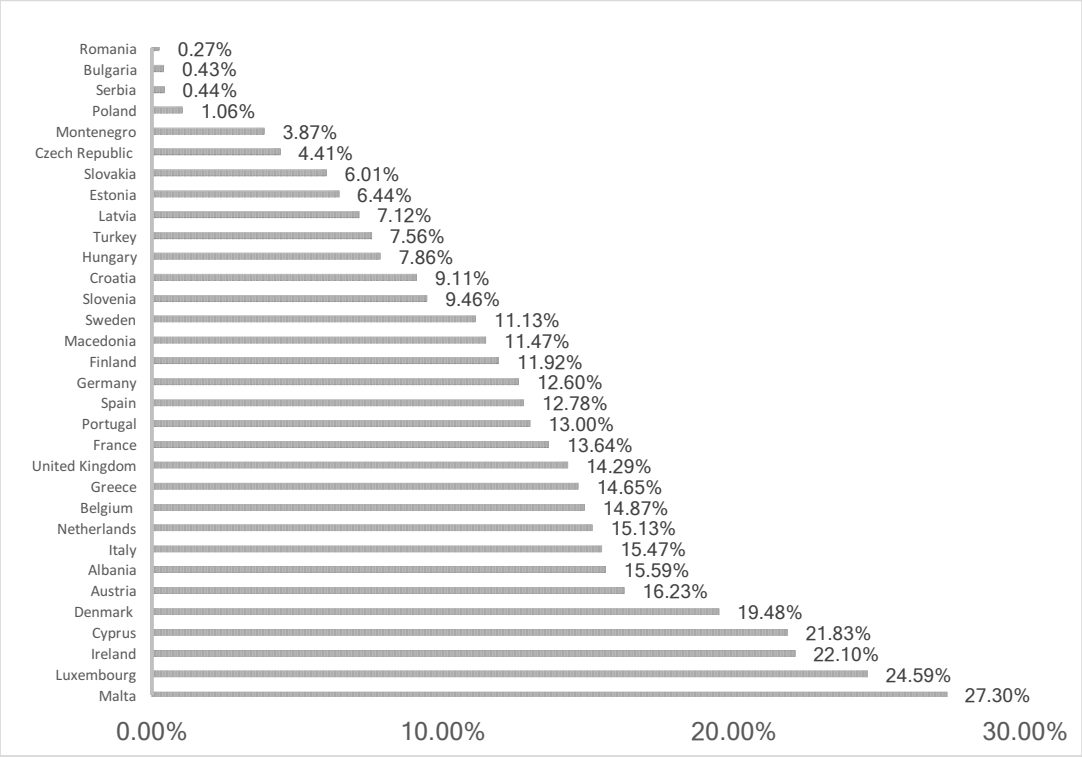
4.2. Empirical Results

The enhanced hyperbolic distance function efficiency results and mean efficiency scores for each country are presented in Table 3. The first observation for the overall efficiency scores between 1990-2011 is that environmental technical efficiency increases, some more than others. The estimated mean environmental technical efficiency for the whole sample in 2011 is 0.682, suggesting that a European country, on average, has the potential to increase real GDP by 46.6% (1/0.682-1=0.466) while simultaneously reducing its inputs and CO2 emissions by 31.8%, hence bridging the gap with the highest environmentally efficient country. The results further indicate that Malta, on average, has the lowest efficiency scores (0.388), suggesting that Malta could increase real GDP by 158% (1/0.388-1=1.58) and while simultaneously reducing CO2 emissions, capital, labor and energy input by 61.2% (1-0.388=0.612) using current technology.

The results also indicate that Romania has the highest average environmental technical efficiency score (0.989), suggesting that it could increase real GDP by only 1.1% (1/0.989-1=0.0107) and simultaneously reduce CO2 emissions, capital labor and energy by 1.1% (1-0.989=0.0106). Malta and Romania share the most and least percentage change in environmental technical efficiency respectively by 27% and 0.2% over the period 1990-2011. European Environment Agency reported that emissions have risen significantly in the past 25 years in Malta and for the period between 1990-2007 they attribute the increase in emissions to energy, transport and waste sectors with small contributions from tourism (European Environment Agency (EEA) 2015). The main reason for Malta's low environmental efficiency score is its high urbanization which is not supported with adequate environmental policies. The seasonal tourism and high transportation bring about inefficient use of resources and the lack of environmental policies hurts Malta's overall environmental efficiency. Romania's high environmental efficiency on the other hand is mainly due to its share of agricultural land and forests with 61% and 28% respectively of the overall land cover (European Environment Agency (EEA) 2015). Besides there are strict environmental policies that protect the environmentally significant and sensitive areas such as the Danube Basin and Black Sea coastal regions.

Figure 1 presents the percentage changes in environmental technical efficiency for each country from 1990 to 2011. As observed from Figure 1, following Malta with the highest efficiency increase from 1990 to 2011 is Luxembourg and Ireland with 24.5% and 22.1%, respectively. One of the strongest economies of the EU, Germany has an efficiency score of 0.576 in 1991 and 0.648 in 2011 which experienced a 12.6% change while France increased efficiency by 13.6% and the UK increased efficiency by 14.2%.

Figure 1. % Change in Environmental Technical Efficiency from 1990-2011



For instance, for Turkey the Intended National Determined Contribution (INDC) submitted to the COP21 indicates a greenhouse gas reduction of 21% below business as usual (BAU) in 2030. Our results indicate that Turkey for the period between 1990 and 2011 operated under an average environmental technical efficiency of 0.751, suggesting that Turkey could increase real GDP by 33.20% while simultaneously reducing CO2 by 24.9%. Our results, based on previous performance, indicate that Turkey has the potential to meet its targets set in its INDC reports. On the other hand, overall EU average

environmental technical efficiency score is 0.640, indicating that EU has the potential to increase real GDP by 56.60% while simultaneously reducing CO2 by 36%. This falls in line with the EU INDC, which presents a target of 40% domestic greenhouse gas emissions reduction by 20303.

The interesting point observed from Table 3, in general, is that new members and the candidate countries have higher scores of environmental technical efficiencies than EU-15. Main reason behind such a result could be that the EU-15 countries are mostly developed countries that have transitioned into tertiary industries. Among the types of industrial structures that most countries follow through starting with primary heavy industries followed by secondary stage based on specialization and efficiency. The third stage of industrial development which is the tertiary industry, relative to other stages of industrialization is less energy intense which eventually translates into lower emissions.

This implies that EU-15 have more potential to increase their environmental technical efficiency in the years to come compared to that of the new members and candidate countries. Another surprising result is that becoming a EU member does not seem to have a significant effect on environmental technical efficiency. Particularly looking at the new members and comparing the pre and post membership trends from before and after 2004, we cannot observe a distinctive change in the trend due to EU accession. However, overall results suggest that there is a catching-up process in environmental technical efficiency among the sampled countries since the countries that experience the highest efficiency increase are the ones with the lowest efficiency scores in 1990.

Because this is the first study to derive the environmental technical efficiency scores and study the relationship between environmental technical efficiency, emissions and GDP for EU candidate and member countries, we do not have the chance to compare our results with the previous findings. However, a research fellow at the World Resource Institute published a recent article (Aden 2016), which utilizes data from BP Statistical

[3] The emission reduction targets are retrieved directly from the INDC's submitted to UNFCCC and is available at http://www4.unfccc.int/submissions/indc/

Review of World Energy 2015 and World Bank Development Indicators to direct attention to 21 countries that have reduced annual GHG emissions while experiencing GDP growth. Through analyzing the GHG emissions and GDP statistics of different countries, Aden (2016), draws attention to the fact that emission reduction is statistically possible without compromising GDP growth. The article does not mention energy or environmental technical efficiency and ties the simultaneous decrease in emissions with GDP growth to environmental policies, switching to renewable energy, carbon taxes, reducing industrial sector share of their economies and transitioning from high-carbon production to low-carbon production. In that sense, our findings not only support but also present a different approach for providing evidence on simultaneous GDP growth and emissions reduction possible.

Table 3. EHDF Efficiency Results

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean
EU-15																							
Austria	0.512	0.516	0.520	0.524	0.528	0.532	0.536	0.540	0.544	0.548	0.552	0.556	0.560	0.564	0.568	0.572	0.576	0.579	0.583	0.587	0.591	0.595	0.554
Belgium	0.539	0.543	0.547	0.551	0.555	0.559	0.563	0.567	0.571	0.575	0.578	0.582	0.586	0.590	0.594	0.597	0.601	0.605	0.608	0.612	0.616	0.619	0.580
Denmark	0.452	0.457	0.461	0.465	0.470	0.474	0.478	0.482	0.487	0.491	0.495	0.499	0.504	0.508	0.512	0.516	0.520	0.524	0.528	0.532	0.536	0.540	0.497
Finland	0.605	0.609	0.613	0.616	0.620	0.623	0.627	0.631	0.634	0.638	0.641	0.644	0.648	0.651	0.655	0.658	0.661	0.665	0.668	0.671	0.674	0.677	0.642
France	0.565	0.569	0.573	0.577	0.581	0.585	0.589	0.592	0.596	0.600	0.603	0.607	0.611	0.614	0.618	0.622	0.625	0.629	0.632	0.636	0.639	0.643	0.605
Germany		0.576	0.579	0.583	0.587	0.591	0.595	0.598	0.602	0.606	0.609	0.613	0.617	0.620	0.624	0.627	0.631	0.634	0.638	0.641	0.645	0.648	0.613
Greece	0.544	0.548	0.552	0.556	0.559	0.563	0.567	0.571	0.575	0.579	0.583	0.586	0.590	0.594	0.598	0.601	0.605	0.609	0.612	0.616	0.620	0.623	0.584
Ireland	0.411	0.415	0.420	0.424	0.428	0.433	0.437	0.441	0.446	0.450	0.455	0.459	0.463	0.467	0.472	0.476	0.480	0.485	0.489	0.493	0.497	0.501	0.456
Italy	0.527	0.531	0.535	0.539	0.543	0.547	0.551	0.555	0.559	0.563	0.567	0.571	0.574	0.578	0.582	0.586	0.590	0.593	0.597	0.601	0.605	0.608	0.568
Luxembourg	0.375	0.380	0.384	0.389	0.393	0.398	0.402	0.406	0.411	0.415	0.420	0.424	0.428	0.433	0.437	0.442	0.446	0.450	0.455	0.459	0.463	0.468	0.422
Netherlands	0.534	0.538	0.542	0.546	0.550	0.554	0.558	0.562	0.565	0.569	0.573	0.577	0.581	0.585	0.588	0.592	0.596	0.600	0.603	0.607	0.611	0.614	0.575
Portugal	0.580	0.584	0.588	0.591	0.595	0.599	0.603	0.606	0.610	0.614	0.617	0.621	0.624	0.628	0.631	0.635	0.638	0.642	0.645	0.649	0.652	0.655	0.619
Spain	0.585	0.589	0.593	0.596	0.600	0.604	0.607	0.611	0.615	0.618	0.622	0.625	0.629	0.633	0.636	0.639	0.643	0.646	0.650	0.653	0.656	0.660	0.623
Sweden	0.625	0.628	0.632	0.635	0.639	0.642	0.646	0.649	0.652	0.656	0.659	0.662	0.666	0.669	0.672	0.675	0.679	0.682	0.685	0.688	0.691	0.694	0.660
United Kingdom	0.551	0.555	0.559	0.563	0.567	0.571	0.575	0.579	0.583	0.586	0.590	0.594	0.598	0.601	0.605	0.609	0.612	0.616	0.620	0.623	0.627	0.630	0.592
Average EU15	0.529	0.536	0.540	0.544	0.548	0.552	0.556	0.559	0.563	0.567	0.571	0.575	0.579	0.582	0.586	0.590	0.594	0.597	0.601	0.605	0.608	0.612	
New Members																							
Bulgaria	0.981	0.981	0.982	0.982	0.982	0.982	0.982	0.983	0.983	0.983	0.983	0.984	0.984	0.984	0.984	0.984	0.984	0.985	0.985	0.985	0.985	0.985	0.983
Croatia						0.609	0.613	0.617	0.620	0.624	0.627	0.631	0.634	0.638	0.641	0.645	0.648	0.651	0.655	0.658	0.661	0.665	0.637
Cyprus	0.415	0.419	0.423	0.428	0.432	0.437	0.441	0.445	0.450	0.454	0.458	0.463	0.467	0.471	0.476	0.480	0.484	0.488	0.493	0.497	0.501	0.505	0.460
Czech Republic			0.810	0.812	0.814	0.816	0.818	0.820	0.822	0.824	0.826	0.828	0.830	0.832	0.834	0.835	0.837	0.839	0.841	0.843	0.844	0.846	0.829
Estonia						0.702	0.705	0.708	0.710	0.713	0.716	0.719	0.722	0.725	0.728	0.730	0.733	0.736	0.739	0.741	0.744	0.747	0.725
Hungary		0.703	0.706	0.709	0.712	0.715	0.718	0.721	0.724	0.726	0.729	0.732	0.735	0.737	0.740	0.743	0.745	0.748	0.751	0.753	0.756	0.758	0.732
Latvia						0.677	0.680	0.683	0.686	0.689	0.692	0.695	0.698	0.701	0.704	0.707	0.710	0.713	0.716	0.719	0.722	0.725	0.701
Malta	0.341	0.345	0.350	0.354	0.359	0.363	0.368	0.372	0.377	0.381	0.385	0.390	0.394	0.399	0.403	0.408	0.412	0.416	0.421	0.425	0.430	0.434	0.388
Poland	0.954	0.955	0.955	0.956	0.956	0.957	0.957	0.958	0.958	0.959	0.959	0.960	0.960	0.961	0.961	0.962	0.962	0.962	0.963	0.963	0.964	0.964	0.959
Romania	0.988	0.988	0.988	0.988	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.990	0.991	0.991	0.989
Slovakia			0.753	0.755	0.758	0.760	0.763	0.765	0.768	0.770	0.773	0.775	0.777	0.780	0.782	0.784	0.787	0.789	0.791	0.793	0.796	0.798	0.776
Slovenia						0.598	0.602	0.606	0.609	0.613	0.617	0.620	0.624	0.627	0.631	0.634	0.638	0.641	0.645	0.648	0.651	0.655	0.627
Average New Members	0.736	0.732	0.746	0.748	0.750	0.717	0.720	0.722	0.725	0.727	0.730	0.732	0.735	0.737	0.739	0.742	0.744	0.747	0.749	0.751	0.754	0.756	
Candidate Countries																							
Albania	0.524	0.528	0.532	0.537	0.541	0.545	0.549	0.553	0.557	0.560	0.564	0.568	0.572	0.576	0.580	0.584	0.587	0.591	0.595	0.599	0.602	0.606	0.566
Macedonia			0.589	0.593	0.597	0.600	0.604	0.608	0.611	0.615	0.619	0.622	0.626	0.629	0.633	0.636	0.640	0.643	0.647	0.650	0.653	0.657	0.624
Montenegro																0.581	0.585	0.589	0.592	0.596	0.600	0.604	0.592
Serbia																	0.928	0.929	0.930	0.931	0.931	0.932	0.930
Turkey	0.723	0.725	0.728	0.731	0.734	0.737	0.739	0.742	0.745	0.747	0.750	0.752	0.755	0.758	0.760	0.763	0.765	0.768	0.770	0.772	0.775	0.777	0.751
Average Candidates	0.623	0.627	0.617	0.620	0.624	0.627	0.631	0.634	0.638	0.641	0.644	0.648	0.651	0.654	0.658	0.641	0.701	0.704	0.707	0.710	0.712	0.715	

One of the primary objectives of this essay is to check for efficiency convergence. The results of the β-convergence and σ-convergence are presented in Table 4. The environmental technical efficiency scores are used in the convergence analysis. We have tested the whole sample for both the β-convergence and σ-convergence over the period 1990-2011. The results presented in Table 4 show that the coefficients of $ln\mathrm{F}_{\mathrm{it}-1}$ and D_{it-1} are negative and statistically significant at conventional levels, indicating that both β-convergence and σ-convergence exist among the EU and candidate countries.

Table 4. Regression results for efficiency convergence

β - convergence		
α		-0.0002*
		(0.0007)
β	$(ln\mathrm{F}_{\mathrm{it}-1})$	-0.0119*
		(0.0001)
σ - convergence		
α		-0.0020*
		(0.0001)
β	(D_{it-1})	-0.161**
		(0.0284)

Note: The figures in the parentheses are the standard-errors. *, **, and *** denote significance level at 1%, 5% and 10%, respectively.

The existence of β-convergence implies that although the efficiency levels of the sample countries differs in terms of their initial levels, based on the comparative differences in their efficiency growth rates, they will converge to a steady state. The existence of β-convergence is a necessary condition to test for σ-convergence. From Table 4, the existence of σ-convergence implies that the dispersion of efficiency scores among the sampled countries decreases overtime.

5. Conclusion

This essay introduces a new perspective on the analysis of environmental technical efficiency by employing parametric hyperbolic distance functions and further looking into efficiency convergence among the EU member and candidate countries for the period

1990-2011. Departing from a recent study of Cuesta et al. (2009) we have estimated the environmental technical efficiency using a translog production function which allowed for increases in desirable output GDP, and decreases in the inputs capital, labor and energy as well as the undesirable output CO2 emissions. We have found that the EU-15 countries in contrast to the new members and the candidate countries have a greater potential for reducing CO2 emissions while increasing GDP and reducing energy use simultaneously. Although the environmental technical efficiency scores vary among the EU members and candidates, countries with higher GDP levels tend to have higher potential in reducing carbon emissions. One common feature among the EU members and candidates is that for the period between 1990 and 2011 environmental technical efficiency follows an increasing trend which led us to check for any convergence exists or not in terms of efficiency. Departing from the traditional output production function, this essay, using hyperbolic distance function, has enabled the policy makers to take into consideration the environmental aspect of the production process by allowing the reduction of undesirable outputs and inputs while simultaneously increase production. However, one of the most important contribution of this study is that it provides evidence on the existence of environmental technical efficiency convergence among the EU member and candidate countries.

The results of this study have at least two policy implications. First, based on the estimated environmental technical efficiency scores, new policies can be designed specific to each member and candidate to improve efficiency and production. Transitioning from high carbon intense production to a low carbon economy, increasing the share of renewable energy in the energy profile and improving production technology towards higher energy efficiency are some of the policies that can be adopted towards increasing environmental technical efficiency. Our results could provide insights towards matching policies to the right country that needs it and fits best. Furthermore, our results suggest that policy makers should follow the Odyssee-Mure project, which provides energy consumption and efficiency trends as well as an evaluation of energy efficiency policy measures.

The second policy implication is based on the existence of convergence which is perhaps the most significant finding and contribution of this study. EU members are bound to a common and consistent set of environmental policies and candidates are required to satisfy these policies during their accession process. Therefore, the existence of environmental technical efficiency convergence among EU member and candidates provides a good example of collaborative action that facilitates coordination and better dialog among countries. This form of collective action help raise efficiency in the countries that lag behind and catch up with a standard that benefits all parties. Eco-design Directive is one of the common set of EU-wide rules that target the improvement of environmental performance while reducing energy and resource consumption. The results of this essay also support and prove that such Directives are economically sound and applicable with sound results.

A similar agreement (The Paris Agreement) was ratified on April 22, 2016 by 174 countries including the EU member and candidates, that will help reduce carbon emissions provided that countries fulfill their goals stated in their INDC's. The common feature of these Directives and Agreements is that besides being a binding roadmap for policymakers, they also provide financial or technological support to those countries that lack the sufficient resources and help them converge to a common and higher efficiency and emissions standards.

There are several ways to build on this study by further research. First, to expand the sample countries to a wider range for example using the UNFCCC members and observing convergence. Second, to include different greenhouse gasses as undesirable outputs, since there are many air pollutants besides CO2, such as carbon monoxide, nitrogen oxide or relatively a more dangerous output SO2 emissions. Including more pollutants may give a wider perspective on environmental technical efficiency for our future study.

PART II

THE ROLE OF INTERNATIONAL TRADE AND URBANIZATION ON ENVIRONMENTAL TECHNICAL EFFICIENCY IN EU MEMBER AND CANDIDATE COUNTRIES

1. Introduction

The adverse effects of global warming have become more evident in the recent years. Rising carbon dioxide (CO_2) emissions, due to excessive use of fossil fuels, is one of the main obstacles for sustainable development and economic growth. Countries concerned about climate change, sustainable development and providing a nurturing environment for the future generations, joined the United Nations Framework Convention on Climate Change (UNFCCC). The Convention established the Kyoto Protocol in 1997 which set binding targets to reduce carbon emissions. In December 2015, the Paris Agreement, successor to Kyoto Protocol, has been accepted by a large number of countries with the aim of keeping global warming below 2°C, above pre-industrial levels. Maintaining global warming below or at certain levels requires countries to lower their CO_2 emissions, in general, the greenhouse gases (GHG) emissions.

Understanding the various causes and effects of climate change is vital in identifying the problem and coming up with a solution. Climate change policy has three pillars; economic, technological and environmental. Carbon taxes, abatement policies, carbon trading, and energy source diversification are some policies/solutions that can be categorized under the economic pillar, while improving production technology, appliances and vehicles to be more energy efficient are some of many solutions under the technological pillar. Environmental pillar deals with the human factor of the problem and advocates green economy, sustainable development, and green accounting. Targeting one of these pillars can produce a solution towards preventing climate change through decreasing GHG emissions. These policies might vary across countries with different technologies, availability of resources and, public opinion towards climate change. Therefore, the cost of each option varies for different countries. For developed countries with diversified sources of energy, transforming their energy mix from a high carbon intense to a low carbon might not become a cost-effective option while, for developing

countries with scarce resources the opposite is true. Similar argument can be made for technological development such that the difference in technological advancement between a developed and developing country will be an issue that would have reflections on the energy intensity of their industry and its productivity.

Another policy option targets the energy input. Decreasing the use of energy, mostly fossil fuels, without compensating the difference with a cheaper and cleaner alternative, will lead to a reduction in CO_2 emissions however with a cost of economic slowdown. Since alternative and clean energy options are not as efficient as fossil fuel yet, countries become hesitant in employing policies that require energy reduction and, refrain from targeting CO_2 emission reductions. In this context, countries devote their efforts on simultaneously reducing CO_2 emissions and increasing productivity. A growing number of studies have been devoted on the topic of technical, environmental and energy efficiency. Technical efficiency refers to improving production capabilities by enhancing labor and capital while energy efficiency refers to generating more output with the same or lower energy input. Environmental efficiency, on the other hand, is a concept that incorporates both technical and energy efficiency with the addition of reducing the bad output, "CO_2 emissions". It can be denoted as, green production or, a production process is environmentally technically efficient if output is increasing and CO_2 emissions is decreasing simultaneously while the inputs are held constant or lowered. When countries target environmental technical efficiency, they conserve energy[4], transform their industry to a less energy intense one, promote green architecture, renewable energy, and green economy. All of which can be categorized under the third pillar of climate change policy that is the environmental pillar.

Although it is important to investigate environmental technical efficiency for countries to determine country specific policies, we believe that it is also significant to

[4] A common misconception that should be addressed is that conservation of energy is not the same concept as energy efficiency. The former means using a constant service less while the latter means using less energy for that constant service. For example, improving a car technology to require less energy will improve its energy efficiency, whereas using that car less refers to conserving energy.

investigate the determinants of environmental technical efficiency. Accurately identifying the determinants will enable countries to focus more on the right determinant to increase environmental technical efficiency. Hence, the main objective of this essay is to investigate the effects of per capita GDP, openness to trade, and urbanization on environmental technical efficiency for a panel of European Union (EU) member and candidate countries for the period 1990-2011, using a Tobit model. The environmental technical efficiency scores were calculated using parametric hyperbolic distance functions by Cuesta and Zofio (2005) and Cuesta et al. (2009)[5].

The contribution of our essay to the existing literature is twofold: First, unlike previous research, this essay uses environmental technical efficiency scores estimated through a parametric hyperbolic distance function approach and adds a new macro-economic variable, urbanization, as a determinant for environmental technical efficiency. Second, this is the first essay that investigates a relationship between the determinants and environmental technical efficiency for the EU member and candidate countries between 1990-2011.

By way of preview, our main empirical results suggest that the relation between environmental efficiency and economic development shows a U-shaped curve supporting a formulation of the Environmental Kuznets Curve (EKC)[6]. Furthermore, the results also suggest that industrial share of GDP have a positive effect which follows an inverse U-shaped curve suggesting that above a threshold level, increasing share of industry negatively effects environmental technical efficiency. Openness to trade is also a significant determinant of environmental efficiency and is inversely correlated with environmental efficiency. Finally, urbanization has a positive and significant effect on environmental technical efficiency.

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[5] The empirical model used to estimate environmental technical efficiency scores is given in Part I Section 3.

[6] Environmental Kuznets curve stated by (Grossman & Krueger 1995) refers to the increasing environmental degradation during the initial, lower income levels followed by a decrease once a threshold of per capita income is reached. Therefore, it is represented with an inverse U-type curve.

The rest of the essay is organized as follows. Section 2 reviews the previous literature on determinants of environmental efficiency. Section 3 discusses the model of the study and econometric methodology. Section 4 discusses the data and empirical results of the estimations. The essay's concluding remarks are provided in section 5.

2. Literature Review

Global consensus on the correlation between increasing energy consumption and rising GHG emissions has made energy efficiency popular and made it one of the most debated topics in the energy, environment, and efficiency studies. Although energy efficiency (EE) has the potential to reduce GHG emissions, the argument against it is that it leads to the phenomenon known as 'Jevons' Paradox'. Jevons argued that "it is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth" Jevons (1865). What Jevons and a more contemporary study by Khazzoom (1980) observed was that increasing EE led to a higher use of energy, therefore causing GHG emissions to rise even further.

Recent studies, therefore, focus more on environmental efficiency and analyze the effects of various economic variables. Zaim and Taskin (2000) utilize non-parametric techniques to estimate an environmental efficiency index and investigate its relation with determinants such as per capita GDP, population density, environmental public research and development expenditures, and share of manufacturing in GDP. They observed a typical inverse U- shaped Kuznets curve between environmental efficiency and per capita GDP and significant relationship between population density, R&D, and share of manufacturing in GDP.

Taskin and Zaim (2001) used a DEA model to compute environmental efficiencies and investigate a relationship between trade composition, the share of polluting exports, and openness with environmental efficiency using OLS and found them to be significant determinants. They also found that increasing level of openness above a threshold has a larger effect on high-income countries whereas it does not have a significant effect on low or middle-income countries. Färe et al. (2004) construct an environmental performance index through a DEA approach using the pollutants CO_2, NO_X (nitrous oxide) and SO_X (sulfur oxide), and further analyze its relation with economic development and population.

In terms of environmental Kuznets curve, the study found that independently CO_2 is positively related to per capita GDP, however, simultaneously CO_2, NO_X and SO_X do not have a clear relationship with per capita GDP.

Färe et al. (2004) also observed from the environmental performance index, with only CO_2 to account for the bad output, that countries with low environmental performance are dependent on oil whereas those with high environmental performance have the highest dependency on nuclear energy. Ramanathan (2005) also found a similar pattern as Färe et al. (2004), in terms of the relationship between fossil fuel dependency and environmental performance. Kumar (2006) investigated environmentally sensitive total factor productivity for 41 developed and developing countries and examined the impact of openness on conventional and environmentally sensitive productivity. Kumar (2006) also used DEA and directional distance functions to derive the productivity index and found as well that openness is a significant determinant.

Zhou et al. (2007) used a non-radial DEA approach to measure environmental performance for OECD countries between 1995-1997. They observed that environmental performance have soared between the years and assert that the change in environmental performance is mainly due to the technological improvements. Kumar and Khanna (2009) measured environmental efficiency and environmental productivity for 38 countries and explained the differences between efficiency and productivity through income levels, share of industrial output, capital per labor, use of commercial energy, and population density in addition to the degree of openness using a Tobit model. Their results are similar to that of (Taskin & Zaim 2001; Kumar 2006) in the sense that both found openness to be a significant determinant of environmental efficiency. Yu-Ying Lin et al. (2013) estimated environmental productivity in 70 countries between the years 1981-2007 through a generalized meta-frontier Malmquist productivity index approach. They also examined the relationship between GDP per capita, capital per labor, use of commercial energy per unit of GDP, and the openness and environmental efficiency. They found that openness is a significant determinant for developed countries whereas failed to observe a significant relationship between openness and environmental efficiency for developing countries. Li and Wang (2014) combined a slacks-based efficiency measure and the meta-frontier to

measure environmental efficiency and formulized a Tobit model to study the effects of per capita GDP, energy intensity, industrial structure, foreign direct investment (FDI) and, openness on environmental efficiency. Their results show that there is positive correlation with per capita GDP, U- shaped relation with industrial structure, negative relation with energy intensity and, openness and, no significant relation with FDI.

The studies specify the determinants of environmental efficiency using efficiency scores calculated through non-parametric approaches, mostly 2-stage DEA. In the second stage analysis, some utilized Tobit methodology (Kumar and Khanna 2009; Li and Wang 2014), whereas others used least squares (Zaim and Taskin 2000; Taskin and Zaim 2001; Kumar 2006). The arguments against these methods are mainly directed towards the efficiency scores that are estimated by DEA. There are major limitations of the DEA methodology. Simar and Wilson (2007) state that in all the two-stage DEA studies, the major problem with the estimated efficiency scores are that they are serially correlated. Similar discussions against the use of DEA to measure efficiencies and the problems it creates are also argued by (McDonald 2009; Simar and Wilson 2011). Cuesta et al. (2009) also added that the DEA approach is non-linear except under the assumption of constant returns to scale. DEA and non-parametric approaches has been studied by numerous researchers those notable are reviewed by (Ang and Zhang 2000; Zhou et al. 2008).

The contribution of this essay to the related literature is that by using environmental technical efficiency scores calculated through a parametric hyperbolic distance function approach, we eliminated the limitations of the DEA approach. The arguments towards using least squares or Tobit analysis to test for exogenous variables' effects on environmental efficiency are related to DEA and this study stays above that argument in terms of its efficiency scores.

3. Model and Methodology

3.1. Determinant Analysis

As summarized in the previous section, numerous variables have been used in the process of analyzing the influencing factors of environmental efficiency. In addition to the common variables such as per capita GDP, industrial share, trade openness we have included the urban population share of total population to the analysis. One other common

variable is the energy intensity however we have chosen not to include it into our analysis. Energy intensity is defined as the ratio between energy use and GDP, identifying the amount of energy used to produce one unit of output. The indicator has been criticized by several scholars because it is misleading and fails to explain phenomena like the climate change. Since the denominator is GDP and at times of economic growth GDP increases faster than energy use, energy intensity will fall. However, this fall does not translate into lower carbon emissions or higher efficiency. In the reverse case, during economic recessions GDP drops faster than energy use, hence energy intensity will rise nevertheless that does not refer to decreasing energy or environmental efficiency. This can easily be observed by looking at the trend of energy intensity and carbon emissions throughout the years. Figure 2 shows a comparison of energy intensity and CO_2 emissions of the World. Although energy intensity has decreased through the years, CO_2 has increased continuously.

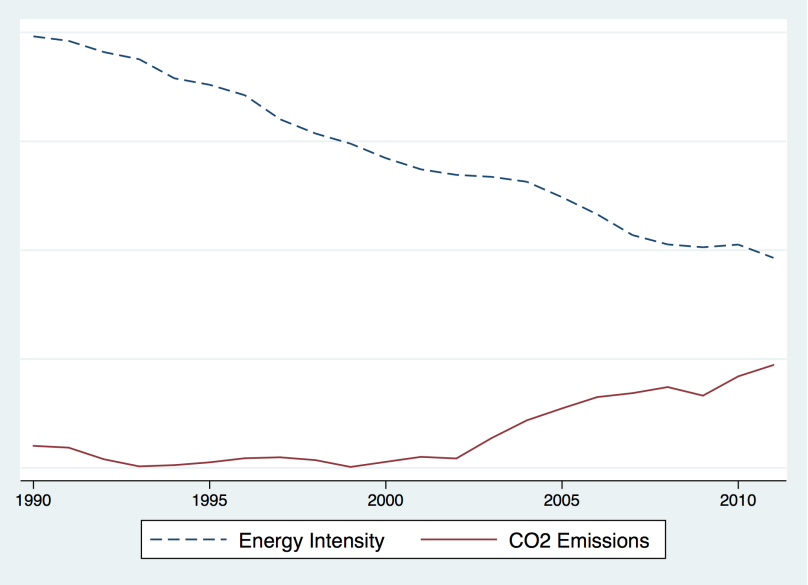


Figure 2. Energy Intensity and CO_2 Emissions for the World

Other factors can also affect energy intensity such as, population, natural resources, type of primary energy source, transformation of the industry from heavy to electronics and, transferring energy intensive heavy production to other countries. Hence, the overall evaluation of the energy, emissions and environmental efficiency analysis will be misleading.

Since the preliminary study by Kraft and Kraft (1978) which investigates the relationship between energy and GNP (Gross National Product), and the vast literature preceding it, there is no doubt to the existence of the correlation between energy and economic growth. In the recent years with phenomenon such as global warming, and climate change, the focus has been on the relationship between the environment and economy. The commonly known theory is pinned as the Environmental Kuznets Curve, asserting that in the first stages of economic development, as per capita income increases, the environment deteriorates until a threshold. At that point, people prefer environmental quality along with higher economic development hence environment gets better as per capita income increase. This is mostly illustrated by an inverse U-shaped curve which is called the EKC. By using the per capita GDP and its quadratic form, our objective is to test the existence of the EKC for environmental technical efficiency.

One other variable we have chosen as a determinant of environmental technical efficiency is the industrial structure. Industrial transformation in countries mostly follow a similar pattern, starting with primary heavy industry mostly focused on iron, steel and machinery which are mostly energy intensive. In the secondary stage, the focus is on division of labor or technical efficiency and, mass production which requires the improvement of production technologies and the primary industrial structure. Following is the tertiary industry which emphasizes on information technologies (IT), electronics and, automated production. As the industrial structure moves forward through these stages, each predecessor loses its demand and the successors' proportion increases. With the improving technology, output and technical efficiency the environmental impact decreases.

Our third variable as a determinant of environmental efficiency is trade openness. Studies (e.g., Taskin and Zaim 2001; Dean 2002) have shown that openness has a significant impact on the environmental performance through terms of trade and export structure. International trade determines a country's industrial structure. Countries, with looser environmental regulations and, focused on primary industries will become offshore production centers for polluting industries. On the contrary, countries that have a

comparative advantage in terms of tertiary industries and strict environmental regulations will have a higher environmental efficiency.

The last variable we have chosen as a determinant is the urban population ratio or urbanization. Urbanizations impact on the environment is analogous to positive externality through economies of scale. The general idea behind economies of scale is that, agglomeration of industries drives innovation, increases know-how, improves the region and, overall the economy. Necessity is the mother of innovation\invention and, necessity arises when larger populations of people live in the same area. Necessities such as transportation, architecture, machines, vehicles, education, healthcare, housing and, better food create incentives to improve these aspects of life. In the long run, healthy environment becomes a necessity and highlights the significance of sustainable development and green technologies.

Highly populated cities increase the compactness of daily life such as commuting and public transportation. For example, in large highly populated cities, people choose walking, cycling or public transportation which increase transportation efficiency, reduce the use of energy and eventually enhance the environmental performance. Green architecture is another positive impact of urbanization that benefits the environment. Buildings that generate its own electricity, refine rain water, and use solar panels, host populations as many as a small village thus increasing coverage of such utilities while saving extra infrastructure cost. Providing efficient infrastructure and public services to a larger population is cheaper and easier to manage in every aspect of housing from construction to waste management, and water sanitation. Urbanization, through dispersing the cost to many, makes environment friendly goods and services accessible and affordable to a larger population.

Finally, urbanization brings a higher standard of living in every aspect of life which in a sense leads to the EKC. With rising standards of living, the necessities or priorities of life shift from food, housing, health and, education to environment. Urbanization speeds up the process of change in priorities of life.

3.2. Empirical Analysis

The regression model we used in this essay is the Tobit model (Tobin,1958) also known as the censored regression. The simplest Tobit model can be formulized as follows

$$y_t^* = \beta_0 + X_t'\beta + \varepsilon_t, \quad t = 1,2,\dots,n \tag{1}$$

$$y_t = \begin{cases} y_t^* & if \quad y_t^* > 0 \\ 0 & if \quad y_t^* \le 0 \end{cases} \tag{2}$$

where $\varepsilon_t | X_t$ is $N(0, \sigma_0^2)$ and $\{y_t, x_t\}$ is i.i.d. X_t is a vector of determinants and β is a vector to be estimated. Another formulation of the Tobit model is $y_t = \max\{0, x_t'\beta + \varepsilon_t\}$. Tobit (censored) Model is different from the conventional regressions in the sense that the dependent variable is censored which means the observations are constraint to a specific range, such as the environmental technical efficiency scores that range between 0 and 1.

Based on the theoretical foundation and, equation **Error! Reference source not found.** and **Error! Reference source not found.** when we take into consideration the environmental technical efficiency $EE \in (0,1)$ and construct a Tobit model, the equation will be as follows

$$EE_{i,t} = \beta_0 + \beta_1 pGDP_{i,t} + \beta_2 \left(pGDP_{i,t}\right)^2 + \beta_3 IND_{i,t} + \beta_4 \left(IND_{i,t}\right)^2 + \beta_5 TO_{i,t} + \beta_6 UR_{i,t} + \varepsilon_{i,t} \tag{3}$$

where, pGDP, IND, TO and UR denote economic development level, industrial share of GDP, trade openness and share of urban population, respectively.

4. Data and Empirical Results

4.1. Data

To investigate the determinants of environmental technical efficiency, this essay uses the panel environmental technical efficiency data of EU member and candidate countries from 1990 to 2011. The efficiency scores have been estimated through a parametric hyperbolic distance function approach following Cuesta and Zofío (2005) and Cuesta et al. (2009). Per capita GDP has been used as a proxy for economic development level, industry value added (% of GDP), trade percent of GDP is used to determine level of openness and percent of urban population is used for urbanization. Data is compiled from World Bank

Development Indicators (WDI) between the years 1990-2011. The definitions of the variables are presented in Table 5. Summary statistics for the calculated efficiency scores, however, are given in Table 6.

Table 5. Data Sources and Descriptions

Variable	Indicator	Units	Source
Efficiency	(EE) Environmental Technical Efficiency	EE ∈ (0,1)	Calculated with parametric hyperbolic distance function
Economic Development	(pGDP) per Capita Gross Domestic Product	Constant 2005 US$	World Bank (WDI)
Industrial Structure	(IND) Industry value added % of GDP	100%	World Bank (WDI)
Trade Openness	(TO) International Trade % of GDP	100%	World Bank (WDI)
Urbanization	(UR) Urban Population % of Total Population	100%	World Bank (WDI)

Table 6. Summary Statistics for Environmental Technical Efficiency

Country	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Austria	22	0.554	0.026	0.512	0.595
Belgium	22	0.580	0.025	0.539	0.619
Denmark	22	0.497	0.027	0.452	0.540
Finland	22	0.642	0.022	0.605	0.677
France	22	0.605	0.024	0.565	0.643
Germany	21	0.613	0.022	0.576	0.648
Greece	22	0.584	0.025	0.544	0.623
Ireland	22	0.456	0.028	0.411	0.501
Italy	22	0.568	0.025	0.527	0.608
Luxembourg	22	0.422	0.029	0.375	0.468
Netherlands	22	0.575	0.025	0.534	0.614
Portugal	22	0.619	0.023	0.580	0.655
Spain	22	0.623	0.023	0.585	0.660
Sweden	22	0.660	0.021	0.625	0.694

UK	22	0.592	0.024	0.551	0.630
Bulgaria	22	0.983	0.001	0.981	0.985
Croatia	17	0.637	0.017	0.609	0.665
Cyprus	22	0.460	0.028	0.415	0.505
Czech Rep.	20	0.829	0.011	0.810	0.846
Estonia	17	0.725	0.014	0.702	0.747
Hungary	21	0.731	0.017	0.703	0.758
Latvia	17	0.701	0.015	0.677	0.725
Malta	22	0.388	0.029	0.341	0.434
Poland	22	0.959	0.003	0.954	0.964
Romania	22	0.989	0.001	0.988	0.991
Slovakia	20	0.776	0.014	0.753	0.798
Slovenia	17	0.627	0.018	0.598	0.655
Albania	22	0.566	0.025	0.524	0.606
Macedonia	20	0.624	0.021	0.589	0.657
Montenegro	7	0.592	0.008	0.581	0.604
Serbia	6	0.930	0.001	0.928	0.932
Turkey	22	0.751	0.017	0.723	0.777

4.2. Empirical Results

The Tobit analysis results, summarized in Table 7, indicate that economic development level, industrial structure have significant effects ($p < 0.01 \ \forall$ t tests) on environmental technical efficiency regardless of other determinants, openness and urbanization. On the other hand, openness to trade and urbanization are also statistically significant determinants of environmental technical efficiency.

In all four of the models, the effect of per capita income on efficiency is negative and significant. However, its quadratic term is statistically positive, suggesting that there is a U-shaped relationship between economic development and environmental technical efficiency. This suggests that as the per capita income increases at the initial stage of economic development, environmental technical efficiency will decrease (by -0.144e-04 for model 4) which will also increase environmental degradation. Once a threshold level of per capita income is reached, the environmental efficiency will start to increase with rising per capita income. Along with increasing environmental efficiency, environmental

degradation will start to decrease. The overall relation between environmental technical efficiency and per capita income therefore, supports the EKC hypothesis.

Table 7. Empirical Estimation Results

	Model 1 *w/o TO and UR*	Model 2 *with TO w/o UR*	Model 3 *with UR w/o TO*	Model 4 *with TO and UR*
$pGDP$	-0.109e-04***	-0.129e-04***	-0.118e-04***	-0.144e-04***
	(7.61e-07)	(7.89e-07)	(8.58e-07)	(8.97e-07)
$pGDP^2$	1.10e-10***	1.61e-10***	1.16e-10***	1.75e-10***
	(1.24e-11)	(1.41e-11)	(1.27e-11)	(1.46e-11)
IND	46.653***	43.007***	48.204***	45.132***
	(4.292)	(4.177)	(4.340)	(4.187)
IND^2	-705.07***	-626.39***	-733.27***	-664.00***
	(66.87)	(65.559)	(67.96)	(65.91)
TO		-0.846***		-0.916***
		(0.124)		(0.125)
UR			0.980**	1.531***
			(0.467)	(0.455)
C	0.070	0.189	0.004	0.082
	(0.066)	(0.066)	(0.075)	(0.073)
χ^2	365.40***	409.84***	369.77***	421.02***
Log Likelihood	469.03	491.2	471.2	496.84

(*, **, ***, statistically significant at 10%, 5%, 1% levels, respectively, the values in parenthesis indicates the standard errors, pGDP, IND, TO and UR denote; economic development level, industrial share of GDP, trade openness and share of urban population respectively, C denotes the constant, w/o=without)

Industrial share of GDP, based on the results of all four models, is also a statistically significant determinant of environmental technical efficiency. Unlike per capita income, the relation between industrial structure and environmental technical efficiency follows an inverse U-shaped curve. As the industrial share of GDP increases, environmental technical efficiency increases however, once a threshold of industrialization is reached, environmental technical efficiency starts to decrease. The inverse U-shaped relationship indicates that there is some diminishing marginal returns in terms of environmental efficiency. The more industrialized a country becomes, at one point, the less energy efficient it will end up to be.

The results from model 2 and 4 indicate that openness to trade is another statistically significant determinant of environmental technical efficiency. Free trade has been studied in numerous studies[7] as a significant source of economic growth, and economic growth is significantly correlated with environmental degradation which was pointed out by Grossman and Krueger (1991, 1995). Therefore, it is logical that increasing openness to trade negatively impacts the environment. Apart from the relation between trade and economic growth, and its reflection on the environment there are other aspects of free trade that cause the negative impact on environment. Ekins et al. (1994) asserted that transportation is a necessity of free trade and with increasing transportation, the use of fossil fuels increases. Increasing use of fossil fuels, releases more CO_2 into the atmosphere which in return exacerbates global warming.

Urban population share of total population is also a statistically significant and positive coefficient, indicating that environmental efficiency increases with the increase in the share of urban population. As previously stated, urbanization provides compactness to life in many aspects from health, access to clean water, transportation, and education. The compactness of urban life improves the possibility to increase energy efficiency which in return can enhance environmental efficiency. For example, in rural areas it requires more energy and infrastructure to provide essential requirements of housing to smaller populations whereas in urban areas where population is denser, similar investments serve a higher population. Economies of scale also improve environmental efficiency through positive externalities such as agglomeration of industries in certain regions which increases both productivity and efficiency through division of labor and specialization.

Industrial revolution was probably the single most effective cause of the increasing urban population in cities, and was also the breaking point at which CO_2 emission started to increase rapidly. However, the devastating environmental impact of this process of high industrialization and urbanization was not as obvious as it is today. In this regard,

[7] see Edwards (1993) for a survey of related literature

promoting urbanization will not necessarily promote environmental efficiency if not supported by environmental regulations, infrastructure, public awareness against emissions, credible zoning for industries and businesses, and clean transportation. Without the accompanying environmental policies and education, increasing urban population, will negatively affect environmental technical efficiency.

5. Conclusion

This essay introduces a new perspective on the determinant analysis of environmental technical efficiency by using efficiency scores estimated via a parametric hyperbolic distance function, and formulates a Tobit model to investigate the relationship between efficiency and its determinants. Apart from the most commonly used variables, per capita income, international trade, industrial structure we have introduced a new determinant, urbanization. Our sample consisted of the EU member and candidate countries over the years between 1990 and 2011. The empirical results suggested that per capita income, industrial share of GDP, openness to trade, and urbanization are all statistically significant determinants of environmental technical efficiency.

Regarding policy implications, the results suggest that targeting all or one of these determinants would have a significant impact on environmental technical efficiency. Although encouraging economic growth at first will not have a positive impact on the environment, sustainable growth after a threshold level of per capita income will increase environmental efficiency. However, as Arrow et al. (1995) suggest, policies that target economic growth are not substitutes for environmental policies. They also argue that economic growth policies must be accompanied by strict environment policies as well. Based on the values of the coefficients of both the per capita income and its quadratic form, targeting only economic growth will have a relatively small effect on environmental efficiency if not supported by environmental policies as well.

Another policy target could be to increase the industrial share of GDP which will highly affect environmental efficiency at first until a level of industrial share is reached. After that level, industrial share of GDP starts to negatively affect environmental efficiency perhaps due to diminishing marginal returns. Increasing the share of industry may not be sustainable if it is not supported by policies that also improve production

technologies towards green, carbon free production. Therefore, it is a more suitable policy to improve both the industrial share and its structure which means growth policy must be supported by an environmental policy for sustainable development.

With all the developing countries, and economies, the world is becoming smaller and the borders less explicit, which inescapably affects the environment. Our results suggested a negative coefficient for trade openness, to which the logical policy implication would be is to control the amount of international trade. In the case of EU, this means controlling the carbon intense new members. The new members that became a member in the last decade consist of the Central East European (CEE) countries also known as the transition (from planned to market economy) economies. Planned economies were known to be more energy and carbon intensive compared to the market economies hence them becoming a member and opening more and more to international trade, negatively affected the environmental efficiency during their period of transition. Therefore, in the case of EU, it would be a better policy option to target the energy and industrial structure of these countries towards a less carbon and energy intensive one, instead of international trade.

Environmental awareness, and climate action are significantly high in EU which is a contributing factor towards the positive correlation between urbanization and environmental efficiency. Countries become a part of a set of environmental policies and regulations as soon as they become a candidate and a member to the EU. In 1973, Environment Directorate General of the European Commission ('DG Environment') was set to preserve, protect and improve EU's environment through policies and legislations. These policies cover a large area of subjects from nature and biodiversity, urban environment, water to chemicals, land, and industry.

On the other hand, projects such as the Odyssee/Mure Project which compiles detailed data on energy efficiency, and CO_2 indicators provide sufficient data, and policy implications for the members. At the end, it boils down to the simple fact that economic, industrial, international trade, and urban policies must be supported by environmental policies to promote environmental efficiency.

CONCLUSION

Two interconnected essays concerning the environmental technical efficiency in EU member and candidate countries have been studied in this research. The first essay calculated the environmental technical efficiency scores and tested the existence of efficiency convergence for the sample countries between the years 1990-2011. The second essay, using the efficiency scores calculated in the first essay, investigated the relationship between environmental efficiency and its determinants, urbanization, trade openness, industrial share of GDP, and economic growth.

The overall results of the first essay have shown a linear increasing trend in environmental technical efficiency scores. Although efficiencies vary across countries we have observed that the least efficient country in terms of initial levels have grown the most within the sample period which signals evidence towards efficiency convergence. β and σ convergence results supported our observation, and proved that efficiency convergence exists for the sample countries. The interesting finding of our study is that countries that have higher GDP, primarily EU15 have lower efficiency scores compared to that of the new members and candidate countries. We have concluded that this difference is mostly due to industrial structure which was also supported in our second essay where we have found that industrial share of GDP and environmental technical efficiency follow an inverse U-shape curve relationship. In the primary stages of industrialization countries increase their environmental efficiency as they go through the stages of industrialization from primary heavy industries to tertiary industries. After a threshold is reached however, environmental efficiency starts to decrease. The EU15 countries are mostly at the latter part of this transformation where increasing their industrial share of GDP harms their environmental efficiency such as the notion diminishing marginal returns.

On the other hand, the new member and candidate countries are mostly at the primary and secondary stage of their industrialization where the focus is on heavy industries, specialization, energy and technical efficiency. Besides, most heavy production of the EU15 is carried through offshore production centers that are economical compared to domestic production which also affects the domestic environmental efficiency and GDP relation.

Urbanization is a positive and significant determinant of environmental technical efficiency. There are two inferences from this finding. First, it is not logical when we consider the fact that the high intensity of population in an area will most definitely harm the environment due to higher rates of production and consumption which will translate into higher emissions. However, the second inference is that if the population is made aware of the sensitive topic that is climate change and its impact on the world, if there are strict policies towards environmental protection and incentives towards commuting, sustainable architecture and green economy the seemingly negative factor could be a positive aspect. Our results towards the positive impact of urbanization supports this inference because EU is highly aware of the consequences and the dangers of climate change and proactive towards keeping emissions low. Through its strict environmental policies and directives, it keeps track of environmental efficiency in its member states and expect the candidates to fulfill similar objectives on their way to membership.

Openness to trade is a negative determinant of environmental technical efficiency. Trade openness is significantly high in EU members and transportation is also free and easily accessible to each member without any cost. In this age where fossil fuel is the main source of energy for transportation it logical to find that openness is a negative determinant especially for EU. Energy efficiency transportation is a necessity at this point for EU to bring down emissions further and increase environmental efficiency.

Our results support a main comprehensive policy implication and that is environmental policies attached to economic, industrial, trade and urbanization policies. It is a similar argument to that of energy/technical efficiency, and environmental efficiency. Policies that target energy or technical efficiency will not translate into environmental efficiency if not accompanied by environmental policies. Neither economic nor industrial policies can be substitutes to environmental policies. Although it may in the short run positively affect environmental efficiency the impacts will not be sustainable. In conclusion for sustainable development and growth, the undesirable output and environmental policies cannot be ignored.

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