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ASSESSING THE READINESS OF COUNTRIES IN COMBATING COVID-19 PANDEMIC WITH SPECIAL REFERENCE TO THE SUSTAINABLE GROWTH

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. Authors CNW and TTD are the mains author of the review. All other authors have equally contributed to literature collection and editing of the review. All authors read and approved the final manuscript.

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ABSTRACT

The pandemic caused by a coronavirus (Covid-19) has been an alarming warning to sustainable development. In the fight against the global pandemic, the performance approaches facing Covid-19 by nations play a crucial role while waiting for vaccines or treatments from the world health organization. This paper used data envelopment analysis with an undesirable output model (DEA-UOM) to measure the efficiency performance against Covid-19 of the selected 50 countries spreading from America, Europe, Asia, to Africa during 2020. In the proposed model, the input variables consist of total tests, hospital beds, population, life expectancy, aged-70-older, and the output variables are total cases, total deaths, and total recovered. The obtained result is shown in two main parts, the efficacy and rank of countries and group classification. The results of this research were based on the real data of the variables, which are statistics in nature. The managerial implication of the model's results not only conveys the overall view in fighting the current pandemic but also offers a guideline for decision-makers in combating and enhancing the healthcare system. Hence, this paper can be a valuable reference to global health agencies to push back this pandemic and improve preventive actions in the fight against the global pandemic for sustainable and resilient development.

Keywords: Covid-19; data envelopment analysis; undesirable output model; efficiency frontier; decision-making; sustainable growth

1. INTRODUCTION

Global pandemics have intensified in recent decades, such as SARS in 2003, H5N1 in 2006, and H1N1 in 2009, each of which has disrupted commercial activities and economic development. The world is now facing another global infectious pandemic known as coronavirus disease 2019 (Covid-19). Recorded to

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root from Wuhan, China, the pandemic has dramatically expanded from country to country [1]. Covid-19 is identified to directly cause respiratory depression with common symptoms like high temperature, cough, and tiredness. Depend on individual physical condition, the severity is different from mild disease, severe disease, critical disease, and even death. The old, low immune systems, or under medical treatment like cardiovascular disease, diabetes, chronic respiratory disease, and cancer are accounted for the high percentage of critical illness and death. On the study of infectious mechanism, He et al. [2] initiated a model to improve the accurate knowledge which strengthens the appropriate measures of protection and management. Though a lot of trials for the vaccine which is believed to be the key for this pandemic, specific vaccines or official medical treatments are still in cover.

Besides effortless research for a specialized vaccine, many countries implement measures actively to prevent the expansion of viruses among the domestic public as well as from outside of countries such as lockdown the country or part of it, border control, actively testing, school closure, and quarantines. Typically, lockdown is considered as one of the main measures that lots of territories and countries (i.e., Vietnam, China, Germany, Spain, India, and Iran) have experienced to slow down the heat of Covid-19 waves [3]. Regarded India only, with 1.3 billion people were reported to social distance, the lockdown was the biggest being home order ever happened [4]. Due to the large scale of the outbreak, the United States took strong lockdown measures to slow down the virus. The highest percent of mandatory lockdown did reach up to over 90% of the population [5-7]. This action was considered successful when it brought the curves of Covid-19's development downward in some hotspot states. In the interim, European countries also fight hard with the pandemic with the affected number just after the Americas. The measure of lockdown was proved to be successful through the research of Kaja et al. by apply crisp-set qualitative comparative analysis. Lockdown, tracking the contact and trace of positive cases, then taking testing measures on a large scale to downsize and preventing the pandemic were actively implemented in countries like European countries, Vietnam, Korea, China to name a few [8,9].

It could be addressed that one of the biggest factors in Covid-19 combating is lying the capacity of medical resources. Pandemic is unavoidable which is proved through the history of humankind. Therefore, while the pandemic is still in expansion, the readiness for the next waves needs seriously considering. More than ever, the question of sustainable development is opened to strengthen the health system all over the world. Nevertheless, the distribution of medical workers is not even where need medical care the most are the deficit places i.e., the African region. Facing the pandemic, the situation of the United States mentioned above can be demonstrated as a vivid example of the weakness of the health system [10-12]. When the burden is on the health care system, the lockdown and social-distancing and border control are implemented, the global economy is severely impacted accordingly. The most vulnerable industry can be listed at the top as airlines, relaxation facilities, oil, and gas drilling [13]. In the leisure facilities industry, leisure travel, tourism and hospitality, restaurant, and accommodation are also listed in severe negative influenced. The global economic growth is shrunken which leads to the unemployment rate high and lowers the GDP sequentially [14].

Therefore, this paper used data envelopment analysis with an undesirable output model (DEA-UOM) to give a managerial framework for the government or decision-makers to improve preventive actions in the fight against the global pandemic for sustainability's quality of life. This study evaluates the efficiency against Covid-19 in 50 countries spreading from America, Europe, Asia to Africa. The DEA-UOM is used to discover the relationship among input variables (total tests, hospital beds, population, life expectancy, and aged-70-older), undesirable output (total cases, total deaths), and desirable output (total recovered). This research brings a general panorama view of the pandemic, based on this, provides the decision-makers a useful reference for controlling the current pandemic as well as preparing for the future. Furthermore, based on the input and output variables, an optimal healthcare system and standard health policy evaluation can be implemented toward sustainable development.

This paper includes five main sections. The first section gives an overview of the research background to the Covid-19 pandemic. The second section shows some relevant studies regarding Covid-19, data envelopment analysis (DEA), and the undesirable output model. Next, material, research methodology, and data collection in 50 countries all over the world are presented in part three. The fourth section delivers the results and discussions. The last part of this study presents the shortcoming of the paper and future gaps.

2. LITERATURE REVIEW

Literature regarding the current state of Covid-19 is reviewed briefly in this section. Alanagreh et al. [15], the authors brought some information about the background of coronaviruses as well as overview the recent trials on special treatment. Based on the studies of infectious mechanisms, Raffaele et al. [16] initiated using the binary classifier in artificial intelligence to explain the critical factors to establish control policies. As reported in the study, the particulate of air pollutants, particularly atmospheric particulate matter 2.5 (PM2.5) was proved to have a relation to the positive cases. As mentioned in the introduction part, lockdown and isolating populations were globally implemented to slow down, prevent the Covid-19 spread, and gained some visual positive results. However, the negative effect of these measures was shown in the study of Juan Gómez-Salgado et al. [17] on 4,180 Spanish and Giulia et al. [18] on almost 9,000 Italians in which released the fact of mental health crisis during the isolating period. On the economic side, Peterson et al. [19] analyzed the influence level on the global economy and concluded that the number of days of quandaries affected a large scale of the economy which turn a health crisis into an economic crisis. Besides the big question on bringing this pandemic to the end needed an answer, sustainability on health and economic development were raised concerns by Vijay et al. [20] in research on enhancing the matter of prosperity, health and peace to Caricom region as a case study through global health diplomacy.

In the attempt of research for prevention of spreading and cease the virus as well as the matter of sustainable development, the recently published papers mainly focused and developed models on estimating, forecasting, and controlling the pandemic. To discover the various mechanisms of infection, Kucharski et al. [21] adopted the stochastic transmission model with a study case in Wuhan and root cases from Wuhan. On a larger scale from three countries, which are China, Italy, and France, Fanelli et al. [22] applied a mean-field model to figure out and predict the expansion of Covid-19. To estimate the new cases and deaths, Wang et al. [23] and Chatterjee et al. [24] respectively applied the patient information-based algorithm and LSTM models. To predict the number of positive cases in a certain period, Sanchez-Caballero et al. [25], Pinter et al. [26] developed and enhanced respectively the prediction models from Verhulst equation and hybrid machine learning method.

Over time, extensive studies have developed on the DEA method to evaluate the performance of special issues by their related data of inputs and outputs. A series of recent studies have indicated the contribution of the DEA method in sustainable development. To energy sustainability, Song et al. [27] calculated the energy efficiency under input from 30 regions in China from 2009 to 2017. A recent study by Wang et al. [28] detected the crucial degrees to the Chinese industry and suggest possible legislative policies for improving the sustainable development of Chinese high technology. In addition, the green development of air transport was guaranteed by the research of Song et al. [29]. The study adopted a three-stage method of DEA to evaluate the Chinese air transport sector operational efficiency. García-Cornejo et al. [30] determined the technical efficiency in farming by applying DEA to initiate sustainability in diversification. In the same way, Ren et al. [31] focused on improving the eco-efficiency in China to promote sustainability on a large scale of ‘’full world’’. Some authors have driven the further application of DEA in measuring the efficiency of operation. Firsova et al. [32] observed the regional innovative efficiency to predict the direct and indirect novelty influence by DEA Malmquist index. Correspondingly, Sánchez-Ortiz et al. [33] evaluated the circular economic performance based on specifying the indicators of resource scarcity, environment, and economic benefit. Hadi-Vencheh et al. [34] applied the two-stage DEA method to analyze a thermal plant in Angola’s operation. The study inspected the operation efficiency and suggested priority updates to handle pollution issues. Correspondingly, Akbar et al. [35] presented both pros and cons of the ‘’belt and road initiative” (BRI). The result extracted through the DEA method proved the economic escalation while the downturn in energy efficiency. To measure the negative effects of tourism seasonality on the environment and economy, Sáez-Fernández et al. [36] employed the DEA method to analyze the related critical factors. In Taiwan, Hu et al. [37] suggested strengthening the health workers in low carrying efficiency regions base on the study of the outcome from the DEA method. Additionally, Lin et al. [38] utilized the efficiency measure function of DEA to make a comparison of group and overall efficiency to support the chartering operations decision.

Moreover, many recent papers utilized the DEA-UOM to handle the unexpected outputs in the analyzing process. A large number of existing studies in the broader literature have actively contributed to environmental sustainability. To illustrate, the study of Wang et al. [39] applied this model in the study of renewable energy efficiency. The CO2 emission, one of the two output factors, was the output that was desired to reduce. In the same concern, Li et al. [40] evaluated the efficiency of Chinese traditional and new energy sources by combining modified Epsilon-based measure DEA and DEA-UOM approach. Correspondingly, Deng et al. [41] identified the quality of the environment in projects in China’s optical valley. In the airport industry, Yang et al. [42] applied the DEA-UOM with the data from 13 Korean domestic airports to measure productivity with environmental factors. In another field, Wang et al. [43] used this method to figure out the performance of the security forces in Taiwan. This study, based on the outcome, proposed to reduce excesses in the inputs and bad outputs as a solution.

Based on the problem characteristics of Covid-19 and several previous studies, this paper proposed a DEA-UOM to measure efficiency, inefficiency in 50 countries all over the world (i.e., 50 DMUs). These DMUs consist of Europe (10 countries), Asia (10 countries), North America (10 countries), South America (10 countries), and Africa (10 countries). The results were analyzed based on the relationship among variables, such as inputs (total tests, hospital beds, population, life expectancy, aged-70-older), good output (total recovered), and bad outputs (total cases, total deaths). In DEA models, DEA-UOM differs from the others by capturing the behavior of bad output variables. Hence, this model is allocated to calculate the efficiency and inefficiency of DMUs when the model included bad outputs. A panoramic picture of pandemic combating is analyzed and provided to decision-makers for managerial consideration. Additionally, the sustainability of healthcare development is recommended based on considering the input and output variables. For this reason, the authors decided to refer to this model to analyze the impacts of Covid-19 on countries and plans for future pandemics.

3. MATERIALS AND METHODS

3.1 Research Process

In order to achieve the objective of the paper, this research is separated into three parts, the proposal of the research process is displayed in Fig. 1. This will work as a guideline for the researchers in processing the paper.

Part 1: Research background: Present the problem characteristics, the paper objective, and data collection for this study. The number of DMUs needed by DEA approaches, the DEA-UOM in this paper must be at least two times much than the sum of input and output variables [44]. This study considered five inputs (total tests, hospital beds, population, life expectancy, aged-70-older) and three outputs (total cases, total deaths, total recovered) with 50 DMUs (i.e., 50 countries from five regions) in the world.

Part 2: Research investigation: The undesirable output model is one of the models in DEA approaches. Causes make this model unique and distinct from the others, is that the model can solve the problem with bad outputs, which are total cases and total deaths in this study. Hence, the authors used DEA-UOM to assess the efficiency and inefficiency of countries against the Covid-19 pandemic. Isotonic and homogeneity are two important attributes of the data set in DEA models. Examining the Pearson correlation coefficient is an essential step before using the DEA-UOM in this study [45]. The research analysis is divided into two parts, which are performance analysis and ranking, and efficiency and inefficiency classification. In the case of efficiency and inefficiency classification, according to the efficiency frontier theory, the DMUs with a value at 1 will be classified to the first-grade in the first analysis. In the second analysis, the rest of the DMUs will be used in the DEA-UOM, and the second-grade of efficiency frontier is installed based on the DMUs which score is at 1. Meanwhile, the rest is deducted by this conceptual computation, until it does not meet in the method of Golany and Roll [44]. In this study, there are two rounds of analysis, all 50 countries are assigned to three classifications. It is shown that those in the first-grade are the most efficient countries, and the least efficient countries are in the third-grade.

Part 3. Conclusions and recommendations: In this part, the results of this research are deeply analyzed and concluded to satisfy the objective of the paper. The results present which countries achieved efficiency and the rest is poor performance, and the classification into the group also is suggested. The research contributions also are shown to provide a guideline for the decision-makers as well as all countries against the Covid-19 pandemic for sustainable development after this global crisis period. The limitation of the research and future studies also are mentioned.

3.2 Pearson Correlation Coefficient

The Pearson is generally used in previous studies, which describes the linear relationship of two variables, where +1 presents a total positive linear, 0 presents no linear, and −1 presents a total negative linear.

Isotropic is an essential DEA data assumption. The relationship between inputs and outputs will be verified before using the DEA model, which means that it should be in a total positive linear relationship. The Pearson correlation index is one of the best statistical tests for estimating the correlation between two variables. The Pearson's formula (r) of two variables (a) and (b) is calculated as Equation (1) [46].

$$r_{ab} = \frac{\sum_{i=1}^{n} a_i b_i - \frac{\sum_{i=1}^{n} a_i \sum_{i=1}^{n} b_i}{n}}{\sqrt{\left(\sum_{i=1}^{n} a_i{}^2 - \frac{\left(\sum_{i=1}^{n} a_i\right)^2}{n}\right)\left(\sum_{i=1}^{n} b_i{}^2 - \frac{\left(\sum_{i=1}^{n} b_i\right)^2}{n}\right)}} \qquad (1)$$

where n is the size of the sample; a_i, b_i denotes the individual sample points related to i.

3.3 DEA-Undesirable Output Model

This paper includes data concerning the behavior of bad outputs (undesirable outputs, i.e., total cases, total deaths) and good output (desirable output, i.e., total recovered), addressing it more properly for the research. The DMUs in this paper are the 50 countries including five regions, respectively. This paper used the DEA-UOM (BadOutput-C) due to matching the problem characteristics. It will be deeply explained as follows.

The matrix of input and output of the DMUs will be standing for (x_0, y_0). The output of the matrix y will be disintegrated into two: the undesirable outputs are Y^b (bad matrices) and the desired outputs are Y^g (good matrices). The general disintegration will be declared (x_0, y_0^g, y_0^b).
The set for production possibility is displayed by.

$$P = \left\{ (x, y^g, y^b) \middle| \begin{array}{c} x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, L \\ \leq e\lambda \leq U, \lambda \geq 0 \end{array} \right\} \quad (2)$$

wherein the power of factor is λ, L denotes the lower bound, and U denotes the upper bound for λ.

In the existence of bad output, a DMU(x, y^g, y^b) is efficient if there is no vector $(x, y^g, y^b) \in P$ in such $x_0 \geq x$, $y_0^g \leq y^g$, $y_0^b \geq y^b$ having at least one variation.

The adjustment of SBM to obtain the objective of the undesirable output model is displayed as.

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}^-}{x_{io}}}{1 + \frac{1}{s}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)} \quad (3)$$

constraint to

$$x_0 = X\lambda + s^-;\ y_0^g = Y\lambda - s^g;\ y_0^b = Y\lambda + s^b; L \leq e\lambda \leq U;\ s^-, s^g, s^b, \quad \lambda \geq 0.$$

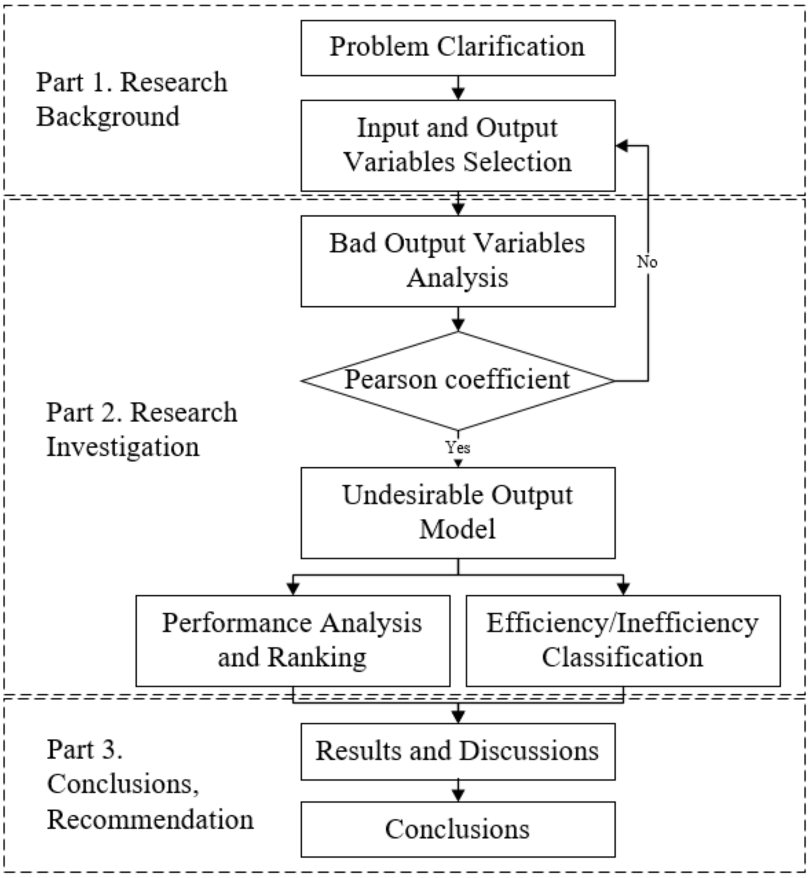

Fig. 1. The proposal for the research process flowchart

The extras in input variables are expressed by the vector s^- and bad outputs are s^b. While s^g expresses the lack of good outputs. s_1 and s_2 denote the number of components in s^b, and s^g, and $s = s_1 + s_2$.

As given by Cooper et al. [47], the DMU$\left(x_0, y_0^g, y_0^b\right)$ is efficient even under a condition of any bad outputs if $\rho^* = 1$. An inefficient DMU, $\rho^* < 1$, can be increased by deleting the extras with the following projection.

$$\begin{aligned} x_0 - s^{-*} &\Rightarrow x_0 \\ y_0^g - s^{g*} &\Rightarrow y_0^g \\ y_0^b - s^{b*} &\Rightarrow y_0^b \end{aligned} \tag{4}$$

The fractional computation can be transformed into linear programming with the consequential variables for the constant return to scale [48].

Meanwhile, v, u^g, u^b and $L = 0,\ U = \infty$.

$$\text{Max}\, u^g y_o^g - v - u^b y_o^b \tag{5}$$

subject to:

$$u^g Y^g - vX - u^b y^b \leq 0 \tag{6}$$

$$v \geq \frac{1}{m}[{}^1\!/_{x_o}] \tag{7}$$

$$u^g \geq \frac{1 + u^g y_o^g - vx_o - u^b y_o^b}{s}\ [{}^1\!/_{y_o^g}] \tag{8}$$

$$u^b \geq \frac{1 + u^g y_o^g - vx_o - u^b y_o^b}{s}\ [{}^1\!/_{y_o^b}] \tag{9}$$

The v and u^b variables are sequentially assigned to as the values of inputs and bad outputs while u^g assigns to the value of good outputs.

Cooper et al. [47], set the weights of desirable output and undesirable output to be the entered-code before running the DEA-UOM. The weight must satisfy the $w_1, w_2 \geq 0$ constraints for the good and bad output variables so that the computed relevant weights will fit $W_1 = sw_1/(w_1 + w_2)$ and $W_2 = sw_2/(w_1 + w_2)$. The final equation will be converted into.

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}^{-}}{x_{io}}}{1 + \frac{1}{s}\left(W_1\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g} + W_2\sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)} \tag{10}$$

The default value for w_1 and w_2 is 1. In this paper, the heading (OBad) is for bad outputs while (O) stands for good outputs.

4. RESULTS ANALYSIS

4.1 Data Collection

4.1.1 Decision-Making Units (DMUs) selection

The selection of DMUs is one basic but highly important part. This research focuses on efficient evaluation against Covid-19 in five main regions, including 50 countries over the world which rank at the top in total case of Covid-19 [5]. Out of these 50 countries, there are 10 countries from Europe, 10 countries from Asia, 10 countries from South America, 10 countries from North America, and 10 countries from Africa. Table 1 below shows the name of the countries that will be analyzed and their DMU labels.

4.1.2 Inputs and outputs selection

DEA is an optimal mathematical programming method for evaluating DMUs, which regarding comparative change in input and output variables. The selection of input and output variables is a necessary step in applying the DEA-UOM to assess the efficiency and inefficiency of the DMUs [49-51]. They have a significant impact on the final DEA results. Based on these global pandemic characteristics which are informed from WHO and many related studies about Covid-19 in the literature review part, the authors decided to select three inputs and three outputs, which are described as follows and can be seen in Fig. 2.

- (I) Total tests (TT): is the total number of people who are checked with Covid-19 by country.
- (I) Hospital beds (HB): the total number of beds that are specially designed for hospitalized patients in need of some form of health care in the country.
- (I) Population (PO): the whole number of residents in a country.
- (I) Life expectancy (LE): is the average number of years that a person is expected to live by country.
- (I) Aged-70-older (AO): the total number of people who are 70 years old or more per population in each country.
- (OBad) Total cases (TC): considered as a good output in the DEA-UOM model, represent the total number of reported cases of each country which is positive with Covid-19.
- (OBad) Total deaths (TD): considered as a bad output in the DEA-UOM model, represent the total number of people of each country who died caused by Covid-19.
- (O) Total recovered (TR): considered as a good output in the DEA-UOM model, represent the

total number of people of each country who recovered after Covid-19.

4.1.3 Research data

The data set of this study, including 50 countries of five regions, were collected from the official website [5,52]. It is important to note that the data is updated from December 2019 until December 2020. The DEA-UOM is sensitive to outliers, the data set is verified for calibration errors to indicate the appearance and importance of input and output variables. Using Boxplot in SPSS software to detect the outliers. Fig. 3 shows that all variables are confirmed. Hospital beds, population, life expectancy, aged-70-older, total cases, total deaths, total recovered have a little variation except for total tests. However, the total tests significantly affect the performance against Covid-19 in each country. Hence, this variable is still retained to analyze in the DEA-UOM. The summary of descriptive statistics in 50 countries is displayed in Table 2. Note: TT is total tests (unit: thousand), HB is hospital beds per thousand, PO is population (unit: million), LE is life expectancy (unit: years), AO is aged-70-older (unit: %), TC is total cases (unit: thousand), TD is total deaths (unit: thousand), TR is total recovered (unit: thousand).

Before using the DEA-UOM to analyze the data, the priority condition is that the variables must be satisfied with the isotopes. In detail, the input variables' values are directly proportional to the output variables' values. Hence, it is necessary to verify the research data first by applying the Pearson correlation, to guarantee the mentioned priority condition. The Pearson correlation coefficient's value range is from −1 to +1. The correlation coefficients among input and output variables have a result shown in Table 3. All Pearson correlation coefficient indexes are positive correlation. Hence, the used data

Table 1. The countries in their respective DMUs in the model

DMUs	Countries	Region	DMUs	Countries	Region
D1	Russia	Europe	D31	Brazil	South America
D2	France	Europe	D32	Argentina	South America
D3	Italy	Europe	D33	Colombia	South America
D4	Germany	Europe	D34	Peru	South America
D5	Poland	Europe	D35	Chile	South America
D6	Ukraine	Europe	D36	Ecuador	South America
D7	Belgium	Europe	D37	Bolivia	South America
D8	Czechia	Europe	D38	Venezuela	South America
D9	Romania	Europe	D39	Paraguay	South America
D10	Switzerland	Europe	D40	Uruguay	South America
D11	India	Asia	D41	South Africa	Africa
D12	Turkey	Asia	D42	Morocco	Africa
D13	Iran	Asia	D43	Egypt	Africa
D14	Indonesia	Asia	D44	Ethiopia	Africa
D15	Iraq	Asia	D45	Tunisia	Africa
D16	Bangladesh	Asia	D46	Libya	Africa
D17	Philippines	Asia	D47	Kenya	Africa
D18	Pakistan	Asia	D48	Ghana	Africa
D19	Israel	Asia	D49	Uganda	Africa
D20	Saudi Arabia	Asia	D50	Cameroon	Africa
D21	United States	North America			
D22	Mexico	North America			
D23	Canada	North America			
D24	Panama	North America			
D25	Dominican Republic	North America			
D26	Costa Rica	North America			
D27	Guatemala	North America			
D28	Honduras	North America			
D29	El Salvador	North America			
D30	Jamaica	North America			

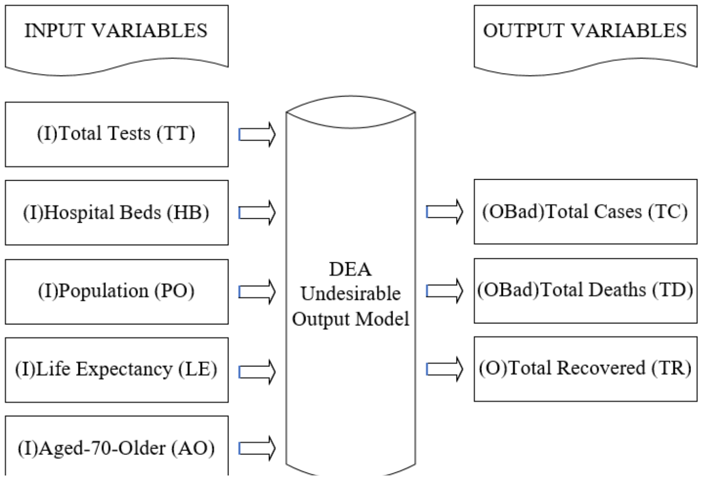

Fig. 2. The input and output variables in the research

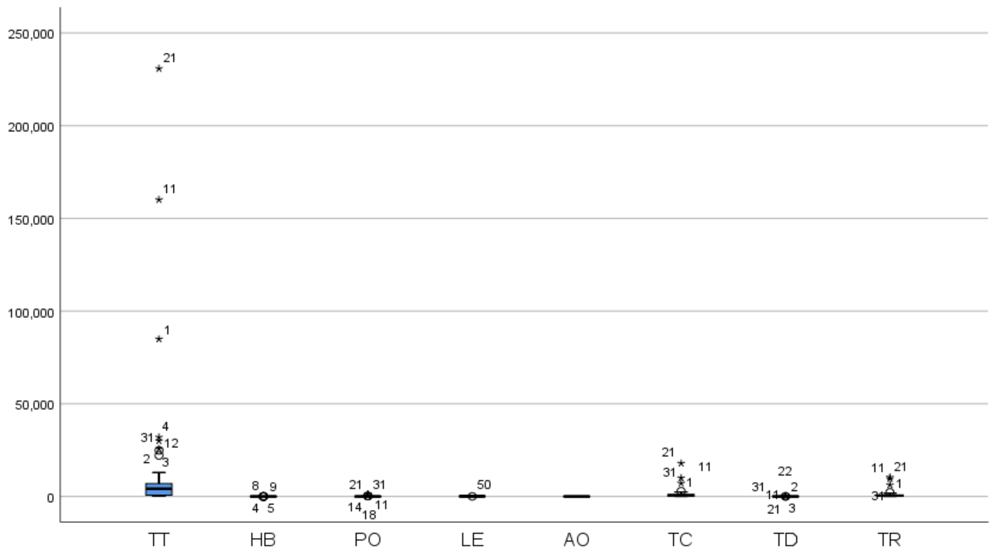

Fig. 3. Boxplot of input and output variables

Table 2. Summary of descriptive statistics in 50 countries

Statistics	Input variables					Output variables		
	TT	**HB**	**PO**	**LE**	**AO**	**TC**	**TD**	**TR**
Max	230,816.17	8.80	1,386.31	83.78	16.24	17,888.35	320.85	10,394.29
Min	129.87	0.30	2.97	59.29	1.31	11.95	0.11	7.70
Avg	15,115.13	2.62	87.66	74.72	5.98	1,287.09	28.85	954.15
SD	39,820.82	2.21	198.90	5.50	3.95	2,925.73	55.47	2,067.53

Note: TT is total tests, HB is hospital beds, PO is population, LE is life expectancy, AO is aged-70-older, TC is total cases, TD is total deaths, TR is total recovered

complies with isotropic and homogeneity conditions and can be used for the DEA-UOM. Except for the correlation index among hospital beds and population (-0.130), life expectancy and population (-0.161), aged-70-older and population (-0.120), approximately equal to 0. These negative values are from the relationship between input variables, which is acceptable for using the DEA model. Among input and output variables, the correlation coefficient index needs to be positive. However, among input variables or output variables, it is no limit. In summary, those data set comply with the precondition of the DEA approach and can be applied for the analysis of the DEA-UOM.

4.2 Results of DEA-Undesirable Output Model

4.2.1 Performance analysis and ranking

Because the requirement of DEA was matched in the above analysis, the DEA-UOM (BadOutput-C) is involved to measure the relative efficiency and inefficiency and rank 50 countries in five regions all over the world. The overall efficiency scores and ranking for the 50 countries analyzed are presented in Table 4.

Table 3. Correlation coefficients among input and output variables

		TT	HB	PO	LI	AO	TC	TD	TR
TT	Correlation	1	0.121	.675**	0.090	0.190	.943**	.834**	.910**
	Sig. (2-tailed)		0.404	0.000	0.536	0.187	0.000	0.000	0.000
HB	Correlation	0.121	1	-0.130	.434**	.781**	0.072	0.050	0.024
	Sig. (2-tailed)	0.404		0.366	0.002	0.000	0.619	0.732	0.870
PO	Correlation	.675**	-0.130	1	-0.161	-0.120	.613**	.511**	.751**
	Sig. (2-tailed)	0.000	0.366		0.263	0.405	0.000	0.000	0.000
LI	Correlation	0.090	.434**	-0.161	1	.699**	0.123	0.170	0.064
	Sig. (2-tailed)	0.536	0.002	0.263		0.000	0.393	0.238	0.661
AO	Correlation	0.190	.781**	-0.120	.699**	1	0.167	0.175	0.084
	Sig. (2-tailed)	0.187	0.000	0.405	0.000		0.247	0.225	0.563
TC	Correlation	.943**	0.072	.613**	0.123	0.167	1	.948**	.963**
	Sig. (2-tailed)	0.000	0.619	0.000	0.393	0.247		0.000	0.000
TD	Correlation	.834**	0.050	.511**	0.170	0.175	.948**	1	.905**
	Sig. (2-tailed)	0.000	0.732	0.000	0.238	0.225	0.000		0.000
TR	Correlation	.910**	0.024	.751**	0.064	0.084	.963**	.905**	1
	Sig. (2-tailed)	0.000	0.870	0.000	0.661	0.563	0.000	0.000	

*Note: ** is correlation is significant at the 0.01 level (2-tailed), TT is total tests, HB is hospital beds, PO is population, LE is life expectancy, AO is aged-70-older, TC is total cases, TD is total deaths, TR is total recovered*

Table 4. Efficiency score and ranking of 50 countries

DMUs	Countries	Score	Rank	DMUs	Countries	Score	Rank
D50	Cameroon	1.0000	1	D27	Guatemala	0.3622	26
D48	Ghana	1.0000	1	D41	South Africa	0.3182	27
D38	Venezuela	1.0000	1	D9	Romania	0.2992	28
D37	Bolivia	1.0000	1	D17	Philippines	0.2783	29
D35	Chile	1.0000	1	D46	Libya	0.2771	30
D34	Peru	1.0000	1	D36	Ecuador	0.2750	31
D33	Colombia	1.0000	1	D13	Iran	0.2473	32
D32	Argentina	1.0000	1	D4	Germany	0.2261	33
D8	Czechia	1.0000	1	D18	Pakistan	0.2203	34
D31	Brazil	1.0000	1	D6	Ukraine	0.2182	35
D26	Costa Rica	1.0000	1	D3	Italy	0.2171	36
D11	India	1.0000	1	D44	Ethiopia	0.1961	37
D12	Turkey	1.0000	1	D39	Paraguay	0.1901	38
D22	Mexico	1.0000	1	D45	Tunisia	0.1739	39
D21	United States	1.0000	1	D28	Honduras	0.1634	40
D20	Saudi Arabia	1.0000	1	D47	Kenya	0.1564	41
D16	Bangladesh	1.0000	1	D14	Indonesia	0.1544	42
D19	Israel	1.0000	1	D29	El Salvador	0.1256	43
D24	Panama	0.6833	19	D23	Canada	0.1235	44
D10	Switzerland	0.5568	20	D43	Egypt	0.0960	45
D25	Dominican Republic	0.4883	21	D30	Jamaica	0.0657	46
D15	Iraq	0.4772	22	D40	Uruguay	0.0478	47
D42	Morocco	0.4481	23	D49	Uganda	0.0259	48
D1	Russia	0.4278	24	D7	Belgium	0.0226	49
D5	Poland	0.3861	25	D2	France	0.0192	50

A score equal to 1 means that the countries' efficiency acquired, vice versa means inefficient (at scores less than 1). From Table 4, it can be seen that there are only 18 out of the 50 countries performing at high relative efficiency of 1 during the considered period of time, including D50-Cameroon, D48-Ghana, D38-Venezuela, D37-Bolivia, D35-Chile, D34-Peru, D33-Colombia, D32-Argentina, D8-Czechia, D31-Brazil, D26-Costa Rica, D11-India, D12-Turkey, D22-Mexico, D21-United States, D20-Saudi Arabia, D16-Bangladesh, and D19-Israel. Thus, these DMUs obtained the first ranking, which means they had better efficiency performance than the rest of the 32 DMUs. D2-France had an efficiency score of 0.0192, ranking at the bottom of the total 50 countries. The efficiency map against Covid-19 in 50 countries during 2020 is shown in Fig. 4.

4.2.2 Efficiency and inefficiency classification

After the above analysis, we concluded that there are 18 DMUs (D50-Cameroon, D48-Ghana, D38-Venezuela, D37-Bolivia, D35-Chile, D34-Peru, D33-Colombia, D32-Argentina, D8-Czechia, D31-Brazil, D26-Costa Rica, D11-India, D12-Turkey, D22-Mexico, D21-United States, D20-Saudi Arabia, D16-Bangladesh, and D19-Israel) achieving efficiency at scores of 1. Next, these DMUs can be ranked as an efficiency frontier's first-grade. Without first-grade countries, other countries will be evaluated by accessing the efficiency one more time for grading as 1 to be categorized to efficiency frontier's second-grade. In the interim, this analogy may deduce the rest of the countries.

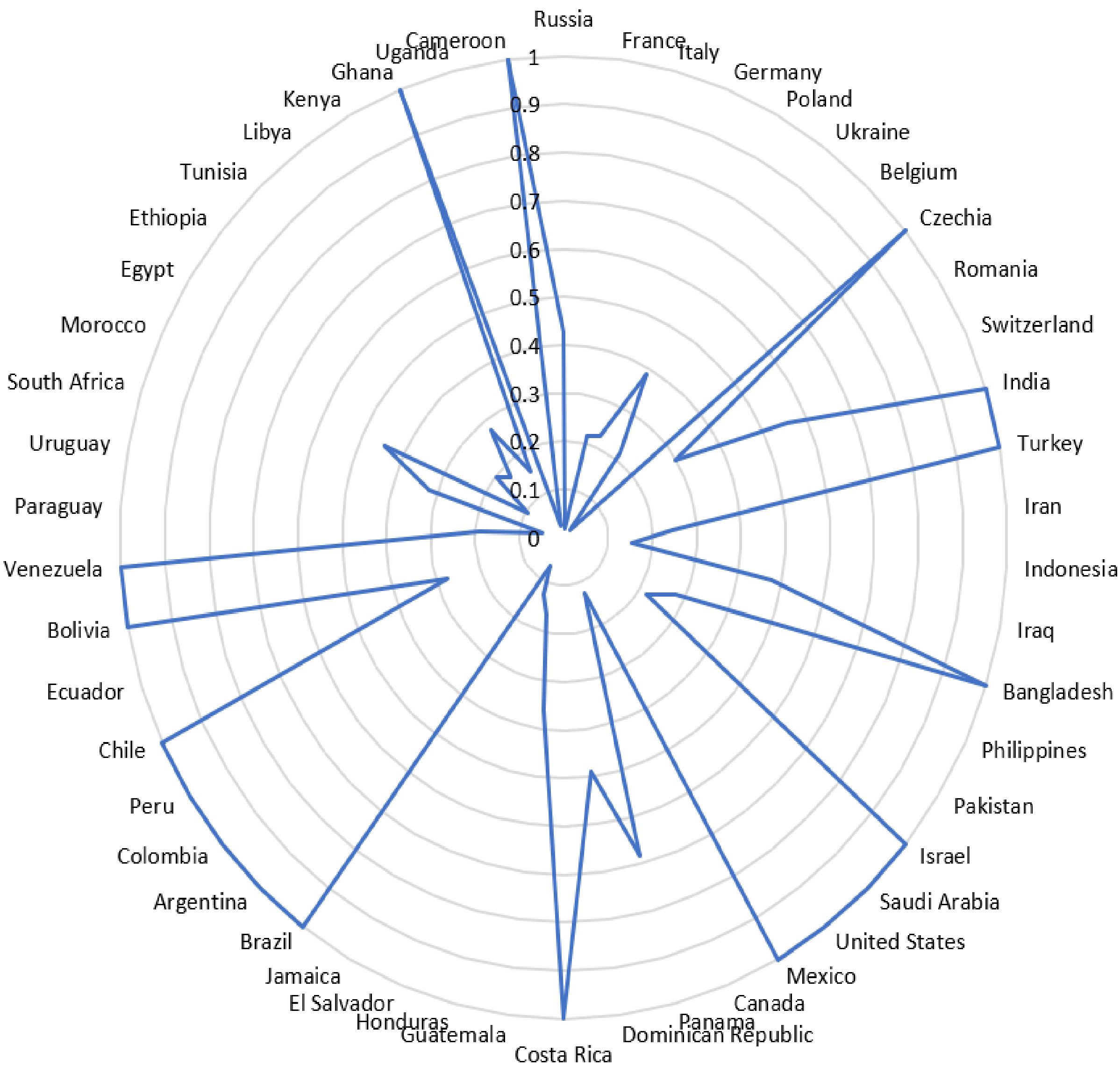

Fig. 4. Efficiency map against Covid-19 in 50 countries during 2020

Efficiency scores and ranking for the rest of 32 countries, shown in Table 5, is analyzed by the DEA-UOM. It can be indicated in Table 5 that 17 DMUs perform in relative efficiency with 1, including D44-Ethiopia, D1-Russia, D42-Morocco, D3-Italy, D41-South Africa, D5-Poland, D40-Uruguay, D36-Ecuador, D9-Romania, D10-Switzerland, D13-Iran, D27-Guatemala, D15-Iraq, D17-Philippines, D18-Pakistan, D25-Dominican Republic, and D24-Panama. These DMUs are in the efficiency frontier's second-grade.

To integrate the above analysis, the performances of all 50 countries in response to the pandemic are categorized into three proportions, as shown in Table 6. The countries which are evaluated as the efficiency frontier's first-grade are the most efficient nations in dealing with Covid-19 among all 50 countries in the world. The efficiency frontier's second-grade performs the best in the rest 32 countries. Nevertheless, the 15 countries at last were not examined because of the Golany and Roll [44] procedure. That is, the sum of input and output sectors must be more than haft of the total number of DMUs. To conclude, the first-grade performs the best efficiency, while the third-grade does the least efficiency.

Table 5. Efficiency score and ranking for 2nd round

DMUs	Countries	Score	Rank	DMUs	Countries	Score	Rank
D44	Ethiopia	1.0000	1	D24	Panama	1.0000	1
D1	Russia	1.0000	1	D14	Indonesia	0.8288	18
D42	Morocco	1.0000	1	D4	Germany	0.6256	19
D3	Italy	1.0000	1	D6	Ukraine	0.5635	20
D41	South Africa	1.0000	1	D28	Honduras	0.4635	21
D5	Poland	1.0000	1	D45	Tunisia	0.4479	22
D40	Uruguay	1.0000	1	D46	Libya	0.4473	23
D36	Ecuador	1.0000	1	D23	Canada	0.4008	24
D9	Romania	1.0000	1	D39	Paraguay	0.3970	25
D10	Switzerland	1.0000	1	D47	Kenya	0.3022	26
D13	Iran	1.0000	1	D29	El Salvador	0.2915	27
D27	Guatemala	1.0000	1	D43	Egypt	0.2387	28
D15	Iraq	1.0000	1	D30	Jamaica	0.1213	29
D17	Philippines	1.0000	1	D2	France	0.0657	30
D18	Pakistan	1.0000	1	D49	Uganda	0.0492	31
D25	Dominican Republic	1.0000	1	D7	Belgium	0.0455	32

Table 6. Classification of efficiency frontier

1st grade		2nd grade		3rd grade	
DMUs	**Countries**	**DMUs**	**Countries**	**DMUs**	**Countries**
D50	Cameroon	D44	Ethiopia	D14	Indonesia
D48	Ghana	D1	Russia	D4	Germany
D38	Venezuela	D42	Morocco	D6	Ukraine
D37	Bolivia	D3	Italy	D28	Honduras
D35	Chile	D41	South Africa	D45	Tunisia
D34	Peru	D5	Poland	D46	Libya
D33	Colombia	D40	Uruguay	D23	Canada
D32	Argentina	D36	Ecuador	D39	Paraguay
D8	Czechia	D9	Romania	D47	Kenya
D31	Brazil	D10	Switzerland	D29	El Salvador
D26	Costa Rica	D13	Iran	D43	Egypt
D11	India	D27	Guatemala	D30	Jamaica
D12	Turkey	D15	Iraq	D2	France
D22	Mexico	D17	Philippines	D49	Uganda
D21	United States	D18	Pakistan	D7	Belgium
D20	Saudi Arabia	D25	Dominican Republic		
D16	Bangladesh	D24	Panama		
D19	Israel				

5. DISCUSSIONS AND CONCLUSIONS

This paper applied a DEA undesirable output model to calculate the efficiency terms against Covid-19 in 50 countries including America, Europe, Asia, and Africa. The five outputs selected for this model included total tests, hospital beds, population, life expectancy, and aged-70-older, and the three inputs included total cases, total deaths, and total recovered. A model of undesirable outputs is applied to formulate scores of the characteristics in handling unchangeable bad and good outputs. DEA-UOM is applied to examine the efficiency of 50 countries. Overall, Cameroon, Ghana, Venezuela, Bolivia, Chile, Peru, Colombia, Argentina, Czechia, Brazil, Costa Rica, India, Turkey, Mexico, United States, Saudi Arabia, Bangladesh, and Israel appeared to be the most efficient countries that succeeded in tackling the pandemic, while the efficiency of France scored 0.0192, which is the least efficient performing nation.

After applying the DEA-UOM to analyze the 50 countries, we classified them into three levels based on their efficiency in coping with the Covid-19 pandemic. There are 18 countries belong to the first-grade of efficiency frontier (Cameroon, Ghana, Venezuela, Bolivia, Chile, Peru, Colombia, Argentina, Czechia, Brazil, Costa Rica, India, Turkey, Mexico, United States, Saudi Arabia, Bangladesh, and Israel), which scored 1 relatively, meaning that they appeared to succeed in handling the epidemic. Alternatively, the second level of the classification including Ethiopia, Russia, Morocco, Italy, South Africa, Poland, Uruguay, Ecuador, Romania, Switzerland, Iran, Guatemala, Iraq, Philippines, Pakistan, Dominican Republic, and Panama. The last 15 countries made the third-grade of efficiency frontier.

The results of efficiency and inefficiency classification, which can be a valuable reference to decision-makers in potential quantitative methods and policies conducted by the first-grade groups. Furthermore, the input and output variables of this model are recommended to be under consideration for the other groups and the rest of countries all over the world for sustainable health care. Also, the model's results are acceptable based on some recent studies, for example, Taghrir et al. [53] reviewed the efficiency of mass quarantine in disease control in China. The importance of resource allocation and innovative healthcare delivery methods was addressed as critical solutions in this paper; Chang et al. [54] applied an agent-based model to generate key features of Covid-19 transmission. The result showed the age-dependent portion of significant cases. The study utilized the model to distinguish several intervention approaches, including limitations on international air travel, social distancing, home quarantine, with different levels of compliance, and school closures; Legido-Quigley et al. [55] proposed concerning factors that might support the recovery of Spain's healthcare system in the battle with Covid-19. Five critical factors, including governance, financing, service delivery, health workers, and information, were intensively discussed.

In battling Covid-19, countries should not lose sight of sustainable development. The impact of Covid-19 on impoverished countries would be mitigated through achieving global health coverage, increasing health personnel' ranks and abilities, and enhancing early warning systems for global health risks. Experts also suggest that countries focus instead of promoting gross domestic product growth, which also runs counter to the principles of sustainability, to improve well-being [56]. Moreover, rich countries have launched massive stimulus schemes to sustain their own economy, with little attention paid to the misery of poorer countries. That support would need to be designed not only to bring Covid-19 under control but also to build economic and social resilience and ensure that countries are able to develop sustainably if negative spillovers to other countries are to be avoided. The positive effect of the pandemic is an opportunity to invest in a decade of action that not only helps people to recover from Covid-19, but that resets the development path of people and the planet towards a more fair, resilient, and green future.

The paper's main contribution is the method for mathematically measure the performance facing the Covid-19 pandemic in 50 countries of five regions. The DEA-UOM treatment of the bad outputs (i.e., total case, total deaths) as a less powerful variable named this paper significant from the other research. Therefore, this model is considered as a proper method to measure the efficiency sector having undesired output variables. The managerial implication of the model's results not only conveys the overall view in fighting with the current pandemic but also offers a guideline for decision-makers in combating and enhancing the healthcare system. Hence, this paper also could support the countries government and decision-makers to improve preventive actions in the fight against the global pandemic for sustainability's quality of life.

However, some limitations to this paper are (1) the number of DMUs, input and output variables of all countries are not recorded (i.e., United Kingdom), thus, future studies should add more countries and regions, especially in the most recent situations (i.e., India's severe case in 2021); (2) further studies should review this to concern more input variables (i.e., stringency index, population density, handwashing facilities), and output variables (i.e., total GDP, GDP per capita). For instance, a targeted group aged between 23 to 50 years should be considered. These people have to go outside for the bread and butter and livelihood. Furthermore, these people are more likely to get the infection and potential to become super spreaders. Their home confinement will seriously hamper the sustainable growth of the respective countries. Besides, the most vital indicator that is the proportion of the population fully vaccinated in assessing the combat readiness should be added to enhance the robustness and comprehension of the empirical results; and (3) future studies should include quantitative approaches, such as merging the DEA-UOM with a qualitative method, which employs the multiple criteria decision-making process under uncertain environment (i.e., fuzzy set theory) to provide more robust results [57,58].

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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