ECO-EFFICIENCY ANALYSIS USING ANALYTIC HIERARCHY PROCESS APPROACH

Aylin Çiğdem Köne
Muğla Sıtkı Koçman University
Turkey
ckone@mu.edu.tr

Tayfun Büke
Muğla Sıtkı Koçman University
Turkey
tbuke@mu.edu.tr

ABSTRACT

The environmental efficiencies of 31 member countries of the European Environment Agency between 1990 and 2011 were evaluated using the gross domestic product using purchasing power parity. Categories of imparting pressure on the environment, including global warming, acidification, tropospheric ozone formation and particle formation potentials were considered for each country. These environmental pressure categories were weighted using the Analytical Hierarchy Process methodology. Calculations of the results indicated the Netherlands, Germany, the United Kingdom, Hungary and Ireland ranked 10th, 15th, 17th, 21st and 22nd respectively in 1990, and their ranking changed to 4th, 8th, 3rd, 17th and 11th respectively in 2011. These results point out a marked shift in the trend of economic and environmental efficiency. On the contrary, Portugal, Malta, Croatia and Turkey were ranked 7th, 9th, 13th and 14th respectively in 1990, and at the end of the period, they dropped to 14th, 15th, 22nd and 28th respectively. There seems to be a positive linear relationship that exists between calculated eco-efficiency scores and income, but a high value for gross domestic product using the purchasing power parity does not automatically imply good environmental performance or vice versa.

Keywords: Eco-efficiency; air pollutants; environmental pressure; weighting, AHP

1. Introduction

Sustainable development has been accepted as a major development strategy by several countries since 1992 at the United Nations Conference on Environment and Development (UNCED). UNCED also noted that it is quite clear that the main cause of global pollution is the continued use of natural resources at previous levels. The acceptance of this fact by the international community led to a discussion of special measures to ensure sustainable economic development. In this context, strategies to optimize resources play a particularly important role. Eco-efficiency, a tool for sustainability analysis that shows an empirical relationship between economic activity, environmental cost or value and environmental impact, has been proposed as a way to encourage this transformation (Figge & Hahn, 2004; Huppes & Ishikawa, 2005; Mickwitz et al., 2006).

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

Eco-efficiency plays an important role in expressing how effective economic activity is in terms of goods and services of nature. By definition, eco-efficiency is the delivery of competitively priced goods and services that meet human needs and bring quality of life while gradually reducing the ecological impact and resource intensity throughout life. Eco-efficiency can be defined as the value of a product or service per environmental impact (Verfaille & Bidwell, 2000; Fet, 2003; Kuosmanen & Kortelainen, 2005; Michelsen, et al., 2006).

The aim of this study is to evaluate the environmental efficiencies of 31 member countries of the European Environment Agency between 1990 and 2011 by using the gross domestic product using purchasing power parity (GDPPPP) and environmental pressure categories, including global warming (GLWP), acidification (ACP), tropospheric ozone formation (TFP) and particle formation potentials (PP) for each country. These environmental pressure categories have been weighted by applying the Analytical Hierarchy Process (AHP) methodology (Saaty, 1980; Saaty & Peniwati, 2007). The calculated results are examined regarding changes in environmental performance and its constituents during the working period, identifying the basic factors of environmental performance for each country, and presenting the possibilities and advantages of the used methodology.

This study includes the following EEA countries with the abbreviations: Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Hungary (HU), Iceland (IS), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), Netherlands (NL), Norway (NO), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), Switzerland (CH), Turkey (TR) and United Kingdom (GB). Due to insufficient data, Greece and Liechtenstein are excluded.

2. Literature review

A number of researchers have focused on different measures for eco-efficiency analysis of various alternatives. An eco-efficiency analysis for 24 power plants in a European country was investigated using Data Envelopment Analysis (DEA) (Korhonen & Luptacik, 2004). In the Kymenlaakso region of Finland, eco-efficiency has been examined at a regional level as an approach to increase the competitiveness of economic activities and to reduce the harmful effects on the environment (Seppälä et al., 2005). An empirical study was employed to describe the pattern of a regional industrial system's eco-efficiency by using real data from 30 provinces in China (Zhang et al., 2008). An environmental performance index was constructed by applying frontier efficiency techniques and a Malmquist index approach. The proposed model was applied to the dynamic environmental performance analysis of 20 member states of the European Union from 1990–2003. The proposed index is used for several air pollutants and the real gross domestic product for each country (Kortelainen, 2008). A comparitive eco-efficiency analysis was examined for the USA and six European countries for the period 1960–2002 (Holm & Englund, 2009). Eco-efficiency analysis has been investigated for different European countries using a disaggregated sector-based approach (Wursthorn et al., 2010). Farming eco-efficiency has been investigated using DEA techniques. For example, eco-efficiency scores were calculated at farm and environmental levels for Spanish farmers working in the rain-fed agricultural system in Campos County (Picazo-Tadeo et al., 2011). The degree of eco-efficiency convergence in 22 OECD countries was analysed for the

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

period 1980–2008. The researchers focused on three air pollutants namely, carbon dioxide, nitrogen oxides and sulphur oxides (Camarero et al., 2013). The environment efficiency and resource problem of European countries has been evaluated by specifying a DEA model (Robaina-Alves et al., 2015). Masternak-Janus, et.al, (2016) examined the concept of eco-efficiency at a regional level as an approach to promote the sustainable transformation of regions, using Poland as an example and employing the data envelopment analysis. The industrial eco-efficiency of 30 provinces in China between 2005 to 2013 was measured using the three-stage data envelopment analysis model. According to the results obtained, industrial eco-efficiency is affected by regulation, technical innovation, economic level and industrial structure (Zhang et al., 2017).

3. Data and methodology

3.1. Data

Individual air pollutants like sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), methane (CH_4), particulate matter (PM_{10}) and carbon dioxide (CO_2) released into the atmosphere are not limited to the emission source. These materials only way of transportation over a long distance have a number of drawbacks on the environment and this results in that classification of the air pollutants causing environmental pressure. Associated environmental pressure categories of the air pollutants and their conversion factors are presented in Table 1 (Houghton et al. 1996; De Leeuw, 2002; EEA, 2011).

In this study, the individual air pollutants namely SO_2, NO_x, NH_3, CO, NMVOC, PM_{10} (EEA, 2015a) CH_4 and CO_2 equivalent (EEA, 2015b) are obtained from the European Environmental Agency while Gross Domestic Product using Purchasing Power Parity (GDPPPP) and population data are taken from the International Energy Agency (IEA, 2014). After the individual air pollutants information is obtained, inventories were prepared, the environmental pressure categories of GLWP, ACP, TFP and PP were calculated by means of the conversion factors given in Table 1. In this present work, per capita values for GDPPPP, GLWP, ACP, TFP and PP were used in the eco-efficiency calculation in order to make good comparisons between small and high population countries. A summary of the descriptive statistics for the years 1990, 1995, 2000, 2005 and 2010 are given in Table 2.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

Table 1
Individual air pollutants and their conversion factors for environmental pressure categories

Pollutant (Mg)	ACP (Mg of AP eq.)	TFP (Mg of TFP eq.)	PP (Mg of PP eq.)
SO_2	0.03125		0.54000
NO_x	0.02174	1.22000	0.88000
NH_3	0.05882		0.6400
CO		0.11000	
NMVOC		1.00000	
CH_4		0.014000	
PM_{10}			1.00000

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

Table 2
Descriptive statistics of the variables by years

	GDPPPP (2005 USD per capita)	GLWP (g CO_2 eq. per capita)	ACP (g AP eq. per capita)	TFP (g TFP eq. per capita)	PP (g PP eq. per capita)
1990					
Mean	19426	12282476	3411	101865	113061
Minimum	7524	3418618	1270	32565	32368
Maximum	42691	33772383	7699	315545	1116244
1995					
Mean	19957	10661394	2594	83272	77021
Minimum	6182	3996591	1072	34123	27017
Maximum	48280	24823150	5804	226023	488143
2000					
Mean	23699	10400587	2155	69836	55722
Minimum	6838	4211369	928	35263	23147
Maximum	60993	22338666	7100	176857	166812
2005					
Mean	26500	10689907	1864	62659	50350
Minimum	9362	4805016	833	33400	20107
Maximum	68167	28101283	6953	204177	159597
2010					
Mean	27289	9954574	1599	50610	42551
Minimum	10921	5353920	736	27028	17108
Maximum	68537	24113306	9756	138256	200481

3.2. Methodology for evaluating eco-efficiency values

According to the definition of eco-efficiency (EE) in terms of GDPPPP and environmental pressure categories, GLWP, ACP, TFP and PP can be written as (Kuosmanen & Kortelainen, 2005; Kortelainen, 2008; Camarero et al., 2013; Camarero et al., 2014):

$$EE = {(GDPPPP)}\Big/{(W_{GlWP})(GlWP) + (W_{ACP})(ACP) + (W_{TFP})(TFP) + (W_{PP})(PP)} \quad (1)$$

Where GLWP, ACP, TFP and PP values are aggregates of the pressures exerted on the environment by the four pressure categories into a single environmental pressure score, whereas W_{GLWP}, W_{ACP}, W_{TFP} and W_{PP} are the weights assigned to GLWP, ACP, TFP and PP pressure categories.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

Environmental pressure categories have different measurement units in Equation 1. For this reason, normalization should be done to make the variables comparable. In this paper, the “Distance to Reference Value Normalization” method is applied because it is widely used in environmental problems (Seppälä & Hämäläinen, 2001; OECD, 2008; Saling et al. 2002; Plaia, and Ruggieri, 2011; Plaia, et al., 2013). Descriptive statistics of the normalized values of variables are given in Table 3.

Table 3
Descriptive statistics of the normalized values of variables by years

	GDPPPP	GLWP	ACP	TFP	PP
1990					
Mean	0.4550	3.5928	2.6856	3.1280	3.4930
Minimum	0.1762	1.0000	1.0000	1.0000	1.0000
Maximum	1.0000	9.8790	6.0622	9.6897	34.4860
1995					
Mean	0.4134	2.6676	2.4200	2.4403	2.8508
Minimum	0.1280	1.0000	1.0000	1.0000	1.0000
Maximum	1.0000	6.2111	5.4142	6.6238	18.0680
2000					
Mean	0.3885	2.4696	2.3222	1.9804	2.4073
Minimum	0.1121	1.0000	1.0000	1.0000	1.0000
Maximum	1.0000	5.3044	7.6509	5.0154	7.2066
2005					
Mean	0.3887	2.2247	2.2375	1.8760	2.5041
Minimum	0.1373	1.0000	1.0000	1.0000	1.0000
Maximum	1.0000	5.8483	8.3469	6.1131	7.9374
2010					
Mean	0.3982	1.8593	2.1726	1.8725	2.4872
Minimum	0.1593	1.0000	1.0000	1.0000	1.0000
Maximum	1.0000	4.5039	13.2554	5.1153	11.7186

After normalization is applied to Equation 1, it can be written in the dimensionless form for a country *i* as follows:

$$(EE)_i = \left(\frac{GDPPPP_i}{GDPPPP_{max}}\right) \Big/ \left((W_{GlWP})\left(\frac{GlWP_i}{GlWP_{min}}\right) + (W_{ACP})\left(\frac{ACP_i}{ACP_{min}}\right) + (W_{TFP})\left(\frac{TFP_i}{TFP_{min}}\right) + (W_{PFP})\left(\frac{PP_i}{PP_{min}}\right)\right)$$

(2)

Where $GDPPPP_{max}$ is the maximum reference value while $GLWP_{min}$, ACP_{min}, TFP_{min} and PP_{min} are minimum reference values of 31 countries for each study year.

According to Equation 2, relative EE of a country *i* within maximum GDPPPP and minimum environmental pressure categories (GLWP, ACP, TFP and PP) is equal to 1.000. Weights of the environmental pressure categories in Equation 2 can be determined by some multi-attribute calculation models like the AHP methodology (Zhou et al., 2006). In this paper, the weights of each environmental pressure category were determined using the AHP methodology.

The AHP is an effective tool for dealing with the complexity inherent in the multi-criteria decision-making problem, and can be modelled by dividing the problem at various levels so that it forms a hierarchy. The highest level of the hierarchy is the main objective of the decision problem. The lower levels are tangible and/or non-material criteria and sub-criteria that contribute to the goal. The bottom level is formed by alternatives to be evaluated in terms of criteria. The pairwise comparisons are made with judgments using numerical values taken from the AHP absolute fundamental scale of 1-9 in each hierarchical level. These comparisons lead to dominance matrices in which ratio scales are derived in the form of the main eigenvectors. These matrices are positive and reciprocal ($a_{ij} = 1/a_{ji}$). The method also calculates the consistency ratio to confirm the consistency of the decisions, and the acceptability of these decisions should be about 0.10 or less (Saaty, 1980; Saaty & Peniwati, 2007).

A questionnaire was prepared using paired questions for the comparison analysis to determine the weight of the indicators with the AHP method (Aragonés-Beltrán et al., 2015). An example of an AHP questionnaire for pairwise comparison of indicators according to the AHP absolute fundamental scale of 1-9 is presented in Table 4 (Saaty, 1980). Twenty-five experts responded to the questionnaires. All of the experts are academicians in different environmental engineering departments of 9 universities in Turkey. The personal decisions of the experts were combined to produce only one value for the priorities of the aims; this is evaluated by deducting the geometric mean of those decisions (Saaty & Peniwati, 2007). The four evaluation criteria are grouped into a cluster; GLWP, ACP, TFP and PP criterions consider global warming, acidification, tropospheric ozone forming and particulate formation potentials respectively (Houghton et al. 1996; De Leeuw, 2002; Kortelainen, 2008). The AHP decision model for weights of the environmental pressure categories is shown in Figure 1.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

Table 4
A AHP questionnaire for pairwise comparison of indicators

From your point of view, which indicator is more important according to their relative degrees of importance of the air quality for global scale. CR1: GLWP CR2: ACP					
Which indicator do you consider more important?	CR1 ○	CR2 ○			
In which degree?	1	3	5	7	9

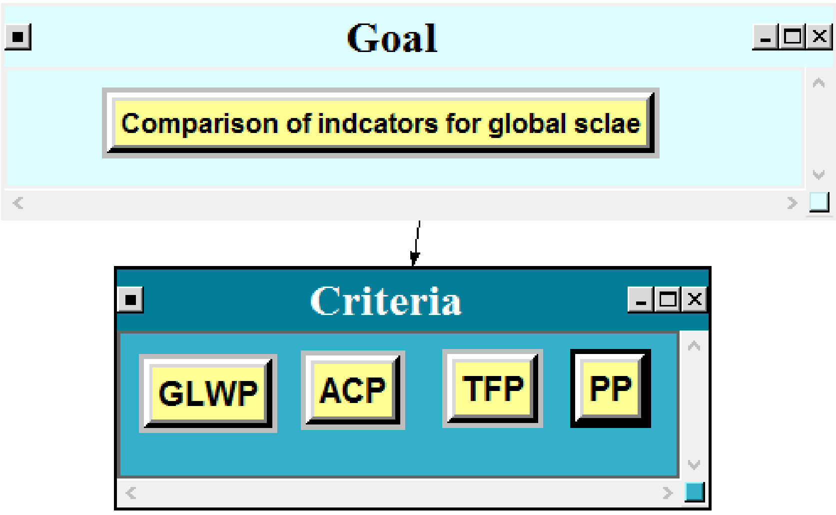

Figure 1. The AHP decision method

The Super Decisions software v.2.2.3 was used to calculate the weights of the environmental pressure categories. The pairwise comparison matrix values obtained from the expert's judgements were input into this program. There is less than a 0.10 inconsistency ratio between the comparison matrix of pairs. Therefore, the pairwise comparison matrix is consistent. The calculated weights of the environmental pressure categories are given Figure 2. The highest weight factor is calculated GLWP (see Figure 2).

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

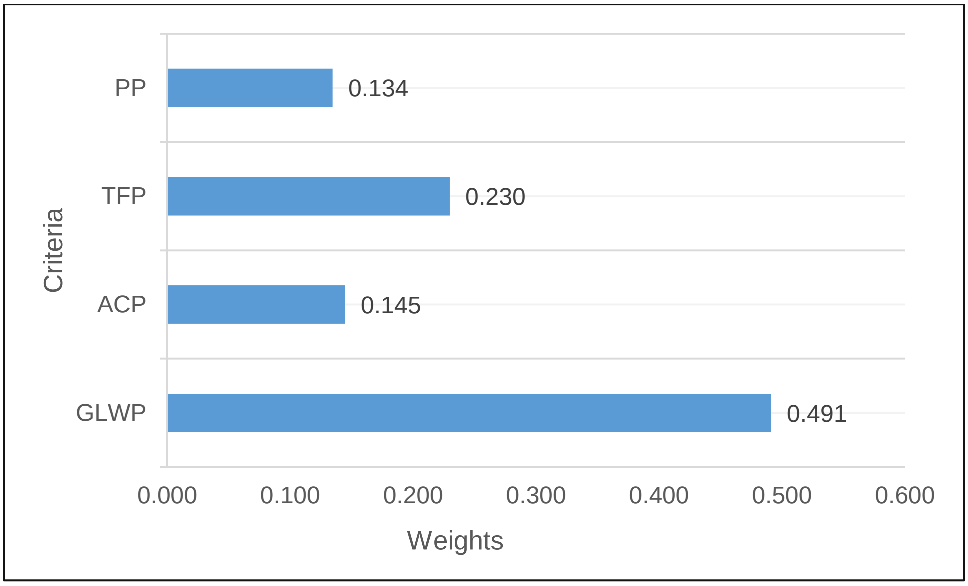

Figure 2. Weights calculated by using AHP method

4. Results and discussion

The calculated relative EE scores of the 31 EEA member countries for the period 1990-2011 are presented in Figure 3. As seen in Figure 3, the average eco-efficiency scores increase over the time period 1990-2011. This seems reasonable if one remembers that environmental regulations aimed at reducing pollutant emissions have been in force the longest and in most cases are the most restrictive. The eco-efficiency scores of AT, BE, FR, DE, IT, NL, NO, SE and CH are higher than the average eco-efficiency scores over the time period 1990-2011. Conversely, the eco-efficiency scores of BG, CZ, EE, FI, HU, IS, LV, LT, PL, RO, SK and SI are less than the average eco-efficiency scores over the time period 1990-2011. It is also interesting to highlight that the eco-efficiency scores in countries such as HR, IS and TR are lower in 2011 than in 1990. In contrast, the largest improvements correspond to CZ, LU and SK (see Figure 3).

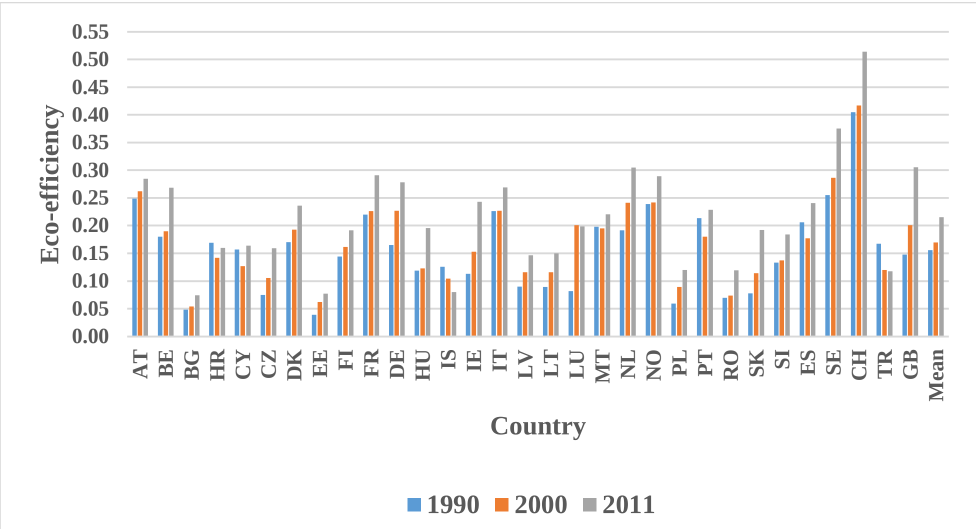

Figure 3. Eco-efficiency scores in EEA member countries

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

As seen in Figure 4, CH and SE are ranked first and second place respectively in both 1990 and 2011, while BG and EE are ranked in the last two places respectively in 1990 and 2011. The economic and environmental conditions of CH and SE in the study period continue to change in a positive direction, while the economic and environmental conditions of BG and EE in study period continue to change in a negative direction. This indicates a marked change in the economic and environmental efficiency trend.

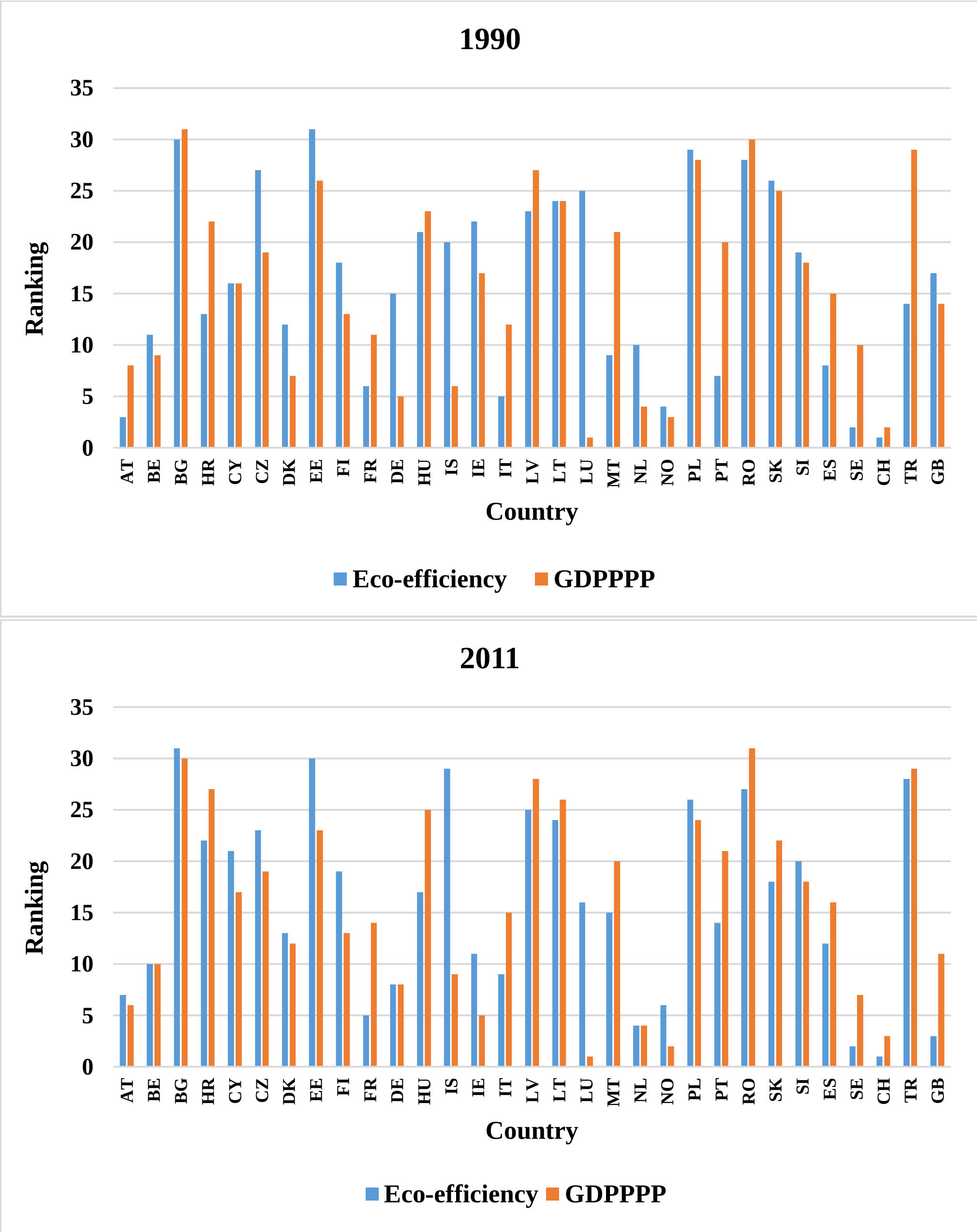

Figure 4. Eco-efficiency/GDPPP ranking of the countries by years

Although there seems to be a positive linear relationship that exists between calculated eco-efficiency scores and income, a high value GDPPPP per capita does not automatically show a high eco-efficiency score, or vice versa. For example, in 1990 and 2011, LU had the highest GDPPP per capita values and was ranked 25th

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

and 16th in the relative eco-efficiency comparison. On the other hand, GB's relative eco-efficiency score in 2011 ranked 3rd, although it was only the 11th largest value for GDPPP per capita (see Figure 4).

Similar studies are found in the literature based on the DEA (Kortelainen, 2008; Camarero et al., 2013; Camarero et al., 2014). On the other hand, the DEA does not provide any prior information about weights of different environmental pressure categories. This is one of the important weaknesses of the DEA. In most cases, optimum DEA weights can have unreasonable values; large weights can be assigned to environmental impacts with secondary presence and in general negligible or zero weights can be left for significant adverse effects. As a result, some activities may seem effective, although they only perform well on a single, relatively insignificant criterion. For these reasons, although the DEA is not tied to normative evaluation, additional information on the relative importance of different environmental influences can easily be added to this metric by applying soft weight constraints (Pedraja-Chaparro, et al., 1997; Allen & Thanassoulis, 2004; Kuosmanen & Kortelainen, 2005). In the opinion of a decision maker, the question still remains: what is the significance of different environmental impact categories compared to each other? In practice, responding to this question requires data on weights between different environmental impact categories. The environmental pressure categories weights that should be specified in the eco-efficiency calculation are often taken to reflect public preferences for environmental issues and can be obtained by integrating expert investigations into multi-feature assessment models such as AHP (Zhou et al., 2006; Saaty & Peniwati, 2007; Köne & Büke, 2014).

In this study, the environmental pressure categories weights are derived by integrating the expert surveys using the AHP to calculate eco-efficiency scores. This is proposed because the weighting scheme proposed in the DEA models do not require any prior information concerning weights of the different environmental pressure categories.

5. Policy implications

As a result of this paper, several policies can be proposed to increase the eco-efficiency scores of the EEA member countries.

(1) In order for eco-inefficient countries to approach leading EEA countries, they should move towards cleaner production processes, such as increasing environmental awareness and also changing their respective production structures towards less contaminating activities.

(2) The country based environmental efficiency performance seems to be a good combination of reducing the density of fossil fuels with improved average productivity of the capital and replacing a significant amount of fossil fuels with energy and renewable energy sources. Nuclear and renewable energy sources already contribute to reducing air pollutant emissions.

(3) As of February 2017, the number of nuclear power plants operating and under construction in the world are 449 and 60 respectively (IAEA, 2017). Advanced designs for all types of nuclear reactors will be developed. Therefore, the use of nuclear energy will be safer in the future (IAEA, 2017a). Increasing the proportion of nuclear energy in the total primary energy supply will depend on the social acceptability of nuclear reactors. For this reason, the public should be educated about the radiological risks of nuclear reactors.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

(4) Eco-efficiency is related to features like production, the trade sector and the flow of foreign direct investment. In this sense, some countries may decide not to produce goods that pollute the environment in their own right, but measures should be taken to restrict the importability of these goods from other countries.
(5) Existing taxes should be rearranged to include negative external costs in energy prices.
(6) People should be motivated to be aware of environmental issues and rational use of energy to increase environmental efficiency.

6. Conclusions

Assessing eco-efficiency can be considered a new tool to provide sound information to support policy maker's decisions that will contribute to long-term sustainable development. Accordingly, in recent years, research has emerged to evaluate eco-efficiency across firms, industries or economies. Working from the definition of eco-efficiency, the eco-efficiency scores of the 31 member countries of the EEA were evaluated for four environmental pressure categories for the period 1990-2011. These environmental pressure categories were weighted by applying the AHP methodology.

The main policy suggestion of this study is the need to make stricter regulations on air pollution emissions in developed countries, especially in countries where the environmental eco-efficiency level is lower. Moreover, although environmental regulations and intergovernmental agreements to date have focused heavily on CO_2 emissions, future regulations and agreements should take care to reduce NO_x, SO_2 and PM_{10} emissions, which have a significant negative impact on eco-efficiency in all countries.

Finally, this study has relatively evaluated eco-efficiency comparatively in the EEA countries. However, there is a great potential for collecting a large amount of information about this topic of interest and designing better environmental policies for policy makers. In this context, it would be a useful approach and very important to determine the criteria and especially the criteria weights for evaluating the eco-efficiency scores of countries.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v9i2.477

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