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ASSESSMENT OF CONTINENT-WISE ENERGY EFFICIENCY BASED ON CO_2 EMISSIONS: A SLACK-BASED DEA APPROACH

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ABSTRACT

This study uses the Data Envelopment Analysis (DEA) slack-based model (SBM) and Malmquist Productivity Index (MPI) to evaluate energy efficiency based on CO_2 emissions in 42 countries belonging to 6 continents. First, the data envelopment analysis was employed to calculate the efficiency scores for the countries individually and continent basis and then Malmquist index was used to examine the improvement. The study period chosen was 2011-2020. The results of this study showed that on the basis of continents there has been fluctuations in energy efficiency except for Australia, with an efficiency score of equal to one throughout the study period. Additionally, from the results of Malmquist Productivity Index it was found that the 42 countries showed no significant energy enhancement during the period of 2011-2020.

KEYWORDS: ***Energy Efficiency, CO_2 emissions, Continents, Data Envelopment Analysis, Malmquist Productivity Index***

1. INTRODUCTION

The past couple of years had been focused on the emerging sustainable energy in finance. The European Bank for Reconstruction and Development (EBRD) Sustainable Energy Initiative (SEI) has been something of a market chief, setting up an intentional spotlight on financing sustainable energy, and fostering the finances, specialized and business instruments to limit the transaction expenses, risks and multiple the capacity to subsidize at scale diverse energy effectiveness openings. Various multilateral developmental banks and business banks are creating comparative portfolios for sustainable energy and energy efficiency (EBRD, N.D).

By bringing reduction in the volume of energy consumption can have an impact on the productivity improvement from the energy efficiency which leads to various benefits. Financial yield changes ascribed to energy efficiency can be around 0.25 to 1% of (GDP) development. Future financial improvement might be changed by cost saving energy efficiency gains rather than the current worldview of buyer burning through to take advantage of cheap energy.

Various advantages of energy efficiency contribute to both small scale and large scale financial growth. A developing group of proof focuses to generous worth in the different advantages of energy proficiency. Funding in energy efficiency can possibly make an increment in the tax revenue, give more significant yields on trading and investment, and lower the expenses of unemployment and social welfare. Similarly, positive wellbeing results are reliably most grounded among vulnerable groups of the population consisting of youngsters, the old, and those with prior diseases. Reduction in energy consumption helps in decreased respiratory illness, address psychological well-being and reduce fuel destitution that is related with tension, stress, depression, panic attacks etc. Energy efficiency also can be an essential investment opportunity for organizations prompting further development of business horizons, decreased operating and overhead costs. Suppliers of energy are moving to another pattern of benefitting by providing energy services and various advantages to consumers, rather than simply selling more units of energy. Direct advantages to sellers incorporate lower transmission costs, and reduction in the management costs of customers (EBRD, 2015)

The importance of measuring energy efficiency reaches a global level. One of the significant energy effectiveness techniques in the EU is a necessity that Member States set up energy efficiency obligations (EEO) plans or elective estimates that would convey a developing degree of energy reserve funds from measures conveyed to end use energy clients. Similarly in the US, such schemes are called energy efficiency resource standards (EERS's) and have been implemented in 26 states. In Australia, similar EEO arrangements have been embraced in three states in addition to the Australian Capital Territory. The New South Wales EEO conspire in Australia started in 2003 as a feature of a bigger emissions exchanging plan and was really the primary functional white authentication scheme on the planet. In the Southeast Asia, The International Energy Agency (IEA) has a set 25 energy efficiency policy recommendations to be followed by its countries to attain sustainable energy efficiency. Renewable Energy and Energy Efficiency Partnership (REEEP) supported this drive as a component of its ninth call for recommendations, as energy effectiveness however regularly ignored is critical for a maintainable pathway towards energy security. The International Energy Agency (IAE) with the help of 50 energy efficiency specialists from Latin America and the Caribbean, along with the United Nations Economic Commission for Latin America and the Caribbean (UN ECLAC), and the Ministry of Energy and Mines of Peru has made policy recommendations for energy efficiency. The policies focuses on approaches from measures to execute required least energy performance principles for buildings and appliances, to further develop transport framework and energy management and efficiency growth for the industry. South Africa's National Energy Efficiency Strategy (NEES) focuses on measures to advance energy saving, decrease the adverse consequence of energy use on the climate, lessen energy expenses for the economy, contribute towards maintainable turn of events, and to accomplish a public energy strategy (European council for an energy efficient economy, 2017)

By taking a look at these energy efficiency schemes implemented across various continents, this paper evaluates the energy efficiency attained by the countries belonging to the 6 continents over the course of the period.

2. LITERATURE FRAMEWORK

The concern of energy supply when there is huge gap between the demand and supply of energy in the market is on a global level. Due to this the efficient and optimum utilization of energy becomes the focal point of attention. In particular, the best approach to keep up with the balance between financial turn of events and energy utilization has become generous for governments, specialists and public. And henceforth an intensive research has been conducted to evaluate the energy efficiency at country and continental level. As far as our knowledge is concerned till date there has been no study conducted to evaluate energy efficiency in the context of continent wise.

In the past few years various techniques have been applied to measure energy efficiency. Countless structural factors, like mechanical design and energy utilization structure, are epitomized in energy intensity (Ramanathan, 2002). It basically estimates the corresponding connection between energy and financial yield (Ghali and EI-Sakka, 2004). In light of this limit, Hu andWang (2006) built the total-factor energy proficiency list (TFEE) in light of information envelopment examination (DEA). TFEE is characterized as the particular worth of target energy input and real energy contribution under the best creation practices without changes in different outputs. This definition gets through the impediment of the conventional single-factor energy productivity list. From that point forward, DEA has turned into a standard technique for contemplating energy efficiency and environmental efficiency globally (Honma and Hu, 2008; Lu et al., 2013; Zhou et al., 2009).

Mardani (2018) led a survey on DEA utilized in estimating energy and climate where the author looked into 145 past examinations utilizing the DEA strategy for evaluating energy and climate. Energy efficiency has for quite some time been investigated, covering not exclusively nations businesses yet in addition inside or across districts and nations. Utilizing the DEA strategy, Hu and Kao (2007) led an examination in on the subject of energy reserve funds, focusing on the economies of the 17 Asia-Pacific Economic Collaboration (APEC) nations during 1991–2000, where energy, work, and capital were utilized as information sources also, the GDP was chosen as the output. The results showed that Hong Kong, Philippines, and the US had the most elevated energy efficiency. Wei et al. (2007) conducted an analysis on the steel and iron energy efficiency by applying Malmquist index. The total-factor energy efficiency model was employed by Honma and Hu (2018) to study the regional energy efficiency in Japan. Zhang et al. (2011) also employed DEA window analysis to examine the dynamic trends followed in the total-factor energy efficiency.

Sengupta (1994) and Fare and Grosskopf (1996) made a significant contribution to the advancement of dynamic DEA. Sengupta introduced a dynamic DEA model by presenting the adjustment cost way to deal with risk and output variances on the dynamic creation frontiers when consolidating shadow values of semi fixed inputs and their ideal ways into a logical linear programming issue. Moghaddam and Ghoseiri (2011) created a fuzzy dynamic multi objective DEA model to survey the performance of rail lines. Soleimani-damaneh (2013) gave another strategy to acquire a calculation with computational benefits, utilizing dynamic DEA models for assessing returns to scale. Škrinjarić, T. (2014) applied a dynamic slacks-based approach to deal with assess the relative efficiency of stocks in each quarter, assembling quarterly information of the Zagreb Stock Exchange. Sueyoshi et al. (2013) managed dynamic DEA window investigation in a time-shift frontier to survey the environmental performance of U.S. coal-terminated force plants during and inferred that it is vital for the United States to broaden the extent of the Clean Air Act (CAA) for controlling the measure of CO2 outflows.

The importance of considering undesirable outputs in energy efficiency assessment is important. Numerous nations, particularly developing countries, have spent more endeavors in advancing green and maintenance of sustainable environment. Shi et al. (2010) created an extended DEA model by treating undesirable output to assess the mechanical energy efficiency and examined the energy-saving potential in 28 authoritative districts in China. Bai et al. (2012) utilized a super efficiency DEA strategy to quantify the energy productivity of 11 areas in western China under the structure of total- factor energy efficiency where both desirable and undesirable outputs are taken into consideration. In this way, it is of huge importance to examine the effect of undesirable outputs on energy efficiency. The wide reach of DEA can be affirmed in the article of Emrouznejad et al. (2008) that has summed up past DEA results attained. Besides, Zhou et al. (2008) summed up in excess of 100 DEA applications in energy and climate strategy.

A few investigations employed a direct distance function technique with output angle, to manage the evaluation assessment issue with undesirable outputs. Gómez-Calvet et al. (2014) evaluated the energy efficiency of the EU by utilizing a SBM model. The examination noted down that the coordination and consistency of energy ecological approaches would assist with advancing the EU's energy efficiency. Xie et al. (2013) utilized a SBM model to work out the energy effectiveness of the OECD and the BRIC. Similarly, Tsutsui and Goto (2008) utilized a weighted SBM model to quantify the general administration effectiveness of 90 electric force organizations in the U.S.

SFA is another parametric estimation method employed to study the energy efficiency by making use of maximum likelihood estimation (MLE). This technique utilizes a parametric modelling approach to deal with measure a frontier value and in this manner gives a measure to assess energy efficiency. Boyd et al. (2008) utilized SFA strategy in the American Energy Star Program to work out an energy performance indicator. Lin and Wang (2014) utilized the excessive energy-input SFA to study the total- factor energy efficiency and the relating energy preservation capability of China's iron and steel industry.

Some studies have examined the energy force dependent on single factor energy efficiency assessment. Okajima and Okajima (2013) presented the meaning of energy intensity and talked about the purposes behind the expansion in Japan's energy intensity. In light of the panel data regarding 75 nations, Jimenez and Mercado (2014) utilized Fisher ideal index to deteriorate the energy intensity and examined the energy efficiency of Latin American nations. Chang (2014) utilized the contrast between standardized energy intensity and actual energy intensity to ssquantify energy intensity of the EU, and along these lines analysed and dissected the energy efficiency of the EU.

Ang (2006) proposed an analytical structure for following economy-wide energy efficiency patterns, which is based upon a well-established energy strategy examination tool known as index composition analysis (IDA). The IDA-based logical system has been taken on by various nations including Canada, New Zealand and the US for following their economy-wide energy efficiency patterns (Ang et al., 2020).

3. METHODOLOGICAL FRAMEWORK

Data Envelopment Analysis (DEA) is a non-parametric technique which is based on linear programming. It is used to evaluate the relative efficiency of a homogenous set of companies. It was first developed by Charnes, Cooper and Rhodes (1978) and further extended by Bankar, Charnes and Cooper (1984). This technique is considered each individual observation and calculates a discrete piecewise frontier determined by the set of efficient companies. It compares the companies that use multiple inputs to produce multiple outputs. The technique is most suitable for measuring the technical efficiencies of those decision-making units (DMUs)[1]

[1] A DMU is regarded as the entity responsible for converting inputs into outputs and whose performances are to be evaluated. For the purpose of securing relative comparisons, a group of DMUs is used to evaluate each other with each DMU having a certain degree of managerial freedom in decision making. In the present study the DMUs are the selected petroleum companies.

which are homogeneous and are in the same line of business. For example, if the performance of a firm is evaluated, all the companies should be in the same business. Though, the firm in the same business may be diverse in their size, age, location and other attributes. The notion of DEA is based on the concept of Pareto Optimality. It means, within the given limitations of resources and technology, there is no way of producing more of the desired commodity without reducing the output of some other desired commodity.

Mathematically, we solve the following problem when evaluating the efficiency;

Suppose that there are N firms each producing *m* outputs from *n* inputs. Firm *t* uses the input bundle $x^t = (x_{it}, x_{2t}, .., x_{nt})$ to produce the output bundle $y^t = (y_{1t}, y_{2t} .., y_{mt})$. As noted above, measurement of average productivity requires aggregation of inputs and outputs. But no prices are available. What we would need in this situation is to use vectors of "shadow" prices of inputs and outputs.

Define $u^t = (u_{1t}, u_{2t}, .., u_{nt})$ as the shadow price vector for inputs and $v^t = (v_{1t}, v_{2t}, .., v_{mt})$ the shadow price vector for outputs. Using these prices for aggregation we get a measure of average productivity of firm *t* as follows:

$$AP_t = \frac{\sum_{r=1}^{m} v_{rt}\, y_{rt}}{\sum_{i=1}^{n} u_{it}\, x_{it}} = \frac{v^{t\prime} y^t}{u^{t\prime} x^t} \qquad (3.1)$$

Note that the shadow price vectors used for aggregation vary across firms. Two restrictions are imposed, however. First, all of these shadow prices must be non-negative, although zero prices are admissible for individual inputs and outputs. Second, and more importantly, the shadow prices have to be such that when aggregated using these prices, no firm's input-output bundle results in average productivity greater than unity. This, of course, also ensures that $AP_t \leq 1$ for each firm *t*. These restrictions can be formulated as follows:

$$AP_j = \frac{v^{t\prime} y^j}{u^{t\prime} x^j} = \frac{\sum_{r=1}^{m} v_{rt}\, y_{rj}}{\sum_{i=1}^{n} u_{it}\, x_{ij}} \leq 1;\ (j = 1, 2, ..., t, .., N); \qquad (3.2)$$

$$u_{it} \geq 0;\ (i = 1, 2, ..., n);\ \ v_{rt} \geq 0;\ (r = 1, 2, .., m)\ .$$

In general, there are many shadow price vectors (u^t, v^t) satisfying these restrictions. Out of them we choose one that maximizes AP_t as defined above.

This is a linear fractional functional programming problem and is quite difficult to solve as it is. There is, however, a simple solution[2]. Note that neither the objective function (AP_t) nor the constraints are affected if all of the shadow prices are multiplied by a non-negative scale factor *k* (*>0*). Therefore, define

$$w_{it} = k\, u_{it}\ \ (i = 1, 2, .., n) \qquad (3.2a)$$

and

$$p_{rt} = k\, v_{rt}\ \ (r = 1, 2, ..., m) \qquad (3.2b)$$

Then the optimization problem becomes

$$\max\ \frac{p^{t\prime} y^t}{w^{t\prime} x^t}$$

$$\text{s.t.}\ \frac{p^{t\prime} y^j}{w^{t\prime} x^j} \leq 1,\ (j = 1, 2, ..., N); \qquad (3.3)$$

$$p^t \geq 0;\ w^t \geq 0.$$

Now, set

[2] This approach was introduced earlier by Charnes and Cooper (1968).

$$k \equiv \frac{1}{\sum_{i=1}^{n} u_{it}\, x_{it}} \quad . \qquad (3.4)$$

Then, $w^{t}{}' x^{t} = 1$ and the problem becomes

$$\max \sum_{r=1}^{m} p_{rt}\, y_{rt}$$

$$\text{s.t.} \sum_{r=1}^{m} p_{rt}\, y_{rj} - \sum_{i=1}^{n} w_{it}\, x_{ij} \leq 0; \quad (j = 1, 2, ..., t, .., N);$$

$$\sum_{i=1}^{n} w_{it}\, x_{it} = 1; \qquad (3.5)$$

$$p_{rt} \geq 0; \quad (r = 1, 2, ..., m):$$

$$w_{it} \geq 0; \ (i = 1, 2, ..., n).$$

This is a linear programming (LP) problem and can be solved using the simplex method.

3.1 DEA Models

There are basic models of DEA — CCR model and BCC model. The CCR model, developed by Charnes, Cooper and Rhodes in 1978 and BCC model, developed by Banker, Charnes, and Cooper in 1984. CCR model defines the relative efficiency for any DMU as a ratio of the weighted sum of outputs to a weighted sum of inputs where all efficiency scores are restricted to lie between zero and one.

CCR model is based on a CRS technology assumption which implies that if the input levels of a feasible input-output correspondence are scaled up or down, then another feasible input-output correspondence is obtained in which the output levels are scaled by the same factor as the input levels (Thanassoulis, 2001). Thus, under the CRS technology assumption, constructed production frontier is linear, revealing that the output will increase at the same rate as inputs are increased. Further, when the CCR model is applied, estimated efficiency scores of a firm remain same whether input-oriented or output-oriented DEA model is applied.

On the other hand, the BCC DEA model is based on the VRS technology assumption which measures the pure technical efficiency, i.e., conversion of inputs into output. Bankar, Charness and Cooper added a convexity constraint in the CCR model. The CCR model is based on the assumption that the constant return to scale (CRS) exists at the efficient frontiers whereas BCC assumes variable returns to scale (CRS) frontiers.

The CCR model measures the overall technical efficiency (OTE)[3], while the BCC model measures the pure technical efficiency (PTE)[4], net of scale-effect which is also known as managerial efficiency. If a firm scores the value of both CCR-efficiency and BCC-efficiency equal to one, it is said that the firm is operating the most productive scale Size (MPSS).

The BCC model assists to decompose the OTE into PTE and SE. In other words, scale efficiency (SE) of a firm is measured by dividing the OTE from PTE. If PTE of a firm is equal to 1 and its OTE is less than 1, it indicates that the firm is capable to convert efficiently its inputs into the output, however, it is OTE- inefficient because its size is either too big or too small related to the optimum size. Therefore, inefficiency in any firm may occur due to its inefficient operations or due to the disadvantageous conditions under which it prevails.

3.2 Malmquist Productivity Index (MPI)

Malmquist profitability Index of efficiency change is a multiplicative composite of efficiency and technical change as the major reason for productivity changes can be found out by looking at the estimations of the productivity change and system change indexes. Put in an unexpected way, the profitability misfortunes depicted can be the aftereffect of either efficiency decays, or technique regresses, or both.

The output-based Malmquist profitability record is characterized as takes after (Caves et al. 1982):

$$\mathbf{MPI} = \left[\frac{d_0^{s}(x_t\ ,\ y_t)}{d_0^{s}(x_s\ ,\ y_s)} \times \frac{d_0^{t}(x_t\ ,\ y_t)}{d_0^{t}(x_s\ ,\ y_s)}\right]^{1/2} \qquad \textbf{\textit{(3.2.1)}}$$

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[3] The OTE is also known as global technical efficiency.

[4] The PTE is also known as local/managerial technical efficiency.

Where,

d_0^s is a distance function measuring the efficiency of conversion of inputs xs to outputs ys in the period s. [Note: DEA efficiency is considered a distance measure as it reflects the efficiency of transforming inputs to outputs (Fare et al. 1994)]

Notably, if there is a technical change in period t, then

$\boldsymbol{d_0^t(x_t\ ,\ \ y_t\ )} =$ Efficiency of conversion of input in period $\boldsymbol{s}$ to output in period $s \neq \boldsymbol{d_0^s(x_s\ ,\ \ y_s)}$

The Malmquist productivity index is a geometric average of the efficiency and technical changes in the two periods being considered. Following Grosskopf et al. (1994), the Malmquist productivity index in (3.15) in Grosskopf et al. (1994) can thus be written as

$$\textbf{MPI} = \frac{d_0^t(x_t\ ,\ y_t)}{d_0^s(x_s\ ,\ y_s)}\left[\frac{d_0^s((x_s\ ,\ y_s)}{d_0^t((x_s\ ,\ y_s)} \times \frac{d_0^s(x_t\ ,\ y_t)}{d_0^s(x_t\ ,\ y_t)}\right]^{1/2} \qquad \textit{(3.2.2)}$$

= Efficiency change × Technical change

The MPI was used to estimate changes in the overall productivity of individual pharmaceutical company over a period of time. MPI > 1 means that productivity increases; MPI = 1 means that productivity does not change; MPI < 1 indicates that productivity decreases. The change in efficiency is called "catch-up effect" and the efficiency change term relates to the degree to which a firm improves or decline its efficiency. Efficiency change greater than 1 indicates progress in relative efficiency from period s to t, while efficiency change equal to 1 and efficiency change less than 1, indicate no change and regress in efficiency respectively.

The change in the technical efficiency is called "frontier-shift effect" (or innovation effect). It reflects the change in the efficient frontiers between the two periods of time. Technical change greater than one stands for technical progress; technical change less than one, shows technical regress; and technical change equal to one, shows no change in the TFP Index.

Figure-1 MPI Indices using CRS technology assumptions

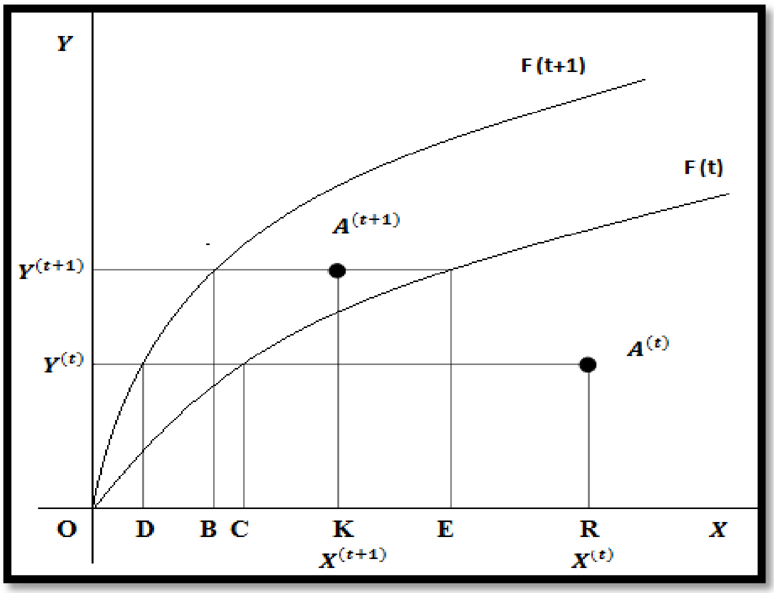

Figure-1 describes the MPI with one input (x) and one output (y) under CRS technology assumption and its decomposition into efficiency change and technical change, MPI under CRS technology indicates a rise in potential productivity as the technology frontier shifts from t to t+1. Points $A^{(t)}$ and $A^{(t+1)}$ represent the input-output combinations of a DMU in periods t and $t+1$ respectively. In both periods, the DMU is operating below the frontier. Technical efficiency change and technical change are represented by the distance functions.

4. EMPIRICAL RESULTS

The study consists of 42 countries belonging to 6 continents during 2011-2020 according to the Enerdata Yearbook 2020 and the World Bank data in 2020. The study made use of five variables, out of which three are input variables and two are output variables. The input variables are energy consumption, labor force and gross capital formation and the desirable output is GDP and the undesirable output is CO_2 emissions. Due to data non-availability of several countries, this study selected 42 countries as the research sample.

Table 1 represents the Descriptive Statistics for the research samples for 2011-2020. The GDP of all 42 countries has fluctuated during the period 2011-2020. While the CO2 emissions for all the countries has generally shown an increasing trend from 2011, but it decreased towards the end of 2020. The energy consumption for all the countries have increased from 2011 but declined in 2020. Labor force and gross capital formation was largest in 2019 and lowest labor force in 2011 and gross capital formation in 2020. In table 2 Descriptive Statistics of Input and Output is given.

Table-1 Year-wise Descriptive Statistics

Year	Input and Output	Ave	Stdev	Min	Max
2011	CO2 Emissions	665.8974989	1494.831725	29.28293164	8488.02207
	GDP	1.177330055	0.105161926	0.772613738	1.362464767
	Energy consumption	266.9494138	523.9240226	18.44292552	2722.605408
	Labor Force	57197463.64	136093162.8	1705590	778344058
	Gross Capital Formation	24.63293221	6.612641838	13.54449848	46.6601211
2012	CO2 Emissions	675.2111066	1516.71901	31.11260853	8748.967277
	GDP	1.141433445	0.125425465	0.642898891	1.316421737
	Energy consumption	270.310458	532.706052	19.37849533	2820.686419
	Labor Force	57626171.74	136547137.9	1827785	781065455
	Gross Capital Formation	24.35543971	7.126952368	12.83498521	46.2252656
2013	CO2 Emissions	688.0277825	1577.856124	31.25057787	9161.181904
	GDP	1.152712719	0.075411865	0.999908117	1.308025576
	Energy consumption	274.2318157	546.2734212	19.4924412	2911.629087
	Labor Force	57984746.69	137143818.5	1957568	783402649
	Gross Capital Formation	23.97649292	7.212960096	14.21199742	46.39894934
2014	CO2 Emissions	686.903824	1573.877089	31.8993602	9082.943498
	GDP	1.15500945	0.095199975	0.723153343	1.284762558
	Energy consumption	276.648703	556.0546208	20.54586666	2965.952037
	Labor Force	58347127.02	137686590.4	2081461	785158444
	Gross Capital Formation	24.11691974	7.377866164	13.39649572	45.82395276
2015	CO2 Emissions	683.9238879	1562.699834	31.66858709	9076.666647
	GDP	1.142228756	0.150629791	0.315128049	1.297436667
	Energy consumption	276.700358	557.3011139	20.79174205	2993.721448
	Labor Force	58770038.02	138136456.3	2192963	786338801
	Gross Capital Formation	24.64144794	7.165866145	14.28863701	50.7807206
2016	CO2 Emissions	681.3637364	1550.470164	31.22167353	9032.770953
	GDP	1.148413696	0.099951276	0.746900525	1.402006624
	Energy consumption	278.2221711	553.644753	20.55396534	2977.153116
	Labor Force	59178689.71	138525846.4	2265866	786996409
	Gross Capital Formation	24.45473466	7.013515688	14.96954698	50.77772418
2017	CO2 Emissions	690.1134775	1569.350586	32.73300921	9185.718136
	GDP	1.159652604	0.078486522	0.85289724	1.286477746
	Energy consumption	283.274184	564.9512401	20.6823932	3070.091366
	Labor Force	59639098.24	138839390.8	2336844	787183156
	Gross Capital Formation	24.58626565	6.85335772	14.6255876	48.54367934

2018	CO2 Emissions	701.1356863	1604.322954	32.15683529	9345.788853
	GDP	1.152858133	0.084132199	0.764398694	1.285739971
	Energy consumption	290.128447	588.1368716	20.4364253	3201.226673
	Labor Force	60052984.38	138960138.2	2386269	785986113
	Gross Capital Formation	24.73411449	6.896707872	15.09504163	47.27871682
2019	CO2 Emissions	700.3819762	1626.751453	32.08372255	9561.89056
	GDP	1.132125254	0.089712507	0.703697647	1.276302233
	Energy consumption	292.4065283	600.1475417	20.73156521	3309.291016
	Labor Force	60535723	139299192.7	2428518	783981188
	Gross Capital Formation	24.9179497	7.485460415	14.57503828	45.99121807
2020	CO2 Emissions	667.6357019	1614.474093	30.00430431	9716.772478
	GDP	0.8379915	0.265783098	1.15551E-06	1.18776373
	Energy consumption	281.7461617	596.0428573	20.01499	3381.399
	Labor Force	58965356.4	135879553.6	2386040	770950792
	Gross Capital Formation	24.03379817	7.910302204	7.511166872	44.82931021

Table-2 Consolidated Descriptive Statistics of Input and Output

Input and Output	Ave	Stdev	Min	Max
CO2 Emissions	684.0594678	1552.71802	29.28293164	9716.772478
GDP	1.119975561	0.15889112	1.15551E-06	1.402006624
Energy consumption	279.0618241	556.4300445	18.44292552	3381.399
Labor Force	58829739.89	136232853	1705590	787183156
Gross Capital Formation	24.44500952	7.102888547	7.511166872	50.7807206

In this study, DEAP software was used to measure the energy efficiency scores of the countries. Since both desirable output and undesirable output is necessary to produce economic output, both of them have been included in the study. The consumption of energy results in the CO_2 emissions which is our undesirable output. The country wise results of DEA SBM are presented in Table 3 while continent-wise results of DEA SBM are presented in Table 4. The results shows that 9 out of 42 countries have efficiency score always equal to one during 2011-2020. In Asia, China, Kuwait, and Saudi Arabia have attained the perfect efficiency scores. For Europe it is Czech Republic and Portugal. In North America it is the US. While both Australia and New Zealand has managed to attain equal to one and in Africa, South Africa has scored the efficiency score equal to one.

Both Uzbekistan and Kazakhstan have attained the efficiency score equal to one by the end of 2020. Both Turkey and Malaysia had an efficiency score equal to one in 2011 but it declined gradually. In Europe, Germany, and Ukraine attained their efficiency score equal to one by 2020. While Poland who had its efficiency score one in 2011, declined from there on but eventually attaining its efficiency score in 2020. Similarly, in South America, Mexico had its efficiency score one in 2011, but it declined and fluctuated from 2012-2019 and attained its efficiency score equal to one in 2020. Even though Brazil had fluctuated efficiency scores throughout 2011-2015, the country attained efficiency score equal to one in three consecutive years from 2016-2018, but it dropped in 2019-2020. Canada had an efficiency score of 94.1% in 2011, and it attained the efficiency score one from 2012-2019, but it dropped to 96.3% in 2020. In South Africa, Egypt had its efficiency score one for the first consecutive four years but declining to 90.8% in 2015. Even though Egypt managed to attain the efficiency score one in 2016, it dropped in both 2019 and 2020.

Table-3 Efficiency Score for 2011-2020

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Algeria	0.868	0.859	0.817	0.833	0.799	0.821	0.783	0.816	0.787	0.817
Argentina	0.984	0.791	0.831	0.856	0.756	0.889	0.898	1	1	0.952
Australia	1	1	1	1	1	1	1	1	1	1
Belgium	0.681	0.623	0.641	0.72	0.693	0.916	0.907	0.867	0.894	0.882
Brazil	0.734	0.643	0.67	0.681	0.518	1	1	1	0.98	0.556
Canada	0.941	1	1	1	1	1	1	1	1	0.963
Chile	0.876	0.755	0.778	0.832	0.834	0.843	0.852	0.853	0.838	0.903
China	1	1	1	1	1	1	1	1	1	1
Colombia	0.935	1	0.857	0.669	0.699	0.73	0.786	0.848	0.836	0.904
Czech Republic	1	1	1	1	1	1	1	1	1	1
Egypt, Arab Rep.	1	1	1	1	0.908	1	1	1	0.958	0.912
France	0.64	0.584	0.653	0.657	0.824	0.696	0.784	0.734	0.681	0.579
Germany	0.886	0.906	0.905	0.917	0.967	0.957	0.949	0.967	0.989	1
India	0.729	0.753	0.748	0.794	0.792	0.806	0.827	0.844	0.843	0.828
Indonesia	0.739	0.7	0.64	0.693	0.697	0.721	0.739	0.771	0.806	0.835
Iran, Islamic Rep.	0.906	0.906	1	1	1	1	1	1	0.932	0.897
Italy	0.948	1	1	0.932	1	1	1	0.993	1	0.799
Japan	0.932	0.971	0.959	0.993	0.954	1	0.969	0.904	0.903	0.975
Kazakhstan	0.982	1	1	0.983	1	1	1	0.93	0.922	1
Kuwait	1	1	1	1	1	1	1	1	1	1
Malaysia	1	0.875	0.9	0.874	0.818	0.833	0.898	0.894	1	0.92
Mexico	1	0.912	0.755	0.779	0.759	0.839	0.809	0.803	0.817	1
Netherlands	0.982	1	1	1	0.965	0.987	1	0.924	0.941	0.911
New Zealand	1	1	1	1	1	1	1	1	1	1
Nigeria	0.889	0.858	0.954	0.86	0.518	0.984	1	0.825	0.583	0.396
Norway	0.812	0.785	0.936	1	1	1	1	1	1	1
Poland	1	0.975	0.944	0.956	0.965	0.991	0.984	0.967	0.974	1
Portugal	1	1	1	1	1	1	1	1	1	1
Romania	0.774	0.8	0.829	0.783	0.842	0.852	0.835	0.858	0.865	0.843
Russian Federation	0.925	0.91	0.886	0.887	0.918	0.891	0.904	0.923	0.945	0.952
Saudi Arabia	1	1	1	1	1	1	1	1	1	1
South Africa	1	1	1	1	1	1	1	1	1	1
South Korea	0.908	0.899	0.89	0.88	0.883	0.895	0.919	0.904	0.847	1
Spain	0.721	0.73	0.836	0.835	0.807	0.851	0.86	0.854	0.807	0.693
Sweden	0.752	0.574	0.637	0.754	0.801	0.773	0.78	0.794	0.825	0.858
Thailand	0.656	0.844	0.616	0.662	0.662	0.77	0.754	0.718	0.709	0.67
Turkey	1	0.84	1	0.873	0.896	0.845	1	0.867	0.804	0.927
Ukraine	0.875	0.743	0.807	1	0.668	0.759	0.828	0.936	1	1
United Arab Emirates	0.878	0.878	0.902	0.987	0.945	1	0.984	0.981	0.989	1
United Kingdom	0.94	0.875	0.912	0.895	0.775	0.879	0.878	0.93	0.849	0.687

United States	1	1	1	1	1	1	1	1	1	1
Uzbekistan	0.941	0.992	1	1	1	0.985	0.9	0.903	0.988	1
Average	**0.901**	**0.881**	**0.888**	**0.895**	**0.873**	**0.917**	**0.924**	**0.919**	**0.912**	**0.897**

Table-4 Continent-wise Efficiency Scores for 2011-2020

CONTINENTS	COUNTRIES	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Asia	China	1	1	1	1	1	1	1	1	1	1
	India	0.729	0.753	0.748	0.794	0.792	0.806	0.827	0.844	0.843	0.828
	Indonesia	0.739	0.7	0.64	0.693	0.697	0.721	0.739	0.771	0.806	0.835
	Iran, Islamic Rep.	0.906	0.906	1	1	1	1	1	1	0.932	0.897
	Japan	0.932	0.971	0.959	0.993	0.954	1	0.969	0.904	0.903	0.975
	Kazakhstan	0.982	1	1	0.983	1	1	1	0.93	0.922	1
	Kuwait	1	1	1	1	1	1	1	1	1	1
	Malaysia	1	0.875	0.9	0.874	0.818	0.833	0.898	0.894	1	0.92
	Saudi Arabia	1	1	1	1	1	1	1	1	1	1
	South Korea	0.908	0.899	0.89	0.88	0.883	0.895	0.919	0.904	0.847	1
	Thailand	0.656	0.844	0.616	0.662	0.662	0.77	0.754	0.718	0.709	0.67
	United Arab Emirates	0.878	0.878	0.902	0.987	0.945	1	0.984	0.981	0.989	1
	Uzbekistan	0.941	0.992	1	1	1	0.985	0.9	0.903	0.988	1
	Turkey	1	0.84	1	0.873	0.896	0.845	1	0.867	0.804	0.927
	Average	**0.905**	**0.904**	**0.904**	**0.910**	**0.903**	**0.918**	**0.928**	**0.908**	**0.910**	**0.932**
Europe	Belgium	0.681	0.623	0.641	0.72	0.693	0.916	0.907	0.867	0.894	0.882
	Czech Republic	1	1	1	1	1	1	1	1	1	1
	France	0.64	0.584	0.653	0.657	0.824	0.696	0.784	0.734	0.681	0.579
	Germany	0.886	0.906	0.905	0.917	0.967	0.957	0.949	0.967	0.989	1
	Italy	0.948	1	1	0.932	1	1	1	0.993	1	0.799
	Netherlands	0.982	1	1	1	0.965	0.987	1	0.924	0.941	0.911
	Norway	0.812	0.785	0.936	1	1	1	1	1	1	1
	Poland	1	0.975	0.944	0.956	0.965	0.991	0.984	0.967	0.974	1
	Portugal	1	1	1	1	1	1	1	1	1	1
	Romania	0.774	0.8	0.82	0.78	0.84	0.85	0.83	0.85	0.86	0.843

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	Russian Federation	0.925	0.91	0.886	0.887	0.918	0.891	0.904	0.923	0.945	0.952
	Spain	0.721	0.73	0.836	0.835	0.807	0.851	0.86	0.854	0.807	0.693
	Sweden	0.752	0.574	0.637	0.754	0.801	0.773	0.78	0.794	0.825	0.858
	Ukraine	0.875	0.743	0.807	1	0.668	0.759	0.828	0.936	1	1
	United Kingdom	0.94	0.875	0.912	0.895	0.775	0.879	0.878	0.93	0.849	0.687
	Average	**0.862**	**0.834**	**0.866**	**0.889**	**0.882**	**0.903**	**0.914**	**0.916**	**0.918**	**0.880**
South America	Argentina	0.984	0.791	0.831	0.856	0.756	0.889	0.898	1	1	0.952
	Brazil	0.734	0.643	0.67	0.681	0.518	1	1	1	0.98	0.556
	Chile	0.876	0.755	0.778	0.832	0.834	0.843	0.852	0.853	0.838	0.903
	Colombia	0.935	1	0.857	0.669	0.699	0.73	0.786	0.848	0.836	0.904
	Mexico	1	0.912	0.755	0.779	0.759	0.839	0.809	0.803	0.817	1
	Average	**0.906**	**0.820**	**0.778**	**0.763**	**0.713**	**0.860**	**0.869**	**0.901**	**0.894**	**0.863**
North America	Canada	0.941	1	1	1	1	1	1	1	1	0.963
	United States	1	1	1	1	1	1	1	1	1	1
	Average	**0.9705**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0.9815**
Australia	Australia	1	1	1	1	1	1	1	1	1	1
	New Zealand	1	1	1	1	1	1	1	1	1	1
	Average	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
South Africa	Algeria	0.868	0.859	0.817	0.833	0.799	0.821	0.783	0.816	0.787	0.817
	Egypt, Arab Rep.	1	1	1	1	0.908	1	1	1	0.958	0.912
	Nigeria	0.889	0.858	0.954	0.86	0.518	0.984	1	0.825	0.583	0.396
	South Africa	1	1	1	1	1	1	1	1	1	1
	Average	**0.939**	**0.929**	**0.943**	**0.923**	**0.806**	**0.951**	**0.946**	**0.910**	**0.832**	**0.781**

The average efficiency score of all forty-two countries saw a fluctuating trend in its efficiency scores except for Australia. Australia managed to have a constant efficiency sore of equal to one throughout 2011-2020. In Asia the efficiency score was 90.5% in 2011 and increased to 93.2% in 2020, the highest efficiency score throughout the period. Europe had an average efficiency score of 86.2% in 2011 and achieved its highest score in 2019 with a 91.8%, but it dropped to 88% by 2020. South America had its highest average efficiency score in 2011 with a 90.58% but dropped to a bottom of 86.3% in 2020. North America attained average efficiency score equal to one for the consecutive eight years ranging from 2012-2019 and declined to 98.15% by 2020. South Africa had an average efficiency score of 93.9% in 2011, but it dropped to a bottom of 78.1% in 2020, making it the lowest average efficiency score among all the continents in 2020. And the average efficiency score of all the 42 countries was 90.1% in 2011, dropping to the lowest of 87.3% in 2015 and recovering to 91.7% in 2016 and declining to 89.7% by 2020.

Analyzing the difference in the efficiency levels during different time spans gives analysts a superior view of the adjustment of efficiency after some time, which empowers them to evaluate how these progressions impact efficiency and can help in foreseeing the variances of future execution. To do this, we applied the Malmquist Productivity Index to calculate the Malmquist Input-oriented Variable return to scale (I-V) model in our review, which assists with working out the change in aggregate productivity. In this review, we analyzed the adjustment of three groups namely, efficiency change (EFFCH), technical change (TECHCH) and total productivity change (MPI).

Table-5 Malmquist Index Summary of Countries Means

COUNTRIES	EFFCH	TECHCH	TFPCH
Algeria	0.999	0.984	0.984
Argentina	0.981	0.986	0.967
Australia	1	0.995	0.995
Belgium	1.021	0.937	0.957
Brazil	0.973	1.026	0.999
Canada	1.011	0.967	0.977
Chile	0.999	0.978	0.977
China	1	1	1
Colombia	0.993	0.964	0.958
Czech Republic	1.017	0.969	0.986
Egypt, Arab Rep.	0.986	0.992	0.978
France	0.977	0.99	0.967
Germany	0.999	0.995	0.994
India	1.014	0.995	1.009
Indonesia	1.01	1.003	1.013
Iran, Islamic Rep.	0.998	0.996	0.994
Italy	0.994	0.992	0.986
Japan	0.997	0.995	0.991
Kazakhstan	1	0.99	0.991
Kuwait	1	0.96	0.96
Malaysia	1.008	0.991	0.998
Mexico	1.009	0.998	1.007
Netherlands	0.995	0.969	0.965
New Zealand	0.972	0.954	0.927
Nigeria	0.915	1.006	0.921
Norway	1.025	0.964	0.988
Poland	1	0.997	0.997
Portugal	1	0.983	0.983
Romania	0.998	0.982	0.981
Russian Federation	1.004	0.991	0.995
Saudi Arabia	1	0.983	0.983
South Africa	1.001	1.002	1.003
South Korea	0.997	0.985	0.982
Spain	0.974	0.982	0.956
Sweden	1.031	0.944	0.973
Thailand	1.003	0.979	0.982
Turkey	0.996	0.998	0.994
Ukraine	1.029	1.02	1.049
United Arab Emirates	1.015	0.974	0.989
United Kingdom	0.956	0.995	0.951
United States	1	0.978	0.978
Uzbekistan	1.015	0.980	0.995
Mean	**0.998**	**0.985**	**0.983**

Table-6 Continent-wise MPI

CONTINENTS	COUNTRIES	EFFCH	TECHCH	TFPCH
Asia	China	1	1	1
	India	1.014	0.995	1.009
	Indonesia	1.01	1.003	1.013
	Iran, Islamic Rep.	0.998	0.996	0.994
	Japan	0.997	0.995	0.991
	Kazakhstan	1	0.99	0.991
	Kuwait	1	0.96	0.96
	Malaysia	1.008	0.991	0.998
	Saudi Arabia	1	0.983	0.983
	South Korea	0.997	0.985	0.982
	Thailand	1.003	0.979	0.982
	Turkey	0.996	0.998	0.994
	United Arab Emirates	1.015	0.974	0.989
	Uzbekistan	1.015	0.98	0.995
	Average	**1.004**	**0.988**	**0.992**
Europe	Belgium	1.021	0.937	0.957
	Czech Republic	1.017	0.969	0.986
	France	0.977	0.99	0.967
	Germany	0.999	0.995	0.994
	Italy	0.994	0.992	0.986
	Netherlands	0.995	0.969	0.965
	Norway	1.025	0.964	0.988
	Poland	1	0.997	0.997
	Portugal	1	0.983	0.983
	Romania	0.998	0.982	0.981
	Russian Federation	1.004	0.991	0.995
	Spain	0.974	0.982	0.956
	Sweden	1.031	0.944	0.973
	Ukraine	1.029	1.02	1.049
	United Kingdom	0.956	0.995	0.951
	Average	**1.001**	**0.981**	**0.982**
South America	Argentina	0.981	0.986	0.967
	Brazil	0.973	1.026	0.999
	Chile	0.999	0.978	0.977
	Colombia	0.993	0.964	0.958
	Mexico	1.009	0.998	1.007
	Average	0.991	0.990	0.982
North America	Canada	1.011	0.967	0.977
	United States	1	0.978	0.978
	Average	**1.006**	**0.973**	**0.978**
Australia	Australia	1	0.995	0.995
	New Zealand	0.972	0.954	0.927
	Average	0.986	0.975	0.961
South Africa	Algeria	0.999	0.984	0.984
	Egypt, Arab Rep.	0.986	0.992	0.978
	Nigeria	0.915	1.006	0.921
	South Africa	1.001	1.002	1.003
	Average	**0.975**	**0.996**	**0.972**

The Malmquist Productivity Index results presented in Table-5 which shows that the average efficiency score of all the 42 countries was 0.983, indicating an insignificant decrease of 0.2% in efficiency. The average technical change and the improvement in efficiency and the technical regress resulted in a loss of 1.5% and 1.7% respectively. The continent wise results are given in Table-6. The average efficiency score of Asian countries was 1.004, indicating and 0.4% increase in efficiency and in Europe it was 1.001, with a 0.1% increase, and South America with 0.55% increase, all insignificant. While in the case of North America, Australia and South Africa, the efficiency scores decreased by 0.9%, 1.4% and 2.5% respectively. The average technical change of all the continents also decreased with the highest percentage of 2.7% in South America and 2.5% in Australia. Similarly, the improvement in efficiency and the technical regress resulted in loss in total productivity for all the continents with a highest loss of 3.9% in Australia and lowest of 0.8% in Asia.

5. DISCUSSION

The research employed a DEA SBM and the Malmquist Productivity Index to assess the energy efficiency of 42 countries belonging to 6 continents having CO_2 emissions during 2011-2020. To evaluate the energy efficiency the study used input variables consisting Labor force, Energy consumption and gross capital formation and output variables consisting of GDP (desirable) and CO_2 emissions (undesirable). First, the energy efficiency scores for all the countries were calculated continent wise and overall; then the comparison is made. The Malmquist Productivity Index were employed later on to measure the efficiency change during the period 2011-2020.

The results from DEA analysis confirmed that the efficiency scores for Asia, North America and Australia were more efficient than that of Europe, South America and South Africa. And from the results of Malmquist Productivity Index, the 42 countries showed no significant energy enhancement during the period of 2011-2020. Even though countries such as Belgium, Canada, Czech Republic, India, Indonesia, Malaysia, Mexico, Norway, Russia, South Africa, Sweden, Thailand, Ukraine, UAE and Uzbekistan had an improvement in terms of energy efficiency, but the increment was insignificant.

6. CONCLUSION

The major contribution of the present research paper is the study of energy efficiency in the context of continents using DEA analysis. From a policy perspective, this study reveals that on the basis of continents there has been fluctuations in energy efficiency except for Australia, with an efficiency score of equal to one throughout the study period. However South America needs to adopt a strong regulatory framework for energy efficiency improvement as it is the continent with the lowest efficiency scores during 2011-2020. They ought to work on individuals' attention to energy efficiency and urge individuals to follow the conduct of optimum utilization of resources. Considering that energy strategies and policies vary among nations, there is critical opportunity to get better in energy effectiveness by knowledge sharing, between the countries with a specific accentuation on measures for energy productivity in certain nations (Jebali, Essid and Khraief, 2017).

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