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Article

Economic Development, Industrialization, and Poverty Eradication: A Benchmarking Analysis of Developing, Emerging, and Developed Countries

Afonso Delgado [1], **Paulo Caldas** [2,3,4,*] and **Miguel Varela** [2,5]

1 Instituto Superior Técnico, University of Lisbon, 1049-001 Lisboa, Portugal
2 Business and Economic School, Instituto Superior de Gestão, Av. Mal. Craveiro Lopes 2A, 1700-284 Lisbon, Portugal
3 CEG-IST, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais 1, 1040-001 Lisbon, Portugal
4 University of New England, Armidale NSW 2350, Australia
5 CEFAGE, Faculdade de Economia, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal
* For correspondence: paulo.caldas@isg.pt

Abstract This study utilizes benchmarking techniques to monitor productivity change in relation to Sustainable Development Goals (SDGs) 1, 8, and 9, addressing the challenges faced by countries in interpreting measures. The first SDG 1, "No Poverty", aims to completely eliminate poverty. The objective of SDG 8, "Decent Work and Economic Growth", is to foster comprehensive economic advancement. Finally, SDG 9, "Industry, Innovation, and Infrastructure", focuses on the creation of durable and sustainable infrastructure, as well as promoting innovation to drive economic progress. Economic development, job creation, wealth creation, and poverty eradication are crucial for sustainable development. However, there is no other study estimating the evolution of countries' performance in terms of these SDGs, whether countries have converged or not, and how each of these SDGs contributes to this performance development. This is the main goal of the present study, which compares 85 countries (2010–2020) from different profiles (developing, emerging, and developed) in terms of several SDG indicators. We applied data envelopment analysis (DEA) and Malmquist productivity indices that quantify changes in efficiency and technology over time to assess productivity dynamics and improvements. Results showed that emerging countries showed the highest productivity development, followed by developing countries and finally developed countries. The slower productivity development in developed countries indicates stagnation, allowing emerging countries to converge in terms of wealth creation, distribution, and poverty reduction.

Keywords sustainable development goals; economic development; poverty eradication; United Nations; data envelopment analysis; Malmquist index

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List of acronyms and symbols:

BoD	Benefit of Doubt
DEA	Data Envelopment Analysis
DMU	Decision-making unit
GDP	Gross Domestic Product
HDI	Human Development Index
$\boldsymbol{M}$	Malmquist index
MTC	Technology change
MTEC	Efficiency change
SDG	Sustainable Development Goal
SFA	Stochastic Frontier Analysis
TFP	Total Factor Productivity
UN	United Nations
$\boldsymbol{x}(\boldsymbol{X})$	Input
$\boldsymbol{y}(\boldsymbol{Y})$	Output
$\boldsymbol{\theta}$	Efficiency score
$\boldsymbol{\lambda}$	Intensity coefficient

1. Introduction

Economic development, industrialization, and poverty alleviation are three interrelated concepts that are essential for sustainable economic growth and improving people's lives [1]. Economic development refers to the process of improving the economic well-being of a country or region, usually measured by indicators such as GDP, per capita income, and poverty rates. Economic development can be achieved through various means, such as promoting international trade, attracting foreign investment, and implementing sound economic policies [2]. Industrialization is one of the most important drivers of economic development [3]. It involves the transition from an agrarian or rural economy to a more industrialized and urbanized economy characterized by the growth of manufacturing, trade, and services. Industrialization can create jobs, increase productivity, and generate income for individuals and the government [4]. Eradicating poverty is an important goal of economic development [5]. This involves reducing and eventually eliminating poverty, which is defined as a lack of access to basic needs such as food, shelter, and health care. Poverty eradication can be achieved through a combination of measures, such as providing social safety nets, improving access to education and health care, and creating economic opportunities. In summary, economic development, industrialization, and poverty reduction are interdependent concepts that are critical to improving people's lives and achieving sustainable economic growth. A well-designed and implemented development strategy that takes into account the needs and priorities of various stakeholders can help achieve these goals.

Eliminating poverty is a complicated, long-term objective that needs a multifaceted strategy to ensure economic sustainability. Education, (access to) health care, economic opportunities, social safety nets, infrastructure development, empowerment of women, minorities, marginalized groups, and sustainable development to promote environmental protection and address climate change can reduce poverty by ensuring sustainable economic growth that benefits all members of society, including future generations. One of the best ways to fight poverty is through education [6]. It gives individuals the skills and information to obtain better-paying professions, create enterprises, and enhance their economic prospects. Health care is crucial to poverty alleviation. Poor health may increase health care expenditures and income loss, worsening poverty. Health care that is inexpensive and accessible may enhance health and alleviate poverty. Providing employment, microfinance, and entrepreneurial programs may assist in eliminating poverty by helping individuals sustain themselves and their families. Cash transfers, food subsidies, and health care may assist the elderly, handicapped, and children get basic income and support. Roads, bridges, and water supplies may boost rural economies, increase market and service access, and alleviate poverty. Increasing upstream industry and employment seems to be the key to alleviating or eliminating downstream poverty. Now, nations must be monitored for economic progress, industrialization, and poverty elimination.

All these aspects are difficult to measure and organize. To this end, there is a fundamental tool that countries should use to measure and monitor their behavior at several specific points of their sustainable development [7]. This tool created by the UN corresponds to the 17 SDGs of the 2030 agenda, after the introduction of the Millennium Development Goals (2000–2015). This study considers SDGs 1, 8, and 9. SDG 1, often known as "No Poverty", focuses on the urgent need of eliminating severe poverty on a worldwide scale. Its objective is to guarantee that every person has access to the fundamental requirements for a life of dignity. SDG 8, also known as "Decent Work and Economic Growth", aims to advance long-lasting and comprehensive economic expansion, encourage complete and fruitful employment, and guarantee satisfactory working conditions for everyone. It highlights the need of establishing fair work prospects and tackling the difficulties associated with informal employment. SDG 9, often known as "Industry, Innovation, and Infrastructure", emphasizes the significance of constructing robust infrastructure, advocating for equitable and sustainable industrialization, and nurturing innovation. The objective is to improve connection, especially in underdeveloped areas, and promote the use of technical innovations for economic progress. The pursuit of sustainable development involves three interconnected goals: eradicating poverty, achieving inclusive economic growth with decent work opportunities, and developing resilient infrastructure and promoting innovation. These goals collectively form a holistic and sustainable framework for global progress. These three indeed seem to be the ones explaining better the economic growth of countries and as such their classification into developing, emerging, and developed. It is, thus, essential to understand whether developing and emerging countries are approaching the developed ones in terms of poverty eradication, decent work, industrialization and innovation, and ultimately economic growth. In other words, one must test whether the former are becoming the latter or not.

Figure 1 portrays the relationship between SDGs 1, 8, and 9. The achievement of SDGs 1 and 8 is closely interconnected since the attainment of decent employment directly helps to the decrease of poverty. Promoting economic development via the creation of productive work opportunities is an effective means of lifting communities out of poverty, while also promoting resilience and sustainability. In addition, the advancement of infrastructure development fosters effectiveness and durability, in line with the concepts of both Sustainable Development Goal 8 and Sustainable Development Goal 9. The three objectives of eliminating poverty (SDG 1), creating decent employment (SDG 8), and promoting sustainable industrialization and innovation (SDG 9) are interrelated. Eliminating poverty is made possible by the establishment of decent work, which, in turn, depends on sustainable industrialization and innovation to assure long-term economic growth and development. This holistic approach demonstrates the interconnectedness of these objectives in tackling worldwide difficulties and advocating for a comprehensive plan for sustainable development. That way, one can create wealth and distribute it equitably, thus contributing to the eradication of poverty as well as to social protection, justice, and resilience against extreme events caused by climate change. It is worth mentioning that the poorest populations are usually the most affected by this kind of event [8], as happened recently in Nigeria (2022), where the worst floods in a decade have displaced over a million people, claims the World Economic Forum. These SDGs are also very much related to the daily lives and well-being of people, as concluded by Arriani & Chotib [9].

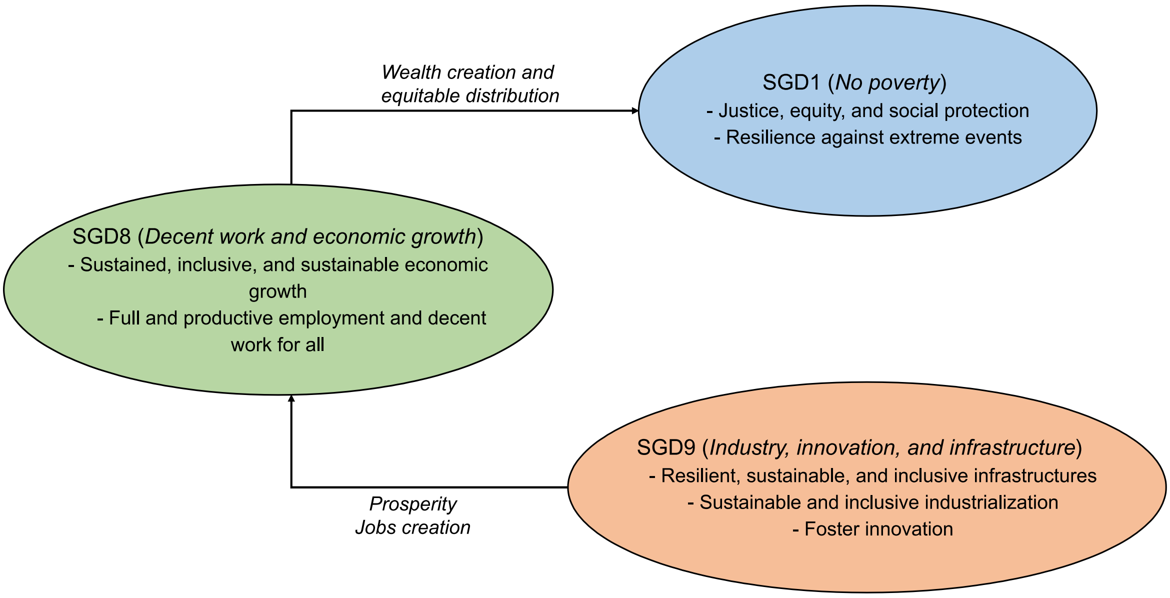


Figure 1. Relationship between Sustainable Development Goals 1, 8, and 9.

The 17 SDGs formulated by the UN account for 169 targets and 232 indicators to monitor the sustainability evolution of each country. Through the indicators associated with each SDG, countries can benchmark themselves against the best practices worldwide and guide towards more sustainable practices [10]. Jacob [11] clearly underlines the need to strengthen the performance measurement system attached to the 2030 agenda for sustainable development and the associated SDGs. Thus, SDG implementation requires a performance monitoring system based on fully known and accessible data. After collecting this data, it might be challenging to evaluate the findings and define the relative ranking position since multiple indicators sometimes provide inconsistent results. It is difficult to determine if developing and emerging nations are approaching developed ones or whether the gap has grown. Dynamic performance analysis shows its relevance. Thus, rather than analyzing nations' static performance in a particular moment, which may be uncommon, we should analyze their dynamic performance development or productivity change. Solving this issue may show nations their route, allowing them to decide on actions and policies in case of undesirable changes.

To evaluate the dynamic performance evolution of countries regarding poverty eradication, decent and properly paid jobs creation, industry and innovation, and economic growth, we resort to solid benchmarking techniques, namely the so-called BoD [12,13] integrated with the Malmquist index [14–16]. This study significantly contributes to the literature by introducing a novel approach to monitoring and benchmarking countries' performance in achieving SDGs 1, 8, and 9. The novelty lies in the application of BoD and Malmquist productivity indices to estimate the evolution of countries' performance over the period 2010–2020. While many studies have addressed individual SDGs, this research uniquely combines benchmarking techniques to comprehensively assess the interconnected goals of those three SDGs. The study's importance lies in its holistic examination of the synergies and trade-offs between these goals, shedding light on whether countries have converged in their efforts and how each SDG contributes to overall performance development. By including a diverse set of 85 countries with different development profiles, the research offers a global perspective, providing valuable insights for policymakers and stakeholders striving to enhance sustainable development strategies worldwide.

2. Literature Review

A lot has been discussed in the literature about the UN 2030 agenda, the SDGs, and their usefulness in improving people's quality of life and the world's sustainability. Among the 17 goals and their numerous indicators, it is possible to find out many synergies, but also some trade-offs. In other words, while some dimensions seem to contribute positively to the improvement of others, they may also have a negative impact on a few. For instance, Bali Swain & Ranganathan [17] identify 66 negative interactions or trade-offs and 238 positive interactions or synergies out of a total of 316 interactions. Another problem raised by Dang & Serajuddin [18] is the scarcity of data to monitor the progress of the SDGs. In view of that, the authors propose that the relevant international organizations interested in data collection should collaborate more with national organizations in order to disseminate these data. This also points to the need to further refine the indicators of each SDG despite its difficulty, because the interpretation of targets may lead to different conclusions by various assessment methods.

Even though the existence of such inconsistencies in the UN 2030 agenda, the implementation of the SDGs is still quite important both for society and companies' well-being [19]. Sustainability holds a prominent position in the political, economic, and social panorama, being a reason for debate in all areas of society [20].

According to Barbier & Burgess [21], there was a generalized improvement worldwide regarding most of the SDG indicators from 2000 to 2016. However, the same authors identified a considerable drop in performance concerning SDGs 8 and 9. What stood out more positively in both country profiles (high-income and low-income countries) was precisely SDG 1. This one, according to Leal Filho et al. [22], is quite important, in the sense that the achievement of any SDG goals and targets is at risk if not given due attention to this SDG 1. For the same authors, the main threats to this SDG are climate change and, more recently, the COVID-19 pandemic. Since SDG 1 is more linked to poorer countries such as developing ones, Maksimov et al. [23] suggest that for these nations the existence of small and medium enterprises is critical, as they are the ones that sell and employ, allowing the population to retain reasonable wages above the poverty line.

One of the essential tools that countries should adopt to be effective in achieving their goals in relation to the SDGs is the strengthening of international partnerships, but there is a disparity in the division of these international partnerships in the world, as stated by Blicharska et al. [24]. As lower-income countries have fewer partnerships, mainly because of their lower resource capacity, this results in greater difficulty for their development as they have less external aid. The same authors also state that developed countries have more interest in partnerships related to SDG 8 mainly with other developed countries, not with emerging nor developing ones.

To achieve the goals proposed by SDGs 8 and 9, investment in technological innovation and measures to transform the economy are needed. However, Chen et al. [25] state that there are problems, mainly in developing and emerging countries, related to economic leakages. For instance, the informal sector may have a negative impact on the association of innovation and energy efficiency; additionally, there may exist a lack of technological diffusion in these countries. The aforementioned authors mention that countries with higher levels of grey economy, such as developing countries, have lower energy consumption per unit of production due to the informal sector being less energy intensive. In other words, the larger the informal economy, the lower the energy consumption and the overall economy.

The main regions of the countries that should properly implement the sustainable goals of the SDGs are the urban regions as these represent the majority of the population. According to Wang et al. [26], SDGs 2, 6, 7, 14, and 15 are essential for human survival, while SDGs 1, 3, 4, 5, 8, 10, and 16 cover key aspects of human well-being, and finally SDGs 9, 11, 12, 13, and 17 concern sustainable governance. Their framework was complemented with the DEA methodology and applied to 287 Chinese cities observed between 1985 and 2015. Those authors conclude that China's urban sustainability has been improving, with large cities exhibiting greater improvement than medium and small cities. However, there are dimensions well below expectation, namely the population's health and standard of living. To achieve the SDG targets sustainable cities should implement the construction of efficient buildings, which should contribute a lot to SDGs 12, 7, 3, and 11, but less to SDGs 9, 15, and 13 and are not connected with the targets of SDGs 1, 2, and 5 [27].

Africa is the continent with the largest number of underdeveloped and poorer countries, where their economies are less linked to the industrial sector and more to the agricultural sector. Therefore, it is essential to conduct studies to identify the priority areas for improvement in this sector and the countries' progress in it. Nhemachena et al. [28] point out that agriculture is the driver of prosperity, economic growth, livelihoods, and, in turn, poverty eradication in Africa. To improve the sector, one must improve progress towards the SDGs with increased investment of more resources in the sector and implementation, monitoring, and evaluation of regional and continental commitments in the agricultural sector. In southern Africa, Botswana, Angola, Namibia, Zambia, and South Africa have achieved the best performance scores, as mentioned by those authors.

Global progress towards meeting the goals of the UN 2030 Agenda has been considerably delayed in the last two years due to the COVID-19 pandemic. This led to stagnation and recession in several sectors worldwide, according to Odey et al. [29], for whom Africa was the most affected continent on the way to achieving the SDGs. For these authors, Ghana, South Sudan, Rwanda, Ethiopia, and Ivory Coast were present in the group of countries with the fastest economic growth before the pandemic, but afterward, it considerably slowed down, leading Africa to lag further behind in socioeconomic development, compared with other continents.

According to the previous studies, it is possible to assess that the analysis of the evolution of countries regarding the various SDGs is quite important, in the sense that it allows to understand which are the strengths and weaknesses of these entities toward their overall sustainability. Although there are some inconsistencies and problems with the SDGs indicators, such as trade-offs between them and the data scarcity for some observations, the benchmarking analysis between groups of country profiles remains extremely necessary, but the existing one is still occasional. Unlike the studies above, this study focuses specifically on SDGs 1, 8, and 9, while using a DEA model and the Malmquist index to visualize the productivity evolution of the various countries belonging to the three different profile groups. This division of countries into profile groups makes it possible to conduct a fair evaluation (more homogeneous comparison), helping us to understand which of these groups of countries has obtained the best productivity evolution relative to those SDGs. This analysis will also include the year 2020, a rather abnormal period due to the COVID-19 pandemic.

3. Models

This study is based on benchmarking techniques, which is a concept widely used nowadays. Benchmarking is a procedure of constant comparison of comparable entities, like countries, based on their achievements measured through various dimensions, like the indicators of each SDG. There are many benchmarking models, but we can cluster them into two: average benchmarking models and frontier benchmarking models [30].

Average benchmarking models are based on average values such as the average costs of a group of companies, through the TFP used in the Malmquist, Hicks-Moorsteen, Törnqvist, and Fischer productivity indices. Regarding frontier benchmarking models, they construct a frontier where the best practices are positioned, and the distance to the frontier reflects how low the performance levels are and how much the evaluated dimensions need to improve. Examples of frontier models include but are not limited to, corrected least squares, SFA, and DEA. Meanwhile, it is possible to integrate both the average and frontier benchmarking models. For instance, it is common to merge the Malmquit index with DEA, and many examples can be found in the literature, including Li et al. [31], Wang [32], Huang et al. [33], and Tachega et al. [34].

SFA relies on details of a stochastic nature in predicting the efficient frontier, which can be either a cost function or a production function. It means that it basically constructs an association model like in ordinary least squares, relating a dependent variable (e.g., total costs) with some independent variables (e.g., produced goods or services). This model requires a likelihood function to guide the distribution of stochastic errors and formal specifications for the efficiency frontier. However, wrong specifications about the frontier and the error distribution can bias the final performance score. Because of the nature of data regarding SDG indicators, SFA cannot be used for this study's purposes [35].

In opposition to SFA, DEA is strictly nonparametric, which is to say that no assumption about the frontier shape has to be made. Instead, DEA is based on the concepts of linear programming to construct the frontier empirically and to project the inefficient entities in that frontier. In short, the frontier constructed by DEA is piecewise linear, and any inefficient entity is dominated by the former. Different from SFA, DEA can use several inputs and several outputs. These features have decisively contributed to the DEA's popularity among researchers. However, the model is not foolproof, exhibiting some disadvantages. Perhaps the most critical one is the sensitivity to the imperfect knowledge of data (e.g., data noise or gaps) and the relation between the sample's size and the number of variables used to model the problem. The latter is popularly known as the *curse of dimensionality* and it can be preventable if a large sample is used. In opposition, the former is more complicated to solve, often demanding the exploitation of complex statistical procedures to replace the imperfectly known quantities or intricate stochastic mathematical models to model that imperfect knowledge [36]. Notwithstanding these caveats or difficulties, and according to the literature, DEA can outperform its main competitors because of its nonparametric nature and all the associated properties [35].

Let $\boldsymbol{x}_0$ be the set of m inputs used by an entity 0 (a country, for instance) to produce a set of s outputs, generically denoted by $\boldsymbol{y}_0$. The complete sets of inputs used and outputs produced by all entities under analysis are, respectively, denoted by $\boldsymbol{X}$ and $\boldsymbol{Y}$. DEA searches for an efficiency score, $\boldsymbol{\theta}_0$, associated with the entity 0, by running a linear model, as follows:

$$\begin{aligned} &\boldsymbol{\theta}_0 = \max \boldsymbol{\theta} \\ &\text{s.t.} \\ &\boldsymbol{\lambda}^\top \boldsymbol{X} \leq \boldsymbol{x}_0 \\ &\boldsymbol{\lambda}^\top \boldsymbol{Y} \geq \boldsymbol{\theta} \cdot \boldsymbol{y}_0 \\ &\boldsymbol{\lambda} \geq 0 \end{aligned} \tag{1}$$

where $\boldsymbol{\lambda}$ is a vector of intensities. In this model, the output-orientation was assumed, which is to say that the inputs are held constant, while the outputs are maximized as much as possible. The model in Equation (1) assumes constant returns to scale, but if another assumption has to be made a new constraint can be added. Particularly, the variable returns to scale, commonly found in the literature, imposes the additional constraint $\mathbf{1}^\top \boldsymbol{\lambda} = 1$. The efficiency score obtained via Equation (1) will be larger than or equal to 1: the equality is achieved for the technically efficient entities, while the difference between the score and the unit reveals how much of the outputs need to be increased (proportionally) to reach plain efficiency.

BoD is a DEA-based model that aggregates a set of key performance indicators into a single synthetic or composite indicator measuring the overall performance of a country [37]. In view of that, each group of countries is associated with a frontier where the top performers or benchmarks are positioned; any country dominated or enveloped by this frontier cannot be a benchmark and there is room for improvement [38]. Multipliers, often called weights, associated with each indicator are optimal in the sense that they are computed using an optimization (linear programming) model whose objective is to find the maximum possible performance score [39]. In other words, BoD is a benevolent or optimistic model, and it is not possible to find a set of multipliers or weights resulting in a higher performance score and leaving no room for complaints about the achieved results [40]. If a country has a small score, typically lower than 1 (or 100), then it is certain that it cannot be a benchmark, being outperformed by other(s). Mathematically, it corresponds to solving Equation (1) with indicators in the place of the outputs, while assuming inputs as unitary.

BoD can be easily joined to the Malmquist index [41], thus allowing the analysis of productivity change in different periods [42]. Using this tool, it is possible to collect results of productivity change for the various countries. Individual results provide a comparison between them, identifying the countries and profile groups (developed, emerging, and developing countries) that stood out the most. Using the Malmquist index, it is not only possible to disclose whether countries are approaching their own frontier but also whether frontiers containing the best practices of each group are approaching each other. Therefore, it becomes clear that this is a useful tool to answer the research question associated with our main goal.

Roughly speaking, the Malmquist index measures the relationship between the distances relative to two different efficiency frontiers [43]. In short, an entity is observed in two moments and these observations are projected twice each: once in the frontier associated with that very moment, and once in the frontier associated with the other moment. These projections follow the mathematical model of BoD (or DEA)—the interested reader is referred to Ferreira & Marques [44] for details. The Malmquist index, $\boldsymbol{M}$, is, then, a comparison of these projections through some ratios, such that if $\boldsymbol{M} > 1$ (< 1), then there was a productivity increase (decrease) in the period comprising both moments. Now, let us consider that the entity 0 is observed in the moment t and projected in the frontier estimated with the data of moment τ (which can be smaller than, equal to, or larger than t). In that case, the efficiency score is estimated with the following linear program:

$$\begin{aligned} &\boldsymbol{\theta}_0^{t,\tau} = \max \boldsymbol{\theta} \\ &\text{s. t.} \\ &\boldsymbol{\mu}^\top \boldsymbol{X}^\tau \leq \boldsymbol{x}_0^t \\ &\boldsymbol{\mu}^\top \boldsymbol{Y}^\tau \geq \theta \cdot \boldsymbol{y}_0^t \\ &\boldsymbol{\mu} \geq 0 \end{aligned} \tag{2}$$

where $\boldsymbol{\mu}$ denotes a vector of intensities. This way, the Malmquist index can be written (and decomposed) as follows:

$$\boldsymbol{M}_0^{t,\tau} = \underbrace{\frac{\boldsymbol{\theta}_0^{\tau,\tau}}{\boldsymbol{\theta}_0^{t,t}}}_{MTEC} \cdot \underbrace{\sqrt{\frac{\boldsymbol{\theta}_0^{\tau,t}}{\boldsymbol{\theta}_0^{\tau,\tau}} \cdot \frac{\boldsymbol{\theta}_0^{t,t}}{\boldsymbol{\theta}_0^{t,\tau}}}}_{MTC} \tag{3}$$

In fact, $\boldsymbol{M}$ can be endlessly decomposed into sub-indices reflecting the components of productivity change [41]. Two remarkable ones are the $MTEC$, and the MTC. While the former expresses whether the observed entity has approached or driven away from the efficiency frontier, the latter reveals if there was any technology improvement or not, namely through shifts in benchmarks that compose the frontier (and frontier shifts, accordingly). If $MTEC > 1$ (< 1), then the entity improved (worsened) its efficiency, getting closer to the frontier; if $MTC > 1$ (< 1), then the benchmarks present in the frontier increased (decreased) their own productivity, pulling the frontier towards a technological improvement. Since $\boldsymbol{M} = MTEC \times MTC$, should these two sub-indices be larger than one, the Malmquist index will identify unequivocally productivity enhancement for that entity.

4. Case Study

4.1. Sample

In economic growth terms, it is common to split countries into developing, emerging, and developed, and such a classification depends on the industry and the human development levels. The latter, for instance, is frequently quantified via the HDI, which, in turn, results from dimensions like income, education, and life expectancy [45]. Of course, these are tightly associated with poverty or wealth [46]. Developing countries comprise all countries with a low standard of living, a still developing level of industrialization, and a low HDI [47]. The emerging ones in general can no longer be considered developing, due to their HDI and average standard of living and developing industrial sector, except for some already with a strong industry. Finally, those countries considered developed have a high HDI and standard of living, with low poverty rates and high levels of industrialization. Whether developing and emerging countries are approaching or moving away from their developed counterparts regarding their performance in economic development, industrialization, and poverty eradication is a question that has no answer in the literature. Likewise, it is worth to know if developed countries have improved or worsened their performance with time.

This study is composed of 85 DMUs, consisting of several countries grouped into three different country profile groups (developed, emerging, and developing), and 25 different geographic regions. The sample contains 41 developing countries, 11 emerging countries, and 33 developed countries consisting. The division of these profile groups allows us the creation of three independent and distinctive evolution frontiers, leading to the opportunity to understand the evolution towards sustainability of each group and to verify whether the speed of such evolution is decreasing or accelerating. Figure 2 portrays the selected countries.

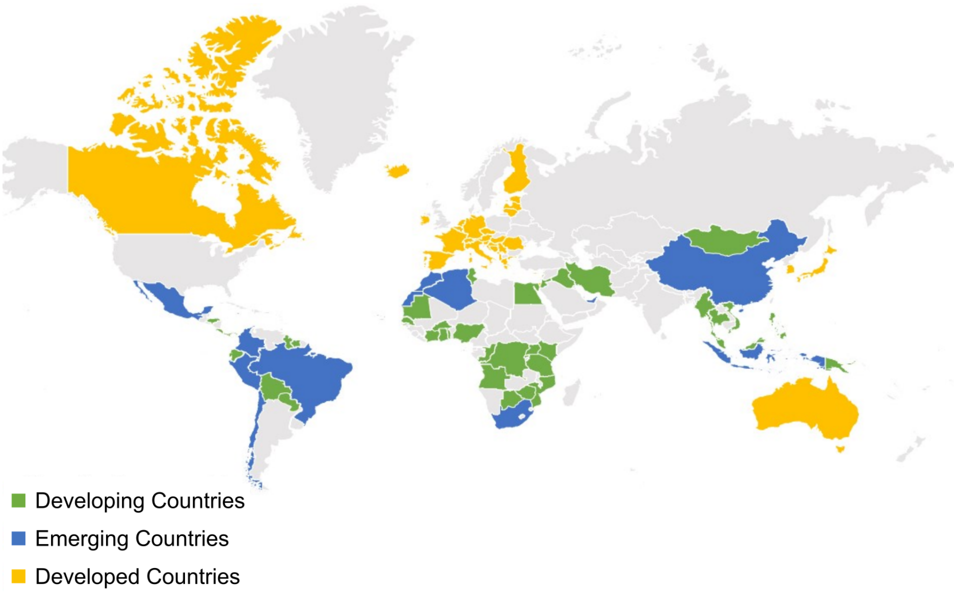


Figure 2. World map indicating the countries present in the study and their division per profile group.

4.2. Variables

The analysis of productivity change is also composed of several indicators used to monitor each country's sustainability regarding SDGs 1, 8, and 9. Table 1 presents the considered performance indicators, whose selection was strictly based on what the UN considers to be the most influential to describe the performance in terms of those SDGs, and also on the data availability. The absence of any key performance indicator was mostly because of meaningful data missing, such that estimating gaps could introduce serious bias in results. Data were collected directly from the UN database (publicly available), considering the period 2010–2020.

In Table 1 the polarity of each indicator is shown, meaning that we have desirable and undesirable outputs (or those with positive and negative polarity, respectively). Undesirable indicators are understood as those that present negative aspects that must be fought against, such as the unemployment rate or CO_2 emissions. Desirable indicators represent and value positive aspects on the path towards sustainable development, such as access to basic services and the annual GDP growth rate. Because of these different polarities and the existence of non-discretionary (or undesirable) indicators, we used a transformation of data as follows:

$$\hat{\boldsymbol{y}}_r = \begin{cases} \dfrac{\boldsymbol{y}_r - \min \boldsymbol{y}_r}{\max \boldsymbol{y}_r - \min \boldsymbol{y}_r} \cdot 100 + \varepsilon, \text{if the indicator is desirable} \\ \dfrac{\max \boldsymbol{y}_r - \boldsymbol{y}_r}{\max \boldsymbol{y}_r - \min \boldsymbol{y}_r} \cdot 100 + \varepsilon, \text{otherwise} \end{cases} \tag{4}$$

where $\hat{\boldsymbol{y}}_r$ is used in Equations (1)–(3) instead of $\boldsymbol{y}_r$, and ε is a very small quantity (say 0.01) used to avoid the variable assuming null values (problematic in DEA applications). This way, all variables get a positive polarity and can be treated like outputs with a unitary input. For the cases of variables with possible negative entries (e.g., indicators 8.1.1 and 8.2.1), we shift them (by adding them to the minimum value) so they only have non-negative values. Afterward, we apply Equation (4) for rescaling them. Interestingly, all transformed indicators have the same range and, as such, the same discriminatory power (their magnitudes have no impact on the final result), which is desirable in performance assessment [48].

Table 1. Description of SDG targets and units of measurement of indicators used.

SDG	Goal	Description of the Goal	Indicator	Description of the Indicator	Direction
1	1.1	Eradicate extreme poverty	1.1.1	Proportion of individuals living below the International Poverty Line of US$1.90/day	⇩
	1.4	Equal rights to property, basic services, technology, and economic resources	1.4.1	Proportion of population living in households with access to electricity	⇧
8	8.1	Sustainable Economic Growth	8.1.1	Annual Gross Domestic Product (GDP) growth	⇧
	8.2	Diversify, innovate and upgrade for economic productivity	8.2.1	Annual GDP growth per person employed	⇧
	8.4	Improve resource efficiency in consumption and production	8.4.2	Domestic material consumption in ton per capita	⇩
	8.5	Full employment and decent work with equal pay	8.5.2	Unemployment rate	⇩
	8.10	Universal access to banking, insurance and financial services	8.10.1.a	Number of commercial bank branches per 100,000 adults	⇧
			8.10.1.b	Number of ATMs per 100,000 adults	⇧
9	9.1	Developing sustainable, resilient and inclusive infrastructure	9.1.2	Air transport, cargo in million ton - Km	⇧
	9.2	Promoting inclusive and sustainable industrialization	9.2.1	Percentage of manufacturing value added GDP	⇧
			9.2.2	Percentage of employees in industry	⇧
	9.4	Upgrade all industries and infrastructure to sustainability	9.4.1	CO_2 emissions (ton) per capita.	⇩
	9.c	Universal access to information and communication technology	9.c.1	Proportion of population covered by a mobile network	⇧

Note: ⇧ positive polarity (the higher, the better); ⇩ negative polarity (the lower, the better).

Because of data availability, we considered three main versions for the analysis (for the sake of sensitivity analysis), and it is possible to verify in Figure 3. In short, the three versions differ in terms of the amount of indicators used in each version. This is because there is a trade-off between the data availability and the time span that we would like to use in this study. Of course, an analysis covering a broader timeframe leads to fewer indicators. The first version is the most complete in terms of the number of indicators, the second version is an intermediate in the matter of that same number, while the third is the smallest version at this same point. Version 1 consists of using most of the indicators considering a period of analysis from 2010 to 2017. Indeed, indicators 8.4.2 and 9.2.2 have no data for 2018, 2019 and 2020. Different from version 1, version 2 disregarded these two indicators from the analysis, meaning that we could extend our analysis to the period 2010–2019. Finally, the last and smallest version in terms of the number of indicators is the third version. With respect to version 2, this list does not include SDG 1 neither the indicators 8.2.1, 8.10.1.a, 8.10.1.b, 9.1.2 and 9.c.1. The low number of indicators in this version results from the fact that the data associated with these indicators are absent for 2020 (a year featured by the COVID-19 pandemic). Despite having the lowest number of indicators, it is the version that covers the longest period of analysis from 2010 to 2020. The use of several versions offers flexibility, enabling decision-makers to choose versions that are in line with individual requirements. The ability to adjust the period and indicators allows for the accommodation of diverse research aims. Additionally, it reduces risks by providing backup options and enables seamless adjustment to changing data accessibility. Ensuring consistency proves to be difficult when dealing with different versions, which increases the chance of reaching different results. The resource intensity is heightened as a result of the need for continuous data validation for every iteration. The presence of complexity might impede comprehension, possibly resulting in decision paralysis. The absence of coherence in providing a consolidated storyline might hinder stakeholders' overall understanding. The efficacy of the technique relies heavily on the careful balancing of these aspects.

Version 1	SDG 1		SDG 8						SDG 9							
	1.1	1.4	8.1	8.2	8.4	8.5	8.10		9.1		9.2		9.4		9.c	
	1.1.1 (%)	1.4.1 (%)	8.1.1 (%)	8.2.1 (%)	8.4.2 (ton/capita)	8.5.2 (%)	8.10.1.a (Bank Branches/100000 adults)	8.10.1.b (ATMs/100000 adults)	9.1.2 (nº air passenger/1000 hab)	9.1.2 (Mton-km)	9.2.1 (%)	9.2.2 (%)	9.4.1 (t/cap)	9.4.1 (ton/1000 hab)	9.c.1 (nº/100 persons)	9.c.1 (%)

Version 2	SDG 1		SDG 8					SDG 9						
	1.1	1.4	8.1	8.2	8.5	8.10		9.1		9.2	9.4		9.c	
	1.1.1 (%)	1.4.1 (%)	8.1.1 (%)	8.2.1 (%)	8.5.2 (%)	8.10.1.a (Bank Branches/100000 adults)	8.10.1.b (ATMs/100000 adults)	9.1.2 (nº air passenger/1000 hab)	9.1.2 (Mton-km)	9.2.1 (%)	9.4.1 (t/cap)	9.4.1 (ton/1000 hab)	9.c.1 (nº/100 persons)	9.c.1 (%)

Version 3	SDG 8		SDG 9		
	8.1	8.5	9.2	9.4	
	8.1.1 (%)	8.5.2 (%)	9.2.1 (%)	9.4.1 (t/cap)	9.4.1 (ton/1000 hab)

Figure 3. Identification of the indicators used for each version.

5. Results and Discussion

To avoid a too large paper, in this section, we present the main results associated with version 2, although similarities and differences between this and the other versions are henceforth highlighted.

5.1. Positive and Negative References

This first analysis began by verifying the five best and five worst developing, emerging, and developed countries in terms of productivity evolution regarding the set of considered indicators. Three tables (Tables 2–4) were built for each of the versions, making it possible to observe the five best and five worst countries both in the biennial comparison and in the comparison between the first year and the last year for each country profile group. The biennial evaluation between successive years is represented from M1 to M9, where M1 refers to the Malmquist index for 2010–2011 and M9 for 2018–2019. The cumulative Malmquist index (as well as its decomposition) is also presented in the last three columns of each table. These results allow us to rank countries considering the whole period.

In this version, the values did not vary much from the values in the first version, both for developing, emerging, and developed countries. The values and ranks of the countries from M1 to M7 have not changed significantly, except for only a handful of cases. These slight changes between M1 and M7 are due only to the difference in the number of indicators considered. Notably, a model with more variables (like in version 1) is less restrictive, exhibiting in general a higher average performance compared with a more restrictive model (like in version 2).

For developing countries in M8, the Democratic Republic of Congo had the highest prosperity in its productivity change with a Malmquist index of 2.1294, followed by Rwanda with 1.9041. These values mean that, for instance, Rwanda increased its overall productivity by 90.41% in a single period. The success of the Democratic Republic of Congo in this period is due to improvements in some indicators such as reductions in the proportion of individuals living below the international poverty line and the unemployment rate from 72.65% to 71.61% and 4.26% to 4.18% respectively. Also, the country increased the most desirable indicators such as the proportion of the population living in households with access to electricity from 18.01% to 18.75%, and the annual GDP growth from 0.4% to 2.46%. However, between M1 and M9 the country that stood out on the positive side was Nigeria, for its year-on-year consistency of improvements in productivity developments. Only in M4 did Nigeria have a Malmquist index value below one, 0.9195, and belonged five times to the group of the top five countries, and in M8 it was not part of this group but was quite close with a value of 1.1737.

Regarding emerging countries, in the periods M8 and M9 there were not very discrepant values from the expected, being these very close to the ones observed in the previous periods. Between M1 and M9, China and the United Arab Emirates remained the most prominent countries in relation to the first version, but China's value rose considerably, which shows that the two extra years analyzed and the decrease in two indicators benefited China. In the opposite case, for the period between 2010 and 2019, Brazil ceased to be the worst country in terms of productivity.

Regarding developed countries, it is possible to observe that the elimination of the two indicators resulted in a slight reduction in the Malmquist index result for most countries in some periods up to M7 in comparison with the first version. An example of this reduction is Romania, which in M1 of the first version had a Malmquist index value of 1.3354 and in the second version,

Table 2. Identification of the top five and bottom five countries for the developing group, complementing the Malmquist index results for version 2.

	DMU	M1	DMU	M2	DMU	M3	DMU	M4	DMU	M5	DMU	M6	DMU	M7	DMU	M8	DMU	M9	DMU	M1–M9	MTEC1–MTEC9	MTC1–MTC9
Best 5 developing countries	Uganda	1.305	Thailand	1.794	Paraguay	1.719	Papua New Guinea	1.628	Thailand	1.466	Iraq	1.849	Democratic Republic of Congo	1.481	Democratic Republic of Congo	2.129	Nigeria	1.189	Nigeria	4.131	1.586	2.605
	Panama	1.268	Iraq	1.600	Togo	1.345	Malaysia	1.309	Côte d'Ivoire	1.277	Iran	1.824	Nigeria	1.289	Rwanda	1.904	Tanzania	1.186	Angola	3.699	1.957	1.891
	Togo	1.263	Zimbabwe	1.442	Nigeria	1.190	Myanmar	1.212	Angola	1.267	Tanzania	1.362	Angola	1.284	Vietnam	1.299	Jamaica	1.176	Tanzania	3.172	1.000	3.172
	Tanzania	1.184	Myanmar	1.385	Lebanon	1.177	Rwanda	1.212	Nigeria	1.263	Nigeria	1.318	Myanmar	1.283	Angola	1.251	Angola	1.168	Uganda	2.006	1.000	2.006
	Bolivia	1.174	Democratic Republic of Congo	1.269	Myanmar	1.169	Uganda	1.180	Botswana	1.254	Angola	1.278	Ghana	1.246	Mozambique	1.220	Botswana	1.166	Togo	1.949	1.211	1.610
Worst 5 developing countries	Lebanon	0.764	Ghana	0.917	Mongolia	0.900	Iraq	0.876	Philippines	0.906	Mongolia	0.813	Cape Verde	0.919	Côte d'Ivoire	0.897	Lebanon	0.876	Papua New Guinea	0.674	0.795	0.848
	Zimbabwe	0.748	Côte d'Ivoire	0.908	Democratic Republic of Congo	0.747	Mozambique	0.808	Sao Tome and Principe	0.901	Rwanda	0.736	Mauritania	0.820	Sao Tome and Principe	0.887	Mongolia	0.843	Iraq	0.628	0.740	0.848
	Thailand	0.738	Mongolia	0.855	Zimbabwe	0.727	Paraguay	0.708	Togo	0.890	Mozambique	0.726	Rwanda	0.742	Ghana	0.881	Vietnam	0.792	Zimbabwe	0.565	0.400	1.412
	Myanmar	0.732	Botswana	0.845	Rwanda	0.709	Botswana	0.670	Zimbabwe	0.695	Democratic Republic of Congo	0.718	Iran	0.433	Zimbabwe	0.865	Myanmar	0.735	Mongolia	0.525	0.981	0.536
	Papua New Guinea	0.471	Panama	0.832	Iraq	0.536	Thailand	0.449	Papua New Guinea	0.682	Egypt	0.676	Iraq	0.423	Myanmar	0.861	Thailand	0.568	Thailand	0.517	1.000	0.517

Table 3. Identification of the five best and worst countries for the emergent group, with a complement of the Malmquist index results for version 2.

	DMU	M1	DMU	M2	DMU	M3	DMU	M4	DMU	M5	DMU	M6	DMU	M7	DMU	M8	DMU	M9	DMU	MI–M9	MTEC1–MTEC9	MTC1–MTC9
Best 5 emerging countries	United Arab Emirates	2.241	Indonesia	1.159	United Arab Emirates	1.453	China	1.184	Peru	1.511	China	1.189	China	1.249	China	1.173	Mexico	1.080	China	3.647	1.000	3.647
	Indonesia	1.227	United Arab Emirates	1.117	China	1.343	Indonesia	1.102	China	1.337	Mexico	1.107	Colombia	1.152	Peru	1.143	Peru	1.063	United Arab Emirates	2.370	1.000	2.370
	Chile	1.150	South Africa	1.075	Peru	1.198	Algeria	1.074	Mexico	1.204	Indonesia	1.097	Mexico	1.147	Algeria	1.089	United Arab Emirates	1.035	Peru	2.100	1.126	1.865
	Colombia	1.104	Chile	1.039	Morocco	1.153	Peru	1.058	Morocco	1.160	Chile	1.045	Morocco	1.121	Mexico	1.070	China	1.021	Mexico	1.921	1.299	1.479
	Peru	1.086	Colombia	1.035	Indonesia	1.130	Colombia	1.044	South Africa	1.090	Colombia	0.998	Indonesia	1.084	Colombia	1.048	Indonesia	1.017	Indonesia	1.821	1.312	1.388
Worst 5 emerging countries	South Africa	1.074	Peru	0.998	Colombia	1.068	Mexico	1.037	Chile	1.043	Algeria	0.970	South Africa	1.044	South Africa	1.013	South Africa	0.982	South Africa	1.325	0.859	1.542
	Algeria	1.038	Algeria	0.994	Brazil	1.042	South Africa	1.015	Colombia	1.021	Morocco	0.941	Chile	0.986	Chile	1.004	Colombia	0.974	Morocco	1.165	1.000	1.165
	Morocco	1.035	Morocco	0.993	Mexico	1.034	Chile	0.981	Brazil	0.994	South Africa	0.930	Brazil	0.975	Indonesia	0.902	Brazil	0.961	Chile	1.158	0.950	1.219
	Mexico	0.989	China	0.962	Chile	0.990	Brazil	0.965	Indonesia	0.942	Peru	0.864	Peru	0.965	Morocco	0.889	Chile	0.924	Brazil	0.797	0.814	0.979
	Brazil	0.915	Brazil	0.924	Algeria	0.866	Morocco	0.918	Algeria	0.763	United Arab Emirates	0.794	United Arab Emirates	0.854	United Arab Emirates	0.827	Algeria	0.902	Algeria	0.747	0.764	0.977

Table 4. Identification of the five best and worst countries for the developed group, with a complement of the Malmquist index results for version 2.

	DMU	M1	DMU	M2	DMU	M3	DMU	M4	DMU	M5	DMU	M6	DMU	M7	DMU	M8	DMU	M9	DMU	MI–M9	MTEC1–MTEC9	MTC1–MTC9
Best 5 developed countries	Romania	1.319	Iceland	1.323	Romania	1.937	Czech Republic	1.861	Serbia	1.872	Romania	3.397	Spain	1.937	Serbia	2.017	Estonia	1.385	lceland	2.513	1.104	2.276
	Latwia	1.291	lreland	1.256	Serbia	1.629	lceland	1.651	lreland	1.716	lceland	2.269	Czech Republic	1.351	Greece	1.279	Greece	1.111	Ireland	2.412	1.000	2.412
	Switzerland	1.222	Albania	1.1749	Malta	1.335	Malta	1.647	Cyprus	1.363	Slovenia	1.602	Cyprus	1.318	Switzerland	1.239	Austria	1.1045	Estonia	1.7605	1.834	0.960
	Belgium	1.209	Lukembourg	1.1031	Hungary	1.213	lreland	1.440	Albania	1.328	Czech Republic	1.423	France	1.248	Hungary	1.211	Finland	1.083	Czech Republic	1.699	1.371	1.239
	Iceland	1.172	Malta	1.092	Israel	1.188	Montenegro	1.340	Latwia	1.223	Germany	1.139	Ireland	1.229	Latwia	1.136	Portugal	1.071	Israel	1.4791	1.051	1.4072
Worst 5 developed countries	Portugal	0.780	Montenegro	0.7295	Finland	0.873	Lukembourg	0.910	France	0.794	Estonia	0.902	Belgium	0.969	Malta	0.9216	Cyprus	0.830	Portugal	0.761	1.000	0.761
	Croatia	0.722	Germany	0.6918	Cyprus	0.830	Lithuania	0.8786	lceland	0.775	Malta	0.868	Netherlands	0.9596	France	0.8701	Malta	0.781	Bosnia and Heregovina	0.726	0.996	0.730
	Japan	0.6711	Romania	0.562	lreland	0.768	Albania	0.606	Slovenia	0.723	Bosnia and Herzegovina	0.835	Luxembourg	0.9086	Czech Republic	0.6941	France	0.774	Spain	0.6828	0.8591	0.795
	Montenegro	0.6458	Serbia	0.459	Lukembourg	0.765	Serbia	0.565	Malta	0.719	lreland	0.816	Albania	0.8975	Spain	0.485	Bosnia and Herzegovina	0.773	Montenegro	0.3659	0.755	0.4845
	Lukembourg	0.487	Slovenia	0.458	Switzerland	0.735	Romania	0.480	Montenegro	0.594	Serbia	0.592	Switzerland	0.831	Romania	0.404	lceland	0.568	Lusembourg	0.292	0.994	0.294

it decreased to 1.3187. In M8 Serbia had a high Malmquist index result, this result is due to considerable improvements in three indicators, such as the undesirable indicator 1.1.1 (reduction from 5.41% in 2017 to 0.08% in 2018), and the desirable indicators 9.1.2 and 9.c.1 which rose from 7.36 to 17.71 and 70.33% to 73.36% respectively. However, in the long-term evaluation, the most successful countries remained Iceland and Ireland, in relation to the previous version between M1–M7. However, Iceland's Malmquist index value decreased considerably and Ireland's value increased slightly, showing that the characteristics registered in this version benefited Ireland and harmed Iceland in the final result of the long-term productivity evolution.

With regard to the third version, the results reveal that the specific characteristics of this version contribute values that are quite different from the other versions. In other words, the analysis of a smaller number of indicators means that if any one of them varies considerably, the Malmquist indices have greater variations and can reach quite extreme results. If the year 2020 is included, the evolution values for most of the countries included in this study will be considerably reduced for the specific reason that there was a COVID-19 pandemic in 2020 and all the emerging and developed countries had Malmquist index values below 1, which means that their productivity evolution worsened. On the contrary, Guyana obtained a rather high value for that period. This success of Guyana in this very delicate period for most countries is due to the high GDP growth (8.1.1) from a value of 4.85% in 2019 to 42.79% in 2020.

It is interesting to note that, although there is productivity growth in any of the three groups of countries, the evolution in developing and emerging countries is more remarkable than the growth in developed countries. This leads us to conclude that, in terms of SDGs 1, 8, and 9, there is an improvement of the three production frontiers (where benchmarks are located), and these have been converged. In other words, although some countries have worsened their performance in poverty eradication and wealth creation (including some developed countries), the evaluated sample seems to tend to a common trend line.

5.2. Comparison of Results with the Literature

Barbier & Burgess [21] recently mentioned that, regarding the indicator 1.1.1 (undesirable), there was an improvement of 85.5% between 2000 and 2016 worldwide. This indicator (proportion of individuals living below the international poverty line of US$1.90/day) goes from 20.8% to 3.0%, which is positive because it has a negative polarity, i.e., it is undesirable. Indicators 8.1.1 (annual GDP growth) and 9.2.1 (percentage of manufacturing value added GDP) suffered a decline: while the former went from 1.7% to 0.8%, the latter decreased from 13.0% to 11.4%, which shows a decline of 52% and 11.8% respectively. However, for developing countries, those authors verified that indicator 1.1.1 watched an improvement smaller than the world's average (65.4% passing from 81.3% to 28.1%). Meanwhile, indicators 8.1.1 and 9.2.1 have also observed a decline of 146.7% and 7.0% respectively, which led the authors to conclude that these countries had a slower evolution than the rest of the world. With regard to indicator 8.1.1 these countries are the ones that have regressed the most, giving more emphasis to the idea that these countries are far behind the rest. However, concerning indicator 9.2.1 these countries stand out compared with the rest of the countries analyzed (despite the negative trend observed), thus showing the existence of emerging and developed countries with a greater decay in this respect.

With regard to the current study, it can be seen that for the first two versions, the overall behavior of nations was positive, with an increase in productivity, as highlighted in Table 5. This table contains the number of countries where there was an increase in productivity, the number of countries with unchanged productivity (countries where the value of the Malmquist index is in the interval]1.01,0.99[), and the number of countries with falling productivity in each biennium and long-term period analyzed, concerning version 2.

Table 5. Identification of the number of countries in the global that achieved an increase, decrease, and unchanged productivity for each period of version 2.

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M1–M9
No. of countries with productivity growth	48	42	54	46	45	43	53	50	40	52
No. of Countries with unchanged productivity	6	6	3	10	5	4	7	3	5	1
No. of countries with falling productivity	31	37	28	29	35	38	25	32	40	32

Looking at Table 5, it is straightforward to conclude that the countries improving their productivity clearly outnumber those worsening it. Interestingly, only one country remained equal in terms of productivity in the entire period (M1–M9). The long-term period M1–M9 (2010–2019) remains positive, despite the overall worsening of performance in M9. The figure for the M1–M9 long-term period is higher than for most periods, except M3 and M7. These results suggest that the overall performance trend between 2010 and 2019 is positive as there are more countries that are better in 2019 than they were in 2010 for the indicators analyzed, which shows that there is a positive overall evolution.

Contrary to the first two versions, version 3 is the most pessimistic one. The values of both productivity increase and productivity decrease are very close. In some periods, such as M2, M3, M9, and M10 the value of the number of countries with a productivity decrease is higher than the opposite group, which never happened in the previous versions. M10 (2019–2020) is the sub-period where the worst performance of all stands out, with 79 countries having a drop in their productivity, representing approximately 93% of this study's sample. This negative value might mainly be due to the start of the COVID-19 pandemic, which caused countries to suspend their work regarding productivity developments [29].

In fact, Odey et al. [29] note that COVID-19 has brought every sector in the world to stagnation and regression at an unprecedented rate, including the SDGs themselves, where SDG trackers and sustainable development reports highlight profound delays and implications towards SDG targets across the world. Because M10 has seen a sharp decline in productivity and the other sub-periods have not been quite positive, it has made the long-term period M1–M10 perform quite negatively overall, with approximately 89% of countries experiencing a high productivity decline between the years 2010 and 2020.

However, Table 5 only allows us to observe the general behavior of the countries and not to make the comparison between the three groups of country profiles described above. To this end, Tables 6–8 were constructed.

Tables 6–8 show the separation between the profile groups for those that had productivity increase, unchanged, and decrease (version 2). From Table 6 it is possible to see that for the 48 countries that obtained productivity increase, 24 are developing countries, 8 are emerging and 16 are developed. In each cell, two percentages are also present. For instance, concerning the developing countries, 58.5% of them have improved their productivity in M1. In general, more than half of these countries exhibited productivity gains in the overall period. However, these 24 entities represent half (50%) of those who watched productivity improvement during M1 (among all entities, either developed, developing, or emerging). For this case of the M1 sub-period, it can be seen that the profile group that presents the greatest success was that of the emerging countries since 72.7% of these countries increased their productivity.

It is also noticeable that the values for countries with increasing productivity and falling productivity remain very close to the values of version 1. It corroborates the idea that indicators 8.4.2 and 9.2.2 have little or even no influence on the overall assessment.

According to version 2, the figures do not change much from M1 to M8 (2010–2018), but for M9 (2018–2019) there was a rather sharp decline in the number of developed countries in the productivity growth group, going from an average value in the previous sub-periods of 17 to 8 countries in M9, which is quite a lot in a single biennium. For this reason, the value of this profile group increased in the unchanged productivity and falling productivity groups, which suggests that the technological change of the developed countries watched a slowdown (allowing the frontiers of developing and emerging countries could converge to it). Ultimately, the values of the long-term period M1–M9 were quite positive mainly for emerging and developing countries, as both had less than 40% of their countries with falling and more than 60% and 80% with increasing productivity, respectively. In the case of developed countries, it was not as positive as in the other groups. Of course, when indicators reach their maximum levels (even the theoretical ones), it means that no more wealth can be created nor poverty can be eradicated—it implies a stagnation of the frontier of the developed countries.

When comparing the results above with the conclusions of Barbier & Burgess [21], it is noticeable that both are not in agreement in the sense that the literature article mentions that developing countries were the ones that obtained the most negative results. In this study, the first two versions indicate the opposite, in the sense that the countries with the smallest productivity growth were the developed ones. However, what the literature refers to is in the direction of version 3 in which developing countries performed worse than the other profile groups. The

Table 6. Register of the number of countries with increased productivity in version 2.

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M1–M9
Developing countries	24(50%/58.5%)	26(61.9%/63.4%)	29(53.7%/70.7%)	20(43.5%/48.8%)	22(48.9%/53.7%)	23(53.5%/56.1%)	23(43.3%/56.1%)	25(50%/61%)	27(67.5%/65.8%)	26(50%/63.4%)
Emerging countries	8(16.7%/72.7%)	6(14.3%/54.5%)	9(16.7%/81.8%)	8(17.4%/72.7%)	8(18.2%/72.7%)	4(8.9%/36.4%)	7(13.2%/63.6%)	7(14%/63.6%)	5(12.5%/45.5%)	9(17.3%/81.8%)
Developed Countries	16(33.3%/48.5%)	10(23.8%/30.3%)	16(29.6%/48.5%)	18(39.1%/54.5%)	15(34.1%/45.5%)	16(35.6%/48.5%)	23(43.3%/69.7%)	18(36%/54.5%)	8(20%/24.2%)	17(32.7%/51.5%)

Table 7. Register of the number of countries with unchanged productivity in version 2.

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M1–M9
Developing countries	2(33.3%/4.9%)	2(33.3%/4.9%)	0(0%/0%)	7(70%/17.1%)	1(20%/2.4%)	1(25%/2.4%)	4(57.1%/9.8%)	1(33.3%/2.4%)	0(0%/0%)	1(100%/2.4%)
Emerging countries	1(16.7%/9.1%)	3(50%/27.3%)	1(33.3%/9.1%)	0(0%/0%)	1(20%/9.1%)	1(25%/9.1%)	0(0%/0%)	1(33.3%/9.1%)	0(0%/0%)	0(0%/0%)
Developed Countries	3(50%/9.1%)	1(16.7%/3%)	2(66.7%/6.1%)	3(30%/9.1%)	3(60%/9.1%)	2(50%/6.1%)	3(42.9%%/9.1%)	1(33.3%/ 3%)	5(100%/15.6%)	0(0%/0%)

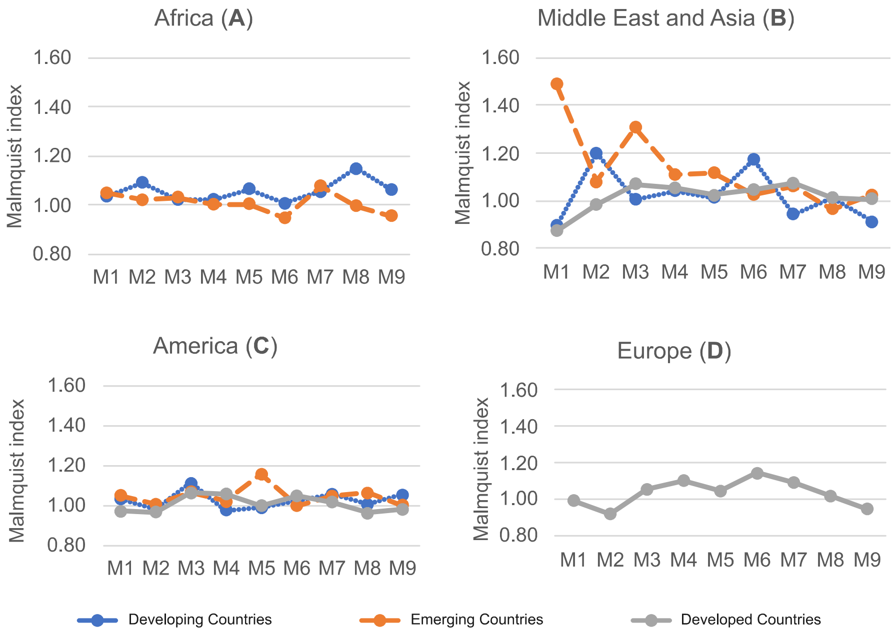
Table 8. Register of the number of countries with falling productivity in version 2.

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M1–M9
Developing countries	15(48.4%/36.6%)	13(35.1%/31.7%)	12(42.9%/29.3%)	14(48.3%/34.1%)	18(51.4%/43.9%)	17(44.7%/41.5%)	14(56%/34.1%)	15(46.9%/36.6%)	14(35%/34.1%)	14(43.8%/34.1%)
Emerging countries	2(6.5%/18.2%)	2(5.4%/18.2%)	1(3.6%/9.1%)	3(10.3%/27.3%)	2(5.7%/18.2%)	6(15.8%/54.5%)	4(16%/36.4%)	3(9.4%/27.3%)	6(15%/54.5%)	2(6.3%/18.2%)
Developed Countries	14(45.2%/42.4%)	22(59.5%/66.7%)	15(53.6%/45.5%)	12(41.4%/36.4%)	15(42.9%/45.5%)	15(39.5%/45.5%)	7(28%/21.2%)	14(43.8%/42.4%)	20(50%/60.6%)	16(50%/48.5%)

justification for this result is that this study uses the DEA method and the Malmquist index, which analyze the evolution of productivity related to several SDG indicators simultaneously, thus having as a final result several influences from each indicator. Besides, despite considering a broader period than its two alternative versions, the third one is the poorest in terms of the number of variables. Soon the difference in conclusions between both studies, especially in versions 1 and 2, but for version 3 the conclusions are more similar due to the fact that this version has a smaller number of indicators under study, being two of them the same used by Barbier & Burgess [21]—8.1.1 and 9.2.1. Another point that enables the divergence of conclusions is the period under study.

5.3. Continental Analysis

Following the analysis carried out previously for the evolution of productivity for each country profile group, several graphs were constructed for version 2 that present the evolution of productivity for each profile group existing in the study, per continent; see Graph 1. The graphs allowed for a more regional analysis, which leads to an understanding of how SDGs 1, 8, and 9 have changed in each region.



Graph 1. Graphs referring to the productivity evolution of the profile groups of the countries existing in Africa (**A**), Middle East and Asia (**B**), America (**C**), and Europe (**D**).

Concerning the African continent, we can observe that only the curves for developing and emerging countries are present because this continent has no developed country. The emerging countries in this case focus only on the Malmquist index values of South Africa. In all three versions, the average scores of emerging countries are higher than those of developing countries in the M1 period, indicating that, regardless of the number of indicators analyzed, emerging countries performed and evolved more positively than their developing counterparts. In M2 both groups obtained opposite growth in productivity developments regardless of the version, i.e., developing countries had a growth peak, while emerging countries obtained a slight decline relative to M1. In the first two versions, from M2 until M7, the behavior of the countries of both groups was quite identical. After M7 the second version recorded a sharp drop in both M8 and M9. In the end, developing countries showed larger productivity levels than the emerging ones.

Unlike Africa, the graph for the Middle East and Asia already includes the curves for the developed countries. In the three versions, emerging countries recorded average Malmquist index values well above the other profile groups in the M1 period, close to 1.5, and the other two groups recorded values below 1 (meaning a decay in productivity). However, only the developed countries registered a more constant or consistent behavior after M2. Both emerging and developing countries showed more pronounced oscillations, with emerging countries experiencing a large growth followed by several falls and slight rises, while developing countries showed a peak at M6 similar to M2. Finally, at M9, developed countries leave the prominent position they had until then and move to the second-best group in this period, behind emerging countries. However, the differences are not statistically significant.

For the American continent, the first two versions exhibit a similar behavior of developing and emerging countries' productivity until the M7 period. The same cannot be said of the developed countries, showing that the differences in the characteristics of the two versions had a different type of influence on the countries in this group, especially between the M1 and M4 periods. In the first version, these countries watched a constant productivity growth. Differently, according to the second version, there was no longer constant growth over the periods up to M4; instead, there was only a high development peak in M3, while from M1 to M2 and M3 to M4 there were slight decreases in the productivity. In the second version, both developing and developed countries experienced a high reduction of productivity from M7 to M8, followed by a sharp growth to M9. Emerging countries had the opposite behavior, with an increase at M8 and a high reduction at M9.

For the European continent, there is only the curve for the developed countries, because there are no developing or emerging countries in this continent. In the first two versions, the behavior of the curve was quite similar until the M7 period, corroborating the idea that these two versions are quite close and that the reduction of the two indicators had little influence in the countries until M7. In version 2, after M7, there was a constant fall until M9, making M9 the second worst period in terms of productivity growth, being only behind M2. Regarding the last period (2018–2019), the continent that stood out the most for developing countries was Africa, and for emerging and developed countries it was the Middle East and Asia.

The results of the third version are different from the other two versions, especially with the sharp drop seen in M10, confirming the idea that 2020 was a very negative year in fighting against poverty, unemployment, and wealth uneven distribution. All continents were negatively affected in this period.

6. Summary, Limitations, and Future Work

This paper was developed as part of the study of the productivity evolution of several countries belonging to different profile groups for three SDGs, 1, 8, and 9, covering topics from the wealth creation and distribution to poverty eradication. The benchmarking analysis undertaken to search for possible best practices and how they have evolved over time is quite important to solve the existing problem of monitoring the productivity evolution of countries towards the SDGs. With this monitoring, countries are able to understand how their productivity evolution is going, and accordingly, it is possible to draw conclusions, anticipations, and measures to be taken so that this evolution remains positive. This analysis also allows us to obtain a general observation of how the world and its various groups of countries are evolving and the reasons for these evolutions and behaviors.

The results obtained from the Malmquist indices allowed us to identify the five countries that stood out most positively and negatively for each profile group, concluding that these countries are not the same in all sub-periods. Variations occur throughout these periods, with some countries being in the best position in a certain period, but the following being in the worst position, due to the general degradation of the indicators in relation to the improvement obtained in the previous period.

In this study, it was also identified that the three existing profile groups did not evolve in the same way, as expected. The group of emerging countries obtained a better evolution of productivity in the set of indicators of the three SDGs in the various periods, exhibiting a higher percentage of their countries in the group watching improved productivity. Next were the developing countries. Although developed countries observed a lower percentage in this improvement group, this does not mean that their evolution was negative. It implies that this group had slowed down their productivity growth, reaching a nearly steady state.

Mathematical modeling, such as the use of methods like DEA and the Malmquist index, is a potent tool for evaluating efficiency. However, it does have a number of intrinsic limitations. An important issue is the susceptibility of these models to the quality of the data. The precision of the outcomes is significantly contingent upon the dependability of the input data, and any flaws or biases in the data might potentially result in deceptive conclusions. Future research should give priority to the development of rigorous procedures for data collecting, validation, and cleaning in order to improve the reliability of these models. Furthermore, both the DEA and the

Malmquist index fail to include possible non-linearities in real-world systems, since they presuppose linearity in the connections between inputs and outputs. Researchers need to investigate methods for integrating non-linear modeling methodologies in order to more effectively capture the intricacies of many businesses, hence guaranteeing a more precise depiction of the underlying processes. One alternative is to use the so-called log-DEA [49] to account for this non-linearity problem or the Stochastic Multicriteria Acceptability Analysis [36,50] for the imperfect knowledge of data.

Mathematical models may provide a problem in terms of interpretability. The outcomes produced by the DEA and the Malmquist index sometimes include intricate mathematical expressions that may provide difficulties for stakeholders without a solid quantitative foundation to grasp. Subsequent research should prioritize the creation of interfaces, visual representations, and explanatory instruments that are easy for users to navigate and understand. This will aid in effectively conveying the results of models to a wide range of individuals. Effective implementation of suggestions obtained from these models in real-world decision-making settings relies on clear communication of results.

In addition, these models often make the assumption of a stationary environment, disregarding the dynamic characteristics of several real-world systems. The Malmquist index quantifies efficiency improvements over time; however, it may not fully account for the ongoing adjustments and variations that may place in dynamic sectors. Researchers should investigate methods to expand these models by including dynamic components, taking into account variables such as technical progress, market volatility, and evolving regulatory frameworks. A suggestion for further research could be the Hicks-Moorsteen index [44]. This would provide a more thorough comprehension of efficiency fluctuations in developing sectors.

During the process of developing this study, other limitations emerged that did not allow this paper to be as complete as possible. These limitations arose mainly in the area of database construction, as some countries did not present data for many of the indicators of the three SDGs, which led to their exclusion from the database; the United States of America is an example of these cases. On the other hand, there are indicators with values for only a few countries, so they were also removed. Only 85 countries remained for the indicators presented in the three versions. For future work, it should be possible to conduct studies that encompass more countries than those used in this document, as well as include more SDGs or even all SDGs of the UN agenda 2030. This will make it possible to increase the robustness of this type of study.

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Author Contributions

Conceptualization: A.D.; Data curation: A.D.; Formal analysis: A.D.; Investigation: A.D.; Methodology: A.D.; Resources: A.D.; Software: A.D.; Supervision: P.C.; Validation: P.C., & M.V.; Writing – original draft: A.D.; Writing – review & editing: A.D.

Conflicts of Interest

The authors have no conflict of interest to declare.

References

1. Karahasan, B. C. (2023). To make growth reduce poverty, industrialize: Using manufacturing to mediate the effect of growth on poverty. *Development Policy Review*, *41*(4), e12689. https://doi.org/10.1111/dpr.12689
2. Halkos, G., & Gkampoura, E.-C. (2021). Where do we stand on the 17 Sustainable Development Goals? An overview on progress. *Economic Analysis and Policy*, *70*, 94–122. https://doi.org/10.1016/j.eap.2021.02.001
3. Yang, B., Usman, M., & Jahanger, A. (2021). Do industrialization, economic growth and globalization processes influence the ecological footprint and healthcare expenditures? Fresh insights based on the STIRPAT model for countries with the highest healthcare expenditures. *Sustainable Production and Consumption*, *28*, 893–910. https://doi.org/10.1016/j.spc.2021.07.020
4. McMillan, M., & Zeufack, A. (2022). Labor productivity growth and industrialization in Africa. *Journal of Economic Perspectives*, *36*(1), 3–32. https://doi.org/10.1257/jep.36.1.3

5. Fonseca, L. M., Domingues, J. P., & Dima, A. M. (2020). Mapping the sustainable development goals relationships. *Sustainability*, *12*(8), 3359. https://doi.org/10.3390/su12083359
6. Brown, P., & James, D. (2020). Educational expansion, poverty reduction and social mobility: Reframing the debate. *International Journal of Educational Research*, *100*, 101537. https://doi.org/10.1016/j.ijer.2020.101537
7. Guo, H., Liang, D., Sun, Z., Chen, F., Wang, X., Li, J., et al. (2022). Measuring and evaluating SDG indicators with Big Earth Data. *Science Bulletin*, *67*(17), 1792–1801. https://doi.org/10.1016/j.scib.2022.07.015
8. Winsemius, H. C., Jongman, B., Veldkamp, T. I. E., Hallegatte, S., Bangalore, M., & Ward, P. J. (2018). Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts. *Environment and Development Economics*, *23*(3), 328–348. https://doi.org/10.1017/S1355770X17000444
9. Arriani, R. R., & Chotib. (2021). The Correlation of SDG 1 and 8 and Spatial Effect of Human Development Index in Central Java. *IOP Conference Series: Earth and Environmental Science*, *940*, 012063. https://doi.org/10.1088/1755-1315/940/1/012063
10. Giles-Corti, B., Lowe, M., & Arundel, J. (2020). Achieving the SDGs: Evaluating indicators to be used to benchmark and monitor progress towards creating healthy and sustainable cities. *Health Policy*, *124*(6), 581–590. https://doi.org/10.1016/j.healthpol.2019.03.001
11. Jacob, A. (2017). Mind the Gap: Analyzing the Impact of Data Gap in Millennium Development Goals' (MDGs) Indicators on the Progress toward MDGs. *World Development*, *93*, 260–278. https://doi.org/10.1016/j.worlddev.2016.12.016
12. Cherchye, L., Moesen, W., Rogge, N., & Van Puyenbroeck, T. (2007). An introduction to 'benefit of the doubt'composite indicators. *Social Indicators Research*, *82*, 111–145. https://doi.org/10.1007/s11205-006-9029-7
13. Greco, S., Ishizaka, A., Tasiou, M., & Torrisi, G. (2019). On the methodological framework of composite indices: A review of the issues of weighting, aggregation, and robustness. *Social Indicators Research*, *141*, 61–94. https://doi.org/10.1007/s11205-017-1832-9
14. Camanho, A. S., & Dyson, R. G. (2006). Data envelopment analysis and Malmquist indices for measuring group performance. *Journal of Productivity Analysis*, *26*, 35–49. https://doi.org/10.1007/s11123-006-0004-8
15. Tone, K. (2004). Malmquist productivity index. In *Handbook on data envelopment analysis* (pp. 203–227). Springer, Boston.
16. Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometrica*, *50*(6), 1393–1414. https://doi.org/10.2307/1913388
17. Bali Swain, R., & Ranganathan, S. (2021). Modeling interlinkages between sustainable development goals using network analysis. *World Development*, *138*, 105136. https://doi.org/10.1016/j.worlddev.2020.105136
18. Dang, H.-A. H., & Serajuddin, U. (2020). Tracking the sustainable development goals: Emerging measurement challenges and further reflections. *World Development*, *127*, 104570. https://doi.org/10.1016/j.worlddev.2019.05.024
19. Leal Filho, W., Azeiteiro, U., Alves, F., Pace, P., Mifsud, M., Brandli, L., et al. (2018). Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG). *International Journal of Sustainable Development and World Ecology*, *25*(2), 131–142. https://doi.org/10.1080/13504509.2017.1342103
20. Eisenmenger, N., Pichler, M., Krenmayr, N., Noll, D., Plank, B., Schalmann, E., et al. (2020). The Sustainable Development Goals prioritize economic growth over sustainable resource use: a critical reflection on the SDGs from a socio-ecological perspective. *Sustainability Science*, *15*, 1101–1110. https://doi.org/10.1007/s11625-020-00813-x
21. Barbier, E. B., & Burgess, J. C. (2019). Sustainable development goal indicators: Analyzing trade-offs and complementarities. *World Development*, *122*, 295–305. https://doi.org/10.1016/j.worlddev.2019.05.026
22. Leal Filho, W., Lovren, V. O., Will, M., Salvia, A. L., & Frankenberger, F. (2021). Poverty: A central barrier to the implementation of the UN Sustainable Development Goals. *Environmental Science and Policy*, *125*, 96–104. https://doi.org/10.1016/j.envsci.2021.08.020
23. Maksimov, V., Wang, S. L., & Luo, Y. (2017). Reducing poverty in the least developed countries: The role of small and medium enterprises. *Journal of World Business*, *52*(2), 244–257. https://doi.org/10.1016/j.jwb.2016.12.007
24. Blicharska, M., Teutschbein, C., & Smithers, R. J. (2021). SDG partnerships may perpetuate the global North–South divide. *Scientific Reports*, *11*, 22092. https://doi.org/10.1038/s41598-021-01534-6
25. Chen, M., Sinha, A., Hu, K., & Shah, M. I. (2021). Impact of technological innovation on energy efficiency in industry 4.0 era: Moderation of shadow economy in sustainable development. *Technological Forecasting and Social Change*, *164*, 120521. https://doi.org/10.1016/j.techfore.2020.120521
26. Wang, C., Quan, Y., Li, X., Yan, Y., Zhang, J., Song, W., et al. (2022). Characterizing and analyzing the sustainability and potential of China's cities over the past three decades. *Ecological Indicators*, *136*, 108635. https://doi.org/10.1016/j.ecolind.2022.108635
27. Wen, B., Musa, S. N., Onn, C. C., Ramesh, S., Liang, L., Wang, W., et al. (2020). The role and contribution of green buildings on sustainable development goals. *Building and Environment*, *185*, 107091. https://doi.org/10.1016/j.buildenv.2020.107091

28. Nhemachena, C., Matchaya, G., Nhemachena, C. R., Karuaihe, S., Muchara, B., & Nhlengethwa, S. (2018). Measuring baseline agriculture-related sustainable development goals index for Southern Africa. *Sustainability*, *10*(3), 849. https://doi.org/10.3390/su10030849
29. Odey, G. O., Alawad, A. G. A., Atieno, O. S., Carew-Bayoh, E. O., Fatuma, E., Ogunkola, I. O., et al. (2021). COVID-19 pandemic: Impacts on the achievements of sustainable development goals in Africa. *Pan African Medical Journal*, *38*, 251. https://doi.org/10.11604/pamj.2021.38.251.27065
30. Romano, G., Ferreira, D. C., Marques, R. C., & Carosi, L. (2020). Waste services' performance assessment: The case of Tuscany, Italy. *Waste Management*, *118*, 573–584. https://doi.org/10.1016/j.wasman.2020.08.057
31. Li, Z., Crook, J., & Andreeva, G. (2017). Dynamic prediction of financial distress using Malmquist DEA. *Expert Systems with Applications*, *80*, 94–106. https://doi.org/10.1016/j.eswa.2017.03.017
32. Wang, D. D. (2019). Performance assessment of major global cities by DEA and Malmquist index analysis. *Computers, Environment and Urban Systems*, *77*, 101365. https://doi.org/10.1016/j.compenvurbsys.2019.101365
33. Huang, B., Zhang, L., Ma, L., Bai, W., & Ren, J. (2021). Multi-criteria decision analysis of China's energy security from 2008 to 2017 based on Fuzzy BWM-DEA-AR model and Malmquist Productivity Index. *Energy*, *228*, 120481. https://doi.org/10.1016/j.energy.2021.120481
34. Tachega, M. A., Yao, X., Liu, Y., Ahmed, D., Li, H., & Mintah, C. (2021). Energy efficiency evaluation of oil producing economies in Africa: DEA, malmquist and multiple regression approaches. *Cleaner Environmental Systems*, *2*, 100025. https://doi.org/10.1016/j.cesys.2021.100025
35. Amaral, C., Pedro, M. I., Ferreira, D. C., & Marques, R. C. (2022). Performance and its determinants in the Portuguese municipal solid waste utilities. *Waste Management*, *139*, 70–84. https://doi.org/10.1016/j.wasman.2021.12.020
36. Ferreira, D. C., Marques, R. C., & Pedro, M. I. (2018). Explanatory variables driving the technical efficiency of European seaports: An order-α approach dealing with imperfect knowledge. *Transportation Research Part E: Logistics and Transportation Review*, *119*, 41–62. https://doi.org/10.1016/j.tre.2018.09.007
37. Matos, R., Ferreira, D. C., & Pedro, I. (2021) Economic analysis of Portuguese public hospitals through the construction of quality, efficiency, access, and financial related composite indicators. *Social Indicators Research*, *157*, 361–392. https://doi.org/10.1007/s11205-021-02650-6
38. Nunes, A. M., & Ferreira, D. C. (2022). Social inequity and health: From the environment to the access to healthcare in composite indicators, the Portuguese case. In W. Leal Filho, D. G. Vidal, M. A. P. Dinis, & R. C. Dias (Eds.), *Sustainable Policies and Practices in Energy, Environment and Health Research Addressing Cross-cutting Issues*. *World Sustainability Series*. Springer, Cham. https://doi.org/10.1007/978-3-030-86304-3_21
39. Cherchye, L., Moesen, W., Rogge, N., & Van Puyenbroeck, T. (2011). Constructing composite indicators with imprecise data: A proposal. *Expert Systems with Applications*, *38*(9), 10940–10949. https://doi.org/10.1016/j.eswa.2011.02.136
40. Rogge, N. (2018). On aggregating benefit of the doubt composite indicators. *European Journal of Operational Research*, *264*(1), 364–369. https://doi.org/10.1016/j.ejor.2017.06.035
41. Álvarez, I. C., Barbero, J., & Zofío, J. L. (2020). A Data Envelopment Analysis Toolbox for MATLAB. *Journal of Statistical Software*, *95*(3), 1–49. https://doi.org/10.18637/jss.v095.i03
42. Ferreira, D. C., Marques, R. C., Pedro, M. I., & Santos, G. (2022). PPP hospitals in Portugal: What does benchmarking tell us about their relative performance? In S. Verweij, I. van Meerkerk, & C. Casady (Eds.), *The Performance Advantage of Public-Private Partnerships: An International Assessment of Empirical Evidence*. Edward Elgar. https://doi.org/10.4337/9781800889200.00012
43. Kerstens, K., & Van de Woestyne, I. (2014). Comparing Malmquist and Hicks-Moorsteen productivity indices: Exploring the impact of unbalanced vs. balanced panel data. *European Journal of Operational Research*, *233*(3), 749–758. https://doi.org/10.1016/j.ejor.2013.09.009
44. Ferreira, D. C., & Marques, R. C. (2016). Malmquist and Hicks–Moorsteen productivity indexes for clusters performance evaluation. *International Journal of Information Technology & Decision Making*, *15*(5), 1015–1053. https://doi.org/10.1142/S0219622016500243
45. Lind, N. (2019). A Development of the Human Development Index. *Social Indicators Research*, *146*, 409–423. https://doi.org/10.1007/s11205-019-02133-9
46. Resce, G. (2021). Wealth-adjusted Human Development Index. *Journal of Cleaner Production*, *318*, 128587. https://doi.org/10.1016/j.jclepro.2021.128587
47. O'Sullivan, A., & Sheffrin, S. M. (2003). *Economics: Principles in Action*. Pearson Prentice Hall.
48. Ferreira, D. C., Caldas, P., Varela, M., & Marques, R. C. (2023). A geometric aggregation of performance indicators considering regulatory constraints: An application to the urban solid waste management. *Expert Systems with Applications*, *218*, 119540. https://doi.org/10.1016/j.eswa.2023.119540
49. Ferreira, D. C., Marques, R. C., & Nunes, A. M. (2021). Pay for performance in health care: a new best practice tariff-based tool using a log-linear piecewise frontier function and a dual–primal approach for unique solutions. *Operational Research*, *21*, 2101–2146. https://doi.org/10.1007/s12351-019-00502-3
50. Ferreira, D. C., Figueira, J. R., Greco, S., & Marques, R. C. (2023). Data envelopment analysis models with imperfect knowledge of input and output values: An application to Portuguese public hospitals. *Expert Systems with Applications*, *231*, 120543. https://doi.org/10.1016/j.eswa.2023.120543