THEORY AND RESEARCH IN ENGINEERING

EDITOR:
PROF.DR.ADNAN HAYALOĞLU

gece kitaplığı

İmtiyaz Sahibi / Publisher • Yaşar Hız
Genel Yayın Yönetmeni / Editor in Chief • Eda Altunel
Editörler / Editors • Prof. Dr. Adnan Hayaloğlu
Kapak & İç Tasarım / Cover & Interior Design • Gece Kitaplığı

Birinci Basım / First Edition • © Eylül 2020
ISBN • 978-625-7243-79-7

© copyright
Bu kitabın yayın hakkı Gece Kitaplığı'na aittir.

Kaynak gösterilmeden alıntı yapılamaz, izin almadan hiçbir yolla çoğaltılamaz.

The right to publish this book belongs to Gece Kitaplığı. Citation can not be shown without the source, reproduced in any way without permission.

Gece Kitaplığı / Gece Publishing
Türkiye Adres / Turkey Address: Kızılay Mah. Fevzi Çakmak 1. Sokak Ümit Apt. No: 22/A Çankaya / Ankara / TR
Telefon / Phone: +90 312 384 80 40
web: www.gecekitapligi.com
e-mail: gecekitapligi@gmail.com



Baskı & Cilt / Printing & Volume
Sertifika / Certificate No: 47083

Theory and Research in Engineering

EDITOR

Prof. Dr. Adnan Hayaloğlu

gece kitaplığı

CONTENTS

CHAPTER 1

DETERMINATION OF THE SUITABLE AREAS FOR SOLAR POWER PLANTS (SPP) USING ANALYTIC HIERARCHY PROCESS (AHP) AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN THE EASTERN MEDITERRANEAN BASIN, TURKEY

Ozan ARTUN.....1

CHAPTER 2

A TUTORIAL FOR CREATING A RECOMMENDATION SYSTEM FOR ARTICLES BY USING PYTHON TOOLS

Mustafa AL-ASADI & Sakir TASDEMIR & Ilker Ali OZKAN.....19

CHAPTER 3

CALENDERING OF PAPER AND ITS EFFECTS ON PRINTABILITY

Öznur ÖZDEN & Sinan SÖNMEZ 37

CHAPTER 4

FOOD-BASED NANOGEL PRODUCTION

Nil ACARALI.....61

CHAPTER 5

PROCESSING, MICROSTRUCTURE AND PROPERTIES OF SIALON CERAMICS FOR THE USE OF HIGH TEMPERATURE APPLICATIONS

Nurcan CALIS ACIKBAS & Gokhan ACIKBAS 73

CHAPTER 6

ADVANCE OXIDATION PROCESS STUDY OF SUGAR INDUSTRY WASTEWATER WITH CLAY AS A CATALYST

Şefika KAYA & Yeliz AŞÇI.....107

CHAPTER 7

THE ENVIRONMENTAL PERFORMANCE EVALUATION OF OECD COUNTRIES THROUGH DATA ENVELOPMENT ANALYSIS

Irmak TEMIZ & Yeliz BURUK SAHIN & Ezgi AKTAR DEMİRTAS 119

CHAPTER 8
OVERVIEW OF BIOCOMPOSITES WITH PLANT-DERIVED COMPONENTS IN TERMS OF MATRIX AND REINFORCEMENT MATERIALS
İpek YALÇIN & Hande SEZGIN 145

CHAPTER 9
THE ROLE OF BIOPOLYMER SELECTION IN THE DESIGN OF ELECTROSPUN SMALL CALIBER VASCULAR GRAFTS TO REPLACE THE NATIVE ARTERIAL STRUCTURE
Janset ÖZTEMUR & İpek YALÇIN ENIS 167

CHAPTER 10
A JAVASCRIPT FRAMEWORK FOR VOICE BROWSING
İzer ÖZLÜ & Özgün YILMAZ 193

CHAPTER 11
TOPOLOGY OPTIMIZATION FOR ADDITIVE MANUFACTURING IN THE AVIATION AND AUTOMOTIVE INDUSTRY
Neslihan TOP & İsmail ŞAHİN & Harun GÖKÇE 207

CHAPTER 12
ON PERFORMANCE OF FLOWER POLLINATION ALGORITHM IN TRAINING NEURAL NETWORK
Ebubekir KAYA 227

CHAPTER 13
FLOW PROFILES IN FLUID BED DRYERS
Sultan KEPÇEOĞLU & Aytaç MORALAR & Soner ÇELEN 245

CHAPTER 14
CURRENT STUDIES ON WIRELESS SENSOR NETWORKS
Murat DENER 267

CHAPTER 15
A MODEL PROPOSAL FOR DIGITAL TRANSFORMATION OF CITIES
Murat DENER 283

CHAPTER 16

DYEING OF WOOL YARNS WITH ***PARTHENOCISSUS QUINQUEFOLIA*** L. LEAVES EXTRACT

Selime MENTEŞ ÇOLAK & Meruyert KAYGUSUZ & Fatoş Neslihan ARĞUN 299

CHAPTER 17

CHALLENGES IN INVENTORY MANAGEMENT AND A PROPOSED FRAMEWORK

Fatih YİĞİT & Bahar YALÇIN 311

CHAPTER 18

TAGUCHI BASED MULTIPLE REGRESSION MODELING OF CONCRETE CONTAINING SILICA FUME STRENGTHENED USING POLYMER WITH PHOSPHAZENE EXPOSED TO FREEZE-THAW

Harun TANYILDIZI 335

CHAPTER 19

FREQUENT FAULTS ON THE DC SIDE IN PHOTOVOLTAIC SYSTEMS

Hasan DEMİR.....353

CHAPTER 20

HOT-AIR AND MICROWAVE-ASSISTED FOAM-MAT DRYING OF AVOCADO

Ayşe Nur YÜKSEL & Gülşah ÇALIŞKAN KOÇ 369

Chapter 7

THE ENVIRONMENTAL PERFORMANCE EVALUATION OF OECD COUNTRIES THROUGH DATA ENVELOPMENT ANALYSIS



Irmak TEMIZ[1]
Yeliz BURUK SAHIN[2]
Ezgi AKTAR DEMİRTAS[3]

1 Yüksek Mühendis, Eskisehir Osmangazi University, Department of Industrial Engineering, irmak.cicek1988@gmail.com
2 Dr. Öğr. Üyesi, Eskisehir Osmangazi University, Department of Industrial Engineering, yelizburuk@ogu.edu.tr
3 Prof Dr., Eskisehir Osmangazi University, Department of Industrial Engineering, eaktar@ogu.edu.tr

1. INTRODUCTION

The humanity has passed through several societal development stages as hunter-gatherer, agricultural, industrial and now is experiencing knowledge age and these stages have brought along the transformation from manufacturing/producing into consuming. Along with increasing population, the consumer society has come across with overconsumption and environmental hazards. Such problems as global warming, drought, climate change, decreasing supply of drinking water, and air pollution has come to a serious extent and have started to threaten all the mankind. This serious increase has made it necessary to take immediate action against environmental problems and initiate environmental protection measures. With the aim of creating a sustainable society, the governments are obliged to create and apply policies that will make a balance between economic development and environment protection. From the sustainability aspect, environmental assessments have an increasing significance and constitute the first and foremost step of policies related to green environment of countries.

For these reasons, the fact that countries specify their place in terms of environmental performance relative to others' is of much significance with regard to designating the reasons of being inefficient of under-performing countries, building environmental friendly strategies, and creating new policies. Along with rising significance of environmental protection, the use of Data Envelopment Analysis (DEA) has also increased within environment performance evaluations. DEA is based on linear programming and is a nonparametric method which aims to evaluate the relative efficiency of decision-making units. Different from parametric methods, it does not necessitate the functions correlating inputs and outputs (Hosseinzadeh-Bandbafha et al., 2018). DEA is particularly used in cases where multiple inputs and outputs could not be transformed into weighted input and output sets and is firstly used by Charnes et al. (1978) to measure the efficiency of state schools in the United States. DEA then has been used to evaluate the efficiency of universities, hospitals, banks, and firms in manufacturing sector and also to compare the efficiency of resource utilisation of countries and regions (Eva et al., 2016; Omrani et al., 2018; Dobos and Vörösmarty, 2019). No subjective comments are needed for the weights of utilised resources and emissions within the environment performance evaluations made through DEA since the weights are objectively determined by the model itself.

Another important point while evaluating the environment performance is that the inputs and outputs should be compatible with the targets of evaluated Decision Making Units (DMUs). While the variables are constituted by only inputs and outputs while making efficiency analysis

through the DEA, there are inputs and two-group output variables during the environmental performance evaluation. "The outputs aimed to be achieved" as a result of used inputs during the production indicate the desired output while the environment-polluting outputs (wastes released into the air, water and soil, emissions, etc.) indicate undesirable outputs (Wang and Zhao, 2017).

Sueyoshi and Goto (2011) have presented a new DEA method combining operational and environmental efficiency analyses in which outputs are classified as desired and undesirable. This proposed technique has been applied on Japanese electricity distribution companies. With the aim of evaluating the energy and environmental efficiency of electricity distribution companies in 30 different regions in Japan between 1997 and 2010, Wang et al. (2013) have made use of multi-directional efficiency analysis and window analysis. Sueyoshi and Goto (2013) have combined DEA with Malmquist index in order to evaluate the environmental efficiency of 10 OECD (Organisation for Economic Co-operation and Development) countries. With the aim of measuring the environmental performance, Meng et al. (2013) have put forward a radial DEA approach composed of a static and dynamic environmental performance index value. This method was first used to build an environmental performance model between 1998 and 2009 for industrial organisations in different Chinese cities. Zhang et al. (2015) evaluated the ecological energy efficiency of China between 2001 and 2010. The results of all these studies have indicated that the Chinese government should immediately intensify its improvement efforts in central and western regions to maintain a sustainable development. Sözen and Karık (2017) have compared the renewable energy performances of 33 OECD and BRICS countries with those of Turkey between 2009 and 2013. Within this study in which they have formed two different models based on different inputs and outputs, they have carried out analyses to determine the efficiency scores in the course of time and technical enhancements through DEA and Malmquist Productivity Index (MPI). Mavi and Mavi (2019) have measured the energy and environmental efficiencies of OECD countries through DEA and analysed environmental performances via MPI. Besides, they have developed the model of common set of weights by using ideal point method.

The studies carried out to measure environmental performance has been presented in Table 1 by considering their input, desired output, undesirable output and the methods. When these studies are examined, it has been observed that the most common inputs and outputs while analysing the environmental performances are population, the consumption of fossil and non-fossil fuels, CO_2, SO_2, and NO_2 emissions, workforce, water and energy amounts, waste water and solid waste amounts, gross national domestic product, capital, and electricity consumption.

Table 1 *Literature Review*

Reference	Input	Output	Undesired Output	Methodology/ Approach
Guo et al. (2011)	Capital stock, Labour, Energy	Gross domestic product (GDP)	CO_2 emission	Environmental DEA model
Sueyoshi and Goto (2011)	Total assets, , # Employees	Total sales, # Customers	CO_2 emission	Range-Adjusted Measure, DEA
Wu et al. (2012)	Capital stock, Labour, Energy	Industrial value added	CO_2 emission	Dynamic energy performance index, DEA
Wang et al. (2013)	Energy, Labour, Capital stock	GDP	CO_2 emission	A multi-directional efficiency analysis and window analysis
Sueyoshi and Goto (2013)	Combustible, Nuclear, Hydro+renewable	Electricity	CO_2 emission	DEA, Malmquist index
Lin et al. (2013)	Labour, Capital, Energy	GDP	CO_2 emission	DEA, A directional distance function metafrontier approach
Meng et al. (2013)	Labour force, Energy	Industrial value added	CO_2 emission, Waste gas, Waste water, Solid waste	Non-radial DEA, static and a dynamic environmental performance index
Chen et al. (2014)	Energy, Social fixed assets investment	GDP	Raffle of waste water, solid, and gas	Linear monotonic decreasing trans-formation approach, DEA
Wu et al. (2014)	Investment in fixed assets, electricity	GDP	NO_2	Slacks-based measure
Zhang et al. (2015)	Capital, Labour, Energy	GDP	SO_2 emission, CO_2 emission chemical oxygen demand	A metafrontier slack-based efficiency measure approach
Wang et al. (2016)	Energy, Labour, Capital, R&D investment, IPC investment	Industrial value added	CO_2, SO_2, solid emissions, waste water emissions	A non-radial DEA mode
Sözen and Karık (2017)	Electricity capacity, Energy supply Energy consumption, Energy production, Electricity consumption, Labour force/ population, Net capital account	Hydro capacity, Geothermal capacity, Solar photovoltaic capacity, Wind capacity, Electricity production from hydro, geothermal, solar photovoltaic, wind	-	DEA, Malmquist productivity index (MPI)
Yao et al. (2018)	Capital, Labour, Water, Energy	GDP	Solid, water, gas	SBM DEA
Mavi and Mavi (2019)	Labour, Energy	GDP, Renewable energy	Greenhouse gas emission, Municipal waste	Common weight analysis for MPI

Ouyang and Yang (2020)	Income, population, government spending, coal consumption, oil consumption, natural gas consumption, land	GDP, human development index, consumption	CO_2 emissions	A multiplicative network DEA

The purpose of this study is to analyse the environmental performance of OECD countries, specify the place of Turkey among these countries and propose some recommendations regarding to improve the current performance of Turkey. Since multiple input and output variables have been included, DEA method has been used after considering the advantages mentioned above. The distinctive feature of this study comes from the fact that the analyses and evaluations of environmental performances of countries have been carried out through input and output oriented CCR models with the assumption of constant returns to scale by dealing with such variables the first time as environmental tax and electricity production from renewable energy sources. Super efficiency model has been used to specify efficient countries in terms of environmental performance. Besides, window analysis has been used to make an evaluation in terms of time course. Lastly, the efficiency change between years has been measure through Malmquist TFP index.

2. MATERIALS AND METHODS

DEA has firstly been developed by Charnes et al. (1978) with the aim of measuring the relative efficiency of systems called DMUs manufacturing/ producing similar products or services. This method allows measuring the relative total factor efficiency of DMUs in cases which there are many input and output variables having different units of measure and when they cannot be demeaned into a common criterion. DEA compares each of DMUs only with the best DMUs. Identified as the best, these DMUs comprises the efficient frontier and they constitute the benchmark with which any other DMUs will be measured against. The method assumes that the DMUs on the efficient frontier are relatively efficient. These are called reference sets of inefficient DMUs.

2.1. Input-Output Selection

Identifying the input and output variables used for determining DMUs and their efficiency in DEA is of significance in terms of the fact that the analysis will yield correct results. Using different input and output sets may cause changes within the efficiency value of DMUs. If an important variable is skipped within the model, the efficiency value of DMU actively using this variable will decrease. For this reason, the input and output variables to be used during the analysis should be cautiously and meticulously determined. The fact that redundant number of inputs and

outputs are used within the model negatively affect the distinction power of the analysis. Therefore, the optimum number of inputs and outputs should be used in line with the purpose of the study. If there are many inputs and outputs, then the number of DMUs should be increased, as well.

If the number of selected input is (m) and output is (s) in a DEA model, it is compulsory for the reliability of the research to have at least 3*(m+s) + 1 decision making unit. According to Sherman (1984), the optimum number of decision making unit is n>m+s while n=number of observations, m=number of inputs, and s=number of outputs. The general view about this issue is that the number of DMUs should be at least twice as many as the number of inputs and outputs.

Since some of the outputs within the study are undesirable, the approaches related to this situation have been examined as well. Dyckhoff and Allen (2001) indicate three basic approaches for modelling undesirable outputs. In the first method, undesirable outputs of DEA are modelled as $f(y) = 1/y$.

In his method, Rheinhard et al. (1999) have modelled undesirable outputs as inputs. As indicated by Scheel (2001), undesirable outputs could be considered as inputs. This transformation could be used with both the assumptions of constant returns to scale and variable returns to scale. The third approach could be used with only the assumption of variable returns to scale. The conversion of $f(y) = -y + \beta_i$ is used for undesirable outputs along with the use of transformation. In order to get rid of negative values, a positive β_i scalar having enough greatness should be added onto the undesirable output (Ali and Seiford, 1990). This study has adopted the first approach and has applied inverse function method for undesirable outputs.

2.2. **Model Selection**

It is possible to use both the assumptions of constant returns to scale (CRS) and variable returns to scale (VRS) in DEA. The CCR model measures the total efficiency with the assumption of CRS while BCC model measures the technical efficiency with the assumption of VRS. What kind of model should be set up depends on whether the inputs and outputs are controlled or not. The input oriented models examine the extent of decrease of inputs while the outputs are held at a certain level; however, the output oriented models examine the extent of increase of outputs while the inputs are constant at a certain level (Malana and Malano, 2006; Aldamak and Zolfaghari, 2017). In other words, the main aim of input oriented models is to use minimum number of inputs to produce the current output while the main aim of output oriented models is to reach the maximum number of outputs with the current input. An output oriented model should be set up if there is less or much control over the inputs and an input oriented model

should be established if there is less or much control over the outputs. This study has made use of input and output oriented CCR models whose details are provided in the following parts.

Input Oriented CCR Model

In a process having n DMUs, n models are set up and the relative efficiency of each DMU is measured. n optimisation models are solved within this process. The objective function of models, for example for the DMU_k, coincides with the optimisation of ratio between the total weighted output and total weighted input (Cooper et al., 2011).

To maximize the efficiency of DMU k, the objective function and the constraints of the linearized input oriented CCR model is shown in Equation (1-4):

m: the number of input

s: the number of output

v_i: the weight of input i

X_{ik}: the amount of input i used by DMU_k

u_r: the weight of output r for DMU_k

Y_{rk}: the amount of output r produced by DMU_k

Y_{rj}: the amount of output r produced by DMU_j

X_{ij}: the amount of input i used by DMU_j

ε: very small positive integer.

$$E_k = \max\left(\sum_{r=1}^{s} u_r Y_{rk}\right) \quad (1)$$

$$\sum_{i=1}^{m} v_i X_{ik} = 1 \quad (2)$$

$$\left(\sum_{r=1}^{s} u_r Y_{rj}\right) - \left(\sum_{i=1}^{m} v_i X_{ij}\right) \leq 0 \quad \forall j = 1,..,n \quad (3)$$

$$u_r, v_i \geq \varepsilon \geq 0 \qquad i = 1, \ldots, m \qquad r = 1, \ldots, s \quad (4)$$

The data obtained through the solution of the model is the efficiency value of DMU_k (E_k). The fact that the value of efficiency is equal to 1 means that the DMU is efficient while the value less than 1 means the DMU is inefficient. Alternatively called envelopment model, the dual form could also be used within analyses.

Output Oriented CCR Model

To minimize the efficiency of DMU k, the objective function and the constraints of the linearized output oriented CCR model is shown in Equation (5-8).

$$E_k = \min\left(\sum_{r=1}^{m} v_i X_{ik}\right) \tag{5}$$

$$\sum_{r=1}^{p} u_r Y_{rk} = 1 \tag{6}$$

$$\left(\sum_{r=1}^{p} u_r Y_{rj}\right) - \left(\sum_{i=1}^{m} v_i X_{ij}\right) \geq 0 \qquad \forall j = 1,..,n \tag{7}$$

$$u_r, v_i \geq \varepsilon \geq 0 \qquad i = 1,\dots,m \qquad r = 1,\dots,s \tag{8}$$

While input/output oriented models give information about efficient and inefficient DMUs, they do not provide any information about the ranking of these units. Developed by Anderson and Petersen (1993), the super efficiency model particularly aims to solve this problem and enables ranking decision making units by making a comparison between them. Within this model, each of the efficient DMUs is excluded from efficient production frontier and their super efficiency scores are obtained by calculating the distance of each excluded DMU to the re-defined efficiency frontier. When each of the decision making units is ranked in an ascending sort in terms of their super efficiency score, the superiority relationship between them could be observed. Except the feature of being able to exclude the evaluated DMUs from the reference set, the super efficiency model is equal to dual CCR-DEA.

2.3. Window Analysis

Incorporating the time dimension into the DEA, the window analysis was developed by Charnes, Clark, Cooper and Golany in 1985. The window analysis is based on moving averages method and evaluates the performance of DMUs in a course of time by assuming them as a different unit in each period. This method increases the distinction power of the analysis by increasing the number of DMUs (Halkos and Tzeremes, 2009). However, it is worth noting that while DMUs from a specific period are evaluated relative to each other and themselves, it is assumed that no technological developments have been experienced during this period. Therefore, the analyses made during periods when there are little technological developments yield to more reliable results thanks to using short time periods.

When a series of N (n = 1, ... N) DMUs in a T (t = 1, ... T) time period is considered, on condition that r is the number of inputs and s is the

number of outputs in each DMU, DMU nt indicates n observation within t time through input vector $(x_n^{1t}, x_n^{2t}, \ldots\ldots, x_n^{rt})$ and output vector $y_n^t = (y_n^{1t}, y_n^{2t}, \ldots\ldots, y_n^{st})$. Assuming that the window has started on the k time point (1≤k≤T) and the window width is w (1≤w≤T-k), then the input (X_{kw}) and output (Y_{kw}) matrix of each window (kw) is as shown in Equation (9-10) (Yang and Chang, 2009):

$$X_{kw} = (x_1^k, x_2^k, \ldots\ldots, x_N^k, x_1^{k+1}, x_2^{k+1}, \ldots\ldots, x_N^{k+1}, \ldots\ldots, x_1^{k+w}, x_2^{k+w}, \ldots\ldots, x_N^{k+w}) \quad (9)$$

$$Y_{kw} = (y_1^k, y_2^k, \ldots\ldots, y_N^k, y_1^{k+1}, y_2^{k+1}, \ldots\ldots, y_N^{k+1}, \ldots\ldots, y_1^{k+w}, y_2^{k+w}, \ldots\ldots, y_N^{k+w}) \quad (10)$$

The number of DMU, time period and window size are the concepts used in the analysis. The time period indicates the number of periods during which DMU will be examined. The window size could be identified by the researcher with regard to the number of data. For the advantages and disadvantages of narrow-wide window sizes, please refer Cooper et al. (2011).

2.4 Malmquist Total Factor Productivity (TFP) Index

Malmquist TFP index is used for measuring the extent and reasons of development of productivity in a course of time by using panel data. Developed by Malmquist (1953) with regard to distance functions, this index measures the change of TFP between two points by calculating the relative distance of each data point to common technology. The distance functions could be treated as input-output oriented (Deliktas, 2002). The Malmquist TFP index calculated with regard to distance functions with the assumption of constant returns to scale has been given in Formula 11. Within this index, (t) indicates the base year while (t+1) represents the following year.

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \overbrace{\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}}^{Efficiency\ Change} \times \overbrace{\left[\left(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{1/2}}^{Technological\ Change} \quad (11)$$

The ratio out of the square brackets within the Formula (11) measures the change in technical efficiency between the years of (t) and (t+1) in terms of output-oriented approach. The change of efficiency (EC) is the ratio of technical efficiency during (t+1) period to that of (t) period. The geometric mean of the two ratios in the square brackets indicates the change of technology (TC) (x_{t+1} and x_t) occurred between the two periods. The change in the technical efficiency represents the catch-up effect related to production frontier while the technological change could be expressed as frontier shift (Mahadevan, 2002). The fact that M_0 index is greater than 1 means that the total factor productivity has increased within the period

between (t) and (t+1) while a value of less than 1 means the total factor productivity has decreased within the same period (Coelli et al., 2005).

3. RESULTS AND DISCUSSION

The inputs used within this study in order to measure efficiency are **the amount of energy consumption (EC)** and **the number of labours (L)**. However, the increase in the energy consumption brings along the environmental problems. The emissions resulting from energy consumption causes water, air, and soil pollution and therefore, negatively affects the nature, human health, and bio-diversity. This relationship between energy and environment renders energy as an important factor of environmental performance evaluations. The amount of energy consumed in a year to produce electricity has been provided in a unit equivalent to a million-ton petroleum (mtoe) (an mtoe is equivalent of 4.1868x1016 Joules). The data has been obtained from the website of www.bp.com. The number of labours of OECD countries has been used as the input variable and these data have been obtained from www.oecd.org.

The outputs used to measure the efficiency and the details about the compilation of data have been provided in the following paragraphs.

- **CO_2 emissions:** The main sources of carbon dioxide emissions are electricity production through fossil fuels, industrial activities, settlements and transportation sector. However, 80-85 % of carbon dioxide released into the atmosphere comes from the burning of fossil fuels (petroleum and its derivatives, coal and natural gas). The climate change caused by greenhouse gas emissions is the biggest problem that humanity has ever come across. CO_2 emissions are the most released gas into the atmosphere and have the biggest responsibility in causing global warming and climate change. The burning of solid, liquid and gas fuels results in CO_2 emissions released into the atmosphere. The data measured as metric tonnes per capita has been obtained from http://data.worldbank.org. The emission data used as undesirable output has been applied inverse function method.

- **Combustible renewable waste (CRW):** The combustible and renewable wastes which measured as a percentage of the total energy consumption are composed of solid biomass, liquid biomass, biogas, industrial and municipal wastes and these wastes are used for energy production in several ways. Therefore, both the wastes are utilised and energy is produced. The data has been obtained from http://data.worldbank.org.

- **Electricity generation from renewable sources (EG-RNW):** Except from hydroelectric, this concept includes generation of electricity from such sources and methods as geothermal, sun, tides,

winds, biomasses, and biofuels. The data has been expressed as the total percentage of energy and obtained from http://data.worldbank.org.

• **Gross Domestic Product:** The relationship between GDP and environmental pollution is explained by Environmental Kuznets Curve (EKC). According to the EKC hypothesis, while the environmental pollution increases during the first years of economic growth, the pollution decreases in the following years. Again, with regards to this hypothesis, since the production is mainly based on agricultural-activities in developing countries, the environmental pollution is not observed; however, during the first years of industrialisation, the primary aim is to increase the production and income. Therefore, rapid consumption of natural resources and utilisation of dirty technologies bring along the increase in both the production activities and environmental pollution, though. When the country reaches to a certain extent of income, the awareness of people and the activities of environmental organisations will increase the demand for a cleaner environment and therefore, the use of clean technologies will spread throughout the country. For these reasons, GDP which is an important indicator of economic growth is also one of the important indicators of environmental performance measurements. The data has been recorded in billion dollars and obtained from https://www.iea.org.

• **NOx (nitrogen oxide) and SOx (sulphur oxide) emissions:** Other air pollutants seriously harming the ecosystem and human health are NO_x and SO_x. The NOx emissions are the end product of every burning process and the majority of SOx emissions results from fossil power plants using large amounts of sulphurous solid and liquid fuels. Indicating the total emission amount per capita in metric tonnes, the data has been obtained from www.oecd.org.

• **Environmental Tax Revenue (ETR):** The purpose of environmental taxes is to decrease the economic activities directly or indirectly polluting the environment and encourage environmental friendly production and consumption methods. Environmental taxes are important tools for governments in terms of determining the relative prices of products and services. The environmental tax revenues indicated as % of GDP have been assumed as one of the important outputs. The data has been obtained from www.oecd.org.

Due to the reasons mentioned above and different from other studies in the literature, environmental taxes and electricity generation from renewable resources have been utilised as output variables within the study.

The data of 28 countries has been analysed in terms of output oriented

CCR model through the academic version of EMS 1.3 software and the efficiency scores (Column 3) and peers and peer weights for inefficient countries (Column 4) have been provided in Table 2. Statements out of brackets within benchmark column indicate the number of reference country (peer) while the statements in the brackets indicate peer weights, dual variables in other words, used to determine the target value of the related country.

Table 2 *Efficiency Scores and Benchmarks of OECD Countries*

No	Country	Score	Benchmarks (peers and peer weights)
1	Austria	111.41%	4 (0.82) 10 (0.24) 27 (0.55) 28 (0.03)
2	Belgium	114.78%	10 (0.83) 27 (1.25)
3	Canada	141.74%	10 (7.03)
4	Denmark	100.00%	
5	France	122.60%	10 (1.74) 27 (11.45)
6	Germany	123.25%	10 (1.56) 27 (17.48)
7	Greece	158.45%	4 (0.16) 27 (1.71)
8	Italy	114.58%	27 (10.72)
9	Nthrlds	120.51%	10 (0.84) 27 (3.07)
10	Norway	100.00%	
11	Portugal	115.33%	4 (0.45) 20 (0.71) 27 (0.19)
12	Spain	144.52%	27 (9.65)
13	Sweden	118.42%	4 (1.08) 10 (0.61) 27 (0.17)
14	Turkey	113.97%	27 (8.95)
15	United Kingdom	121.37%	27 (13.77)
16	United States	104.69%	10 (44.86) 27 (15.69)
17	Australia	121.86%	10 (1.88) 27 (3.32)
18	Czech Republic	174.04%	4 (0.29) 10 (0.24) 27 (1.77)
19	Finland	100.00%	
20	Hungary	100.00%	
21	Japan	148.38%	10 (1.12) 27 (29.23)
22	New Zealand	119.84%	4 (0.13) 24 (0.01) 27 (0.95)
23	Poland	160.74%	27 (6.74)
24	Slovak Republic	100.00%	
25	Chile	168.65%	4 (1.37) 24 (0.14) 27 (0.68)
26	Israel	102.10%	10 (0.02) 27 (1.73)
27	Ireland	100.00%	
28	Switzerland	100.00%	

As observed in Table 2, DMUs having 1 point are efficient while those having more than 1 point are inefficient. According to the data of last one year, of 28 countries, 7 are efficient and 21 are inefficient. Denmark, Norway, Finland, Hungary, Slovakia, Ireland, and Switzerland are efficient countries. The efficiency average of all countries has been measured as 122.19%.

21 countries have been found as inefficient with regard to environmental performance. Among efficient countries, Denmark has been the reference point of 7 countries while Norway, Hungary, Slovakia, Ireland and Switzerland have been the reference point of 12, 1, 2, 20 and 1 countries, respectively. Finland has not been referred by any country.

The method of target values related to outputs of inefficient countries has been sampled for Turkey and it has been concluded that Turkey, with a score of 113.97%, is an inefficient DMU. In order to take place among the efficient countries, Turkey whose target values have been given in Table 3 has to hold up Ireland as an example.

Table 3 *Output Target Values of Turkey*

Output Values of Turkey	Target Values of Turkey
CO_2= 0.220	0.140*8.949= 1.253
CRW= 2.930	3.99*8.949= 35.706
EG_RNW %= 4.760	21.8*8.949= 195.096
GDP = 1677.62	213.65*8.949= 1911.934
NO_X = 0.100	0.06*8.949= 0.537
SO_X = 0.040	0.240*8.949= 2.148
ETR %= 3.830	2.17*8.949= 19.419

In order to be efficient in terms of environmental performance, Turkey has to increase its $1/CO_2$ emission values which have been applied inverse function from 0.220 to 1.253. Therefore, as the $1/ CO_2$ value increases, the emission value of CO_2 will decrease. Similarly, the emission value of $1/NO_X$ has to be increased from 0.100 to 0.537 and that of SO_X has to be increased from 0.040 to 2.148. Besides, Turkey has to increase the amount of combustible and renewable waste by 32.776 units from 2.930 to 35.706 and its GDP by 234.314 from 1677.620 to 1911.934. The increase in each unit of GDP enables a six-thousandth rise in the efficiency. Moreover, if the revenue from environmental taxes is increased from 15.589% to 19.419%, Turkey will become an efficient country. However, such a high rate of increase in environmental taxes does not seem possible for developing countries whose GDP is relatively lower. 4.7% of electricity is generated from renewable resources in Turkey and since the target is 195%, it seems impossible to reach that goal.

Table 4 provides a summary of the target of output amounts calculated through output oriented CCR models and the target of input amounts calculated through input oriented CCR models for inefficient countries to become efficient. When the input target values are examined in Table 4, it could be observed that Turkey has to decrease its number of labours from 28.774 to 19.300.

Table 4 *Input and Output Target Values of Inefficient Countries*

	OUTPUTS						INPUTS		
DMU	CO_2	CRW	EG_ RNW	GDP	NO_X	SO_x	ETR	EC	L
Austria	0.249	21.999	58.088	407.463	0.085	0.646	5.114	33.800	4357.600
Belgium	0.267	9.177	28.716	519.695	0.100	0.559	4.482	55.800	4966.900
Canada	0.773	35.278	12.017	2.127.982	0.211	2.179	14.898	326.074	19124.500
Denmark	0.170	22.450	55.830	249.130	0.050	0.500	4.110	17.400	2905.600
France	1.794	54.417	252.561	2.973.034	0.739	3.287	28.534	237.600	29429.000
Germany	2.619	77.604	383.756	4.208.641	1.096	4.681	41.251	312.100	41961.300
Greece	0.267	10.526	**46.490**	406.482	0.111	0.493	4.389	26.300	4167.847
Italy	1.501	42.783	233.753	2.290.889	0.643	2.573	23.268	146.900	23126.564
Netherlands	0.522	16.445	68.300	909.051	0.209	0.996	8.432	80.900	8895.800
Norway	0.110	5.020	1.710	302.810	0.030	0.310	2.120	46.400	2721.400
Portugal	0.266	16.436	36.059	314.483	0.091	0.525	4.101	24.600	4864.975
Spain	1.351	38.502	210.362	2.061.645	0.579	2.316	20.940	132.200	20812.333
Sweden	0.276	28.042	65.208	492.093	0.083	0.772	6.121	49.625	5184.500
Turkey	1.253	35.706	195.086	1.911.934	0.537	2.148	19.419	122.600	19300.999
United Kingdom	1.927	54.928	300.108	2.941.196	0.826	3.304	29.873	188.600	29691.422
United States	7.131	287.800	418.708	16.936.238	2.287	17.672	129.149	2.296.500	155921.800
Australia	0.671	22.669	75.561	1.277.696	0.255	1.379	11.183	132.600	12268.400
Czech Republic	0.323	14.689	55.060	521.537	0.128	0.642	5.525	40.200	5297.900
Finland	0.120	26.930	18.910	207.560	0.040	0.130	2.880	26.700	2697.300
Hungary	0.230	7.910	9.650	228.330	0.080	0.360	2.600	20.000	4444.200
Japan	4.215	122.243	639.176	6.583.658	1.787	7.362	65.802	452.300	66087.500
New Zealand	0.156	6.711	27.850	235.382	0.064	0.292	2.595	15.326	2436.300

Poland	0.944	26.911	147.031	1.440.968	0.405	1.619	14.636	92.400	14546.593
Slovak Republic	0.180	7.180	7.440	146.720	0.060	0.120	1.730	15.500	2721.900
Chile	0.354	34.473	92.292	511.166	0.118	0.890	7.399	35.400	5961.965
Israel	0.244	6.989	37.746	374.845	0.104	0.421	3.791	24.500	3778.300
Ireland	0.140	3.990	21.800	213.650	0.060	0.240	2.170	13.700	2156.800
Switzerland	0.230	9.600	3.800	442.360	0.120	1.042	1.760	28.500	4695.600

In order for efficient countries to be sorted among themselves, the super efficiency model has been utilised and the results have been provided in Table 5. According to the data given in Table 5, the top three countries have been found as Denmark, Switzerland, and Finland. Even if it has the same amount of inputs with 59.26% (100-40.74), Denmark continues to be an efficient country. It is possible to make similar comments about other countries.

Table 5 *Super Efficiency Scores*

Efficient Countries	Super Efficiency Score	Rating
Denmark	40.74%	1.
Switzerland	73.39%	2.
Finland	77.39%	3.
Ireland	79.58%	4.
Norway	89.36%	5.
Slovak Republic	90.54%	6.
Hungary	92.72%	7.

The efficiency change of countries in three-year period has been evaluated through window analysis and the results have been given in Table 6. Due to the limited data, the window size has been determined as two. The Period 1 column indicates the efficiency values of first year with regard to the data of the same year. As for the efficiency scores of the second year, the first rows of Period 2 column give the first two years' data while the second rows contain the last two years' data (the data of the first year has been excluded from the calculation) related to the calculated efficiency scores of the second year. Period 3 column gives the efficiency scores of the third year calculated by the last two years' data.

According to the data in Table 6, Denmark and Ireland are efficient countries thanks to their stable performance each year. This result is supported by the zero value of range and standard deviation scores. Although the efficiency score of some countries as Norway has a little decrease within the years, they could be stated as generally efficient countries. Inefficient

in the first year, Finland and Hungary has become efficient in the last two years. The best efficiency performance average belongs to Denmark and Ireland with 100 points and these countries are respectively followed by Switzerland, Finland, Norway, Slovakia, and Hungary. The worst average in efficiency performance belongs to Czech Republic with 173.30 points and it has to increase its outputs by 73.3% (1.733-1= 0.733) in order to be an efficient country. The highest values in range and standard deviation belong to Chile which has a fluctuating efficiency performance. It could be observed that Turkey is not an efficient country between these periods and due to the rises and falls in the efficiency value, it could be stated that Turkey has a fluctuating performance. The mean, range, and standard deviation of efficiency scores of Turkey have been found as 115.15, 10.94, and 4.54, respectively. Since the year and country based average efficiency value is 122.2, Turkey is in a better situation with an average of 115.15.

Table 6 *The Results of Window Analysis of Countries*

DMU	P1	P2	P3	Mean	Range	Std. Dev.
Austria	108.91	109.47	---	110.47	3.2	1.52
	---	112.11	111.39			
Belgium	112.09	113.52	---	114.44	5.26	2.23
	---	117.35	114.78			
Canada	145.24	143.45	---	143.78	3.5	1.55
	---	144.7	141.74			
Denmark	100	100	---	100	0	0
	---	100	100			
France	115.85	115.84	---	118.77	6.76	3.45
	---	120.77	122.60			
Germany	118.63	119.39	---	122.32	9.36	4.29
	---	127.99	123.25			
Greece	160.79	157.44	---	161.37	11.36	5.15
	---	168.8	158.45			
Italy	116.74	115.26	---	117.04	7	3.16
	---	121.58	114.58			
Netherlands	118.04	118.61	---	120.15	5.4	2.43
	---	123.44	120.51			
Norway	100	100	---	100.04	0.16	0.08
	---	100.16	100			
Portugal	100.95	110.28	---	110.57	14.72	6.87
	---	115.38	115.67			
Spain	146.87	140.72	---	145.21	8	3.45

	---	148.72	144.51			
Sweden	117.31	117.31	---	118.12	2.12	1.02
	---	119.43	118.42			
Turkey	120.85	109.91	---	115.15	10.94	4.54
	---	115.85	113.97			
United King.	129.61	126.42	---	127.66	11.88	5.04
	---	133.25	121.37			
United States	106.11	105.19	---	105.67	1.99	0.90
	---	106.68	104.69			
Australia	121.27	119.69	---	121.57	3.78	1.56
	---	123.47	121.85			
Czech Republic	168.63	170.52	---	173.30	11.36	4.99
	---	179.99	174.04			
Finland	101.44	100	---	100.36	1.44	0.72
	---	100	100			
Hungary	105.74	100	---	101.44	5.74	2.87
	---	100	100			
Japan	142.61	141.09	---	145.10	7.29	3.80
	---	148.30	148.38			
New Zealand	105.76	105.05	---	111.79	11.45	7.5
		116.5	119.84			
Poland	165.25	163.51	---	165.50	11.74	5.01
		172.48	160.74			
Slovak Repub.	100	101.30	---	100.82	1.99	0.99
	---	101.99	100			
Chile	138.94	122.55	---	139.35	46.11	20.72
	---	127.23	168.66			
Israel	138.02	135.99	---	129.82	41.06	18.72
	---	143.16	102.10			
Ireland	100	100	---	100	0	0
	---	100	100			
Switzerland	100	100	---	100.32	1.28	0.64
	---	101.28	100			
Mean	121	122.38	122.2	122.15		

In the last part of study, the efficiency change of 28 OECD countries has been measured through Malmquist TFP index and the results have

been analysed by DEAP 2.1 package. The first three columns of Table 7 include the values of EC, TC, and TFP for the first and second years while the latter three columns contain the same values for the second and third years and the last three columns bear the data of average change of EC, TC, and TFP. Countries having a value of greater than 1 for their efficiency are those successfully reached to the production frontier. When the average changes are taken into consideration, it has been observed that of 28 countries, 12 have experienced a decrease while 8 countries have experienced an increase in their EC performance. 8 countries have experienced no change in their EC value. The countries increasing their EC value most are Israel, the United Kingdom, and Turkey by 15.6%, 3.3%, and 3%, respectively. On the other hand, the countries experiencing the biggest fall are Chile, Portugal, and New Zealand by 10.1%, 6.9%, and 6.3%, respectively. Countries having greater than 1 TC are those producing more outputs with the same amount of input by increasing their technological capacity. While it has been found out that all countries have increased their technological capacity, those having the biggest rise are Denmark by 4.8%, New Zealand by 4.5%, and Switzerland by 4.4%. In terms of TFP, 24 countries have increased their performance while 4 countries have experienced a fall in this index value. TFP value of 85.7% of the countries has increased while there has been a fall in the 14.3%. The biggest rise belongs to Israel with 19.8% while the sharpest fall has been experienced by Chile with 6.8%. The EC performance of Chile has been observed as the cause of this fall.

Table 7 Results of Malmquist TFP Index

	1st-2nd years			2nd-3rd years			Average		
DMU	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP
Austria	0.987	1.008	0.995	0.983	1.025	1.007	0.985	1.016	1.001
Belgium	0.973	1.015	0.988	0.989	1.037	1.025	0.981	1.026	1.006
Canada	1.005	1.006	1.010	1.012	1.009	1.021	1.008	1.007	1.016
Denmark	1.000	1.001	1.001	1.000	1.098	1.098	1.000	1.048	1.048
France	0.994	1.007	1.000	0.945	1.044	0.986	0.969	1.025	0.993
Germany	0.988	1.005	0.994	0.969	1.048	1.015	0.978	1.026	1.004
Greece	1.025	1.004	1.029	0.990	1.076	1.065	1.007	1.039	1.047
Italy	1.022	0.994	1.017	0.993	1.069	1.061	1.008	1.031	1.039
Netherlands	0.985	1.010	0.995	0.984	1.042	1.025	0.985	1.026	1.010
Norway	1.000	0.996	0.996	1.000	1.024	1.024	1.000	1.010	1.010
Portugal	0.930	0.994	0.925	0.932	1.068	0.996	0.931	1.031	0.960
Spain	1.057	0.988	1.044	0.962	1.070	1.029	1.008	1.028	1.036
Sweden	0.991	1.013	1.004	0.983	1.030	1.013	0.987	1.022	1.009
Turkey	1.114	0.987	1.100	0.953	1.068	1.017	1.030	1.027	1.058

United Kingdom	1.039	0.987	1.025	1.028	1.038	1.098	1.033	1.027	1.061
United States	0.995	1.014	1.009	1.005	1.014	1.019	1.000	1.014	1.014
Australia	1.003	1.010	1.013	0.982	1.032	1.013	0.993	1.021	1.013
Czech Republic	0.979	1.010	0.989	0.980	1.054	1.033	0.979	1.032	1.010
Finland	1.000	1.045	1.045	1.000	1.002	1.002	1.000	1.023	1.023
Hungary	1.000	1.079	1.079	1.000	1.008	1.008	1.000	1.043	1.043
Japan	1.006	1.005	1.011	0.951	1.052	1.000	0.978	1.028	1.005
New Zealand	0.988	0.998	0.986	0.888	1.095	0.972	0.937	1.045	0.979
Poland	1.024	0.987	1.011	1.004	1.069	1.073	1.014	1.027	1.041
Slovak Republic	1.000	0.961	0.961	1.000	1.093	1.093	1.000	1.025	1.025
Chile	1.119	1.018	1.139	0.723	1.054	0.762	0.899	1.036	0.932
Israel	1.002	1.012	1.014	1.332	1.062	1.414	**1.156**	**1.037**	**1.198**
Ireland	1.000	1.033	1.033	1.000	1.053	1.053	1.000	1.043	1.043
Switzerland	1.000	1.000	1.000	1.000	1.090	1.090	**1.000**	**1.044**	**1.044**
Average	1.007	1.006	1.014	0.982	1.052	1.032	0.994	1.029	1.023
<1							12	-	4
=1							8	-	-
>1							8	28	24

4. CONCLUSION

While the environmental performance of OECD countries is analysed, the current situation in Turkey has been evaluated within this study. Such variables as environmental taxes and energy production from renewable resources have been assessed together through DEA method and several analyses have been carried out through input and output oriented CCR models under the assumption of constant returns to scale function.

When the recent OECD data has been examined, it could be observed that countries releasing the least CO_2 emissions are Switzerland, Hungary, and Portugal while those releasing the most CO_2 emissions are the USA and Australia. With its highly developed industry and large population, the USA is among the countries that release the most amount of CO_2 into the atmosphere. On the other hand, meeting 60% of its energy need from hydroelectric power plants, Switzerland is the country having the least amount of CO_2 emissions. As the most important action to prevent increasing environmental pollution is to reduce CO_2 emissions, people should increase energy efficiency, reduce energy consumption, make some technological changes to enable less use of energy, and using such low-carbon fuels as natural gas and non-fossil fuels rather than coal which contains high amounts of carbon.

When the amount of energy from combustible and renewable wastes

is analysed, it could be observed that Denmark, Finland, and Sweden has the most amount of energy production from these resources. Meeting its energy need from renewable energy resources, Denmark aims to cease the complete use of fossil fuels and as for the wastes, Denmark either recycles the majority of them or meets its regional heating needs through the heat produced by the burning of wastes. 67% of its 11 million tonnes of waste is recycled while 27% is burnt in combustion plants. Denmark meets 20% of the country's heating need and 5% of its energy consumption through the energy obtained from wastes. Sweden treats domestic waste of the country with modern techniques and uses biogas obtained at the end of this process for both heating and generating electricity. Sweden uses 99% of domestic waste to generate electricity and uses the remaining 1% as agricultural fertilizer. Energy production from wastes is of much significance in terms of contributing many problems including global warming. Accordingly, the increased amounts of greenhouse gas emissions could be decreased. The fact that wastes are transformed into energy and industrial chemicals both decreases the dependence on external resources for energy and chemicals and provides economic benefits. As the income level of people or countries is increased, more environmental friendly products are produced and consumed.

It has been found out that the country having the largest amount of electricity generation from renewable resources is again Denmark. Being generated from a renewable resource, the wind energy is among the cleanest energy and Denmark meets one-third of the country's energy need from wind. On the other hand, Finland has efficient waste treatment facilities and power plants generating electricity from solid wastes.

Environmental taxes are of much significance in terms of protecting the environment, as well. The purpose of imposing such taxes is to direct manufacturers and consumers to environmental friendly activities by increasing the prices of products and services. Products having the potential of harming the environment are applied higher pricing and therefore, by steering the behaviour of individuals, production and consumption preferences are supposed to change. The fact that individuals contribute to the cost of protecting the environment is ensured only through environmental taxes. Reducing the production by creating a cost for products polluting the environment or for the firm manufacturing these products is a common policy applied throughout the world. Denmark has the highest amount of revenues coming from environmental taxes and is one of the first countries applying "Ecological Tax Reform" incorporating environmental taxes, efficient tools in improving the quality of natural environment and protecting it, and the use of revenues from these taxes. Therefore, it is possible to state that Denmark has pioneered the environmental tax applications.

The fact that inefficient countries determine the policies that will enable reaching the target values by taking countries such as Denmark and Sweden as a reference point and putting the applicable ones into practice will substantially reduce environmental threat.

Through the super efficiency model, efficient countries have been sorted and three years' performance evaluation has been carried out via window analysis. Denmark, Switzerland, and Finland has been found out as the most efficient countries at the end of the super efficiency analysis. According to the results of window analysis, Denmark and Ireland has been found as having the best efficiency performance and there has been observed periodical fluctuations in the performance of other countries.

Lastly, the change in the efficiency of countries between the years has been measured through Malmquist TFP index. According to the results, the countries increasing their EC value most are Israel, the United Kingdom, and Turkey by 15.6%, 3.3%, and 3%, respectively. Countries having the biggest rise in their TC have been found out as Denmark by 4.8%, New Zealand by 4.5%, and Switzerland by 4.4%. When the overall situation is analysed, TFP value of 85.7% of the countries has increased while there has been a fall in the 14.3%.

For the future studies, it could be recommended that the input and output selection could be carried out by expert views and such multiple-criteria decision making techniques as AHP and DEMATEL could be used. The methodology adopted within the study could be used as a guide for different efficiency analysis scenarios and DMUs.

REFERENCES

Aldamak, A. & Zolfaghari, S. (2017). Review of efficiency ranking methods in data envelopment analysis. *Measurement*, *106*, 161-172.

Ali A. I. & Seiford L. M. (1990). Translation invariance in data envelopment analysis. *Operations Research Letters*, *9*(6), 403–405.

Andersen, P. & Petersen, N.C. (1993). A procedure for ranking efficient units in data envelopment analysis. *Management Science*, *39*(10), 1261-1264.

Charnes A, Clark C. T, Cooper W. W & Golany B. (1985). A developmental study of data envelopment analysis in measuring the efficiency of maintenance units in the U.S. Air Forces. *Annals of Operations Research*, *2*(1), 95–112.

Charnes A. Cooper W. W. & Rhodes E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444.

Chen, J., Song, M. & Xu, L. (2014). Evaluation of environmental efficiency in China using data envelopment analysis. *Ecological Indicators*, *52*, 577-583

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. and Battese, G. E. (2005). An introduction to efficiency and productivity analysis, Springer Science & Business Media.

Cooper, W. W., Seiford, L. M., & Zhu, J. (2011). Data envelopment analysis: History, models, and interpretations. In Handbook on data envelopment analysis, Springer, Boston, MA.

Deliktas, E. (2002). Efficiency and Analysis of Total Factor Productivity Growth in Private- Owned Manufacturing Industry in Turkey. *METU Studies in Development*, *29*(2), 247-284.

Dobos, I. & Vörösmarty, G. (2019). Inventory-related costs in green supplier selection problems with Data Envelopment Analysis (DEA). *International Journal of Production Economics*, *209*, 374-380.

Dyckhoff, H. & Allen, K. (2001). Measuring ecological efficiency with data envelopment analysis (DEA), *European Journal of Operational Research*, *132*(2), 312–325.

Eva, M., Sagarra, M. & Agasisti, T. (2016). Assessing organizations' efficiency adopting complementary perspectives: An empirical analysis through data envelopment analysis and multidimensional scaling, with an application to higher education. *In Handbook of operations analytics using data envelopment analysis*, Springer, Boston, MA.

Guo, X.D., Zhu, L., Fan, Y. & Xie, B.C. (2011). Evaluation of potential reductions in carbon emissions in Chinese provinces based on environmental DEA. *Energy Policy*, *39*(5), 2352-2360.

Halkos G.E. and Tzeremes N.G. (2009). Exploring the existence of Kuznets curve in countries' environmental efficiency using DEA window analysis. *Ecological Economics*, *68*(7), 2168–2176.

Hosseinzadeh-Bandbafha, H., Nabavi-Pelesaraei, A., Khanali, M., Ghahderijani, M. & Chau, K.W. (2018). Application of data envelopment analysis approach for optimization of energy use and reduction of greenhouse gas emission in peanut production of Iran. *Journal of cleaner production*, *172*, 1327-1335.

Lin, E.Y-Y., Chen, P-Y. & Chen, C-C. (2013). Measuring the environmental efficiency of countries: A directional distance function metafrontier approach. *Journal of Environmental Management*, *119*, 134-142.

Mahadevan, R. (2002). A DEA Approach to Understanding the Productivity Growth of Malaysia's Manufacturing Industries. *Asia Pasific Journal of Management*, *19*(4), 587-600.

Malana, N. M. & Malano, H. M. (2006). Benchmarking productive efficiency of selected wheat areas in Pakistan and India using data envelopment analysis. *Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage*, 55(4), 383-394.

Malmquist, S. (1953). Index numbers and indifference surfaces. *Trabajos de Estadistica, 4*(2), 209–242.

Mavi, N. K. & Mavi, R. K. (2019). Energy and environmental efficiency of OECD countries in the context of the circular economy: Common weight analysis for malmquist productivity index. *Journal of environmental management*, *247*, 651-661.

Meng, F. Y., Fan, L. W., Zhou, P. and Zhou, D. Q. (2013). Measuring environmental performance in China's ındustrial sectors with non-radial DEA, *Mathematical and Computer Modelling*, *58*(5-6), 1047-1056.

Omrani, H., Shafaat, K. & Emrouznejad, A. (2018). An integrated fuzzy clustering cooperative game data envelopment analysis model with application in hospital efficiency. *Expert Systems with Applications*, *114*, 615-628.

Ouyang, W. & Yang, J. B. (2020). The network energy and environment efficiency analysis of 27 OECD countries: A multiplicative network DEA model. *Energy*, *197*, 117161.

Rheinhard S., Lovell C. A. K., Thijssen G. (1999). Econometric estimation of technical and environmental efficiency: An application to Dutch dairy farms. *American Journal of Agricultural Economics*, *81*(1), 44–60.

Scheel H. (2001). Undesirable outputs in efficiency evaluations. *European Journal of Operational Research*, *132*(2), 400–410.

Sherman H. D. (1984). Data Envelopment Analysis as a New Managerial Audit Methodology-Test and Evaluation. *Auditing*, *4*(1), 35.

Sozen, A. & Karık, F. (2017). Comparison of Turkey's renewable energy performance with OECD and BRICS countries by multiple criteria. *Energy Sources, Part B: Economics, Planning, and Policy*, *12*(5), 487-494.

Sueyoshi, T. & Goto, M. (2011). Measurement of returns to scale and damages to scale for DEA-based operational and environmental assessment: how to manage desirable (good) and undesirable (bad) outputs? *European journal of operational research, 211*(1), 76-89.

Sueyoshi, T. & Goto, M. (2013). DEA environmental assessment in a time horizon: Malmquist ındex on fuel mix, electricity and CO_2 of ındustrial nations. *Energy Economics, 40*, 370–382.

Wang, J. & Zhao, T. (2017). Regional energy-environmental performance and investment strategy for China's non-ferrous metals industry: a non-radial DEA based analysis. *Journal of cleaner production*, *163*, 187-201.

Wang, J., Zhao, T. & Zhang, X. (2016). Environmental assessment and investment strategies of provincial industrial sector in China — Analysis based on DEA model. *Environmental Impact Assessment Review, 60*, 156-168.

Wang, K., Wei, Y. M. & Zhang, X. (2013). Energy and emissions efficiency patterns of Chinese regions: a multi-directional efficiency analysis. *Applied Energy*, *104*, 105-116.

Wu, F., Fan, L.W., Zhou, P. & Zhou, D.Q. (2012). Industrial energy efficiency with CO2 emissions in China: A nonparametric analysis. *Energy Policy*, *49*, 164–172.

Wu, J., An, Q., Yao, X. & Wang, B. (2014). Environmental efficiency evaluation of industry in China based on a new fixed sum undesirable output data envelopment analysis. *Journal of cleaner production*, *74*, 96-104.

Yang H. H. & Chang C. (2009). Using DEA window analysis to measure efficiencies of Taiwan's integrated telecommunication firms. *Telecommunications Policy*, *33*(1-2), 98–108.

Yao, X., Feng, W., Zhang, X., Wang, W., Zhang, C. & You, S. (2018). Measurement and decomposition of industrial green total factor water efficiency in China. *Journal of Cleaner Production*, *198*, 1144-1156.

Zhang, N., Kong, F. & Yu, Y. (2015). Measuring ecological total-factor energy efficiency ıncorporating regional heterogeneities in China. *Ecological Indicators*, *51*, 165-172.