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Measuring Progress towards Sustainability in the European Union within the 2030 Agenda Framework

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Abstract: The adoption of the 2030 Agenda and its 17 Sustainable Development Goals (SDGs) revived the challenge to efficiently address economic prosperity, environmental quality and social welfare goals. To fulfill such purposes, policymakers need to measure and monitor the global progress made by countries towards the achievement of the SDGs. Composite indicators have frequently been used for sustainability performance assessment in a range of areas related to Sustainable Development and recently some attempts have been made to analyze trends within the 2030 Agenda framework. The objective of this study is to propose a novel composite indicator approach to assess sustainability performance and evaluate whether progress is being made towards the SDGs. Some distinguishing features of the proposed approach involve the computation of weights for the indicators and the use of geometric average at the overall aggregation stage. The approach is applied to the evaluation of the SDGs in EU27 during the period 2010–2020 using the Eurostat SDG dataset. The results obtained suggest that all 27 Member States have progressed favorably, albeit not to the same extent, and differences between countries seem to be decreasing over the years.

Keywords: composite indicators; sustainable development goals; geometric aggregation; multi-criteria decision making; ranking

MSC: 90B50; 91B02; 91B76

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1. Introduction

Over the second half of the previous century, there was sound evidence that GDP growth on its own could not account for the living standards of the population, and attention progressively shifted to the concept of economic development that combines economic progress and quality-of-life improvements. Moreover, the progressive concern about environmental issues and their link with developmental issues became evident when problems regarding the impacts of production on air, soil and water, environmental degradation, and accelerated rate of species extinction started to escalate. All in all, by the end of the 20th century, topics related to Sustainable Development and Sustainability became of foremost importance among researchers and political leaders around the world.

The term Sustainable Development was first formally defined in 1987 in the World Commission on Environment and Development report as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. The concept soon proved to be highly instrumental in developing a world view and a common concern about the future of the planet. This definition has often been claimed to be excessively vague, therefore leading to a diverse spectrum of interpretations usually adapted to fit stakeholders' interests. Nevertheless, the issue indeed captured the widespread interest of institutions, governments, businesses and civil society. The paradigm of sustainable development rapidly turned into a fundamental principle of strategic planning and economic progress, and countless initiatives have been taken both at global and regional scales to address different aspects of the sustainability challenge.

Since the 1990s, the international community has been committing to a number of principles and declarations for implementing sustainable development. The most recent took effect in September 2015 when the 193 United Nations (UN) Member States adopted the 2030 Agenda for Sustainable Development, an ambitious, transformative action plan aimed at "achieving sustainable development in its three dimensions—economic, social and environmental—in a balanced and integrated manner" [1] (p. 3). Ultimately, the core of the Agenda presents an ambitious framework with a broad range of goals derived from the three sustainability pillars. The 17 Sustainable Development Goals (SDGs) and 169 associated targets are intended to address unfulfilled issues such as extreme poverty, inequality and social injustice, and protection of the environment by 2030.

The practical implementation of sustainability and the evaluation of the advances made in that area remain a rather controversial problem that has been receiving considerable attention throughout the past decades. The use of indicators has been widely recognized as an appropriate tool to both assess the achievements towards sustainable development and facilitate the operationalization of the concept [2,3]. However, in the meantime, the detailed examination of a sufficiently large indicator system provides a complete, compartmentalized view of the problem; an integrated assessment of sustainability over time and space is difficult to derive [4,5].

To address this problem, composite indicators are used to synthesize all the information contained in the whole indicator system into a single numerical value, facilitating a systematic evaluation of the sustainability level achieved in each territory and a comparative assessment of the units against the objectives of sustainability. This is a very common approach in diverse areas concerning human and economic development, including environmental and well-being studies [5–11], and it has proved to be rather useful, both as a communication and decision-making tool, for its potential for tracking overall progress and identifying priority areas for action [12,13].

Over the past few years, a wide variety of methods have been used for deriving a composite indicator (referred hereafter as CI) from an initial system, although no single methodology has yet been found more suitable than any other [4,14]. From a technical point of view, the aggregation of individual indicators into a CI is not essentially different from the standard multi-criteria decision making (MCDM) problem, which seeks to assess and rank a set of alternatives according to their performance against several criteria or attributes that, because of their conflicting nature, do not allow an immediate comparison and ordering of the alternatives. This resemblance explains why multi-criteria decision techniques have been profusely used for CI-related studies in a wide variety of fields [15,16]. The simplest and best-known approach is the weighted linear aggregation, with indicator weights that can be obtained either by subjective methods, that introduce decision-maker's preferences [17,18], or objective methods, that draw on the information contained in the data set itself by using mathematical techniques such as Principal Component Analysis or Data Envelopment Analysis, among others [19–29]. Other multicriteria methods that are also used in the literature include the weighted geometric aggregation [18,23,24], the distance functions-based methods [7,11,25,26] and, to a lesser extent, the outranking methods [27].

Focusing on the 2030 Agenda framework, governments and researchers are currently facing the challenge of measuring and monitoring progress towards the SDGs. This is an important task that must be rigorously undertaken in order to evaluate the outcomes of the actions already implemented and to address the unfulfilled goals for the next decade. Using the global indicator framework adopted by the UN Statistical Commission and, in a European Union (EU) context, the EU SDG indicator set, a number of studies have recently appeared that rely on the CI approach for evaluating progress towards the objectives set in the Agenda, both within the goals and across the goals [14,28–31], most of them using a simple mean scheme with equal weights for the aggregation of the individual indicators. It is known that, while arithmetic averages are easy to interpret, they also allow full compensation, meaning that bad performances in certain indicators can be offset with very good performances in some others, a feature that may not agree with the sustainable development conception. Therefore, sustainability CI based on the simple mean approach may not be entirely satisfactory for an accurate evaluation of how the economies are progressing in relation to the 2030 Agenda.

In this work, we intend to contribute to the pool of procedures that assist countries in measuring the level of achievement of the SDGs, avoiding counteracting effects when improvements in some goals occur at the cost of worsening others. To that aim, a non-compensatory composite indicator will be developed and used for a comparative analysis of the sustainability performance of the EU27 Member States and the evaluation of their progress towards the SDGs during the past decade. At a methodological level, the proposed composite indicator presents an innovative scheme that combines a weighted linear average at the first aggregation level, with indicator weights computed with an objective procedure based on the distance-to-an-ideal concept, and a geometric average at the second aggregation level that avoids full compensability. In addition, in the procedure, the presented data are normalized using a concave function, so that differences between normalized scores are more significant for data points at low performance levels. Therefore, the more unsustainable the initial situation, the more noticeable the improvements in indicator values. To gain a dynamic insight, composite indicators are computed using data from the years 2010, 2015 and 2020 using the same normalization procedure and indicator weights for all three cases, so the aggregate scores obtained are comparable over time. Therefore, this analysis provides information about the progress towards the achievement of the SDGs in every individual country of the EU as well as a realistic picture of their situation as compared to peer countries.

The rest of the paper will be organized as follows. After this introduction, the methodological approaches used in the construction of composite indicators for sustainability assessments are reviewed. Section 3 describes the procedure that will be followed to develop a composite indicator of sustainability, with special attention paid at the normalization, weighting and aggregation stages. Section 4 presents the results obtained when the methodology proposed is used for the evaluation of the EU27 countries within the 2030 Agenda framework. After the discussion of findings, some concluding remarks are provided.

2. Methodological Approaches to Sustainability Assessment

The problem under consideration in this research study concerns the comparative assessment of sustainability at the country level. Despite the importance of the topic in today's globalized world, it is still a challenging task due to two main factors: the ambiguous definition of the concept and the obstacles found in its measurement.

Sustainability and Sustainable Development are relatively new terms, dating from the late 20th century, which are often used interchangeably despite the debates over their differences in focus and semantic connotations [32]. Sustainability principles emerged from a widespread critique of an excessive focus on economic growth that urged organizations and policymakers to reconcile increasing incomes, well-being and environmental protection [33]. However, the 1987 Brundtland definition has been argued to be vague enough to fit many different contexts without providing clear guidelines for action [34] and today, sustainability is still acknowledged to be an elusive concept subject to context-specific understanding [35].

Beyond the impreciseness of the sustainability concept, and despite the lack of a rigorous theoretical framework, the important point is that "Sustainable Development" has become one of the main challenges of humanity. It is also accepted that sustainability involves the search for a balance and compromise among social, economic, and environmental priorities, commonly referred to as the "triple-bottom-line" [36]. Although some authors have considered either a cultural or institutional dimension as a fourth pillar, the tripartite categorization is prevalent in the specialized literature [33].

As far as the conceptualization of sustainability is concerned, a major debate topic is whether a weak or strong approach should be chosen [37], which relates to the way the compromise between the sustainability components is managed. Basically, the weak sustainability paradigm assumes universal substitution of natural capital and other types of capital (e.g., human, manufactured) and, therefore, it is assumed that financial gains from economic activities can compensate for the environmental and/or social losses. On the contrary, a strong sustainability position considers that natural capital is essentially non-substitutable as it cannot be assimilated to a stock of resources, so that gains and losses from different sustainability components cannot compensate one another. In sum, this weak/strong duality is aligned with the issue of compensability among criteria in MCDM methods.

The most common approach to measuring sustainability is based on the use of indicators, although a proper choice of metrics to effectively capture the concept is difficult to obtain. At the firm level, there have been many efforts to integrate sustainable indicators in the corporate strategy to improve business performance [38–40]. Governments are also interested in the compilation and analysis of a comprehensive set of Sustainable Development (SD) indicators that provides suitable information for monitoring the sustainability performance of countries or regions, evaluating their SD strategies, and conveying relevant insights to interested parties. However, the management of large amounts of information is not straightforward and reaching a clear conclusion about the overall accomplishment of the sustainability objectives is usually rather difficult.

For that reason, policymakers often demand some type of aggregate index that summarizes the information contained in the indicator set and allows the assessment of sustainability of countries or regions, the comparison with other territory's performance and the communication of results to a non-expert audience [6,41]. Composite indicators, which "are formed when individual indicators are compiled into a single index on the basis of an underlying model" [4] (p. 13), are meant to fulfill all the aforementioned requirements, and, currently, CI are the most widely used framework to analyze and interpret a system of sustainable indicators [42]. However, the use of CI has its drawbacks, since it is acknowledged that through this summarizing process some amount of information may be lost, and they may produce misleading results if they are poorly constructed or misinterpreted [4]. Nevertheless, composite indices are accepted as useful tools for SD policymaking, as long as both the theoretical and methodological assumptions are clearly specified [3,42].

As the international community's interest in tracking overall progress towards sustainable development grew, more and more initiatives aimed at measuring sustainability in different human activities appeared, such as the Human Development Index, Ecological Footprint, Environmental Performance Index, and the Wellbeing Assessment, among others [43], most of which rely on the weak sustainability paradigm. The number of studies approaching the measurement of sustainability with CI in the specialized literature increased significantly [12,44–47], contributing to the existent debate on the appropriateness of analytic tools for SD.

With the adoption of the UN 2030 Agenda, the recent literature focused on measuring the achievement of the 17 SDGs [48], defined to integrate and balance the three dimensions of sustainable development. At an institutional level, Eurostat, OECD, and Bertelsmann Stiftung and Sustainable Development Solutions Network provide three outstanding initiatives to measure and compare SDG performance at a country level and at different geographical scales (European Union, OECD countries and worldwide, respectively). In the Eurostat report [49], the pace and direction of change of indicators is evaluated using the compound annual growth rate (CAGR), which calculates the variation rates per year along a given timespan. Indicator trends are then averaged within each goal to assess countries' progress towards the SDGs. The OECD study [50] evaluates countries' performance in each SDG by averaging the standardized distances of indicators' values to their specified target levels. The SDG Index [30] is also derived using the arithmetic mean, not only at goal level but also across goals, so that a composite indicator for overall sustainability and a performance ranking based on each country's results are obtained.

Both OECD 2019 and Bertelsmann use the concept of distance to target values to evaluate progress towards SDGs, despite a lack of concrete numerical targets for a majority of indicators is acknowledged in both studies. This requires ad hoc procedures for indicators with no performance threshold available, whether science-based estimates, expert opinion or average of the best observed outcomes.

Based on these three approaches, Miola and Schiltz [14] construct several composite indicators using mean values, averaged distance measures and averaged progress measures for the 17 goals and overall sustainability performance at the EU28 level. Their results corroborate some well-known facts regarding the use of CI, that a country's relative position is strongly dependent on the set of indicators used, given that different indicator sets measure different things, and that rankings may also be sensitive to the chosen aggregation method. The study presented in [31] proposes to combine the static information provided by the simple mean indicator at a particular point in time with a measure of progress obtained by transforming Eurostat's progress measure (CAGR) for indicators with a scoring function and then averaging all scores. Their findings suggest that progress and status do not necessarily correlate.

On a different note, other recent contributions have presented different instances of the distance function-based approach, and since in CI building the aggregation technique is intimately related to the level of compensability between indicators [25], their results depart to a greater or lesser extent from the weak sustainability paradigm. In the study presented in [51], the TOPSIS (Technique for Order Preferences by Similarity to Ideal Solutions) method is used to aggregate 32 variable indicators into 6 sustainability dimensions that together relate to 15 of the 17 SDGs. The approach presented in [45] relies on the Goal Programming methodology, both at the goal level and for the overall index. Biggeri et al. [13] define composite indicator values in terms of the distance to theoretical ideal values using a generalized L_p metric, where the parameter p is chosen in a way that allows a degree of flexibility in substitutability among indicators to depend on each country's performance. Ricciolini et al. [52] use a more complex methodology, based on the multi-reference point method, to build composite indicators that approach the strong sustainability paradigm by allowing different compensation schemes at different stages of the aggregation procedure.

As the literature review reveals, the past two decades have witnessed many methodological contributions relying on CI construction for the assessment of sustainability in a broad sense and, more recently, for the evaluation of SDGs achievement. Only a small part of these contributions is oriented towards the strong sustainability paradigm, which is better suited for dealing with serious environmental and social problems. Therefore, in this study, we investigate an alternative approach to build a CI index to measure sustainability in the Agenda 2030 framework and in a strong sense. We also examine how the proposed approach can be used to effectively monitor progress towards the achievement of SDGs in EU27. Following the recommendation in [53], the CI described in the following section will rely on the geometric aggregation, that has been considered by many scholars as superior over the more commonly used arithmetic aggregation [54].

3. Materials and Methods: Building a Composite Indicator for Assessing Sustainability

In this section, a stepwise methodological approach is described for constructing a sustainable development composite indicator that will be used later for evaluating the fulfillment of the Agenda 2030 across the 27 Member States of the EU.

The key steps to be followed when developing composite indicators are described in [4,42]. The conceptual background describing the nature of the phenomenon to be measured will support the selection of an appropriate set of simple indicators to be used. Subsequent steps in the construction of a reliable CI encompass weighting and aggregation of the indicators considered, which are rather controversial topics [55]. Since different methodologies used in those stages can affect the final outcomes [3], all decisions at the methodological level must be fully transparent, so that the limitations of the process are made explicit. The approach suggested in this work is next described in detail.

3.1. Indicator Selection

The consistency of the theoretical framework and the quality of the available data are known to condition the usefulness of the final index; therefore, indicators must be selected according to their relevance, reliability and availability, as well as their ability to fit the studied concept.

Let us assume a sustainability framework as described in the 2030 Agenda, based on 17 dimensions or sustainability components that represent the SDGs (although the same stands analogously for a different framework with p generic dimensions). For the sustainability assessment of n regions or countries, a number m_k of simple indicators are selected within each dimension k. The whole dataset for the analysis is then gathered in a nxm matrix ($m = \sum_{k=1}^{p} m_k$) whose elements I_{ij}^k measure the performance of the i-th country in relation to the j-th indicator in the k-th sustainability dimension ($i = 1, \ldots, n$, $j = 1, \ldots, m_k$, $k = 1, \ldots, 17$).

Indicators may have a positive or negative character, depending on the direction of change needed for an improvement in sustainability. Let us consider the set of indicators as the disjoint union of the set P of positive indicators, of the "more is better"-type, for which higher observed values imply a superior performance in the corresponding sustainability dimension, and the set N of negative indicators, of the "less is better"-type, for which lower observed values are preferred.

3.2. Data Normalization

Due to the usual incommensurability of the indicator measures used, normalization of raw data is needed to eliminate the effects of different unit scales and avoid meaningless aggregations. After normalization, original indicators turn into dimensionless measures with the same improvement direction, which can now be combined for a joint interpretation.

The linear min–max normalization method is one of the most commonly used approaches, according to which the raw indicator values are rescaled to a [0, 1] range with a 0 (respectively, 1) value representing the worst (respectively, best) possible observed outcome for each indicator. Sometimes, this normalization procedure is applied using previously defined upper and lower bounds (for example, satisfying levels of the indicators or required sustainability targets) instead of observed bounds [30].

While such a normalization process is rather useful, it can be still considered a questionable choice given that linearity is not necessarily a requirement for assessing the closeness to the upper bound (or the distance to the lower bound). In fact, it could be argued that a concave rescaling function is more appropriate if used within a benchmarking analysis. With a concave normalization function, differences between normalized scores grow larger when the original scores are lower. In that sense, emphasis is put on poor indicator scores so that the more unfavorable the initial value of the indicator, the more significant effect any performance improvements will have. This feature is especially appropriate for dynamic sustainability evaluations since countries that perform poorly will be encouraged to address their weaknesses.

Following this premise, and using $I_j^{k,\,L}$ and $I_j^{k,\,U}$ to denote, respectively, the lower and upper bounds for indicator j within dimension k, we propose the use of the following expression for the normalized indicator values:

$$N\left(I_{ij}^k\right) = \overline{I}_{ij}^{\,k} = 1 - A\, e^{B\left(I_{ij}^k - I_j^{k,\,L}\right)}$$

where parameters A and B are selected to adjust whichever attainment level should be attributed to indicator values matching the lower or upper bound. Specifically, if the lower bound is considered as a rather poor performance showing a 100ε% of sustainability achievement (that is, $N\left(I_j^{k,\,L}\right) = \varepsilon$) and the upper bound for indicator j should indicate a

$100\beta\%$ of sustainability achievement (that is, $N\left(I_j^{k,\,U}\right) = \beta$), with $0 < \varepsilon < \beta < 1$, then it can be seen that A an B must be set to be:

$$A = 1 - \varepsilon \text{ and } B = \frac{\log\left(\frac{1-\beta}{1-\varepsilon}\right)}{I_j^{k,\,U} - I_j^{k,\,L}}$$

Note that parameter B takes a positive or negative value depending on the negative or positive (respectively) direction of change of each indicator. Therefore, the normalization function is always concave, and the rescaled indicators are expressed as positive variables (more is better type).

The upper and lower bounds for the indicators can be obtained using either exogenous information, such as conceptual thresholds and science-based targets, or the observed data series.

3.3. Weighting the Indicators

Before the aggregation step of the procedure is performed, different weights can be assigned to the underlying components in order to reflect their significance or relevance within the theoretical construct under study. There is no agreed methodology to derive appropriate weights for individual indicators, and despite the fact that the use of an equal-weight scheme is rather common in practical applications, it actually masks a different weighting pattern when the number of indicators is uneven across the considered dimensions. In addition, as observed in [14] (p. 4), "countries that deliberately progress faster in specific indicators at the cost of others will be at a disadvantage when each indicator is given the same weight", which hints at the use of different weighting schemes whenever possible.

Some researchers advocate for the use of expert-based weights, as a way to account for different theoretical backgrounds and concerns, policy priorities and multiple stakeholders' viewpoints, but it is acknowledged that judgments may be influenced by the experts' academic or geographic characteristics [9].

In order to limit the amount of subjectivity inherent in the weighting process, the adoption of objective (that is, data-driven) procedures can be considered. Several strategies exist for this task (see, for example, [4]), which rely exclusively on the information contained in the dataset. In this work, the approach followed for an objective computation of indicator weights makes use of the MCDM closeness-to-an-ideal paradigm.

The computation of weights is supported on a rather intuitive premise: those territories more similar in their performance to a utopian (ideal) country, which is defined as one showing the best performance in all indicators within a given dimension, would be considered the most sustainable. This being so, all n territories would be willing to minimize the distance between their own performance and the ideal performance. Since the simultaneous minimization of the n distances can be formalized as a multi-objective optimization problem, the former could be approached by minimizing the sum of distances of all evaluated units to that ideal unit. Then, using the weighted-Euclidean distance [56], a set of neutral weight values (in the sense of preventing any country to be perceived as "similar to the ideal" only because of a particularly advantageous selection of weights) could be obtained with the following quadratic programming problem, which must be solved to obtain the indicator weights weights w_j^k for the m_k indicators within each of the SDG (k = 1, . . . , 17):

$$\begin{aligned} \min_{s.a} \quad & \sum_{i=1}^{n}\sum_{j=1}^{m_k}\left(w_j^k\left(I_{ij}^k - I_j^{k,\,U}\right)\right)^2 \\ & \sum_{j=1}^{m_k} w_j^k = 1 \\ & w_j^k \geq 0 \end{aligned}$$

This program admits a closed-form solution where the weight w_j^k is found to be proportional to $\left(\sum_{i=1}^{n}\left(I_{ij}^k - I_j^{k,\,U}\right)^2\right)^{-1}$.

In sum, when the above formula is used, it can be said that an impartial set of weights is obtained, in the sense that they do not induce advantageous assessments for any of the units or adverse evaluations for any others and, therefore, the comparisons and rankings derived from the indexes obtained with these weights can be accepted as objective and reliable.

3.4. Data Aggregation

To account for a theoretical framework with several sustainability dimensions, an aggregation procedure will be performed first within each SDG, and the resulting 17 dimensional composite indicators will be next combined to obtain the Sustainability Index.

Stage 1: The m_k indicators within the k-th sustainability dimension are aggregated in a first step; therefore, 17 Goal Composite Indicators (GCI^k, for k = 1, . . . ,17) are obtained. For the aggregation at this stage, the weighted linear average will be used:

$$GCI_i^k = \sum_{j=1}^{m_k} w_j^k I_{ij}^k$$

with weight values computed as described previously. As is known, the weighted average allows for perfect substitutability among the indicators combined, and so it provides a measure of weak sustainability. This is true since a poor performance in one of the indicators is compensable if a very favorable assessment is obtained for another indicator, resulting in an overall acceptable evaluation of that country. Note that a weak sustainability paradigm can be acceptable at this stage of aggregation, since the indicators used within each SDG generally describe a set of complementary policy priorities towards a common goal.

Stage 2: The 17 indexes obtained for each of the sustainability dimensions considered are secondly aggregated into the Sustainability Index (SI). At this stage, the geometric average will be selected:

$$SI_i = \prod_{k=1}^{17}\left(GCI_i^k\right)^{\frac{1}{17}}$$

Contrary to the weighted sum average, the geometric average penalizes heterogeneity across the aggregated dimensions [54]. In addition, it allows only partial compensability among the indicators combined, since poor performances in any of the individual dimensions inevitably will force down the overall assessment and, therefore, it can be used as a measure of strong sustainability. Notice that the hypothesis of progress taking place simultaneously across a number of dimensions that are considered equally relevant is implicitly required by the sustainability concept [12] and, therefore, a strong sustainability paradigm with equal weights as defined in the above formula seems much more convenient at this aggregation stage.

4. Progress towards SDGs in EU27: Results and Analysis

In this section, the methodology described above is applied to assess how the 27 Member States of the EU are performing in achieving the SDGs. The analysis draws on the Eurostat SDG indicator set, which has been developed specifically for the EU context following strict selection criteria to ensure their policy relevance and statistical data quality, striving for a thorough and accurate picture of the situation in the EU in SDGs matters.

The Eurostat SDG indicators set comprises around 100 indicators covering the social, economic, environmental and institutional sides of sustainability put forward by the 2030 Agenda. Assuming the relevance, quality and reliability of these indicators as a given, some of them were discarded from this analysis for availability issues. Particularly, in order to reduce to a minimum any uncertainties or misleading results due to imputation procedures, only indicators with less than 10% missing values were included in the analysis.

The remaining missing values were estimated by linear interpolation. In addition, to prevent duplication of the information, each indicator was used only once, despite some of them being defined as multi-purpose, and the Pearson correlation coefficients between indicators within the same goal were limited to 0.8. Thus, the final data series used in this study consisted of 64 indicators, all of them expressed in relative terms to guarantee that countries with heterogeneous characteristics (in terms of area, population, etc.) are actually comparable so that evaluations do not benefit or undermine any region due to its size. Ideally, the chosen set of indicators should be balanced across the 17 SDGs, but this aspiration could not be met. Instead, the actual number of indicators used per goal is uneven, ranging from two to five indicators per goal. The list of indicators used for each SDG can be seen in Table 1.

To gain insight into the progress made by countries towards sustainability, this study covers the period 2010–2020. Since the changes induced by new policies are not expected to have an immediate effect, data has been collected within a 5-year timespan. Following the methodology described in Section 3, the information gathered for the 27 members of EU is used to build composite indices for each of the 17 SDGs and aggregate sustainability indexes for years 2010, 2015 and 2020. The normalization of raw data was performed using common upper and lower bounds for each indicator variable, which were set as the best and worst observed values across countries and time periods:

$$I_j^{k,\,U} = \begin{cases} \max\left\{ I_{ij}^k(t),\ i = 1,\dots,n; t = 1,2,3 \right\} \text{ for } j \in P \\ \min\left\{ I_{ij}^k(t),\ i = 1,\dots,n; t = 1,2,3 \right\} \text{ for } j \in N \end{cases}$$

$$I_j^{k,\,L} = \begin{cases} \min\left\{ I_{ij}^k(t),\ i = 1,\dots,n; t = 1,2,3 \right\} \text{ for } j \in P \\ \max\left\{ I_{ij}^k(t),\ i = 1,\dots,n; t = 1,2,3 \right\} \text{ for } j \in N \end{cases}$$

These upper and lower bounds are meant to represent fairly good and rather poor (respectively) sustainability status, so they were identified with an 85% and a 10% level of achievement in the corresponding indicator ($\beta = 0.85$, $\varepsilon = 0.1$ in the normalization function). Additionally, for the computation of weights at the indicator level, the procedure described in the previous section was applied simultaneously for the three time points studied so that an only set of weights for indicators in each SDG category was obtained. The resulting aggregation weights are listed in Table 1. With this, the index scores obtained GCI^k ($k = 1, \dots, 17$) and *SI* across the three reference years surveyed are perfectly comparable and can be used to assess progress towards sustainability in the 2030 Agenda framework.

The results of the Sustainability Index *SI* scores for the EU27 countries for years 2010, 2015 and 2020 are reported in the first three columns of Table 2, with the corresponding rank order in parenthesis. The last two columns of Table 2 present the 10-year and 5-year rates of variation in the *SI* scores, which give an idea of the intensity of improvement towards the SDGs in the short and medium terms.

Table 1. Indicators list, with direction of change in parenthesis, and aggregation weights.

SDG1. No Poverty		**SDG9. Industry, Innovation and Infrastructure**	
People at risk of income poverty after social transfer (N)	0.08	Gross domestic expenditure on R&D (P)	0.07
Severely materially deprived people (N)	0.33	R&D personnel, as percentage of population (P)	0.09
People living in households with very low work intensity (N)	0.27	Patent applications to the European Patent Office (P)	0.04
In work at-risk-of-poverty rate (N)	0.16	Share of buses and trains in total passenger transport (P)	0.12
Population living in a dwelling with a leaking roof, damp walls, floors or foundation or rot in window frames of floor (N)	0.17	Air emission intensity from industry (N)	0.68
SDG2. Zero Hunger		**SDG10. Reduced Inequalities**	
Agricultural factor income per annual work unit (P)	0.07	Purchasing power adjusted GDP per capita (P)	0.12
Government support to agricultural research and development (P)	0.06	Relative median at-risk-of-poverty gap (N)	0.54
Area under organic farming (P)	0.08	Income share of the bottom 40% of the population (P)	0.34
Ammonia emissions from agriculture (N)	0.78	**SDG11. Sustainable Cities and Communities**	
SDG3. Good Health and Well-Being		Overcrowding rate (N)	0.38
Healthy life years at birth (P)	0.13	Road traffic deaths (N)	0.39
Share of people with good or very good perceived health (P)	0.20	Recycling rate of municipal waste (P)	0.23
Smoking prevalence (N)	0.17	**SDG12. Responsible Consumption and Production**	
Self-reported unmet need for medical examination and care (N)	0.50	Resource productivity and domestic material consumption(P)	0.12
SDG4. Quality Education		Circular material use rate (P)	0.81
Early leavers from education and training (N)	0.47	Generation of waste excluding major mineral wastes (N)	0.07
Tertiary educational attainment (P)	0.16	**SDG13. Climate Action**	
Adult participation in learning (P)	0.07	Greenhouse gas emissions (N)	0.33
Underachievement in reading, maths or science (N)	0.30	Population covered by the Covenant of Mayors for Climate & Energy signatories (P)	0.54
SDG5. Gender Equality		Average CO_2 emissions per km from new passenger cars (N)	0.14
Gender pay gap in unadjusted form (N)	0.19	**SDG14. Life Below Water**	
Gender employment gap (N)	0.54	Surface of marine sites designated under Natura 2000 (P)	0.14
Seats held by women in national parliaments and governments (P)	0.12	Bathing sites with excellent water quality by locality (P)	0.86
Positions held by women in senior management positions (P)	0.15	**SDG15. Life on Land**	
SDG6. Clean Water and Sanitation		Share of forest area (P)	0.17
Population having neither a bath, nor a shower, nor indoor flushing toilet in their household (N)	0.60	Surface of terrestrial sites designated under Natura 2000 (P)	0.10
Water exploitation index (N)	0.40	Relative sealed surface (N)	0.73

Table 1. *Cont.*

SDG7. Affordable and Clean Energy		**SDG16. Peace, Justice and Strong Institutions**	
Primary energy consumption (N)	0.64	Standardised death rate due to homicide (N)	0.23
Final energy consumption in households per capita (N)	0.18	Population reporting occurrence of crime, violence or vandalism in their area (N)	0.06
Energy productivity (P)	0.09	General government total expenditure on law courts (P)	0.08
Share of renewable energy in gross final energy consumption (P)	0.09	Corruption Perceptions Index (P)	0.13
SDG8. Decent Work and Economic Growth		Population with confidence in EU institutions: European Parliament (P)	0.50
Real GDP per capita (P)	0.06	**SDG17. Partnerships for the Goals**	
Investment share of GDP (P)	0.22	Official development assistance as share of gross national income (P)	0.05
Young people neither in employment nor in education and training (N)	0.21	General government gross debt (N)	0.61
Employment rate (P)	0.22	Share of environmental taxes in total tax revenues (P)	0.13
People killed in accidents at work (N)	0.29	High-speed internet coverage (P)	0.08
		EU imports from developing countries (share of Extra-EU27 imports) (P)	0.13

Table 2. Sustainability Index (*SI*) scores (rank order in parenthesis) and annual growth rates.

	Sustainability Index (*SI*) Scores			**Annual Growth Rates**	
	2010	**2015**	**2020**	**2020–2010**	**2020–2015**
Austria	0.650 (5)	0.679 (4)	0.696(3)	0.70	0.52
Belgium	0.625(10)	0.658 (10)	0.680 (8)	0.85	0.65
Bulgaria	0.525 (23)	0.566 (23)	0.580 (26)	0.99	0.47
Croatia	0.597 (16)	0.631 (14)	0.660 (15)	1.01	0.90
Cyprus	0.594 (17)	0.613 (21)	0.629 (20)	0.57	0.53
Czechia	0.622 (12)	0.649 (11)	0.672 (11)	0.77	0.70
Denmark	0.670 (2)	0.695 (2)	0.706 (2)	0.53	0.31
Estonia	0.520 (24)	0.546 (26)	0.586 (24)	1.20	1.44
Finland	0.652 (3)	0.683 (3)	0.694 (4)	0.64	0.33
France	0.645 (6)	0.672 (6)	0.677 (9)	0.49	0.15
Germany	0.651 (4)	0.671 (7)	0.673 (10)	0.32	0.05
Greece	0.576 (20)	0.564 (24)	0.595 (23)	0.32	1.08
Hungary	0.606 (14)	0.632 (13)	0.654 (18)	0.77	0.69
Ireland	0.629 (9)	0.661 (9)	0.693 (6)	0.98	0.97
Italy	0.604 (15)	0.614 (19)	0.634 (19)	0.48	0.66
Latvia	0.475 (27)	0.578 (22)	0.618 (21)	2.65	1.34
Lithuania	0.555 (21)	0.622 (18)	0.654 (17)	1.66	1.01
Luxembourg	0.554 (22)	0.644 (12)	0.660 (14)	1.78	0.49
Malta	0.497 (25)	0.560 (25)	0.584 (25)	1.63	0.85
Netherlands	0.644 (8)	0.673 (5)	0.689 (7)	0.68	0.49
Poland	0.588 (19)	0.625 (17)	0.606 (22)	0.30	−0.63
Portugal	0.589 (18)	0.613 (20)	0.656 (16)	1.09	1.35
Romania	0.493 (26)	0.471 (27)	0.578 (27)	1.59	4.15
Slovakia	0.619 (13)	0.628 (15)	0.663 (12)	0.69	1.09
Slovenia	0.644 (7)	0.668 (8)	0.694 (5)	0.74	0.74
Spain	0.623 (11)	0.628 (16)	0.662 (13)	0.60	1.04
Sweden	0.680 (1)	0.698 (1)	0.713 (1)	0.48	0.44

According to the rank-order correlations reported in Table 3, the country rankings for the three years studied are highly correlated, which suggests that the relative positions of the EU27 States in terms of their level of fulfillment of the 2030 Agenda have remained quite stable throughout this period. A thorough inspection of Table 2 reveals that, out of the 27 countries, 11 of them (40%) have changed their position in the ranking by 1 or 2 places and 4 of them (15%) have not changed their rank order at all. Particularly, the top overall performing countries, Sweden and Denmark, have maintained their leadership in SDGs achievement over the period 2010–2020, with Finland and Austria following closely, while Romania, Malta and Estonia have systematically remained lagging behind. Interestingly, the 27 Member States have experienced improvements in their *SI* scores throughout the 10-year timeframe, which can be interpreted as a sign of their overall progress towards the SDGs, although not to the same extent. Moreover, the distance between the best and the worst index scores is in 2020 around 30% smaller than in 2010; therefore, in a sense, the differences in performance between countries seem to be reducing over the years. Figure 1 provides an image of the sustainability performance in the EU in 2010 and 2020 according to the *SI* scores.

Table 3. Rank order correlations (Spearman's rho) between the *SI* country rankings.

	2010	**2015**	**2020**
2010	1	0.92	0.92
2015		1	0.95
2020			1

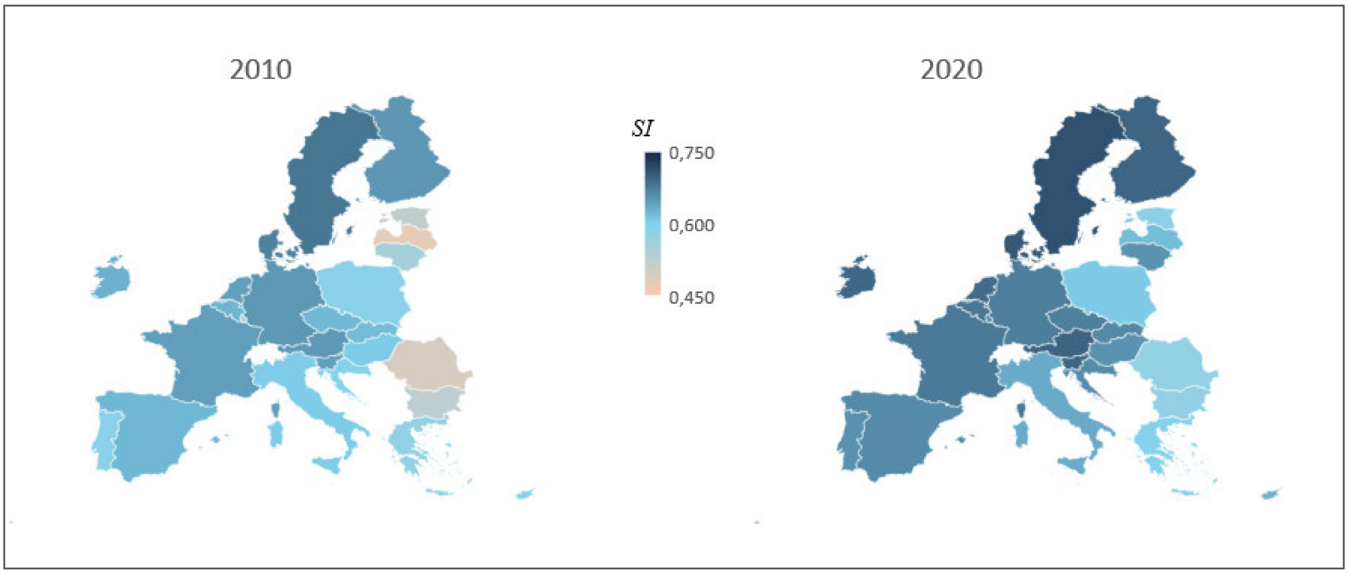

Figure 1. Sustainability Index (*SI*) scores for 2010 and 2020.

For an in-depth analysis of performance across goals, Tables 4 and 5 report annual growth rates of SDGs indexes in the last 10-year and 5-year periods, respectively. A closer look at the rows of both tables gives information on how countries have been progressing in each goal, according to the indicator variables included in this analysis, while their column-wise examination provides indication of how progress towards each goal is being attained across the countries. Overall, it can be said that all EU27 countries have moved away from one or more of the 17 SDGs in both periods considered. For instance, comparing results for the last year available with the performance observed in 2010 (see Table 4), Greece, Spain and France stand for showing negative growth rates in 6 out of 17 SDGs, which explains why they have gone down in the overall performance ranking. Moreover, it can also be confirmed that during the last decade, all the Member States have progressed towards SDG7 and SDG13, which reflects the successful accomplishments made after a decade of commitment to raising the share of renewable energy sources, increasing energy efficiency and fighting climate change.

The steady leadership of Sweden in addressing the objectives of the 2030 Agenda runs in line with it being the European country with the longest tradition of sustainable development strategies, which date back to 1994 [57]. According to the analysis performed here, Sweden stands among the 3 top performers of the EU in 2020 for 8 out of the 17 goals (see Table 6). In particular, Sweden reached the highest score within EU27 in SDG3, SDG5 and SDG8 for the three years considered, confirming its leadership in gender equality and its high standard of living. Sweden has also been strengthening its approach to the environment and climate change, inducing a 3.14% annual growth in SDG13 score over the past decade (Table 4) that made Sweden move upwards from 9th to 1st place in SDG13 ranking during that period. As for Sweden's worst comparative performance, 23rd position in SDG12, eventual progress is expected thanks to the actions that the country is undertaking towards a circular, resource-efficient economy [58].

Table 4. SDGs composite indicators' annual variation rate, 2020–2010, goals 1 to 17.

	GCI^{1}	GCI^{2}	GCI^{3}	GCI^{4}	GCI^{5}	GCI^{6}	GCI^{7}	GCI^{8}	GCI^{9}	GCI^{10}	GCI^{11}	GCI^{12}	GCI^{13}	GCI^{14}	GCI^{15}	GCI^{16}	GCI^{17}
Austria	0.30	−0.06	0.54	0.79	2.09	−0.01	0.79	1.73	0.37	0.14	0.48	0.30	2.52	0.88	0.04	0.60	0.43
Belgium	0.32	0.51	0.27	0.49	1.65	−0.01	1.83	0.83	0.49	0.47	0.76	0.49	2.55	2.82	0.11	0.48	0.41
Bulgaria	2.82	0.37	3.31	−0.83	0.22	0.74	0.11	1.95	−0.18	−2.13	3.66	−0.57	2.61	2.22	0.11	1.78	0.89
Croatia	1.49	0.62	2.09	1.29	0.36	−0.03	0.36	0.86	0.72	0.97	6.37	0.21	0.92	−0.15	0.11	1.01	0.22
Cyprus	−0.61	2.01	0.89	−1.51	1.82	0.63	0.74	1.55	1.33	0.27	0.94	0.35	3.11	0.04	0.21	−0.55	−1.39
Czechia	0.35	0.34	−0.15	0.65	1.49	−0.34	0.76	0.86	0.52	0.98	2.23	0.33	2.61	1.94	0.02	0.52	0.09
Denmark	−0.05	0.31	0.25	0.42	0.67	−0.02	1.35	0.48	−0.02	0.62	0.39	0.12	2.09	1.86	0.12	0.48	−0.08
Estonia	0.35	0.29	−2.97	0.88	1.00	0.53	1.05	2.83	11.82	0.51	3.25	−4.97	3.85	−0.88	0.04	3.54	0.21
Finland	0.01	0.08	−0.26	0.25	0.64	0.02	2.77	0.51	0.10	0.00	0.56	1.26	3.26	0.78	0.01	0.48	0.40
France	−0.11	0.38	0.31	1.02	1.74	−0.04	1.04	−0.36	0.32	−0.15	0.61	0.28	1.51	2.35	0.08	−0.34	−0.20
Germany	−0.25	0.38	0.80	0.69	1.62	0.03	0.97	0.71	0.26	−4.14	0.14	0.21	2.74	0.11	0.02	0.60	0.73
Greece	−0.10	0.18	−0.24	1.36	2.49	−0.66	0.55	−1.92	0.61	−0.52	4.02	0.67	3.39	0.30	0.19	0.79	−5.34
Hungary	1.38	0.43	1.72	−0.24	−0.47	0.17	0.21	2.74	0.33	−2.47	4.30	0.09	2.19	2.05	0.13	0.45	0.32
Ireland	2.12	0.04	0.69	1.32	1.19	0.01	1.27	3.70	0.27	0.97	0.49	1.04	2.66	−0.59	0.13	0.69	0.75
Italy	0.01	0.40	1.37	1.92	2.79	−0.24	0.63	0.28	0.38	−1.98	1.02	0.45	1.95	0.43	0.09	0.19	−1.40
Latvia	2.27	0.41	10.05	1.10	−0.52	0.81	0.36	3.00	0.28	1.39	10.34	0.11	3.05	2.54	0.05	10.77	0.21
Lithuania	1.55	0.32	−0.48	0.68	0.03	0.79	0.11	3.22	0.52	5.46	8.33	−0.13	2.02	1.47	0.10	3.79	0.86
Luxembourg	−0.38	0.14	−0.04	0.09	2.94	0.03	11.87	0.50	−0.05	−0.41	0.88	0.30	9.28	4.50	0.31	0.77	0.41
Malta	0.40	10.04	0.81	4.27	8.89	−0.08	0.61	2.16	0.06	0.16	0.08	−0.19	1.51	0.18	−1.02	−0.64	1.18
Netherlands	−0.13	0.37	0.40	0.31	1.31	−0.01	1.57	0.44	0.51	−0.35	0.03	0.41	2.63	3.68	0.13	0.18	0.20
Poland	1.21	0.21	2.77	0.23	0.70	0.14	0.29	2.44	0.65	1.17	5.95	−0.03	1.63	−12.33	0.06	0.26	0.84
Portugal	0.38	0.13	0.44	7.73	1.71	−0.04	0.26	2.10	2.22	0.35	1.90	0.07	1.52	0.47	0.27	0.43	−1.14
Romania	2.18	0.06	3.17	1.94	0.19	5.46	0.13	4.20	0.38	−0.49	6.70	−0.19	2.18	−0.74	0.07	1.59	0.60
Slovakia	0.51	0.24	0.29	0.09	1.25	−0.02	0.34	1.31	0.58	0.95	3.82	0.02	2.38	−1.31	0.04	0.31	1.00
Slovenia	0.90	0.37	0.48	0.67	1.08	0.02	0.75	0.72	0.26	0.60	3.48	0.66	1.66	1.32	0.03	−0.08	−0.26
Spain	−0.01	0.12	0.87	5.14	1.66	−0.25	0.46	0.84	−0.05	−0.65	0.56	0.20	1.55	0.92	0.18	−0.01	−1.17
Sweden	−0.03	0.15	0.46	0.08	0.65	0.02	1.70	0.50	0.31	−0.10	−0.25	−0.07	3.14	1.75	0.01	−0.20	0.15

Table 5. SDG composite indicators' annual variation rate, 2020–2015, goals 1 to 17.

	GCI^1	GCI^2	GCI^3	GCI^4	GCI^5	GCI^6	GCI^7	GCI^8	GCI^9	GCI^{10}	GCI^{11}	GCI^{12}	GCI^{13}	GCI^{14}	GCI^{15}	GCI^{16}	GCI^{17}
Austria	0.45	0.26	0.25	−0.23	2.06	−0.02	0.63	1.17	0.33	−0.61	0.57	0.04	0.88	0.84	0.01	1.83	0.36
Belgium	1.21	0.73	0.50	0.66	1.00	−0.07	0.88	1.11	0.64	0.66	0.57	−0.17	1.02	0.23	0.07	1.07	0.92
Bulgaria	2.90	0.33	1.39	−1.98	0.14	0.72	0.17	2.71	−0.38	−0.70	2.55	−0.62	−0.10	−2.43	0.13	3.02	0.32
Croatia	2.30	0.42	0.57	0.48	0.24	0.12	0.13	3.14	1.20	0.70	4.83	−0.05	0.25	0.09	0.22	0.40	0.47
Cyprus	0.18	1.30	0.45	−3.91	0.96	2.17	0.60	2.99	0.98	2.68	0.52	−0.21	−0.23	0.08	0.13	1.41	−0.89
Czechia	0.63	0.74	−0.42	−0.15	4.09	−0.12	0.39	1.29	0.33	1.24	1.65	0.29	0.27	0.43	0.02	1.67	−0.42
Denmark	0.46	0.63	0.33	−0.40	0.94	0.01	0.73	0.24	−0.08	1.14	0.07	0.10	0.69	0.60	0.07	0.34	−0.54
Estonia	0.66	0.38	1.86	1.51	2.53	0.41	0.96	1.75	6.35	2.18	0.76	−1.32	2.24	−0.11	0.01	3.88	0.66
Finland	0.18	0.21	−0.53	0.33	0.37	0.02	0.45	1.49	0.29	−0.16	0.54	−0.06	1.66	0.74	−0.03	0.30	−0.15
France	−0.40	0.44	0.08	0.37	1.11	−0.07	1.10	−0.54	0.15	−1.60	0.14	0.25	0.92	1.51	0.12	−0.31	−0.58
Germany	−0.37	0.87	0.43	0.08	1.34	0.09	0.77	0.57	0.27	−7.51	0.00	0.38	1.83	−0.04	0.00	1.90	0.59
Greece	3.78	0.36	5.94	0.69	0.78	−0.86	0.59	5.90	0.64	5.59	1.42	1.18	0.41	0.33	0.12	0.26	−7.96
Hungary	2.79	0.80	2.01	−0.14	−0.89	0.26	−0.07	1.91	0.40	−2.44	4.04	0.32	1.63	0.23	0.05	0.99	−0.03
Ireland	2.23	0.01	0.68	0.63	2.43	−0.03	0.81	3.32	0.24	1.74	0.18	0.24	1.63	0.23	−0.26	1.10	1.38
Italy	1.56	0.50	3.59	0.83	1.18	−0.22	0.41	2.95	0.41	−0.72	0.52	0.19	0.67	−0.23	0.08	2.18	−2.58
Latvia	1.80	0.34	3.31	0.50	−0.19	0.99	0.01	2.11	2.75	−0.67	4.65	0.17	1.83	0.23	−0.01	5.38	−0.08
Lithuania	1.78	0.23	0.89	0.22	0.21	0.82	−0.25	1.84	0.44	4.54	3.22	−0.30	0.56	0.23	0.10	2.63	0.13
Luxembourg	−0.59	0.29	0.32	0.11	2.03	0.03	5.37	0.26	−0.17	−1.21	1.65	−0.21	1.39	−2.13	−0.06	1.08	0.30
Malta	0.89	2.08	0.46	2.78	6.16	−0.16	0.38	2.29	−0.18	0.02	−0.37	0.38	0.85	0.36	−0.53	−1.72	0.94
Netherlands	0.17	1.10	1.02	−0.02	1.18	0.00	1.19	0.29	0.24	−0.44	−0.01	0.57	1.42	0.26	0.34	0.91	0.08
Poland	1.51	0.26	3.73	−0.08	0.68	0.26	−0.11	1.33	0.79	1.96	2.22	−0.10	0.50	−22.04	0.00	0.69	0.73
Portugal	2.40	0.26	2.55	1.89	2.44	0.34	0.28	4.30	2.67	4.74	−0.91	−0.13	0.60	0.66	0.10	1.24	−0.21
Romania	3.55	0.27	3.39	1.32	0.89	4.24	−0.06	11.34	0.19	23.69	2.36	−0.04	1.00	21.21	0.07	0.98	0.06
Slovakia	0.77	0.36	−0.62	0.74	2.45	0.01	−0.12	1.57	0.33	3.01	4.77	−0.23	1.02	3.38	0.00	0.88	0.35
Slovenia	1.43	0.54	0.22	0.02	0.77	0.03	0.52	2.69	0.18	1.34	0.96	0.56	0.47	2.47	−0.02	1.48	−0.99
Spain	1.58	0.20	1.05	2.58	1.50	−0.24	0.59	2.82	−0.12	7.27	0.26	0.12	0.50	0.69	0.09	0.60	−1.59
Sweden	0.06	0.15	0.08	−0.02	0.80	0.00	1.12	0.19	0.31	0.01	−0.49	−0.24	2.15	4.09	0.01	−0.27	−0.37

Table 6. Country's performance rank order within goals 1 to 17 in 2020.

	GCI^{1}	GCI^{2}	GCI^{3}	GCI^{4}	GCI^{5}	GCI^{6}	GCI^{7}	GCI^{8}	GCI^{9}	GCI^{10}	GCI^{11}	GCI^{12}	GCI^{13}	GCI^{14}	GCI^{15}	GCI^{16}	GCI^{17}
Austria	6	7	12	16	13	9	19	10	1	13	8	13	18	1	15	5	18
Belgium	15	23	8	11	2	14	25	11	4	4	10	22	13	8	25	12	21
Bulgaria	25	17	18	26	20	23	13	25	24	27	26	26	24	26	3	26	9
Croatia	11	19	23	12	14	4	7	23	20	19	23	10	5	7	1	9	8
Cyprus	26	26	10	25	21	27	10	20	22	10	19	16	23	11	10	22	25
Czechia	1	10	14	18	23	21	24	7	5	2	15	9	26	4	19	17	19
Denmark	10	4	11	6	6	6	11	6	2	7	3	18	4	5	24	2	6
Estonia	12	2	27	4	22	17	23	8	23	16	13	27	22	24	5	16	20
Finland	3	1	19	3	3	3	26	5	6	3	7	25	7	12	7	6	11
France	14	8	13	10	4	13	15	21	10	14	12	1	10	13	21	23	23
Germany	20	11	9	19	12	11	21	4	7	25	2	7	20	2	23	4	14
Greece	24	9	24	17	25	25	3	27	17	21	22	15	8	9	4	25	27
Hungary	13	16	15	22	26	12	18	12	11	18	20	11	14	20	17	15	13
Ireland	18	18	3	1	16	8	8	3	12	1	5	14	21	23	22	3	17
Italy	22	13	7	23	19	18	6	26	13	23	16	2	3	16	18	18	26
Latvia	21	6	26	14	17	22	9	14	27	24	25	12	12	22	11	27	4
Lithuania	16	15	25	9	11	20	12	19	21	20	17	19	15	6	16	21	12
Luxembourg	17	24	6	13	7	7	27	18	9	8	4	6	27	3	20	1	15
Malta	5	27	2	24	27	19	5	9	18	11	14	5	9	10	27	24	2
Netherlands	9	25	4	7	10	10	20	2	8	6	1	3	16	19	26	11	1
Poland	4	21	16	8	18	15	17	17	19	15	24	21	25	27	14	7	5
Portugal	19	14	22	15	5	16	1	15	26	17	21	20	2	15	13	10	24
Romania	27	20	20	27	24	26	4	24	25	26	27	24	11	21	12	19	3
Slovakia	2	12	21	21	15	5	16	16	14	12	18	17	19	25	6	14	7
Slovenia	7	22	17	5	8	2	14	13	15	5	6	8	17	17	2	13	10
Spain	23	5	5	20	9	24	2	22	16	22	11	4	6	14	9	20	22
Sweden	8	3	1	2	1	1	22	1	3	9	9	23	1	18	8	8	16

Examining *SI* growth rate figures in detail (Table 2), it is revealed that Poland, Germany and Greece had the smallest annual growth rates in the 2010–2020 timeframe, which made them drop several positions in the comparative ranked list. The case of Germany stands as particularly striking, moving down from being among the 3 best performers in 2010 to rank in the 10th position in 2020. This country's commitment to the 2030 Agenda is undoubtedly strong, with a quite comprehensive sustainable development strategy and an independent advisory board—the German Council for Sustainable Development—which facilitates experts from different spheres of society to take part in the governance processes [57]. However, the fact that their SD strategy is not linked to the national budget might be hindering their ability to implement effective policies.

Table 2 also shows that Latvia experienced the largest percentage variation in the *SI* score in the past decade. Not only does Latvia appear as the worst overall performer of the EU27 in 2010, but the composite indicators *GCI* obtained for the year 2010 reveal that Latvia performed rather poorly in 2010 in goals SDG1, SDG3, SDG6, SDG9, SDG10, SDG11 and SDG16. Latvia's long term SD strategy, adopted in 2010, and the subsequent National Development Plan, encouraged specific actions that yielded positive outcomes in several areas, with observed *GCI* improvement rates greater than 1% in 9 of the 17 goals in 2020, reaching up to a 10% growth rate in goals SDG3, SDG11 and SDG16 (see Table 4) and a single unsustainable trend that was observed in SDG5. These excellent results explain the remarkable improvement in its position in the overall ranking, moving upwards from last to 21st position in 2020. Latvia's more recent strategic plan, to be implemented through 2021–2027, outlines some key reforms that are expected to allow further progress towards the objectives of the 2030 Agenda.

The second-best *SI* growth rate in the past decade occurred in Luxembourg, which underwent the most remarkable shift in the overall ranking, moving up from ranking 22nd in 2010 to the 14th position in 2020. The annual variation rates at the goal level for that period (Table 4) reveal that Luxembourg improved its aggregate performance score for a total of 13 SDGs, with some impressive results in SDG7, SDG13 and SDG14 that evidence the positive effects of a SD strategy focused on the transition towards a carbon-neutral economy and the challenge of climate change. Even so, while Luxembourg has made significant progress over the past decade in decoupling environmental pressures from economic growth, treating wastewater and increasing the share of renewables in electricity production, the country still lags behind in air quality within the EU picture [59] so further efforts are still needed. Luxembourg has a solid legal and institutional framework in its favor, which makes it stand as the best performer in SDG16 in 2020.

In the short term, the strongest improvement rate in the *SI* index in 2015–2020 was experienced by Romania, even if the country could not escape the last position in the 2020 performance ranking. Romania's first half of the 2010s was marked by the lingering effects of the 2008 crisis that revealed several structural and functional vulnerabilities in the management of their resources [60]. While the second half of the decade witnessed some advances in sustainability, Romania has yet a difficult path ahead, with additional efforts and resources needed to perform closer to the EU average and to set strategic tools for defining evidence-based and coherent policies.

In order to better illustrate how the weighting and aggregation procedures used affect the results obtained, we performed simple mean aggregations at the goal and overall levels with our normalized dataset. Figure 2 below shows the ranking for both methods with the 2020 dataset for the overall index and selected SDGs. At the overall level, the rankings obtained with *SI* index and with the simple mean show a Spearman rho correlation of 0.89, 0.93 and 0.92 for the years 2010, 2015 and 2020, respectively. With 2020 data, more than 80% of countries changed their position and 40% of them moved two or more places in the ranking. At the goal level, the differences observed in rankings are variable across the SDGs, with the average rank shift ranging from two (see SDG3 ranking in Figure 2) to five places (see SDG14 ranking in Figure 2). Therefore, it can be said that there are significant changes in the rankings obtained with both methods.

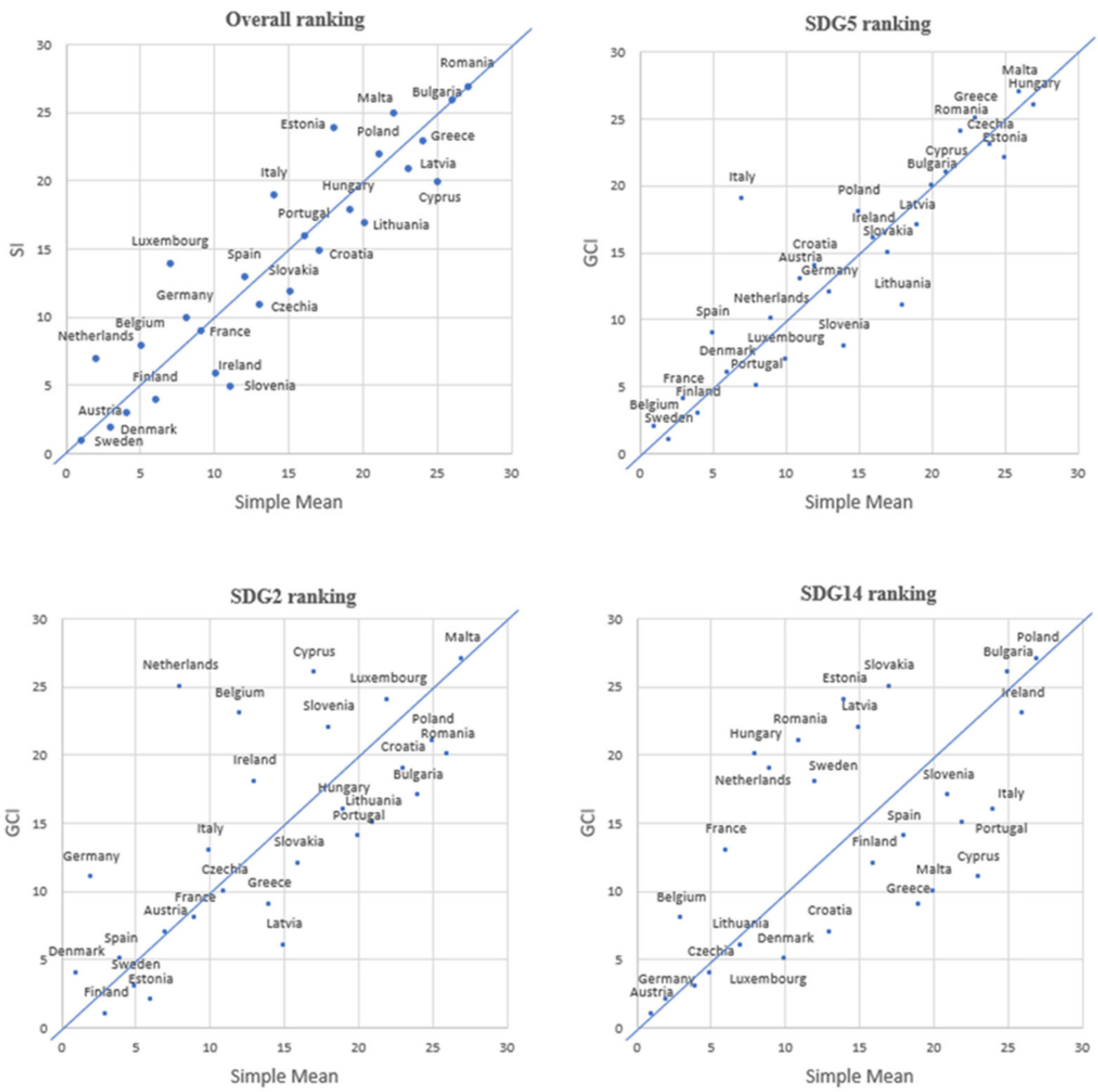

Figure 2. Comparison of rankings with proposed approach and simple mean approach.

5. Discussion of Findings

The comparison of the results obtained in the former section with other studies is not straightforward, given that they differ in several aspects of the methodological design (indicators used, normalization function, weighting and aggregation procedures) and, therefore, they might be portraying different sides of reality. Previous research [14] show that changes in the set of indicators used in the analysis can affect the results even more than the aggregation method used, and different methods for a given set of indicators do not affect countries or goals to the same extent, as seen in Figure 2.

Broadly speaking, the results obtained in this study are found to be consistent with previous analyses pointing out that Nordic countries (Sweden, Finland, Denmark) are steadily progressing towards the achievement of SDGs, whereas some Eastern and Mediterranean countries such Romania, Bulgaria, Malta and Greece are lagging behind. However, the results and conclusions derived from the procedure presented here are much more significant than those obtained from the common approach based on the simple mean.

At the goal level, the use of an equally weighted aggregation is usually justified by the equal importance of indicators for the achievement of SDGs, although it is well-known that indicators' contribution is actually unequal when the number of indicators per goal is uneven [60]. In addition, simple mean aggregation neglects the fact that all SDGs are not monitored with the same precision, and while some goals may be easily captured by comparable, strongly related indicators, some others may need the use of a rather wide and heterogeneous indicator set. Thus, a better estimation of the relevance of each indicator measure to the objectives set in each SDG would contribute to a more accurate assessment of the achievements made in each country. The weighting procedure used here fulfills this requirement while guaranteeing neutrality towards countries so that no specific sustainable policies are favored.

At the overall level, the effect of using geometric instead of the commonly used arithmetic aggregation is evident in Figure 2. While countries such as Sweden, France or Denmark that perform homogeneously across the 17 SDGs hardly experience any shifts in rankings, the geometric aggregation penalizes heterogeneous performances causing lower ranking positions, as in the case of Estonia, Italy or Malta. This is an important feature given that the SDGs must be pursued and achieved simultaneously for a successful implementation of the Agenda.

The study presented gives additional insight on how the European countries have been progressing towards the SDGs. The identification of determinants in *SI* scores and their evolution during the timeframe considered is beyond the scope of this paper, although some factors can be pointed out intuitively. It can be said that progress is conditioned by the countries' economies, which may force the prioritization of actions outside the SDG framework; their initial level of sustainability, since improvements beyond a certain point are more difficult to attain; and their level of commitment to the 2030 Agenda. In addition, with the normalization procedure introduced in Section 3, the score increase obtained after an improvement in a certain indicator measure is much higher when the performance is poor and, therefore, the efforts made by economies ranking in lower positions in 2010 (such as Latvia) were firmly rewarded in subsequent evaluations. The Table 2 figures also reveal that in the 2015–2020 period, most countries reduced the rate of sustainability improvement achieved in the previous 5-year period, with the exception of countries such as Romania, Greece, Spain, Italy or Portugal where the hard recovery from the 2008 crisis had hindered the advances towards sustainability during the first half of the decade. This decline in improvement rates can probably be attributed to the COVID-19 pandemic and its impacts on the economy, labor market, education and poverty, which are yet to be assessed precisely [61]. According to the data analyzed, at the goal level, the effects of the pandemic seem to be more evident in SDG4, SDG6, SDG10, SDG12 and SDG17, where the greater number of reversals in progress (that is, negative GCI annual growth rates) were registered in the 2015–2020 period, according to Table 5. Nevertheless, it is worth noting that the 2020 series may not be fully capturing the impact of the pandemic, and more time will be needed to report on how it slowed down progress towards sustainability.

Given the properties of the index developed here, the methodological approach presented can have implications for policymakers, academics and researchers. It can help in identifying what areas should sustainable strategies focus on, and it can also be used to evaluate the effectiveness of the implemented actions. Moreover, knowing the relative position regarding the other EU Member States raises public awareness about the Sustainable Development Goals and can be, in the best-case scenario, a reward for the efforts made, and an encouragement for improvement in the worst case. Additionally, at a broader level, the procedures described here can be deemed useful in other areas where the composite indicators find application.

6. Conclusions

The measurement of sustainability has been a rather intense research topic in the specialized literature for the past decades. Since the adoption of the 2030 Agenda and related SDGs, organizations, policymakers and researchers have been facing the challenges of sustainability with renewed stimulus. Large datasets have been developed and regularly maintained, providing the information needed to monitor the achievements made within the scope of the 17 SDGs. In the EU context, the implementation of the 2030 Agenda heavily relies on the EU SDG indicator set, a comprehensive set of indicator measures that succeed in capturing the multidimensional nature of sustainable development but cannot offer a clear picture of the overall performance.

Composite indicators have proved their effectiveness for the analysis of large amounts of indicator measures and the assessment of the sustainability condition of countries, highlighting strengths and weaknesses and helping decision makers define improvement strategies. Different methodologies can be used to build CI, but in sustainability studies, the most common approach is based on a linear aggregation of the individual indicators, which assumes a weak sustainability paradigm where low performance in some indicators may be compensated with high performance in others. Given that the fulfillment of the objectives set in the 2030 Agenda requires progress towards the SDGs to occur simultaneously across all goals, a strong sustainability paradigm seems much more convenient.

This work represents a further attempt to assess sustainability performance from a strong perspective. When applied within the 2030 Agenda framework, the methodology described aggregates the indicators in two steps. First, a linear aggregation within each of the 17 SDGs is performed, since at that level indicators usually describe a set of complementary policy priorities and, in that sense, compensability can be accepted. However, rather than the usual average, a neutral weighting scheme is proposed to make all countries appear as sustainably performing as possible by maximizing similarity to an ideal unit or, equivalently, minimizing distances to the ideal unit. In a second stage, the 17 goal composite indicators obtained are then aggregated using the geometric mean, which penalizes countries with low performance in some of the goals while it favors those countries with balanced performances across the 17 SDGs; therefore, the geometric aggregation is more suitable at this stage.

The proposed procedure is applied in the context of the European Union using data from the EU SDG indicator set for the period 2010–2020. The scores of the sustainability indexes *SI* obtained allow a ranking of the Member States according to their level of success in the implementation of the 2030 Agenda. As is known, ranked lists can be used to benchmark countries against each other, which not only is a useful way to raise public awareness in the SDGs, but also a strong incentive to improve performance, stimulate planning processes and even enable learning from countries with better sustainability policies. Instead of the usual linear rescaling procedure, the use of a concave normalization function implies that differences between normalized scores are accentuated for data points at low performance levels, so improvements in indicator values will have a more significant effect the more unfavorable the initial status of the indicator is. In other words, poorly performing countries will be encouraged to address their weaknesses in order to improve their position in the overall ranking. In addition, since the same indicator weights and normalization parameters were used for the three periods considered, comparability of the indexes scores is guaranteed, so that variation rates can be used to gain a dynamic insight into the progress of countries towards the SDGs.

The results obtained show that, although all 27 Member States have experienced some kind of decline in performance for one or more of the 17 SDGs during the last decade, the overall picture shows improvements in performance at annual rates between 0.30% and 2.65%, with differences between countries diminishing over the years. In addition, it can also be confirmed that during the last decade, all countries have progressed towards SDG7 and SDG13, which reflects the successful accomplishments after a decade of commitment to raising the share of renewable energy sources, increasing energy efficiency and fighting climate change.

The effects of the COVID-19 pandemic, which are yet to be assessed precisely, have been perceived in a generalized deceleration in the annual *SI* growth rates during the past five years, with several reversals in progress observed in SDG4, SDG6, SDG10, SDG12 and SDG17.

It must be pointed out that these results are valid in the context of the dataset used. Since different indicators may measure various aspects of the economy, environment, social welfare or institutions, the use of other equally justifiable set of indicators may produce variations in some of the results. Nevertheless, since the indicator selection made here is exclusively based on availability issues (with no attention whatsoever paid to any kind of biased interests), and the methodology used follows an objective and neutral approach, the results derived can be assumed to be sound and acceptable.

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