Policies to Minimize the Socio-economic Impact of SARS-CoV-2:

An International Comparison

José Fabrício Camacho Sousa

Department of Engineering and Management, Instituto Superior Técnico

Abstract

At the end of 2019, a novel coronavirus emerged in Wuhan, China. Two years after, communities are still fighting this virus that put the world in pandemic state: people had to be lockdown, companies and industries sites had to close doors, kids had to make a break in their education, and for several months cities looked inhabited. Countries' governments and health organizations had to join forces to find the best measures to keep people safe and nationals healthcare systems without pressure. If for one hand, COVID-19 brought negative impacts, mostly socially and economically, on the other hand it brought positive impacts for environments and biodiversity. Studying the measures taken and the consequents impacts, it is possible to understand what should be changed for a better and sustainable world. In this research it was used a type of Data Envelopment Analysis, the Benefit-of-Doubt (BoD-DEA) to create a capable and useful "tool" to evaluate countries relative efficiencies during COVID-19 pandemic. This work permits to decision makers understand which areas countries performed better and worse since it was used not only data from the measures that were globally adopted to fight the virus but also other dimensions such as countries' economy, governance and healthcare resources. It was perceived that level of development and income of countries is associated with the efficiency scores obtained: middle- and high-income countries have shown much better results than poorer and less developed countries. Nevertheless, 89%, 86% and 60% of countries from cluster 1, 2 and 3, respectively, achieved an overall efficiency at a rate of 80%.

Keywords: COVID-19 pandemic; Anti-covid policies; Socio-economic analysis; Benchmarking; Benefit-of-Doubt;

1. Introduction

The global public health has been threatened several times since the beginning of humankind. In accordance with the numbers that Rosenwald presented for *The Washington Post* article pandemics affects people from antiquity time till the present day (Rosenwald, 2021). The first one to be registered is the Antonine Plague (165-180 A.D.) with 5 million deaths caused by measles and smallpox that leaded to the fall of the Roman empire. Benedictow (2005) considers the Black Death (1347-1352) pandemic that killed between 75 to 200 million people, to be "*the greatest catastrophe ever*". Many other pandemics others have occurred over time: Italian Plague (1629-1631), Yellow Fever (late 1800s), Swine flu (2009-2010), and Ebola (2014-2016). The history about past pandemics in the world shows that future disease outbreaks will happen inevitably and for that reason understanding the root cause or causes of their origin and finding ways to prevent it; recognize what they have in common and perceive how to control and act under a pandemic condition is very important.

In the present moment, 2022, the world is facing a new pandemic caused by a new type of coronavirus, earlier found associated to the severe acute respiratory syndrome (SARS) outbreak in 2002. COVID-19 is the name given to the disease caused by this novel virus that affects around 7,9 billion people first discovered in Wuhan market, in China. From that moment the number of reported confirmed cases of COVID-19 contagions significantly increased all over the world and the WHO declared the outbreak to be "*a public health emergency of international concern.*" (Santacroce et al., 2020). On March 2020, WHO declares COVID-19 as a pandemic with more than 100.000 cases and 4.000 deaths in 114 countries, Europe becomes the epicentre of pandemic and USA declares state of emergency. More severe population behaviour and hygiene measures had to be taken and in mid/late-March countries seal borders, schools, entertainment/cultural amenities, and nonfundamental shops close doors, employees go home, people start using masks and practicing social distancing and only leave home for supermarkets, pharmacies or hospitals. Vaccines are crucial to stop the fatalities number keep growing and put an end to a pandemic. The start of the vaccination process in the beginning of 2021 made flatten epidemic curves. However, the virus has encountered new ways of development – appears the first variant, denominated by Alpha.

If for one hand the spread of COVID-19 makes nefarious consequences on world economy and healthcare systems, on the other hand it brings positive environmental effects, (El Zowalaty et al., 2020). These positive environmental effects are likely mostly temporary but may serve as an illustration of how changes in our lifestyle can have good consequences on the environment. Regarding biodiversity and environment, the lockdowns provided an opportunity to shift our ideology of human centric worldview to eco-centric worldview since it brought an increase of bird (e.g., vultures) and insect pollinators appearance on plants. Other animals also started to appear in the localities, such as, hedgehogs, deers, badgers and foxes that are usually intimidated or ran over by cars and trucks (Verma & Prakash, 2020). Coyotes have been spotted on the Golden Gate Bridge in San Francisco, and peacocks in Wales, for example (Watts, 2020). Marine life and organisms are taking the lead now with less water pollution and noise pollution. Seems that many species are returning to their natural habitats and reproduction activity due to reductions in pollution level (Khan et al., 2020).

Emissions of nitrogen oxides (NO_x), carbon dioxide (CO_2), several hydrocarbons, and particulate matter were “finally” reduced after several efforts along the past years. When compared with 2019 values, the emissions during coronavirus lockdown were doubtless minor and very polluting areas, such China showed a reduction of approximately 25% in nitrogen dioxide (NO_2) levels (El Zowalaty et al., 2020), Europe reduced up to 45-50% (ESA, 2020), main American cities reduced around 20% (Khan et al., 2020), and ozone layer is healing (NASA, 2021). Transportation restriction led to a much lesser fuel consumption that according with U.S. Energy Information Administration, the oil, gas and diesel demand decreased 9% over 2020 when compared to 2019, that represents the largest decline since 1980 (Baron, 2021).

On the other side, The International Labour Organization (2021) shows that full or partial workplaces closures due to COVID-19 crisis resulted in the loss of around 8,8% of working hours in 2020, which is equivalent to 255 million full-time equivalent jobs. In 2020, the global unemployment rate raised 1,1% which means that 33 million people got unemployed, and 81 million people shifted to inactivity. The sectors that were more harmed were accommodation and food service activities, works in arts, entertainment and recreation, retail, and construction sectors. Taking Portugal as an example of the pressure that companies felt because of COVID-19 pandemic, in accordance with *Associação Industrial Portuguesa* (AIP) about 35% saw the business volume go down in more than 40%, and some of these (17,3%) had a break greater than 70% when compared to 2019 activity. This breaks in companies’ turnover usually result in sacking, and in fact, 27% of the companies analyzed sacked workers or pretend to do it. 6% of the companies proceeded with the insolvency procedure in 2020.

The slowdown in oil extraction and the lift of the measures in late 2021 induced an abrupt change on demand for fuels which resulted in reduced inventories and higher prices for crude oil and petroleum products, having Portugal, for example, registered for the first time ever 2€ per litter of gasoline. The use of new communication technologies, like zoom conferences, and reduce unnecessary consumption and travelling would decrease emissions by factories and transports, and the demand for oil. This can be a big vector to help global warming, living beings’ and environment’s health without compromising the economy. Governments and environmental organizations should also make tighter regulations and supervision-work for companies and industries to treat their wastes properly. Maybe COVID-19 pandemic was a way to the nature call humanity’s attention and make them perceive that people should change their sometimes “selfish” behaviour.

This dissertation will focus mainly in understanding the used policies to minimize the impact of COVID-19 pandemic in people’s health and lives, in countries economy (socio-economic approach) and other factors such as governance and healthcare resources available to measure relative efficiencies between countries.

2. Analysis of measures to face COVID-19

Governments and non-governmental organizations needed to work together to address the pandemic. The biggest challenge on the fight of COVID-19 pandemic is to find the best measures in a very fast and responsive way to not only protect people from being "caught" by the virus, but to also treat the ones that are already infected without compromising harshly the country's economy. Under an environment where health systems are cracking, companies suffering financially, and people reluctant for the change, it is hard to take decisions and create the policies when there are no clear answers.

According with Kissler et al. (2020), prolonged or intermittent social distancing is necessary to keep the care capacities not overwhelmed. However, one-time and intermittent interventions are not sufficient to keep COVID-19 controlled and care capacity bellow "break point". Measures like intensive testing to identify the cases and contact tracing, and lockdown/quarantines to isolate the cases, have been shown to be effective strategies to control the spread of infectious diseases, including the COVID-19 pandemic, in some places like Singapore and Hong Kong (Aleta et al., 2020; Madubueze et al., 2020; Wells et al., 2020). Lockdown is a very strong measure to stop the confirmed positive cases to keep getting higher but that reflects also in less mobility in the cities and in schools, companies and industrial sites closure which holds serious economic consequences.

Teleworking and long-distance learning were also measures created when the economic and educational systems started to feel vulnerable. To ensure that patients receive adequate care and to reduce the pandemic duration, increase the critical care capacity is also very important (Kissler et al., 2020). Hygiene measures are also very important: mask-wearing, hand sanitizing with alcohol-based disinfectants or soap and water, cover mouth and nose while coughing or sneezing with a tissue or bent elbow, clean and disinfect surfaces frequently touched are the guidelines more recurrent (WHO, 2021). Mass vaccination and herd immunity is the most powerful weapon to fight the virus (Moutinho, 2021). Vaccines accumulate immunity in the population and reduces the duration and intensity of some control measures referred before (Kissler et al., 2020). The pandemic situation is always evolving, many resurgences have already happened, and people are still facing COVID-19 in 2022, thus, communities and organizations should keep on track the situation and update COVID-19 prevention strategies based on community spread, health system capacity, vaccination coverage, early detection of COVID-19 increases and population at risk (Christie et al., 2021).

Table 1 summarizes the main measures adopted globally to fight COVID-19 to analyse the policies succinctly.

Table 1 - COVID-19 Pandemic: sum up of main measures and some respective positive/negative impacts (NOTE: RED CELLS: Negative impacts / GREEN CELLS: Positive impacts / RED LETTERS: Negative economic impacts) (Source: The author)

MEASURES	IMPACTS		
Traveling restriction	Reduce CO_2 and other pollutant gases emission	Reduce fossil fuel consumption	Animals' freedom/ecosystems recovery
	Global warming lessens	Psychological pressure on people	Less pollution in touristic spots
Lockdown/ quarantines	Companies labour get affected severely	Families' have more time to be together	Difficult education access; remote learning less effective
	Increase in demand for communication technology companies	Psychological stress / Financial insecurity or fear	Reduce over-consumption – families save money; less waste disposal
Companies/ industrial closure	Reduce noise pollution	Less NO_2 and other pollutant gases emission	Lower income for people that are fired or work less hours – some families can fall below poverty line
	Companies have zero income	Less waste disposal/Less water pollution	Ozone hole heals
Use of PPE[2]	High income for PPE producers	Soil and water pollution	Plastic waste
Massive testing	Enables routines and companies' comeback quicker and easily	Logistic and resources to create testing centres, workforce and results treatment and delivery	Healthcare workers highly exposed to the virus and, therefore, a strong transmission source
	High costs for country	Pressure on national healthcare system and increase on medical waste	Community feels safer since transmission is being tracked
Vaccination	Global economy pressured to develop vaccines quickly	Global chain pressured economically and logistically to develop, produce, deliver, and administer the vaccines to society	More knowledge for future diseases/ infections
	Concern for vaccination material proper disposal	High income for pharmaceutical industry and companies	Countries' economic resources pressured to buy vaccines

3. Case-study: measuring countries relative efficiencies to fight COVID-19 pandemic

3.1. Literature review

Considering the literature, many studies used DEA to create a *best-practice frontier* and compare relative efficiencies to evaluate performance of the policies taken by the governments in several countries. Some that used this methodology with the same of goal of ours are the Pereira et al. (2022); Dogan et al. (2021); Mohanta et al. (2021); Min et al. (2021); Aydin & Yurdakul (2020); Imtyaz et al. (2020); and Mitchell et al. (2021). Regarding the variables used in the literature, it is noticed that the inputs are more related with the resources available (e.g., number of hospitals, number of hospital beds, number of health workers (%)); with demographic factors (e.g., population density (%), public health expenditure, population density, gross national income (GNI) per capita)); and with number of confirmed cases. On the other hand, outputs are more related with the pandemic outcomes (e.g., number of recovered, number of deaths) that are 3 directly related with the healthcare system performance.

DEA seams a good approach to evaluate the countries performance since it uses a *best-practice frontier* to compare (relative) efficiencies. This way, it is obtained analytical results based on real data retrieved from reliable sources about countries in study. However, the variables used seems very limiting since COVID-19 does not only depend in the number of beds, deaths and recovers, for example. The literature seems to study the pandemic with very restrict boundaries, i.e., does not evaluate the pandemic using different dimensions that affects countries efficiencies to fight COVID-19 disease. To counter these problems, the Benefit-of-Doubt (BoD) will be used since this approach accommodates key performance indicators that can evaluate several dimensions at the same time.

3.2. Methodology

Benefit-of-Doubt is a quite used DEA approach proposed by Melyn & Moesen (1991) in the context of macroeconomic performance evolution and revised by Cherchye et al. (2007). This study is a macro-assessment of countries' performance to fight a pandemic. According with Cherchye et al. (2007) it is possible to say about BoD the following:

1) BoD uses indicators instead of the usual inputs and outputs variables from other DEA models. These indicators are called as composite indicator (CIs) that aggregate several weighted performance sub-indicators;
2) The main difference between the usual DEA approaches and the BoD is that the CIs used by this model looks only for the outcomes and do not "bother" itself with the required inputs to achieve the goals since it considers only outputs and for inputs only uses a dummy variable with value equal to one for each DMU;
3) The model gives higher weights to the sub-indicators that have better performance and less weight to the sub-indicators that have lower performance. This results in the BoD model optimizing the CIs (Shwartz et al., 2010). This also means that any country cannot claim that the weights attributed are not favouring their country and favouring the other ones (Yang et al., 2017);
4) This statement is seen by some as a limitation of the model since different DMUs are being weighted differently but even with such flexible weighting a country can be outperformed by some other country in the sample – benchmark idea is present. This is a major factor for this approach success (Cherchye et al., 2007);
5) Information about the weights can be accommodated by the model;

The mathematical formulation of this model and the construction of CIs is the following one:

$$I_c = \max_{w_{c.i}} \frac{\sum_{i=1}^{m} w_{c,i} \cdot y_{c,i}}{\max_{y_{j,i} \in \{studied\ countries\}} \sum_{i=1}^{m} w_{c,i} \cdot y_{j,i}} \quad (1)$$

s.t.

$$\sum_{i=1}^{m} w_{c,i} \cdot y_{j,i} \leq 1 \text{ , n constraints, one for each country j} \quad (1.1)$$

$$w_{c,i} \geq 0 \text{ , m constraints, one for each indicator i} \quad (1.2)$$

Equation 1.1 represents a normalization constraint which imposes that the composite indicator (CI) can't be higher than 1 if the same weighting scheme is being used for another country in the set. Equation 1.2 represents a non-negativity constraint that imposes that the weights used must be positive in order to reflect that CI is a non-decreasing function of the sub-indicators, (Karagiannis & Karagiannis, 2018). Thus, it is easy to understand that if CI is equal to one, that means the best performance (the same performance that is benchmarked) and closer to zero means weaker performance.

3.3. Sample and data treatment

It was intended to analyze the 195 countries that exists in the world but due to high missing data for several countries, 39 of them were excluded from the analysis. Thereby, the analysis was proceeded with 156 countries considering data from a time span that was pertinent and long enough (March 2019 – December 2021). Data was selected from reliable sources and entities to have the best data quality possible but always constrained to its availability (country-coverage, time-coverage).

Cluster analysis (CA) using k-means method with Euclidean distance, based on the Hartigan and Wong algorithm (Hartigan & Wong, 1979) was performed to group countries according to similarities or dissimilarities (distances) among them (Härdle, 2015; Johnson & Wichern, 2007). This separation was done based on eight variable that reflects the countries characteristics and demographic similarities/disparities, stated in Table 2. This means that countries from the same cluster are statistically similar and that can be compared.

Table 2 - Variables used to perform the Cluster Analysis (Source: The author)

a.	GDP per capita	**b.**	citizens over 65 years of age
c.	population density	**d.**	healthcare expenditure as a share of GDP
e.	diabetes prevalence	**f.**	cardiovascular disease death rate
g.	respiratory disease death rate	**h.**	containment and health index

Normalization is very helpful and should be applied since it also removes redundant data and improve the efficiency of clustering algorithms, and so, the quality of the clusters obtained. This is important since the Euclidean distance used in the clustering algorithm is very sensitive to changes in the size of the different variables (Patel & Mehta, 2011). The results obtained after performing the CA, were not very stable and so, to reduce some noise that existed among the dataset, it was performed also a Principal Component Analysis (PCA). The results were now much more stable and resulted in 3 clusters. Cluster 1 has 27 countries, cluster 2, 48 countries, and cluster 3 has 81 countries.

Theoretical framework:

To measure the countries relative efficiencies was also vital to understand which indicators should be selected. Understanding the multidimensional phenomenon to be measured and the usage of dimensions to define better what is intended to measure helps to make an adequate selection. Table 3 shows the indicators, groups and dimensions created and each dimensions implies:

1) *dimension 1*: understand how countries were handling directly with COVID-19 pandemic (through tests, vaccination and other policies);
2) *dimension 2*: measure the healthcare system and resources available to treat people;
3) *dimension 3:* reflect cultural aspects that influence the results obtained in the fight of the pandemic;
4) *dimension 4*: account for economic aspects;

Table 3 - Variables used (Source: The author)

Dimension (CI)	**Group (Partial CI)**	**Variables/KPIs/Indicators**	**Polarity[1]**
1. COVID-19	1.1 Tests and vaccination response	1.1.1 Total Tests Per Thousand	⊕
		1.1.2 Positive Rate	⊖
		1.1.3 Total Vaccinations Per Hundred	⊕
		1.1.4 People Vaccinated Per Hundred	⊕
		1.1.5 People Fully Vaccinated Per Hundred	⊕
		1.1.6 Total Boosters Per Hundred	⊕
	1.2 Policy and strategy response	1.2.1 School Closures	⊕
		1.2.2 Workplace closing	⊕
		1.2.3 Cancel Public Events	⊕
		1.2.4 Restrictions on gatherings	⊕
		1.2.5 Public Transportation	⊕
		1.2.6 Stay at Home Order	⊕
		1.2.7 Restrictions on Internal Movement	⊕
		1.2.8 International Travel Controls	⊕
		1.2.9 Public Information Campaigns	⊕
		1.2.10 Testing Policy	⊕
		1.2.11 Contact tracing	⊕
		1.2.12 Facial coverings	⊕
		1.2.13 Vaccination policy	⊕
		1.2.14 Protection of elderly people	⊕
	1.3 COVID-19 outputs/outcomes	1.3.1 Fatality Ratio	⊖
		1.3.2 Excess Mortality Cumulative Per Million	⊖
		1.3.3 Reproduction Rate	⊖
2. Access and Quality of Health	2.1 Social sanitation and Hygiene, and Development	2.1.1 Share of Population with Access to Basic Handwashing Facilities	⊕
		2.1.2 Human Development Index	⊕
	2.2 Healthcare resources	2.2.1 Hospital beds per 1 000	⊕
		2.2.2 Medical Doctors per 10 000 population	⊕
		2.2.3 Nursing and midwifery personnel per 10 000 population	⊕
		2.2.4 Healthcare Access and Quality Index	⊕
3. Security and Compliance in Governance	3.1 Accountability	3.1.1 Transparency Accountability Index	⊕
		3.1.2 Corruption Perception Index	⊖
	3.2 Political stability	3.2.1 Public trust in politicians	⊕
		~~3.2.2 State legitimacy~~	⊕
		3.2.3 Score of adoption and implementation of national disaster risk reduction (DRR) strategies in line with the Sendai Framework	⊕
		3.2.4 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies (%)	⊕
4. Fragility in Economy and Finance	4.1 Expenditures on Healthcare	4.1.1 Total health expenditure as percentage of GDP (%)	⊕
		4.1.2 Population covered by health insurance (%)	⊕
	4.2 Economic stability	4.2.1 Economic decline indicator	⊖
		4.2.2 Economic globalization index	⊕
		4.2.3 Direct economic loss attributed to disasters	⊖
	4.3 Economic support	4.3.1 Income Support	⊕
		4.3.2 Debt/contract relief for households	⊕

Imputation of missing data:

BOD requires perfect knowledge of data and for that reason different imputation methods were explored and used in attempt to always estimate the best missing values having account the type of data (time series or cross-sectional data) in hands and the degree of missing data. Single imputation was used for variables with lower missing data and multiple imputation for variables with higher missing data the missing data is filled multiple times and then pooled to reflect uncertainty about the values to impute which does not happen in single imputation (Nardo et al., 2008). The imputation of missing data will be divided in two groups in this work: one corresponds to the variables that had a monthly time measurement, i.e., the data points change from month to month (time series data), and the other one corresponds to cross sectional data, i.e., the data points are always the same for the whole period of study.

a. *Time series data:* with the software r to perform the imputation using the package "*ImputeTS*", that includes a collection of algorithms and tools tailored to impute values in time series data with a very user-friendly approach. It was used the function "*na_interpolation*" with the option "*linear*" that fits the best values for the missing points using linear relation within the range of data points. It is looked for both past and future values to estimate the missing value (Koech, 2022), which is an advantage.

b. *Cross-sectional data:* For variables with lower missing data (less than around 10%) it was used single imputation methods (cold-deck, hot-deck and mean imputation). For variables that missing data was higher (around 30%) it was used multiple imputation.

Statistical analysis:

After having the dataset without missing values, it was assessed *Pearson's* and *Spearman's* correlation coefficients between variables from the same dimension to understand correlation and causal relationships. This is done to guarantee that redundant variables are removed to avoid double counting and overweighting and leave only variables that bring new and non-redundant information into the model. It can be highlighted that exists a significative high correlation between variables 3.1.1 and 3.2.2; and between 3.1.2 and 3.2.2 with the *Pearson's* correlation coefficient. Therefore, variable 3.2.2 was bringing redundancy to the analysis and was excluded from the analysis for this reason.

Normalization:

To perform the BoD analysis, variables should be also normalized to make all variables comparable since they usually have different unit measurements. In literature exists several methods and can be highlighted three methods: *Min-Max*, *Z-score* and *Ranking*. In r software using the package "*Compind*", the package used to construct the CIs, there is one function "*normalise_ci*" that permits to normalize the variables prior to the formation of CIs. It was studied the viability of this three methods and *Ranking* method was the best option for the present dataset, delivering more consistent values for all variables and months of the analysis.

Weighting and aggregation:

The traditional Benefit-of-Doubt method using a weighting range restriction was used . According with Vidoli & Fusco (2018) this approach is advantageous since weights are endogenously determined by the observed performances and then, the benchmark is not based on theoretical bounds, but it's a linear combination of the observed best performances. It was imposed weight constraints (the range of weights should be between 5% and 95%) to ensure that all indicators are counted for the analysis. Therefore, as exposed before the model will form the overall composite indicator making a weighting sum of the indicators in a way that the weighting scheme maximizes the countries performance. Hence, since there is no sure about which weights to use, it is looked for the "benefit of the doubt" weights, in a way that the weights used makes the overall relative performances as high as possible. Lovell et al. (1995) defends that this flexibility for attributing weights and the aspect of different countries having different weighting scheme is not a problem, on the contrary, weights must vary between countries, over time, and across objectives. However, it is important to note that countries are still comparable since BoD makes the overall relative performances as high as possible for all countries.

4. Results

The results provided by BoD makes possible to analyze countries performance not only at group and dimensional level but also to have an overall measurement having all dimensions in play all at once to have an overall and global perspective. The analysis was focused mainly on dimensional level (CI 1; CI 2; CI 3; CI 4) and on global level (CF). It is also important to note that the analysis was done for each cluster separately and analogously since the results between clusters are not comparable as explained before.

4.1. Main results for cluster 1:

Table 4 summarizes the results for cluster 1 in each dimension and using the final CI that gives the overall perspective of countries' performances.

Qatar, Bahrain and Mauritius are the top three countries and that relative efficiencies were always more than 90%, which permits to say that they were very efficient since they present excellent results in all dimensions. On the other hand, Sudan, Nepal and

Papua New Guinea are the three countries revealing worst global efficiencies.

Table 4 - Summary of the results obtained with dimensional CIs and final CI for cluster 1(Source: The author)

	Cluster 1
CI 1: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Qatar, Seychelles, Malaysia / Egypt, Mexico, Sudan / 86,6% / 82% / 4
CI 2: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Brunei, Saudi Arabia, United Arab Emirates / Nepal, Sudan, Papua New Guinea / 72,5% / 48% / 2
CI 3: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Bahrain, Bangladesh, India / Bhutan, Fiji, Seychelles / 85,0% / 70% / 3
CI 4: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Mauritius, Qatar, United Arab Emirates / Philippines, Bangladesh, Sudan / 82,4% / 63% / 4
CF : Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Bahrain, Qatar, Mauritius / Sudan, Papua New Guinea, Nepal / 92,4% / 89% / 4

If in one hand COVID-19, and fragility in economy and finance dimensions are the ones that countries achieved better performances (and thus need less improvements), on the other hand access and quality of health and security and compliance in governance dimensions are the ones that show more discrepancies in the relative efficiencies' values. In contrast, efficiency average shows that countries' performances were similar in average and all of them quite efficient. Except for access and quality of health dimension that has a mean below efficiency standards (below 80%). This means that the worst results are achieved for this dimension. In general, seems that countries are offering a poor social sanitation and system and lacks healthcare resources (e.g., few doctors, nurses, beds). It is in this sense that improvements must be made with more urgency. The dimension that achieved better results is the COVID-19 dimension that permits to assume that in general the policies taken, and testing and vaccination processes went well.

Countries revealing worst performances should look for efficient and benchmark countries as "role models" to take insights and learn with them to improve.

It is also noted that results are better when used the final CI when compared to the results obtained with the dimensional CIs. This makes sense since BoD maximizes the performance for each DMU using the results obtained in the dimensional level to compute the final CI. The same is noted for the other clusters.

4.2. Main results for cluster 2:

Table 5 summarizes the results for cluster 2 in each dimension and using the final CI. Countries performing better are Finland, United Kingdom, Denmark, and Austria and worse are Ecuador, Suriname, Brazil, Peru and Colombia. In fact, Finland should be highlighted since it was the only country achieving fully efficiency in all months.

Table 5 - Summary of the results obtained with dimensional CIs and final CI for cluster 2 (Source: The author)

	Cluster 2
CI 1: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Singapore, Israel, Chile / Sweden, Trinidad and Tobago, Ecuador / 84,0% / 73% / 4
CI 2: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Norway, Switzerland, Germany / Ecuador, Suriname, Colombia / 77,2% / 65% / 1
CI 3: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Estonia, Finland, United Kingdom, New Zealand / Brazil, Ecuador, Cuba / 80,4% / 60% / 4
CI 4: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Austria, Netherlands, Iceland / Trinidad, and Tobago, Peru, Suriname / 87,9% / 77% / 6
CF : Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Finland, United Kingdom, Norway / Suriname, Colombia, Ecuador / 91,5% / 86% / 6

Countries showing poorer results should understand in which dimensions that their performance was lower in order to prioritize changes in these areas that have more urgency to be improved. Next, they should look for countries that were efficient in the respective dimension to change their behavior in that direction.

Only access and quality of health dimension measured by CI 2 is bellow efficiency. In general, countries are showing less efficiency in terms of managing healthcare resources (beds, medical doctors, nurses) which reflects in the healthcare provided to their population and/or lack of basic social sanitation and hygiene (depending on the country). It is in this way that countries should focus to make improvements with more urgency.

It is also for this dimension that the discrepancies in the relative efficiencies are bigger. This is a bad factor but easy to justify in this case when very "strong" countries like European countries, such as Austria or Germany, North American countries (USA and Canada), and East Asia and Pacific countries (Japan, South Korea, Australia) are "competing" with some not that evolved countries like Latin American countries (Colombia, Suriname, Ecuador, etc.) that are also present in this cluster.

In the other three dimensions, the performances seem to be very close with an averaged efficiency of around 84%. Considering these three dimensions seems that some countries need to pay more attention to their stability in economy and support for their households and in creating a more trustfully government to engage people to follow the measures taken, than in the policies taken to fight the pandemic since the distance between *efficiency average* and *efficient DMUS (%)* is lower.

Considering the average of the CF, countries performed very good in general but still exists a margin of improvement of 8,5%. It is very clear that European countries are the leading countries in general. North America and East Asia are also fairly good positioned and that Latin American countries appears at last with the worst overall performances. In general, seems that developed countries have more chances to have a better performance fighting a pandemic when compared with countries with less resources, which is natural. Therefore, the importance of preparedness, the existence of resources and capabilities for extreme cases like a pandemic that eventually ends up happening.

4.3. Main results for cluster 3:

Table 6 summarizes the results for cluster 3 in each dimension and using the final CI.

Countries performing better and that should serve as example of "*good practices*" are Hungary, Georgia, Oman, Cape Verde and South Africa; and worse are Somalia, Yemen, Angola, Afghanistan and Niger. Niger was the country revealing worst performance (global score=53,8%) which is not very surprising since it is one of the three countries with worst human development in the world.

It is possible to understand very clearly that 1) countries did not achieve the efficiency in almost all dimensions since the efficiency average is superior to 80% in just only one dimension (COVID-19 dimension); and that 2) the magnitude of the efficiencies' values dispersion is quite high, mainly for dimensions 2, 3 and 4 since the distance between *efficiency average* and *efficient DMUS (%)* is quite remarkable. This means that the performance of countries in these dimensions are in general bad and to aggravate the situation some countries have really bad efficiency in them.

Table 6 - Summary of the results obtained with dimensional CIs and final CI for cluster 3 (Source: The author)

	Cluster 3
CI 1: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Dominican Republic, Mongolia, Morocco / Senegal, Afghanistan, Yemen / 81,5% / 58% / 4
CI 2: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Hungary, Kazakhstan, Croatia / Somalia, Sierra Leone, Niger / 62,8% / 32% / 2
CI 3: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Georgia, Rwanda, Jordan / Somalia, Croatia, Madagascar / 67,3% / 31% / 2
CI 4: Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Hungary, Cape Verde, South Africa / Sierra Leone, Mali, Angola / 75,8% / 47% / 4
CF : Best 3 / Worst 3 / Efficiency Average / Efficient DMUs (%) / Benchmark DMUs (mean)	Georgia, Hungary, South Africa / Niger, Yemen, Afghanistan / 84,5% / 60% / 6

This permits to suggest that countries found below efficiency in these three dimensions, mainly in access and quality of health and in security and compliance in governance dimensions should look for efficient countries in these dimensions to improve their resources in medical facilities (beds, doctors, nurses), provide a more equal and effective access to a safe, hygienic and basic sanitation to population; a more stable, transparent and trustfully government since it helps to make people feel safe in adverse conditions like a pandemic and to respect and comply to the measures and policies impose; and finally, improve their stability and growth in economy and economic support for people.

Countries should understand in which dimensions efficiency was or not achieved in order to improve with more urgency the dimensions in need.

Considering the final CI that accounts for the overall performance, the efficiency average is now a little bit higher (84,5%) which means that the margin for improvement is still relatively high: 15,5%, in average.

Income turns again to show its influence since Yemen is a low-income least developed country and Oman a high-income developing country, that has more resources and thus, better capabilities to fight a pandemic. Therefore, the importance of preparedness, the existence of resources and capabilities for extreme cases like the origin of a new dangerous virus. Countries at the end of the table should look for important aspects that made top countries like Georgia or Hungary achieving so good results.

5. Conclusion

5.1. Main findings

It seems that countries, in general, achieved good levels of performance for COVID-19 dimension (CI 1>80%) showing that the anti-pandemic measures were appropriated and useful to control the disease in most of the cases. However, it is important to note that for cluster 3, only 58% of countries achieved the mentioned good results, which means that 34 countries need more attention and need for improvement since were under what is considered efficient.

Countries shown also a relatively good economic structure which can be reflected in resources for testing, vaccination, and healthcare in general and in the support for their households during the pandemic time (CI 4>80% for cluster 1 and 2; CI 4>75% for cluster 3); and a relatively transparent and trustfully government that influence the availability of people to comply with the measures imposed (CI 3>80%) for countries in cluster 1 and 2. Countries from cluster 3 have shown to be some steps behind (CI 3>70%).

The performance of countries is worse in access and quality of health dimension meaning that it is very urgent for countries to improve mainly their resources in medical facilities to assist population with health needs and the access to basic social sanitation and hygiene and to have better (CI 2>70% for cluster 1 and 2; CI 2>60% for cluster 3).

The final CI offers an integrated view of the several groups and dimensions which is great since it gives an overall measurement of countries' performance. In accordance with the previous paragraph, cluster 3 is the one showing the worst result even though the efficiency average is superior to 80% for all cluster because only 60% of cluster 3 countries are considered efficient at a rate of 80%, a much more reduced value when compared to cluster 1 and 2.

The goal to achieve a clear and comprehensive understanding about countries performance during COVID-19 pandemic is achieved since the created composite indicator permits to aggregate simple individual performance indicators into a performance measurement to evaluate areas, aspects, or dimensions one by one or in an overall or global perspective. This novel CI measures performance at a country level between geographies at a similar development status and statistically similar and is expected to monitor and provide a basis for benchmarking towards a better preparedness and ability to fight a pandemic. The usage of dimensions and groups not only helped for the construction of the final CI but also helps decision makers actors and other important stakeholders to understand which areas need more care and more urgent to be improved, thus, it is possible to refine the knowledge about what went wrong. Therefore, it is recommended to use this CI to identify the more fragile areas that are influencing the results and to compare to other benchmark countries that are efficient in order to extract insights to change behaviours in that direction. This CI has also the advantage of not looking for COVID-19 pandemic in a very limited way, other aspects that also influence the results of the policies taken such as economy, governance and healthcare are accounted. Thereby, the created CI can be used as tool by everyone that wants to understand better countries performance in a pandemic context.

5.2. Main limitations

The results that BoD provides is always associated with the data gathered and with its quality, with the sample constructed and indicators selected, the normalization, imputation methods applied, and with the weighting scheme attributed. Therefore, these mid-decisions will always affect and change the results obtained.

BoD does not accommodate negative indicators and for that reason a data translation had to be performed for indicator 1.3.2, which resulted in an increase in work.

Lack of scientific knowledge and expertise about benchmarking made the work more difficult to select variables and appropriate weighting scheme.

5.3. Future research

It could be assessed a robustness and sensitivity analysis to evaluate some uncertainty in the selection of the simple indicators and arrangements of them in groups and dimensions; to evaluate the imputation methods used; to evaluate the data normalization technique used; etc.

The work done could be proceed with a second-stage DEA method. The usage of second-stage DEA methodologies (e.g., Tobit regression) are always valuable since people can perceive the impact of the variables used on the efficiencies obtained or to analyse how other factors interact and influence the efficiencies.

Another suggestion is to form a panel of experts in benchmarking to attribute a different weighting scheme to the indicators used groups and dimensions to construct the final CI. COVID-19 dimension should be accounted with more importance than other dimensions in order to reflect a better measurement of countries' performance during the pandemic.

References

Aleta, A., Martin-Corral, D., y Piontti, A.P., Ajelli, M., & Litvinova, M., Chinazzi, M., Dean, N.E., Halloran, M.E., Longini Jr., Ira M., Merler, S., Pentland, A., Vespignani, A., Moro, E., & Moreno, Y. (2020). Modelling the impact of testing, contact tracing and household quarantine on second waves of COVID-19. *Nature Human Behaviour*, 4(9), 964–971

Baron, J. (2020). *EIA estimates that global petroleum liquids consumption dropped 9% in 2020.* Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=46596

Benedictow, O. (2005). *The Black Death: The Greatest Catastrophe Ever.* History Today. History Today. https://www.historytoday.com/archive/black-death-greatest-catastrophe-ever

Cherchye, L., Moesen, W., Rogge, N., & Puyenbroeck, T.V. (2007). An Introduction to "Benefit of the Doubt" Composite Indicators. *Social Indicators Research*, *82*(1), 111–145. https://doi.org/10.1007/s11205-006-9029-7

Christie, A., Brooks, J.T., Hicks, L.A., Sauber-Schatz, E.K., & Yoder, J.S., Honein, M.A. (2021). Guidance for Implementing COVID-19 Prevention Strategies in the Context of Varying Community Transmission Levels and Vaccination Coverage. *Morbidity and Mortality Weekly Report*, 70(30), 1044–1047. https://doi.org/10.15585/mmwr.mm7030e2

Doğan, M.İ., Özsoy, V.S. & Örkcü, H.H. (2021). Performance management of OECD countries on Covid-19 pandemic: a criticism using data envelopment analysis models. Journal of Facilities Management, 19(4), 479-499. https://doi.org/10.1108/JFM-01-2021-0005

El Zowalaty, M.E., Young, S.G., & Järhult, J.D. (2020). Environmental impact of the COVID-19 pandemic – a lesson for the future. *Infection Ecology & Epidemiology*, 10(1). https://doi.org/10.1080/20008686.2020.1768023

European Space Agency. (2020). Air pollution remains low as Europeans stay at home. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Air_pollution_remains_low_as_Europeans_stay_at_home

Härdle W.K., & Simar L. (2015). *Cluster Analysis: Applied Multivariate Statistical Analysis*. Springer Berlin Heidelberg, p. 385-405.

Imtyaz, A., Haleem, A., & Javaid, M. (2020). Analyzing governmental response to the COVID-19 pandemic. *Journal of Oral Biology and Craniofacial Research*. 10(4), 504-513, ISSN 2212-4268. https://doi.org/10.1016/j.jobcr.2020.08.005.

International Labor Organization. (2021). *COVID-19 and the world of work*. Seventh edition. https://www.ilo.org/wcmsp5/groups/public/@dgreports/@dcomm/documents/briefingnote/wcms_767028.pdf

Johnson R.A., & Wichern D.W. (2007). *Applied multivariate statistical analysis*. Upper Saddle River, N.J: Pearson Prentice Hall

Karagiannis, R. e Karagiannis, G. (2018). Intra-and inter-group composite indicators using the BoD model. *Socio-Economic Planning Sciences*, 61, 44-51.

Khan, I., Shah, D. & Shah, S.S. (2020). COVID-19 pandemic and its positive impacts on environment: an updated review. *Int. J. Environ. Sci. Technol*. 18, 521–530. https://doi.org/10.1007/s13762-020-03021-3

Kissler, S.M., Tedijanto, C., Goldstein, E., Grad, Y.H., & Lipsitch, M. (2020). Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. *Science*, 368(6493), 860–868. https://doi.org/10.1126/science.abb5793

Lovell, C.K., Pastor, J.T., & Turner, J.A. (1995). Measuring macroeconomic performance in the OECD: A comparison of European and non-European countries. *European Journal of Operational Research*, 87(3), 507–518

Madubueze, C.E., Dachollom, S., & Onwubuya, I.O. (2020). Controlling the spread of COVID-19: Optimal control analysis. *Computational and Mathematical methods in Medicine.* https://doi.org/10.1155/2020/6862516

Min, H., Lee, C.C., & Joo, S.-J. (2021). Assessing the efficiency of the Covid-19 control measures and public health policy in OECD countries from cultural perspectives. *Benchmarking: An International Journal*, ISSN: 1463-5771. https://doi.org/10.1108/BIJ-05-2021-0241

Mitchell, F., Nørreklit, H., Nørreklit, L., Cinquini, L., Koeppe, F., Magnacca, F., Mauro, S.G., Jakobsen, M., Korhonen, T., Laine, T., & Liboriussen, J.M. (2021). Evaluating performance management of COVID-19 reality in three European countries: a pragmatic constructivist study. *Accounting, Auditing and Accountability Journal*, 34(6), 1345-1361. https://doi.org/10.1108/AAAJ-08-2020-4778

Mohanta, K.K., Sharanappa, D.S., & Aggarwal, A. (2021). Efficiency analysis in the management of COVID-19 pandemic in India based on data envelopment analysis. *Current Research in Behavioral Sciences*, Vol. 2, 100063, ISSN 2666-5182. https://doi.org/10.1016/j.crbeha.2021.100063

Moutinho, S. (2021). *Brazilian town experiment shows mass vaccination can wipe out COVID-19*. Science. https://www.science.org/content/article/brazilian-town-experiment-shows-mass-vaccination-can-wipe-out-covid-19

Nardo, M., Saisana, M, Saltelli, A., Tarantola, S., Hoffman, A., & Giovannini, E. (2008). Handbook on Constructing Composite Indicators and User Guide. *OECD Statistics Working Papers.* https://doi.org/10.1787/533411815016

Patel, V.R., & Mehta, R.G. (2011). Performance Analysis of MK-means Clustering Algorithm with Normalization Approach. *2011 World Congress on Information and Communication Technologies*, pp. 974-979. https://doi.org/10.1109/WICT.2011.6141380

Pereira, M., Dinis, D., Ferreira, D.C., Figueira, J.R., & MARQUES, R.C. (2022). A network Data Envelopment Analysis to estimate nations' efficiency on the fight against SARS-CoV-2. *Expert Systems with Applications*. Vol. 210, pp. 118-362

Rosenwald, M.S. (2020). ***History's deadliest pandemics: Plague,*** *smallpox, flu, covid-19*. The Washington Post. https://www.washingtonpost.com/graphics/2020/local/retropolis/coronavirus-deadliest-pandemics/

Santacroce L., Charitos, I.A., & Del Prete, R. (2020). COVID-19 in Italy: An Overview from the First Case to Date. *Electronic Journal of General Medicine*, 17(6), 235. https://doi.org/10.29333/ejgm/7926.

United Nations. (2021). *Human Development Index*. Human Development Reports. https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

Verma, A.K., & Prakash, S. (2020). Impact of COVID-19 on Environment and Society. *Journal of Global Biosciences*, 9(5), 7352-7363. https://ssrn.com/abstract=3644567

Vidoli, F., & Fusco, E. (2018). Compind: Composite indicators functions based on frontiers in R (Compind package version 2.0). *CRAN*

Watts, J. (2020). *Climate crisis: in coronavirus lockdown, nature bounces back – but for how long?*. The Guardian. https://www.theguardian.com/world/2020/apr/09/climate-crisis-amid-coronavirus-lockdown-nature-bounces-back-but-for-how-long

Wells, C.R., Townsend, J.P., Pandey, A., Moghadas, S.M., Krieger, G., Singer, B., McDonald, R.H., Fitzpatrick, M.C., & Galvani, A.P. (2020). Optimal COVID-19 quarantine and testing strategies. *Nature Communications*, 12(1), 1–9. https://doi.org/10.1038/s41467-020-20742-8

World Health Organization. (2021). *Advice for the public on COVID-19*. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

Yang, F.C., Kao, R.H., Chen, Y.T., Ho, Y.F., Cho, C.C., & Huang, S.W. (2017). A common weight approach to construct composite indicators: The evaluation of fourteen emerging markets. *Social Indicators Research*, 137, 463–479. https://doi.org/10.1007/s11205-017-1603-7