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Estimating Relative Efficiency of Electricity Consumption in 42 Countries during the Period of 2008–2017

Chia-Nan Wang [1,2], Quoc-Chien Luu [1,*] and Thi-Kim-Lien Nguyen [1]

1 Department of Industrial Engineering and Management, National Kaohsiung University of Science and Technology, Kaohsiung 80778, Taiwan; cn.wang@nkust.edu.tw (C.-N.W.); lien.nguyen0209@gmail.com (T.-K.-L.N.)

2 Department of Industrial Engineering and Management, Fortune Institute of Technology, Kaohsiung 83160, Taiwan

* Correspondence: jkie2211@gmail.com; Tel.: +886-097-965-2251

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Abstract: Augmentation of electrical equipment is pushing for an increase in energy supply sources all over the world, as electricity consumption (EC) typically rises with growing populations. The value of EC reveals economic development and degree of emissions. Therefore, this research uses the undesirable outputs model in data envelopment analysis (DEA) for estimating relative efficiency of electricity consumption in 42 countries from 2008 to 2017. According to the principle of an undesirable outputs model and studied objectives, variables are selected that included population and EC as inputs, gross domestic product (GDP) as desirable output, and carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) as undesirable outputs. The empirical results indicate that 420 terms of 42 countries during the period of 2008–2017 have 102 efficient and 310 inefficient terms. Moreover, the interplay level between input and output factors every year is presented via scores. The study suggests the effect of EC to human life and propounds the emission status to look for directions to overcome inefficient terms.

Keywords: electricity consumption (EC); undesirable outputs model; data envelopment analysis (DEA); efficient; inefficient

1. Introduction

In modern life, electrical energy is essential to meet the demands of extending technology and electronic equipment [1], as electricity provides energy for lighting, heating, cooling, factories, machines, transportation systems, i.e., [2]. The increasing population leads to increasing electricity consumption (EC); thus, population growth and EC have a significant positive relationship [3]. When electricity is utilized, it contributes to enhancing the economic development index. Lu indicated that a 1% increase in EC from 17 Taiwanese industries boosted the real GDP by 1.72% [4]; Enu and Patrick explained the effect of EC on economic growth in Ghana [5]; Altisnay and Karagol showed the casual relationship between EC and real GDP in Turkey [6]. On the other hand, EC causes pollutant emissions to the environment, including CO_2, CH_4, and N_2O. For instance, a study by the Federal University of Agriculture Abeokuta assessing carbon footprints over the 2011–2012 period showed that 5935 tons of CO_2 represented 63% transportation, 35% campus energy consumption, and 2% farm machineries per student [7]. In Hong Kong, between 2002 and 2015, the annual EC went from 27 to 34.1 million tons; further, CO_2-eq/kWh was increased from 702 to 792 g [8]. Therefore, EC has a positive and significant relationship with both emissions [9,10] and economic growth [11].

Electricity is generated from two sources, i.e., nonrenewable and renewable energy. Renewable energy comprises hydropower, biomass, wind, solar, and geothermal. Nonrenewable energy consists of oil, natural gas, coal, and nuclear. Both sources are applied to generating electricity to provide energy for inhabitants and their applications [12]. The population increase augments the EC as well. When a consumer uses electrical energy, economic growth is extended, and CO_2, CH_4, and N_2O rise as well. Increased emissions lead to polluted environments and climate change. Thus, the purpose of study is to determine the relationship among inputs (population, and EC), desirable output (GDP), and undesirable outputs (emissions), the relation is evaluated via the scores computed by an undesirable outputs model in DEA.

In DEA, the super-SBM, EBM, and Malmquist models can formulate the maximum score and separate values for each decision-making unit (DMU) in every term; however, they cannot deal with desirable and undesirable outputs, whereas an undesirable outputs model only approaches to the highest value of 1, but it can solve with good (desirable) and bad (undesirable) outputs independently [13]. This model reaches bad factors in the operation process; the inefficient DMUs will be suggested, i.e., raising good outputs while simultaneously reducing bad outputs to improve their scores [14,15]. With these characteristics, the study applies an undesirable outputs model into computing the efficiency of EC with its relative elements in 42 countries over the world from 2008 to 2017. The analysis result works out the influence of EC on the economic development, and emissions in which the increased levels of undesirable emissions are the root causes of climate change. A feasible solution is recommended to refine the performance of inefficient terms. Moreover, the study draws a picture of the productivity efficiency between EC and its relative factors in 42 countries over the years.

The study is arranged as follows: Section 1 shows the general points of electricity's application, producing an electricity process, and its effects; Section 2 overviews EC and its background research, the theoretical concept of undesirable outputs model in undesirable model and its application; Section 3 builds upon the proposal research and methodology, and quotes source materials; Section 4 displays the empirical analysis results; Section 5 comments on the general results, gives limitations, and discusses future research.

2. Literature Review

The life of people without electricity was inconvenient, they worked by manual labour, and lived without light. Since electrical energy was invented in the18th century, the life of inhabitants has been changed with access to light, electronic equipment, and high-tech. The effectiveness of production operations is enhanced and upgraded sharply by the use of electrical machines. The process whereby people use electrical energy for lighting, heating, transportation, and so on is called "electricity consumption". The population is the major source that supports electricity development when utilizing electronic equipment. The electricity is consumed at a high or low level, the EC reflects an economic growth level. Chen denoted that the economic growth and population have a vital role on the electrical energy consumption when depending on the non-parametric model [16]. To explore the electricity demand in the future, Gajowniczek [17] displayed an approach to predict electricity load at the individual household level using CART, SVM and a MLP neutral network model; Gajowniczek continued studying electricity demand [18]; Singh [19] proposed Bayesian network prediction for energy usage forecasting.

On the other hand, the electricity causes greenhouse gas [20] that leads to climate change because of the emission of CO_2, CH_4, N_2O [21] from electricity production processes [22]. Emissions from hydropower are estimated by using statistical global emission models through the reservoir water surface [23,24], that from natural gas and coal power plants is calculated by a simple model [25], and that from combustion power plants is counted by the values and data of emission factors exhausted from the circulating fluidized bed boiler [26], or that from wind power plants is formulated by a simple analysis method for the undesirable elements of electricity production processes [27]. In China emissions from EC are determined by a data analysis and measurement method [28], while in the United States a transparent method is used [29]. Hence, the previous researchers applied various methods to an examination of the emission of undesirable factors from EC.

Whereas DEA normally concerns calculating performance with the inputs and good outputs in various models such as dynamic-SBM, super-SBM, EBM, i.e., however, they cannot solve for undesirable outputs in social activities, air pollution, and the industrial manufacturing sector. For this reason, Tone proposed an undesirable outputs model in DEA to evaluate bad outputs [30], displaying a new scheme. A DMU acquires efficiency as the score approaches 1, and it is inefficient when the score is less than 1. Furthermore, the model can compute the performance by combining both undesirable and desirable outputs [31]. The efficiency valuations indicate not only the interplay between desirable and undesirable outputs, but also the ranking of each DMU in every year [32]. Many researchers have applied the undesirable model into their studies. For example, an analysis by the Organization for Economic Co-operation and Development (OECD) of countries with population and energy consumption as input factors, GDP as desirable output, and CO_2 as undesirable output reveals the environmental efficiency [33]; the overall efficiency of the United States's electricity production is evaluated by escalating the desirable output and undesirable outputs [34]; counting the efficiency shows the relationship between labor force, energy consumption, government expenditure as input, GDP as desirable output, and CO_2 emissions as undesirable output [35]. Moreover, the undesirable model is used for examining performance in other aspects such as estimating the impact of production pollutants in the textile industry of China with inputs like labor, and energy, yam and fabric as desirable outputa, and wastewater as undesirable [36]. In addition, the researchers also utilized an undesirable model to analyze and evaluate efficiency in the energy sector. Measuring between inputs including gross fixed capital formation, labor and energy consumption and outputs including CO_2 (undesirable output), and GDP (desirable output) indicated the energy performance in Brazil, Russia, India, China, and South Africa [37].

With the principle of the undesirable outputs model and its previous applications, the paper proposed undesirable outputs model of DEA to analyze the interplay between inputs such as population and EC and outputs such as GDP, CO_2, CH_4, N_2O in the electricity production aspect of 42 countries during the 2008–2017 term.

3. Methodology

3.1. Proposal Research

Our study of the electricity performance process in 42 countries is organized into four steps as shown in Figure 1:

- Step 1: Present the purpose of the selected topic, input, and output variables. The theme and data must be reselected if they are inappropriate. The suitable materials of electricity, as listed on Enerdata [38], Worldbank [39], and Epa [40], are collected. Then, the EC from all over the world is introduced and factors relating the production process with EC are described.
- Step 2: Show the benefits of electricity. The study overviews EC and its influences on the environment; and the undesirable model theory is used to demonstrate in feasibility of the method. Especially, previous studies that relate to EC and the undesirable model to indicate a probability theme are discussed.
- Step 3: The first stage of the analysis process must check the Pearson coefficient to ensure the data is isotonic; any value does not range from −1 to +1 it must be removed and reselected. Next, the suitable values are applied into an undesirable outputs model to compute scores. The scores are used for determining the efficiency/inefficiency of 42 countries over the years. The scores propound their ranking over each term as well. The empirical results present a stable or upward and downward interplay of countries during the period of 2008–2017 in particular. Moreover, the analysis results suggest the current status of the effect level in each year when utilizing electrical energy.
- Step 4: Manifest main points of the empirical results of efficient/inefficient countries, and ranking, in addition to recommendations on the analysis of a variable pathway of each country in every year. The suggestion points out improvements for inefficient countries.

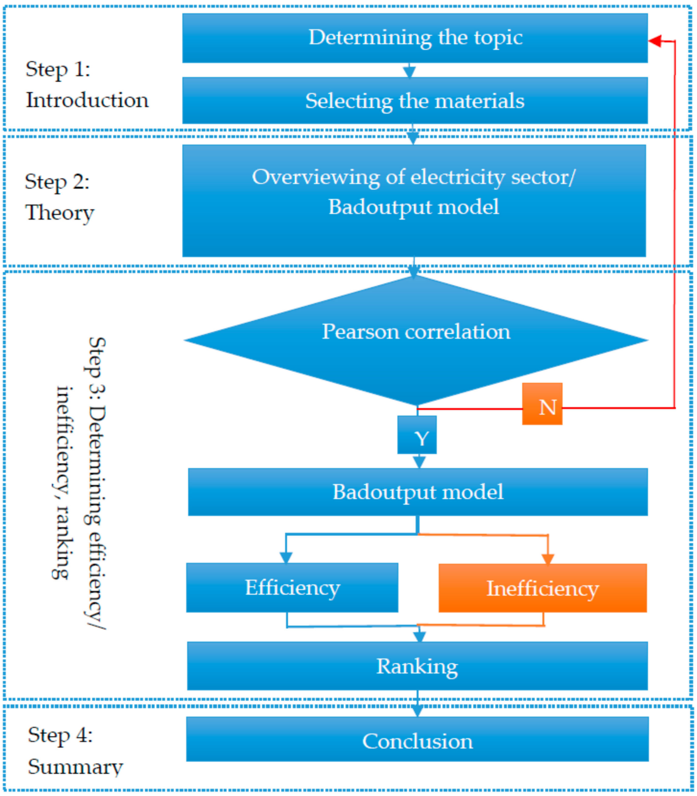

Figure 1. Proposal research.

3.2. Data Source

Electricity is a source fuel that provides lighting, heating, cooling, and runs electronics, machinery, and transportation systems. Hence, in modern life with the increasing use of diverse high-tech and electrical equipment, electricity is an essential element. While on the subject, the research discovers electricity consumption levels and their relative factors. Based on the input and output data posted on websites, including electricity consumption on Enerdata [38], population and GDP on Worldbank [39], emissions, including CO_2, CH_4, and N_2O, are computed when their equations are based on the Epa version 3.2 of June 2014 [40]. The 42 countries selected from Enerdata [38] to estimate the performance as listed in Table 1.

Table 1. Name of countries.

No	Country	No	Country	No	Country
1	Belgium	15	Kazakhstan	29	Japan
2	Czech Republic	16	Russia	30	Malaysia
3	France	17	Ukraine	31	South Korea
4	Germany	18	Uzbekistan	32	Thailand
5	Italy	19	Canada	33	Australia
6	Netherlands	20	United States	34	New Zealand
7	Poland	21	Argentina	35	Algeria
8	Portugal	22	Brazil	36	Egypt
9	Romania	23	Chile	37	Nigeria
10	Spain	24	Colombia	38	South Africa
11	Sweden	25	Mexico	39	Iran
12	United Kingdom	26	China	40	Kuwait
13	Norway	27	India	41	Saudi Arabia
14	Turkey	28	Indonesia	42	United Arab Emirates

Source: Enerdata [38].

Characteristics of each variable are described as follows:

- Population (Input): When the population of a nation increases, the electricity usage increases because the amount of electronic equipment will be augmented as well.
- Electricity consumption (Input): The electricity is consumed by providing electrical energy for light, heating, cooling, machines, and so on.
- GDP (desirable output): The economic performance of every country is measured by market value. In the electricity sector, the volumes of EC are used by consumers for any application, i.e., they contribute to extending GDP indicators.
- CO_2, CH_4, N_2O (undesirable outputs): Coal, oil, natural gas, and biomass are burned in combustion power plants. Nuclear power plants create heat, in addition to the heat of the Sun in solar power, turbines in hydropower plants via the energy power of water from natural waterfalls, tides, and flowing rivers create electricity, or turbines in wind power plants by the wind's energy. These processes all generate electricity, then the generation electricity is transmitted to customers via wires. When the electrical energy is consumed, the EC process produces emissions, including CO_2, CH_4, and N_2O.

3.3. Undesirable Outputs Model

The undesirable outputs model is utilized to calculate the performance of DMUs when its outputs obtain undesirable outputs. In this study, the undesirable outputs model is applied to deal with good (desirable) and (bad) (undesirable) outputs. We utilize an undesirable outputs model to compute the efficiency of the electrical energy consumption in 42 countries. The DMUs are the 42 countries, these countries are set up n DMU (a_0, b_0) (n = 1, 2, ... , s). Let the input factor be A, desirable factor (B^d), and undesirable factor (B^u). Then, the production possibility is given by:

$$P = \left\{ \left(a, b^d, b^u \right), a \geq X\lambda; b^d \leq B^d\lambda; b^u \geq B^u\lambda; L \leq e\lambda \leq U, \lambda \geq 0 \right\} \tag{1}$$

The intensity vector is λ, it means that the above definition corresponds to the constant return to scale technology [41], and the lower and upper bounds of the intensity vector are L and U, respectively $(e = (1, \ldots 1) \in R^+, L \leq 1, U \geq 1)$. There is at least one strict inequality when formulating the efficiency of one DMU (a_0, b_0^d, b_0^u) without vector $(a_0, b_0^d, b_0^u) \in P$ and $a_0 \geq a, b_0^d \leq b^d, b_0^u \geq b^u$. According to the SBM of Tone [42], the objective function of the undesirable model is formulated as follows:

$$\rho^* = \min \frac{1 - \frac{1}{k}\sum_{i=1}^{k} \frac{s_i^-}{a_{i0}}}{1 + \frac{1}{s}\left(\sum_{r=1}^{s_1} \frac{s_r^d}{b_{ro}^d} + \sum_{r=2}^{s_1} \frac{s_r^u}{b_{ro}^u} \right)} \tag{2}$$

Subject to:

$$\begin{aligned} a_0 &= A\lambda + s^- \\ b_0^d &= B\lambda - s^d \\ b_0^u &= B\lambda + s^u \\ s^-, s^d&, s^u, \lambda \geq 0. \end{aligned}$$

The excess in inputs, bad outputs and shortages in good outputs are s^-, s^u, s^d, respectively. The number of factors in s^u and s^d are s_1 and s_2, respectively, and s = s_1 + s_2. Using an optimal solution as ρ^*, s^{-*}, s^{d^*} and s^{u^*} for determining the efficiency of country by undesirable outputs when $\rho^* = 1$, s^{-*} = 0, s^{d^*} = 0, and s^{u^*} = 0. When the DMU is inefficient, ρ^* can be improved in order to become efficient by moving the excesses in inputs and bad outputs, simultaneously increasing the shortfalls in good outputs [42] as follows:

$$\begin{aligned} a_0 - s^{-*} &\Rightarrow a_0 \\ b_0^d + s^{d*} &\Rightarrow b_0^d \\ b_0^u - s^{u*} &\Rightarrow b_0^u \end{aligned} \tag{3}$$

The above program was transformed into an equivalent linear program by Charnes and Cooper [43]. Let the dual variable vectors be x, y^d, y^u. Based on the dual side of the linear program, the dual program in the variable x, y^d, y^u for constant return to scale [30] is defined as below:

$$\max y^d b_0^d - x a_0 - y^u b_0^u. \tag{4}$$

Subject to:

$$\begin{aligned} & y^d B^d - xA - y^u B^u \le 0 \\ & x \ge \tfrac{1}{k}\left[\tfrac{1}{a_0}\right] \\ & y^d \ge \tfrac{1 + y^d b_0^d - x a_0 - y^u b_0^u}{s}\left[\tfrac{1}{b_0^d}\right] \\ & y^u \ge \tfrac{1 + y^d b_0^d - x a_0 - y^u b_0^u}{s}\left[\tfrac{1}{b_0^u}\right] \end{aligned}$$

The virtual prices of inputs, desirable and undesirable outputs are replaced by the dual variables x, y^d, y^u respectively. The profit $y^d b^d - xa - y^u b^u$ [30] does not exceed zero for every DMU, and the profit $y^d b_0^d - x a_0 - y^u b_0^u$ for the DMU concerned when the dual program aims at obtaining the optimal virtual costs and prices for each DMU.

In addition, we set $w_1 \in R^+, w_2 \in R^+$ as the weights of desirable and undesirable outputs, respectively. The weights of bad and good outputs are converted to relative weights with their mathematical expression [30] as follows:

$$\rho^* = \min \frac{1 - \frac{1}{k}\sum_{i=1}^{k} \frac{s_{io}^-}{a_{io}}}{1 + \frac{1}{k}\left(W_1 \sum_{r=1}^{s_1} \frac{s_r^d}{b_{ro}^d} + W_2 \sum_{r=1}^{s_2} \frac{s_r^u}{b_{ro}^u}\right)}. \tag{5}$$

Subject to:

$$\begin{aligned} W_1 &= \frac{s w_1}{w_1 + w_2}. \\ W_2 &= \frac{s w_2}{w_2 + w_1}. \\ &(w_1 \ge 0, w_2 \ge 0). \end{aligned}$$

Consequently, if $\rho^* < 1$, the country is inefficient so the excesses in inputs and undesirable outputs must be removed, and the shortfalls in desirable outputs must be increased. A country reaches efficiency when $\rho^* = 1$.

4. Results

Based on the data in Section 3.2, the study utilizes an undesirable outputs model in DEA to analyze inputs and desirable and undesirable variables that relate to EC.

4.1. Data Analysis

Tables A1 and A2 indicate the summarized statistics of input/output factors of 42 countries. In 2017, the values of population, EC, CO_2, CH_4, N_2O, and GDP attained a maximum of 1,386,395,000, 5683.42, 3779.929, 0.2102, 0.0394, and 19,390,604, respectively. The minimum values of population, EC,

CO_2, and GDP are 2,652,340, 18.051, 12.0054, and 29,549.44, in 2008, 2009, 2009, and 2008, respectively. CH_4 and N_2O have minimum values of 0.0007, 0.0001, respectively, within 2008–2010.

DEA is sensitive to outliers so that the data are tested for measurement errors. The tested results indicate the presence and significance of variables. The outlier detection in the data is checked by using the SPSS software. Table A3 denotes that all cases are valid. Electricity consumption, GDP, CO_2, CH_4, and N_2O have a small difference excluding population as shown in Figure A1; however, the populations are important for the electricity consumption, so this factor is still kept to take part in the analysis process.

Moreover, before the data are applied to analysis by models in DEA, they must be checked via Pearson correlation between input variables and output variables to ensure "isotonicity". The values of the correlation coefficient range from −1 to +1. We have a perfect linear relationship between two variables if the correlation coefficient is equal to 1. On the contrary, the variable must be removed and reselected when the correlation coefficient is not positive and significant. As shown in Tables A4 and A5, the Pearson correlations of 42 countries in the research range from 0.303741 to 1; thus, the input and output factors have a standard qualification.

4.2. Efficienct and Inefficient Terms

As per the math in Section 3.3, the countries acquire efficiency when their scores are equal to 1; they are inefficient if their scores are under 1. Table 2 denotes the scores of every country in each term; the scores account for efficient and inefficient terms as well. Belgium, Czech Republic, France, Italy, Poland, Romania, Spain, Sweden, Turkey, Kazakhstan, Russia, Ukraine, Uzbekistan, Canada, Argentina, Brazil, Chile, China, India, Indonesia, Malaysia, South Korea, Thailand, Egypt, South Africa, Iran, Saudi Arabia, and United Arab Emirates are inefficient countries in whole terms because their scores are always lower than 1. Germany achieved efficiency during the period of 2008–2011 and 2013–2014 with its score at 1; however, it proved inefficient in 2012, 2015, 2016, and 2017, as its scores are 0.9062, 0.776, 0.9115, and 0.9861, respectively. The Netherlands attained performance except it remained inefficient in 2015 with a score of 0.9601. Portugal remained efficient from 2008 to 2016, but the growth of modern society led to increased consumption of electricity, which further led to increased CO_2, CH_4, and N_2O emissions in 2017; as a consequence, it remained inefficient in 2017 with a score of 0.9999. Colombia approached efficiency from 2011 to 2013 and excluding inefficient terms from 2014 to 2017, had scores of 0.7522, 0.7069, 0.9692, 0.7257, 0.5765, 0.517, and 0.5291, respectively. Mexico remained inefficient for nine years, as its scores were from 0.2847 to 0.3641, although its score reached 1 in 2015. Japan was efficient during 2009–2011 and inefficient in 2008 and 2012–2017, when its scores were 0.8572, 0.8379, 0.7002, 0.6128, 0.7925, and 0.6942, respectively. Australia achieved efficient performance status during 2010–2015 and in 2017; its scores in 2008, 2009, and 2016 were 0.6228, 0.5712, and 0.8924, respectively. New Zealand remained efficient from 2009 to 2017, excluding 2008, as its score is 0.7689. Algeria achieved efficiency from 2008 to 2010, but remained inefficient during 2011–2017, as its scores are under 1. Besides, five countries, including the United Kingdom, Norway, United States, Nigeria, and Kuwait, were assigned as efficient in the whole term, as their results compute to be 1. Further, these results reveal the ratio among inputs and desirable and undesirable outputs at the balance level.

Table 2. Scores of 42 countries over the period of 2008–2017.

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Belgium	0.8017	0.8902	0.8611	0.8847	0.8534	0.856	0.8389	0.8116	0.8396	0.8344
Czech Republic	0.5408	0.6169	0.6054	0.6107	0.5418	0.5202	0.4939	0.5161	0.5019	0.5129
France	0.7824	0.8875	0.8604	0.8677	0.7476	0.7681	0.6953	0.5982	0.6601	0.7055
Germany	1	1	1	1	0.9062	1	1	0.776	0.9115	0.9861
Italy	0.8414	1	0.9036	0.8661	0.7512	0.7741	0.6914	0.5955	0.6733	0.6911
Netherlands	1	1	1	1	1	1	1	0.9601	1	1
Poland	0.3474	0.338	0.3516	0.3518	0.3402	0.3395	0.3338	0.321	0.3163	0.3242
Portugal	1	1	1	1	1	1	1	1	1	0.9999
Romania	0.6265	0.6841	0.569	0.558	0.4867	0.5193	0.4855	0.514	0.4696	0.5932
Spain	0.6551	0.7297	0.6761	0.6463	0.546	0.5723	0.5387	0.4956	0.5447	0.5649
Sweden	0.6287	0.6061	0.6952	0.7498	0.7034	0.7421	0.7481	0.7491	0.8222	0.7904
United Kingdom	1	1	1	1	1	1	1	1	1	1
Norway	1	1	1	1	1	1	1	1	1	1
Turkey	0.3291	0.3074	0.3542	0.3248	0.3417	0.3569	0.3143	0.301	0.3051	0.2696
Kazakhstan	0.3377	0.3816	0.3819	0.3657	0.3616	0.3893	0.3342	0.3383	0.2797	0.2683
Russia	0.1705	0.1386	0.1823	0.235	0.2442	0.2494	0.2008	0.1417	0.14	0.1706
Ukraine	0.1298	0.1378	0.1293	0.1278	0.1296	0.13	0.1211	0.1162	0.1142	0.1204
Uzbekistan	0.1632	0.2047	0.2181	0.2153	0.2231	0.2217	0.2197	0.2585	0.242	0.1755
Canada	0.4752	0.475	0.6068	0.588	0.5354	0.5375	0.5343	0.4995	0.5223	0.5243
United States	1	1	1	1	1	1	1	1	1	1
Argentina	0.2914	0.3075	0.3575	0.3892	0.3976	0.3818	0.3284	0.4023	0.3427	0.4249
Brazil	0.2634	0.3039	0.4215	0.4334	0.3803	0.3565	0.2991	0.2273	0.2448	0.2791
Chile	0.4335	0.5036	0.5549	0.5356	0.5146	0.4716	0.4202	0.4461	0.429	0.4385
Colombia	0.7522	0.7069	0.9692	1	1	1	0.7257	0.5765	0.517	0.5291
Mexico	0.3388	0.2847	0.3641	0.3472	0.3424	0.3637	0.3281	1	0.2868	0.3019
China	0.1257	0.1438	0.1609	0.1758	0.1946	0.2228	0.2274	0.2298	0.2181	0.2168
India	0.0903	0.1057	0.1317	0.1167	0.1113	0.1032	0.0932	0.0944	0.1046	0.1132
Indonesia	0.2483	0.2593	0.3491	0.3387	0.328	0.2885	0.246	0.2482	0.2663	0.2718
Japan	0.8572	1	1	1	1	0.8379	0.7002	0.6128	0.7925	0.6942
Malaysia	0.2642	0.2551	0.2819	0.2769	0.2691	0.25	0.2404	0.2407	0.2218	0.217
South Korea	0.2453	0.2345	0.308	0.2986	0.277	0.2896	0.3287	0.3489	0.3744	0.3975
Thailand	0.1782	0.1946	0.2041	0.2005	0.1966	0.1956	0.1785	0.1881	0.188	0.1927
Australia	0.6228	0.5712	1	1	1	1	1	1	0.8924	1
New Zealand	0.7689	1	1	1	1	1	1	1	1	1
Algeria	1	1	1	0.7032	0.5665	0.4903	0.381	0.3433	0.3091	0.289
Egypt	0.1503	0.1708	0.1745	0.1497	0.1612	0.1602	0.1519	0.1705	0.1639	0.1156
Nigeria	1	1	1	1	1	1	1	1	1	1
South Africa	0.1249	0.1489	0.171	0.1704	0.1684	0.1515	0.1412	0.145	0.1369	0.1475
Iran	0.1824	0.1943	0.2128	0.2248	0.2245	0.169	0.143	0.1465	0.1519	0.1421
Kuwait	1	1	1	1	1	1	1	1	1	1
Saudi Arabia	0.2933	0.261	0.3057	0.3363	0.3482	0.3261	0.3033	0.2857	0.2778	0.2721
United Arab Emirates	0.6857	0.6151	0.6582	0.6598	0.6818	0.6636	0.6117	0.6075	0.5588	0.5568

The above analysis results point out the efficient and inefficient terms in every year, where there are 12 efficient countries and 30 inefficient countries during the period from 2009 to 2011; from 2012 to 2013, there are 11 efficient countries and 31 inefficient countries; 2014 has 10 efficient countries, and 32 inefficient countries; 2008 and 2015 have nine efficient countries and 33 inefficient countries; the period of 2016–2017 has eight efficient countries and 34 inefficient countries. Thus, the quantity of inefficient countries is more than that of efficient countries. The empirical results indicate that United Kingdom, Norway, United States, Nigeria, and Kuwait always approach the efficiency without fluctuation.

4.3. Ranking Countries

Based on the scores shown in Table 2, this study gives in Table 3 the position of each of country in every year.

Table 3. Raking countries during the period from 2008 to 2017.

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Belgium	12	13	15	13	13	12	11	11	11	11
Czech Republic	21	18	21	20	20	20	20	19	20	21
France	13	14	16	14	15	15	15	16	15	13
Germany	1	1	1	1	12	1	1	12	9	10
Italy	11	1	14	15	14	14	16	17	14	15
Netherlands	1	1	1	1	1	1	1	10	1	1
Poland	24	25	29	27	30	29	25	28	25	25
Portugal	1	1	1	1	1	1	1	1	1	9
Romania	19	17	22	22	23	21	21	20	21	16
Spain	17	15	18	19	19	18	18	22	17	17
Sweden	18	20	17	16	16	16	12	13	12	12
United Kingdom	1	1	1	1	1	1	1	1	1	1
Norway	1	1	1	1	1	1	1	1	1	1
Turkey	27	27	28	31	29	27	29	29	27	31
Kazakhstan	26	24	25	26	26	24	24	27	29	32
Russia	36	40	37	34	34	34	36	40	39	37
Ukraine	39	41	42	41	41	41	41	41	41	40
Uzbekistan	37	34	34	36	36	36	35	31	33	36
Canada	22	23	20	21	21	19	19	21	18	20
United States	1	1	1	1	1	1	1	1	1	1
Argentina	29	26	27	25	24	25	27	24	24	23
Brazil	31	28	24	24	25	28	31	35	32	28
Chile	23	22	23	23	22	23	22	23	22	22
Colombia	15	16	13	1	1	1	13	18	19	19
Mexico	25	29	26	28	28	26	28	1	28	26
China	40	39	40	38	38	35	34	34	35	34
India	42	42	41	42	42	42	42	42	42	42
Indonesia	32	31	30	29	31	32	32	32	31	30
Japan	10	1	1	1	1	13	14	14	13	14
Malaysia	30	32	33	33	33	33	33	33	34	33
South Korea	33	33	31	32	32	31	26	25	23	24
Thailand	35	35	36	37	37	37	37	36	36	35
Australia	20	21	1	1	1	1	1	1	10	1
New Zealand	14	1	1	1	1	1	1	1	1	1
Algeria	1	1	1	17	18	22	23	26	26	27
Egypt	38	37	38	40	40	39	38	37	37	41
Nigeria	1	1	1	1	1	1	1	1	1	1
South Africa	41	38	39	39	39	40	40	39	40	38
Iran	34	36	35	35	35	38	39	38	38	39
Kuwait	1	1	1	1	1	1	1	1	1	1
Saudi Arabia	28	30	32	30	27	30	30	30	30	29
United Arab Emirates	16	19	19	18	17	17	17	15	16	18

As shown in Table 3, five countries including United Kingdom, Norway, United States, Nigeria, and Kuwait are always at the first position for the whole term. Germany with the first ranking is in 2008, 2009, 2010, 2011, 2013, and 2014. Italy only obtains the first ranking in 2009. The Netherlands is mostly in the first position except for 2015. Portugal obtains first ranking from 2008 to 2016 and it is down to the ninth. Colombia gets the first ranking for three years as 2011, 2012, 2013. Japan attained first position during the period from 2009–2014. Australia is in the first ranking from 2010 to 2015, and in 2017. New Zealand reaches the first position except for 2008. Algeria approaches the first ranking in three years from 2008 to 2011. The remaining terms of Germany, Italy, Netherlands, Portugal, Colombia, Japan, Australia, New Zealand, Algeria, are ranked from 9 to 27. Belgium, Czech Republic, France, Poland, Romania, Spain, Sweden, Turkey, Kazakhstan, Russia, Ukraine, Uzbekistan, Canada, Argentina, Brazil, Chile, Mexico, China, India, Indonesia, Malaysia, South Korea, Thailand, Egypt, South Africa, Iran, Saudi Arabia, and United Arab Emirates stay at the low position without reaching the first position during whole term. Especially, India rank at the bottom position consecutively during the period of 2008–2017 except for 2010 where it raised one level with a ranking as forty-first. Ukraine has the last ranking in 2010.

The above description specifies the ranking of an effect level in electrical energy sources. Increased population, simultaneously industrialization, and modernization all represent an important force that has an impact on accreting emissions. Therefore, the number of efficient countries with first contemporaneous ranking are reduced, from 2009 to 2017 down from 12 to eight countries. Furthermore, many countries such as the Czech Republic, Turkey, Kazakhstan, i.e., have yet to reach first position and thus face a downward trend. On the contrary, the United Kingdom, Norway, United States, Nigeria, and Kuwait maintain a sustainable economy and always stand at the highest ranking.

4.4. Discussion

The empirical results given in Section 4.2 point out the relationship between input and output factors of 42 countries during 2008–2017 when using electricity and reveal their positions in every year as well. The interplay pathway among selected inputs into selected desirable and undesirable outputs in the context of human growth activities in every country is explored based on Table 2. Most countries exhibit a fluctuation, according to each term; however, the United Kingdom, Norway, United States, Nigeria, and Kuwait always approach high scores as 1 and keep a stable position. They obtain an excellent interplay under all the circumstances.

On the other hand, other countries demonstrate a variation in each period. Portugal, The Netherlands, and New Zealand achieve good relations with scores of 1 over nine years, while Portugal kept in balance from 2008 to 2016 and displayed a downward trend in 2017 at 0.9999. The Netherlands dropped in 2015, as its score is only at 0.9601, and the primary score in 2008 is only 0.7689, but its efforts to improve the interplay with upward mobility helped it reach to the high point in the next terms. Italy and Japan achieved a forward movement to obtain a maximum score in 2009; however, both they could not maintain a good relationship, which is down by the end. Algeria and Germany started with a brilliant mark with a maximum value in primal years; Algeria kept it in three years, consecutively, and dropped in the remaining years from 2011 to 2017; Germany has more flourish with a maximum score in six years and an upward trend in the final term from 0.776 to 0.9861. Australia, Colombia, and Mexico fell in 2007, though they pushed up their scores in the next terms; particularly, Australia increased from 2009 to 2010 and held a stable score with a high position over six years consecutively; Colombia augmented in the first terms and decreased in the final terms; as its maximum score of 1 is for only three years from 2011 to 2013, Mexico has a sharp variation from 0.3281 to 1 within one year and then dropped deeply to 0.2868 in the next year. Consequently, these countries fluctuated over time; however, they still display a good interplay during some terms.

Besides, the 27 remaining countries have seen variations every year, thus failing reach to an excellent relationship. Their scores are usually lower than the standard value. Eight countries, i.e., Canada, Czech Republic, Romania, Sweden, Spain, United Arab Emirates, France, and Belgium, are at an average level with most of their values being under 0.5. Nineteen countries, i.e., India, South Africa, China, Ukraine, Egypt, Uzbekistan, Russia, Thailand, Iran, South Korea, Indonesia, Brazil, Malaysia, Argentina, Saudi Arabia, Turkey, Kazakhstan, Poland, and Chile, are seriously affected by emissions, as their valuations are all under 0.5.

As a consequence, the economic development is accreting into producing emissions which are harmful for the environment. According to Chung's directional distance function [15], the performance in this case is refined by increasing the good output while simultaneously reducing the bad outputs. In the study, CO_2, CH_4, and N_2O must decline, but at the same time the GDP still must increase. In addition, the electricity consumption can be reduced when the electricity usage should the saved and replace high-capacity equipment with low-capacity equipment in order to diminish energy consumption. That way, emissions can dwindle to avoid a contaminated environment and climate change, the effect of electricity consumption on climate change was tested by Philli-Sihvola [44]; further, with the inefficient terms, the performance among inputs and desirable and undesirable outputs can be improved.

5. Conclusions

Electricity provides humans with light and operation of machines. Then, if a population is at a high level, the consumption of electricity will increase. As a result, economic growth will be enhanced by displayed in the GDP index; however, electricity production and use brings disadvantages of emitting undesirable factors (CO_2, CH_4, N_2O). Therefore, the study proposes an undesirable outputs model to measure the performance of the elements that relate to the EC process.

For the characteristics of dealing with fixed bad and good outputs, an undesirable outputs model is used help the study formulate scores. The empirical values demonstrate interplay among variables, ranking, and variable pathways of every country in every year. Forty-two countries are defined as efficiency or inefficient after applying an undesirable outputs model to analyzing their performance. The analysis results denote that the United Kingdom, Norway, United States, Nigeria, and Kuwait show stable efficiency and retain a good relationship for the whole term; other countries have changed consecutively every time.

For the 42 countries we not only know about the interplay among inputs, desirable and undesirable outputs but can also understand the quantitative analysis that affect level of emissions. Based on the principle of undesirable outputs model, desirable outputs i.e., GDP should be increased; undesirable outputs including CO_2, CH_4, and N_2O, and inputs, i.e., electricity consumption at the inefficient terms will be reduced, by the way the efficiency will be improved. In addition, they find t a direction to restore balance to their ecosystems.

In general, the study summarizes the basic data of EC and specifies a relationship between EC and related factors; however, limitations remain. First, the inputs and outputs of all countries are not listed, so that the future research should expand to add more countries. Second, the interplay will become deeper when calculations include enough factors. Further study should investigate this in order to obtain more inputs, i.e., capital, assets, and output variables, i.e., revenue. Third, the study only needs the efficiency in the past term through the undesirable outputs model, so further studies could utilize more models to predict the future terms. Fourth, the future direction will use the Spearman correlation coefficient to have a statistical measure of a relationships between paired data.

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Appendix A

Table A1. Statistics of the 42 countries over the period of 2008–2011.

Years	Population	EC (TWh)	CO_2 (Mtons)	CH_4 (Mtons)	N_2O (Mtons)	GDP (Million in USD)
2008	1,324,655,000	3907.229	2598.6199	0.1445	0.0271	14,718,582
	2,652,340	18.517	12.3153	0.0007	0.0001	29,549.44
	118,126,627.26	373.5982	248.4727	0.0138	0.0026	1,336,946.326
	263,672,064.05	728.7291	484.6632	0.027	0.0051	2,411,815.529
2009	1,331,260,000	3724.658	2477.1955	0.1378	0.0258	14,418,739
	2,818,939	18.051	12.0054	0.0007	0.0001	33,689.22
	119,287,116.55	371.3682	246.9896	0.0137	0.0026	1,268,097.807
	266,092,473.27	728.332	484.3991	0.0269	0.0051	2,386,203.268
2010	1,337,705,000	3894.367	2598.6199	0.1445	0.0271	14,964,372
	2,998,083	20.876	12.3153	0.0007	0.0001	39,332.77
	120,434,614.83	397.1979	248.4727	0.0138	0.0026	1,393,321.39
	268,462,393.21	786.178	484.6632	0.027	0.0051	2,506,496.099
2011	1,344,130,000	4051.605	2694.6415	0.1499	0.0281	15,517,926
	3,191,051	23.679	15.7484	0.0009	0.0002	45,915.19
	121,536,746.24	409.9938	272.6786	0.0152	0.0029	1,549,594.858
	270,791,913.9	827.6549	550.4567	0.0306	0.0057	2,671,950.305

Table A2. Statistics of the 42 countries over the period of 2012–2017.

Years	Population	EC (TWh)	CO_2 (Mtons)	CH_4 (Mtons)	N_2O (Mtons)	GDP (Million in USD)
2012	1,350,695,000	4326.079	2877.188	0.16	0.03	16,155,255
	3,395,556	25.399	16.8924	0.0009	0.0002	51,821.57
	122,670,658.43	419.9453	279.1316	0.0155	0.0029	1,583,732.445
	273,099,786.91	851.7249	566.4128	0.0315	0.0059	2,799,627.018
2013	1,357,380,000	4717.568	3137.5601	0.1745	0.0327	16,691,517
	3,598,385	23.689	15.7551	0.0009	0.0002	57,690.45
	123,810,535.81	432.4245	287.745	0.016	0.003	1,622,822.758
	275,389,972.61	899.751	598.4121	0.0333	0.0062	2,899,088.887
2014	1,364,270,000	4938.623	3284.5794	0.183	0.0343	17,427,609
	3,782,450	24.625	16.3776	0.001	0.0002	63,067.08
	124,952,217.6	441.3991	292.8808	0.0163	0.0031	1,662,353.067
	277,690,414.5	927.2612	616.5223	0.0343	0.0064	3,046,071.083
2015	1,371,220,000	5103.889	3301.0023	0.1836	0.0344	18,120,714
	3,935,794	25.268	17.848	0.001	0.0002	66,903.8
	126,084,336.38	448.5672	292.5948	0.0163	0.0031	1,572,917.053
	279,993,795.16	946.811	619.273	0.0344	0.0065	3,157,505.409
2016	1,378,665,000	5366.78	3471.2873	0.1931	0.0362	1,862,4475
	4,052,584	24.5605	16.2416	0.0009	0.0002	67,067.57
	127,216,593.57	459.7215	307.2145	0.0171	0.0031	1,596,048.935
	282,345,525.38	977.6329	635.8452	0.0354	0.0066	3,243,650.311
2017	1,386,395,000	5683.42	3779.929	0.2102	0.0394	19,390,604
	4,136,528	24.4774	16.2794	0.0009	0.0002	48,717.69
	128,333,654.5	471.4782	313.5707	0.0174	0.0033	1,692,506.563
	284,721,026.7	1010.7354	672.2199	0.0374	0.007	3,412,183.899

Table A3. Case Processing Summary.

Factors	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
(I) Population	417	100.00%	0	0.00%	42	100.00%
(I) Electricity consumption (TWh)	417	100.00%	0	0.00%	42	100.00%
(O) GDP (million USD)	417	100.00%	0	0.00%	42	100.00%
(Obad) CO_2 (Mtons)	417	100.00%	0	0.00%	42	100.00%
(Obad) CH_4 (Mtons)	417	100.00%	0	0.00%	42	100.00%
(Obad) N_2O (Mtons)	417	100.00%	0	0.00%	42	100.00%

Table A4. Person's correlation over the period of 2008–2012.

Indicators	Year	Population	EC (TWh)	CO_2 (Mtons)	CH_4 (Mtons)	N_2O (Mtons)	GDP (Million USD)
Population	2008	1	0.580126	0.580126	0.580341	0.579862	0.303741
EC (TWh)		0.580126	1	1	0.999999	0.999986	0.901139
CO_2 (Mtons)		0.580126	1	1	0.999999	0.999986	0.901139
CH_4 (Mtons)		0.580341	0.999999	0.999999	1	0.999985	0.901071
N_2O (Mtons)		0.579862	0.999986	0.999986	0.999985	1	0.901355
GDP (million USD)		0.303741	0.901139	0.901139	0.901071	0.901355	1
Population	2009	1	0.616812	0.616812	0.616607	0.616654	0.33962
EC (TWh)		0.616812	1	1	0.999999	0.999985	0.894023
CO_2 (Mtons)		0.616812	1	1	0.999999	0.999985	0.894023
CH_4 (Mtons)		0.616607	0.999999	0.999999	1	0.999984	0.894111
N_2O (Mtons)		0.616654	0.999985	0.999985	0.999984	1	0.893678
GDP (million USD)		0.33962	0.894023	0.894023	0.894111	0.893678	1
Population	2010	1	0.633979	0.576015	0.576229	0.575756	0.380058
EC (TWh)		0.633979	1	0.994505	0.994535	0.994407	0.900126
CO_2 (Mtons)		0.576015	0.994505	1	0.999999	0.999986	0.934326
CH_4 (Mtons)		0.576229	0.994535	0.999999	1	0.999985	0.93427
N_2O (Mtons)		0.575756	0.994407	0.999986	0.999985	1	0.934449
GDP (million USD)		0.380058	0.900126	0.934326	0.93427	0.934449	1
Population	2011	1	0.664182	0.664182	0.664216	0.664145	0.419236
EC (TWh)		0.664182	1	1	1	0.999989	0.898789
CO_2 (Mtons)		0.664182	1	1	1	0.999989	0.898789
CH_4 (Mtons)		0.664216	1	1	1	0.999989	0.898727
N_2O (Mtons)		0.664145	0.999989	0.999989	0.999989	1	0.899497
GDP (million USD)		0.419236	0.898789	0.898789	0.898727	0.899497	1
Population	2012	1	0.680572	0.680718	0.680613	0.680276	0.440727
EC (TWh)		0.680572	1	0.999997	0.999997	0.999983	0.902231
CO_2 (Mtons)		0.680718	0.999997	1	1	0.999989	0.902234
CH_4 (Mtons)		0.680613	0.999997	1	1	0.999988	0.902301
N_2O (Mtons)		0.680276	0.999983	0.999989	0.999988	1	0.90262
GDP (million USD)		0.440727	0.902231	0.902234	0.902301	0.90262	1

Table A5. Person's correlation over the period of 2013–2017.

Indicators	Year	Population	EC (TWh)	CO_2 (Mtons)	CH_4 (Mtons)	N_2O (Mtons)	GDP (Million USD)
Population	2013	1	0.695153	0.696013	0.695992	0.695301	0.464744
EC (TWh)		0.695153	1	0.999998	0.999998	0.999988	0.907294
CO_2 (Mtons)		0.696013	0.999998	1	1	0.999988	0.907197
CH_4 (Mtons)		0.695992	0.999998	1	1	0.999987	0.907255
N_2O (Mtons)		0.695301	0.999988	0.999988	0.999987	1	0.90767
GDP (million USD)		0.464744	0.907294	0.907197	0.907255	0.90767	1
Population	2014	1	0.706217	0.705663	0.705031	0.705695	0.480833
EC (TWh)		0.706217	1	0.999991	0.999952	0.99998	0.907172
CO_2 (Mtons)		0.705663	0.999991	1	0.999961	0.999989	0.907172
CH_4 (Mtons)		0.705031	0.999952	0.999961	1	0.999947	0.907122
N_2O (Mtons)		0.705695	0.99998	0.999989	0.999947	1	0.906706
GDP (million USD)		0.480833	0.907172	0.907172	0.907122	0.906706	1
Population	2015	1	0.714941	0.708444	0.708326	0.70894	0.491955
EC (TWh)		0.714941	1	0.999494	0.999493	0.999839	0.908562
CO_2 (Mtons)		0.708444	0.999494	1	1	0.999616	0.913374
CH_4 (Mtons)		0.708326	0.999493	1	1	0.999616	0.91337
N_2O (Mtons)		0.70894	0.999839	0.999616	0.999616	1	0.914613
GDP (million USD)		0.491955	0.908562	0.913374	0.91337	0.914613	1
Population	2016	1	0.724975	0.718889	0.71891	0.720908	0.490153
EC (TWh)		0.724975	1	0.998089	0.9981	0.999912	0.8947
CO_2 (Mtons)		0.718889	0.998089	1	1	0.998155	0.897223
CH_4 (Mtons)		0.71891	0.9981	1	1	0.998165	0.897175
N_2O (Mtons)		0.720908	0.999912	0.998155	0.998165	1	0.898646
GDP (million USD)		0.490153	0.8947	0.897223	0.897175	0.898646	1
Population	2017	1	0.73631	0.73631	0.736469	0.73605	0.508286
EC (TWh)		0.73631	1	1	1	0.999992	0.891115
CO_2 (Mtons)		0.73631	1	1	1	0.999992	0.891115
CH_4 (Mtons)		0.736469	1	1	1	0.999992	0.89107
N_2O (Mtons)		0.73605	0.999992	0.999992	0.999992	1	0.891228
GDP (million USD)		0.508286	0.891115	0.891115	0.89107	0.891228	1

Appendix B

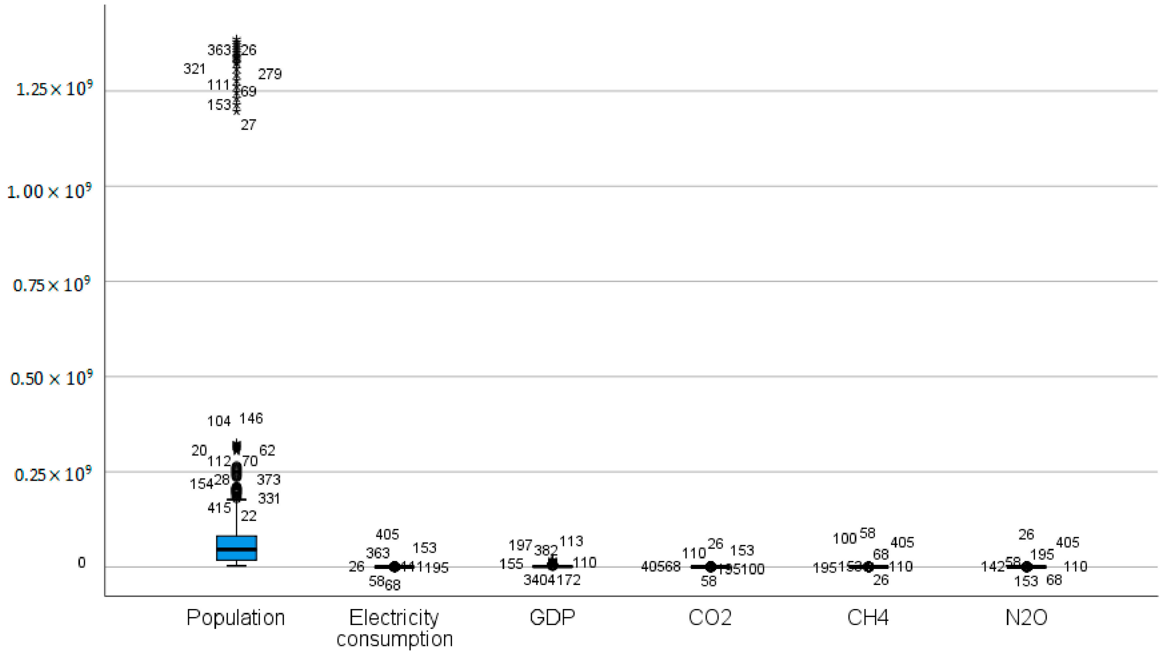

Figure A1. Boxplot of inputs and outputs.

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