

Empirical Paper

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Efficiency ranking of economic growth toward sustainable growth with grey system theory: the case of small countries in advanced and emerging economies

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Abstract: The article refers to the new Synthetic Efficiency Indicator for Economic Growth (SEI-EG) proposed in an earlier publication. Research from 2016–2018 in 11 EU countries revealed small nations were notably more effective at sustainable growth than their larger counterparts. This prompted the authors to ask about the differences between small countries with developed economies and small countries with lower levels of development joining the EU in 2004. The article aims to determine the relative efficiency of transforming growth inputs and debt into sustainability outcomes for small countries in the EU using the SEI-EG index over the period 2016–2020. The study group symmetrically includes six countries each from developed economies and six countries that joined the EU in 2004. The adopted indicator complements the expanded SDGs and aligns with the trend linking research inputs to sustainable development effects.

Keywords: economic convergence, economic growth, gray system theory, gray whitenization, sustainable development

JEL Classification: O47, O40, O32

1 Introduction

Nowadays, the problem of sustainability and its measurement is becoming one of the key economic issues. This is linked to the threat of climate change and also to the search for ways to implement and make effective the Sustainable Development Goals (SDGs) proposed by the United Nations (UN). As defined in September 2015, the “2030 Agenda for Sustainable Development” is a comprehensive development plan for the world established by the UN, through negotiations between member countries, with a 2030 perspective. The adoption of the 2030 Agenda is an unprecedented event in human history. All 193 UN member states have committed to undertake action toward the 17 SDGs [climatescience.org, 2022]. The 17 SDGs contain a total of 163 goals, which are monitored to varying degrees by individual countries. The history of experience in this field proves that 3,528 Events were held worldwide, 1,327 Publications were created, and 6,618 Actions were organized [sdgs.un.org, 2022]. A synthetic picture in the form of measuring distance to targets for countries for which data are available is presented in the ranking of the Sustainable Development Report

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[2022], *From Crisis to Sustainable Development: the SDGs as Roadmap to 2030 and Beyond* [Sachs et al., 2022]. In addition to this broad and globally comparable approach, what is important from an economic point of view is the efficiency of the measures to any reasonable extent in combination with potential funding sources. For this purpose, new indicators are being sought that would additionally have the value of international comparability. The authors' proposed integrated approach to research in this area was to create an index measuring the effects of debt-supported economic growth with benefits for sustainable growth. It was assumed that the transformation of input categories, represented by GDP (per capita in PPS) and general government gross debt (percentage of GDP), into effects related to sustainable development indicators in the selected three key areas: Industry, Innovation, and Infrastructure, should provide an answer to the question of whether countries achieving a long-term relatively higher stage of economic growth are characterized by a higher efficiency of transition of their economies toward sustainable growth. In order to test whether a country's stage of development in the European Union (EU) is relevant to the efficiency studied, 12 small countries at different levels of development were adopted for the analysis. Indirectly, a convergence component was thus introduced into the analysis, as the countries joining the EU in 2004 were countries "catching up," characterized according to the convergence hypothesis by higher economic growth rates with lower initial GDP pc. As previously demonstrated, smaller countries had a higher efficiency of transforming economic growth into sustainable growth in the group of 15 countries (EU15). Germany was the exception. The countries that joined the EU in 2004 are generally, apart from Poland, relatively small. Thus, the countries previously considered can serve as a kind of reference point for them. It is also important that Europe, including the EU, is at the forefront of change for sustainable development. It was assumed that there are significant differences between the individual countries analyzed and, in particular, between the two groups of countries, determined not only by the economic strength of the individual economies, but also by the EU's economic policies to combat climate change [<https://climate.ec.europa.eu>, 2022]. The Green Deal, the EU's climate strategy, has established a target for member states to reduce CO₂ emissions so that by 2030, the Community as a whole will have achieved its climate priorities, i.e., a 55% reduction in greenhouse gas emissions compared to 1990 by 2030 and climate neutrality by 2050 [<https://ec.europa.eu>, 2022]. The availability of data in the study conducted extends to 2020. The research period of 2016–2020 therefore does not yet include the perceived disruption from the COVID-19 outbreak and the shock of the war in Ukraine and thus the risk of a change in the structure of expenditure, including on health or defense, and the risk borne by widespread inflation and the associated higher interest rates. The dramatically low interest rates and low cost of capital seen earlier represented a good time to upgrade infrastructure, invest in education, and support green technology. It was believed that the social rate of return on these investments was many times greater than the cost of public debt at the time [Rachel and Summers, 2019]. For well over a decade, governments in the developed countries have been borrowing at very low interest rates, sometimes even at negative rates. This is going to end, and probably for a long while [www.obserwatorfinansowy.pl, 2022]. On the other hand, it was emphasized that although smaller countries are objectively at a disadvantage, as they generally lack a diversified economic structure and bargaining power in negotiations and are less resilient to crises, the experience of recent years pointed to their strengths in terms of a smart and innovative approach to sustainable growth. This allowed institutional and economic advantage to be built [Browning, 2006; Grøn and Wivel, 2011; Panke, 2012a, 2012b; Wivel, 2013; Pedi and Sari, 2019]. The results of the presented ranking also indirectly testify to other, difficult-to-measure factors influencing the ranking position of individual countries, including, above all, the pro-environmental awareness of companies and consumers and their adoption of sustainable growth measures that affect economic growth itself. It is also important to have economic policies in line with this message.

2 Literature review

The literature review related to the area of transforming economic growth toward sustainable growth contains a broad spectrum of issues, ranging from the call for limiting economic growth and moving toward

the idea of so-called “post-growth,” through attempts to study the impact of various factors and measures for sustainable growth, to the global measurement of distance from SDG targets and also the introduction of climate-related elements into existing measurements of economic development. This approach is consistent with the widely accepted message that sustainable development has acquired greater importance over time, as society as a whole has become more aware of its impact on the environmental scenario. There is also a consensus on the direction of transforming quantitative economic growth toward a more qualitative and responsible dimension. From the point of view of interest in the broader area of sustainable development in the literature, it is legitimate to state that there has been a dynamic growth in this area.

The analysis between 2001 and 2020 shows that the number of articles in this area increased from 49 between 2001 and 2005 to 1,867 between 2016 and 2020 and the number of citations over the same comparable periods increased from 70 to 33,490. In contrast, the number of journals increased from 37 to 6,654. The United States is the country with the highest number of articles (466), followed by Spain (347) and the United Kingdom (332). In Spain, the leader is the Universidad of Salamanca and the most productive author is García-Sánchez, with a total of 22 articles published during the period of time analyzed (2001–2020) [Meseguer-Sánchez et al., 2021]. The literature also draws attention to the choice of method, which is the key step between the sustainability assessment question posed and the answer to it. The choice of method at least narrows the field of assessment across a broad spectrum of issues. Therefore, the choice of method should be based on careful articulation [Zijp et al., 2015]. This is particularly applicable to sustainability assessment, where there is a diversity of methods and interpretations available [Waas et al., 2014].

Many, and especially recent, publications refer to the impact of digitalization or Corporate Social Responsibility (CSR) activities, for sustainable growth [www.economicshelp.org, 2022; Bartosik-Purgat and Filimon, 2022]. On a broader substantive level, the scope of the literature reflects well the objectives stated by Hess [2016] (in his publication *Economic Growth and Sustainable Development*). They are linked to well-known areas of economics research such as economic convergence and income inequality, including the impact of global population growth. The question is also asked: What accounts for the extraordinary growth in the world’s population over the past two centuries, or what causes economic growth?

New questions, related to sustainable growth, are added to the existing key issues. They are as follows:

- How do we measure sustainable development and is sustainable development compatible with economic growth?
- Why is climate change the greatest market failure of all time?
- What can be done to mitigate climate change and global warming? [Hess, 2016]

The emphasis on new phenomena such as climate change and, above all, measurements related to the compatibility of economic growth and sustainable development are closest to the subject of this article.

In this area, the importance of the key book position should be highlighted: *The Climate Casino. Risk, Uncertainty, and Economics for a Warming World* [Nordhaus, 2013]. In contrast, a landmark study related to the implementation of the SDG project is the aforementioned *Global Ranking from Crisis to Sustainable Development the DDGs as Roadmap to 2030 and Beyond*. This ranking measures the distances from the SDG targets in two terms: an overall indicator and an indicator of the impact on other countries. The first indicator, “the overall score measures the total progress toward achieving all 17 SDGs.” The score can be interpreted as a percentage of SDG achievement. A score of 100 indicates that all SDGs have been achieved. In the second indicator, the various countries are ranked based on their spillover score. Each country’s actions can have positive or negative effects on other countries’ abilities to achieve the SDGs. The Spillover Index assesses such spillovers along three dimensions: environmental and social impacts embodied into trade, economy and finance, and security. A higher score means that a country causes more positive and fewer negative spillover effects [Sustainable Development Report, 2022]; 163 indicators are considered. As complementary to it, at a global level, the Energy Transition Index (ETI), 2019, developed for 115 countries ranked by the World Economic Forum (WEF), can be considered. In the Polish studies, the most noteworthy is the Responsible Development Index, version 2.0, in which the pillar “Climate Responsibility” was

included in the 2022 edition. This index is compiled for 159 countries and contains three basic pillars: “present well-being,” “creation of past well-being,” and “non-wage factors” [https://pie.net.pl, 2022]. In the literature, there is a noticeable shift in priorities in the analysis of economic phenomena from a classical to an integrated approach with sustainable growth objectives. This trend is also accompanied by an increase in publications devoted to bibliometric reviews related to the topic of sustainable development itself [Enciso-Alfaro and García-Sánchez, 2022].

3 Research concept and method

The foundations of grey systems theory were presented in 1982 by Deng [1982]. This theory is a tool for modeling uncertainty occurring in a variety of systems – technical, natural, and social [Więcek-Janka et al., 2019]. Grey systems theory is particularly applicable when the system under study is characterized by uncertainty due to the small amount of information, its incompleteness, and burden of errors. In tool terms, gray systems theory includes a set of uncertainty modeling tools that use either grey numbers or whitening functions.

A grey number, in the simplest terms, is understood to be some specific value d^* , which is not known, but the interval (or set) in which this number occurs is known [Mierzwiak et al., 2021]. The most common notation for a gray number is as follows: $\otimes = d^* \in [\underline{a}, \bar{b}]$, where $\underline{a}$ denotes the lower limit of the gray number and $\bar{b}$ its upper limit. At the same time, it is assumed that $\bar{b} \geq \underline{a}$.

Whitening functions, on the other hand, are understood to be functions that allow the transition from grey numbers to white (concrete) numbers. Whitening can use either the decision-maker’s preference functions or can be based on a probability distribution (if known). The most common whitening function assumes the following form [Liu et al., 2017]:

$$\tilde{\otimes} = \alpha \cdot a + (1 - \alpha) \cdot b, \alpha \in [0, 1], \quad (1)$$

where a represents the lower limit of bleached gray number, b the upper limit of bleached gray number, and α the whitening factor.

Among the most popular weight whitening functions are triangular, trapezoidal, and nonlinear functions.

The measurement of the efficiency of transforming growth-related inputs into sustainability-related outputs for the countries constituting the research group in the article was conducted using the author’s “*Synthetic Efficiency Indicator for Economic Growth*” (“SEI-EG”) – based on grey systems theory (especially whitening functions) [Nowak et al., 2020, 2021]. The determination of the described indicator can be presented as a research procedure consisting of seven steps [Kokocińska et al., 2020].

Step 1. Development of the D data matrix that is the subject of the whitening process

The data matrix D adopts the form presented in Eq. (1).

$$D = [d_{ik}] = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \\ i_{11} & i_{12} & \cdots & i_{1m} \\ i_{21} & i_{22} & \cdots & i_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ i_{j1} & i_{j2} & \cdots & i_{jm} \end{bmatrix} \quad (2)$$

where D represents the data matrix; r_{ik} the i -th result for k -th object; $i = 1, 2, \dots, n$, $k = 1, 2, \dots, m$; i_{ik} the i -th effort for the k -th object; and $i = 1, 2, \dots, j$, $k = 1, 2, \dots, m$.

Step 2. Development of a scaled input data matrix D^*

The next step of the method develops a matrix of rescaled input data represented by Eq. (2).

$$D^* = [d_{ik}^*] = \begin{bmatrix} r_{11}^* & r_{12}^* & \cdots & r_{1m}^* \\ r_{21}^* & r_{22}^* & \cdots & r_{2m}^* \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}^* & r_{n2}^* & \cdots & r_{nm}^* \\ i_{11}^* & i_{12}^* & \cdots & i_{1m}^* \\ i_{21}^* & i_{22}^* & \cdots & i_{2m}^* \\ \vdots & \vdots & \ddots & \vdots \\ i_{j1}^* & i_{j2}^* & \cdots & i_{jm}^* \end{bmatrix} \quad (3)$$

where d_{ik}^* means:

1. For maxima:

$$d_{ik}^* = \frac{d_{ik}}{d_{ik}^{max}} \quad (4)$$

2. For minima:

$$d_{ik}^* = \frac{d_{ik}^{min}}{d_{ik}} \quad (5)$$

Step 3. The development of a vector of synthetic input indicators I_k for all decision objects

The vector of synthetic inputs I_k for all decision objects is determined using Eq. (6).

$$I_k = \sum_{i=1}^j i_{ik}^* \quad (6)$$

where I_k represents the synthetic input indicator of the k -th decision object, and i_{ik}^* the scaled i -th input of the k -th decision object.

The vector of synthetic input indicators I_k can also be represented as:

$$[I_1, I_2, \dots, I_m] \quad (7)$$

Step 4. Development of a partial efficiency matrix E

In Step 4 of the method, the matrix of partial efficiencies of the decision objects E is determined as demonstrated in Eq. (8):

$$E = [e_{ik}] = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1m} \\ e_{21} & e_{22} & \cdots & e_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ e_{n1} & e_{n2} & \cdots & e_{nm} \end{bmatrix} \quad (8)$$

where E represents the matrix of partial efficiencies of the research decision objects; $i = 1, 2, \dots, m$ the designation of the partial performance indicator; $k = 1, 2, \dots, n$ the designation of the decision objects; and e_{ik} the i -th partial efficiency indicator for k -th decision object.

The partial efficiencies e_{ik} are determined using Eq. (9).

$$e_{ik} = \frac{r_{ik}^*}{I_k} \quad (9)$$

where r_{ik}^* represents the scaled value of the i -th result for the k -th object, and I_k the value of the synthetic input indicator for the k -th decision object.

Step 5. Determination of the reference and anti-reference vector of partial efficiencies

In Step 5 of the method, the reference and anti-reference vectors are determined as a function of the empirical base. The reference vector contains the best values for the individual partial efficiencies, regardless of which decision object achieved them. The reference vector is of the form presented in Eq. (10).

$$\mathbf{REF} = \begin{bmatrix} e_{1\max} \\ e_{2\max} \\ \vdots \\ e_{n\max} \end{bmatrix} \quad (10)$$

The anti-reference vector, meanwhile, contains the worst values for the individual partial efficiencies, regardless of which decision object achieved them. The anti-reference vector is of the form presented in Eq. (11).

$$\mathbf{AREF} = \begin{bmatrix} e_{1\min} \\ e_{2\min} \\ \vdots \\ e_{n\min} \end{bmatrix} \quad (11)$$

Step 6. Standardization of the partial efficiency matrix E^* to the interval (0,1)

In the next step of the method, the elements of the partial efficiency matrix E^* are normalized to the interval (0,1) according to Eq. (12).

$$e_{ik}^* = \frac{[e_{ik} - \min(e_{ik})] \cdot (e_{\max}^* - e_{\min}^*)}{\max(e_{ik}) - \min(e_{ik})} + e_{\min}^* \quad (12)$$

where $\min(e_{ik})$ represents the minimum value of the i -th partial efficiency in the set of all objects, $\max(e_{ik})$ the maximum value of the i -th partial efficiency in the set of all objects, $e_{\max}^*$ the assumed maximum value of the standardized partial efficiency, and $e_{\min}^*$ the assumed minimum value of the standardized partial efficiency.

If the object in question achieved all the partial efficiencies at the best level (maximum values for the maxima and minimum values for the minima), then it would show a maximum efficiency of 1.00. If the object in question achieved all the partial efficiencies at the worst level (minimum values for the maxima and maximum values for the minima), then it would show a maximum efficiency of 0.00.

Step 7. Determination of the SEI-EG for each decision object

The efficiency of each object is in the interval (0,1) – in each instance no less than the anti-reference vector and no greater than the reference vector. The value of the SEI-EG index is the result of the whitening function, the effect of which can be depicted in the radar diagram. On the radar diagram, as many axes are drawn as partial efficiencies are analyzed. The starting point for each of the standardized partial efficiencies (matrix E^*) on the subsequent axes is determined by the minimum standardized partial efficiency contained in the empirical anti-reference vector (AREF) vector. The apex of the radar

diagram, however, is determined by the maximum partial efficiency contained in the REF vector. On each axis, the relative value of the partial efficiency of the object (country) in question relative to the empirical base is applied. In the proposed model, the weight whitening function for the k -th object assumes the form presented in Eq. (13):

$$f(E^*) = \frac{S_k}{S_{REF}} \quad (13)$$

where $f(E^*)$ represents the whitening function (assigns the grey number the value of the white number), S_k the area of the polygon defined by the values derived from the vector describing the standardized partial efficiencies of the k -th object, and S_{REF} the area of the polygon defined by the values derived from the standardized reference vector.

One method of determining the value S_k is to use the method of calculating the areas of polygons (Gaussian method). This formula is of the form presented in Eq. (14).

$$F = \frac{1}{2} \left| \sum_{i=1}^n X_i (Y_{i+1} - Y_{i-1}) \right| \quad (14)$$

where F represents the calculated surface area, and X_i , Y_i the coordinates of the i -th vertex; vertices are numbered consecutively from 1 to n .

The effect of the procedure presented is to assign each object a performance indicator with the interval (0,1).

4 Research results

The following countries were included in the research: Belgium (o_1), Czech Rep. (o_2), Denmark (o_3), Estonia (o_4), Latvia (o_5), Lithuania (o_6), Hungary (o_7), Netherlands (o_8), Austria (o_9), Slovakia (o_{10}), Finland (o_{11}), and Sweden (o_{12}). These countries can be divided into two groups. The first is the group of highly developed small EU countries (Belgium, Denmark, Netherlands, Austria, Finland, and Sweden). The second group consists of the small countries that joined the EU in 2004 (excluding the smallest countries, i.e., Malta, Cyprus, and Slovenia). The adopted group of countries is quantitatively symmetrical and at different levels of economic growth is represented by six countries. Table 1 provides the basic economic figures for 2020, which are useful for assessing a country's economic strength, and thus enables the material basis for the process of transforming economies toward sustainable growth to be ascertained.

As can be seen from Table 1, these countries, although varying in population, from the smallest Estonia to the relatively large Netherlands, form a group of small countries in relation to economies such as Germany, France, Italy, or Spain. Their feature is a relatively high employment rate, exceeding 70% of the 15–64 year old population for the most part. A clear differentiation, on the other hand, is seen in the GDP pc indicator, assuming that the average for the EU is 100. Indicators for advanced economies oscillate between 114.1 (Finland) and 132.4 (Denmark) and indicators for emerging economies oscillate between 71.8% (Slovakia) and 93.4%, (Czech Rep.) reflecting the convergence component mentioned above.

The general government gross debt is also an important and highly differentiated parameter, which is important from the point of view of creating resources for the transformation of economic growth into sustainable growth. The data presented show that debt in 2020 was generally higher in the first group of countries, although against this background it is important to note Belgium's high ratio, exceeding over 100% of GDP. The second group of countries is characterized by lower debt ratios on average. In this respect, Hungary has a significantly higher rate than the other countries, followed by Slovakia. The related indicator of labor productivity (GDP per person employed) is a measure of economic efficiency that could potentially already be a result of the economic transformation occurring in companies toward sustainable growth. From this point of view, the two Baltic countries distinguish themselves: Estonia and Latvia.

Table 1. Selected macroeconomic indicators 2020

Country	Total population	Total employment From 15 years to 64 years percentage of total population	GDP pc In PPS UE = 100	General government gross debt	Labor productivity, GDP per person employed
	2020	2020	2020	2020	2019/2020
Austria	8,916,864	72.4	124.9	82.3	-4.9
Belgium	11,538,684	64.7	119.0	112.0	-5.4
Denmark	5,834,404	74.4	132.7	42.2	-0.9
Finland	5,529,543	72.1	114.1	74.8	-0.5
Netherlands	17,441,500	77.8	130.5	54.7	-3.4
Sweden	10,353,442	75.5	122.4	39.5	-0.8
Czech Rep.	10,697,858	74.4	93.4	37.7	-3.9
Estonia	1,329,522	73.2	86.1	18.5	2.2
Hungary	9,750,149	69.7	74.5	79.3	-3.5
Lithuania	2,794,885	71.6	87.6	46.3	1.6
Latvia	1,900,449	71.6	72.0	42.0	0.8
Slovakia	5,458,827	67.5	71.8	58.9	-1.5

Source: Eurostat [2023].

PPS, Purchasing Power Standards.

During the specific COVID period, only Estonia and Latvia had a positive productivity indicator. It should be added that the following years brought the recovery of these indicators in all countries. However, the largest increases concerned Latvia and Estonia. According to a report by the WEF, the Baltics are among the most innovative European nations when considering start-up activity Total Early-Stage Entrepreneurial Activity (TEA) and employee creativity in established companies Entrepreneurial Employee Activity (EEA) together. Out of 28 European countries, the three Baltic countries ranked in the top seven together with Sweden, which is an important reference point for the Baltics. Lithuania, Latvia, and Estonia are striving to create an environment conducive to entrepreneurship, modern technology, and international talent and already have something to boast about in this regard [<https://www.obserwatorfinansowy.pl/in-english/business/the-baltic-states-chose-fintech/>, 2022]. Estonia is among the countries with the highest number of start-ups per capita, and the country is among the most technologically advanced in the world. The tax system, the so-called Estonian corporate income tax (CIT), is also in favor of this. Latvia's specialty, on the other hand, is payment and lending solutions; also, using blockchain technology, Lithuania was the latest to start creating a support system for start-ups and technology companies, but is doing so at a fast pace; Lithuania, Latvia, and Estonia are largely in competition with each other. Joint initiatives are virtually non-existent – if they were, the bargaining power of the Baltic countries would be much greater and the achievements more spectacular [<https://www.obserwatorfinansowy.pl/in-english/business/the-baltic-states-chose-fintech/>, 2022]. In the instance of central Europe, the view is that the entire region, including the Czech Republic, has stopped at a certain stage of development that is roughly equivalent to 60% of Germany's GDP. Meanwhile, knowledge, human capital, and research and development (R&D) are the source of economic growth. Foreign investment, productivity, and European funds are a thing of the past. It must also be considered that EU funds account for a third or even half of public investment [<https://www.obserwatorfinansowy.pl/in-english/new-trends/estonia-is-the-most-innovative-country-in-the-cse/>, 2022].

There is also a view in the literature that “The climate problem is not caused by economic growth, but by the absence of effective public policy designed to reduce greenhouse gas emissions. There is nothing

incompatible with capitalism and environmental protection as long as rules are in place that control the environmental impacts of the products and services we make and use” [Cohen and Shinwell, 2020].

Step 1. Development of the D data matrix that is the subject of the whitening process

The inputs in the proposed model are indicated as follows: GDP per capita in PPS – i_1 , general government gross debt (percentage of gross domestic product) – i_2 . The effects are, meanwhile, designated as follows: gross domestic expenditure on R&D by sector (% of GDP) – r_1 , employment in high- and medium-high technology manufacturing and knowledge – r_2 , R&D personnel by sector – r_3 , patent applications to the European Patent Office – r_4 , share of buses and trains in total passenger transport – r_5 , share of rail and inland waterways in total freight transport – r_6 , and average CO₂ emissions per kilometer from new passenger cars – r_7 . The time scope of the analysis covers the years 2016–2020. The example calculations and results in this section of the article are presented for 2020. Table 2 shows the data matrix for the determination of the SEI-EG index.

Table 2. Input data matrix for 2020

	o_1 (BEL)	o_2 (CZE)	o_3 (DEN)	o_4 (EST)	o_5 (LAT)	o_6 (LIT)	o_7 (HUN)	o_8 (NET)	o_9 (AUT)	o_{10} (SLO)	o_{11} (FIN)	o_{12} (SWE)
r_1	3.48	1.99	3.03	1.79	0.71	1.16	1.61	2.29	3.2	0.91	2.94	3.53
r_2	54.4	46.0	54.1	41.5	39.3	39.4	45.2	49.5	45.5	46.7	52.5	58.8
r_3	2.0548	1.5497	2.1242	0.9746	0.7068	1.0117	1.2646	1.7361	1.8359	0.815	2.0365	1.8121
r_4	208.52	19.26	414.99	42.87	15.79	17.89	11.18	366.14	258.61	9.89	343.43	427.10
r_5	13.5	18.3	12.7	11.6	12.3	5.8	21.2	9.9	19.4	18.8	13.0	16.0
r_6	22.6	22.8	10.8	38.6	56.5	64.7	34.1	47.8	32.0	32.0	26.2	29.8
r_7	107.7	120.9	95.3	121.0	119.2	119.3	116.7	82.3	113.0	121.8	100.3	93.4
i_1	39,560	20,170	53,480	19,720	15,500	17,710	14,100	45,670	42,540	16,860	43,030	46,420
i_2	112.8	37.7	42.1	19.0	43.3	46.6	79.6	54.3	83.3	59.7	69.0	39.6

Of the inputs and outputs indicated, apart from r_7 (average CO₂ emissions per kilometer from new passenger cars), all are maxima.

Step 2. Development of a scaled input data matrix D^*

Using Eqs (3)–(4), the variables from Step 1 were rescaled (Table 3).

Table 3. Matrix of scaled inputs for 2020

	o_1 (BEL)	o_2 (CZE)	o_3 (DEN)	o_4 (EST)	o_5 (LAT)	o_6 (LIT)	o_7 (HUN)	o_8 (NET)	o_9 (AUT)	o_{10} (SLO)	o_{11} (FIN)	o_{12} (SWE)
r_1	0.986	0.564	0.858	0.507	0.201	0.329	0.456	0.649	0.907	0.258	0.833	1.000
r_2	0.925	0.782	0.920	0.706	0.668	0.670	0.769	0.842	0.774	0.794	0.893	1.000
r_3	0.967	0.730	1.000	0.459	0.333	0.476	0.595	0.817	0.864	0.384	0.959	0.853
r_4	0.488	0.045	0.972	0.100	0.037	0.042	0.026	0.857	0.606	0.023	0.804	1.000
r_5	0.637	0.863	0.599	0.547	0.580	0.274	1.000	0.467	0.915	0.887	0.613	0.755
r_6	0.349	0.352	0.167	0.597	0.873	1.000	0.527	0.739	0.495	0.495	0.405	0.461
r_7	0.764	0.681	0.864	0.680	0.690	0.690	0.705	1.000	0.728	0.676	0.821	0.881
i_1	0.740	0.377	1.000	0.369	0.290	0.331	0.264	0.854	0.795	0.315	0.805	0.868
i_2	1.000	0.334	0.373	0.168	0.384	0.413	0.706	0.481	0.738	0.529	0.612	0.351

Step 3. The development of a vector of synthetic input indicators I_k for all countries

The vector of synthetic input indicators I_k for all countries has the following form:

$$I_k = [1.740, 0.711, 1.373, 0.537, 0.674, 0.744, 0.969, 1.335, 1.534, 0.845, 1.416, 1.219]$$

Step 4. Development of the partial efficiency matrix E

Table 4 shows the developed partial efficiency matrix E for 2020.

Table 4. Partial efficiency matrix E for 2020

	o_1 (BEL)	o_2 (CZE)	o_3 (DEN)	o_4 (EST)	o_5 (LAT)	o_6 (LIT)	o_7 (HUN)	o_8 (NET)	o_9 (AUT)	o_{10} (SLO)	o_{11} (FIN)	o_{12} (SWE)
e_1	0.567	0.792	0.625	0.944	0.299	0.442	0.471	0.486	0.591	0.305	0.588	0.820
e_2	0.532	1.100	0.670	1.314	0.992	0.900	0.793	0.630	0.504	0.940	0.630	0.820
e_3	0.556	1.026	0.728	0.854	0.494	0.640	0.614	0.612	0.563	0.454	0.677	0.700
e_4	0.281	0.063	0.708	0.187	0.055	0.056	0.027	0.642	0.395	0.027	0.568	0.820
e_5	0.366	1.213	0.436	1.019	0.861	0.368	1.032	0.350	0.597	1.050	0.433	0.619
e_6	0.201	0.495	0.122	1.111	1.296	1.344	0.544	0.553	0.322	0.586	0.286	0.378
e_7	0.439	0.957	0.629	1.266	1.025	0.927	0.728	0.749	0.475	0.800	0.579	0.723

Step 5. Determination of the reference and anti-reference vector of partial efficiencies

The empirical reference vector (REF) has the following form:

$$\text{REF} = [0.944, 1.314, 1.026, 0.820, 1.213, 1.344, 1.266]$$

The empirical anti-reference vector (AREF) has the following form:

$$\text{AREF} = [0.299, 0.504, 0.454, 0.027, 0.350, 0.122, 0.439]$$

Step 6. Standardization of the partial efficiency matrix E to the interval (0,1)

Table 5 shows the effect of standardizing the partial efficiency matrix E to the interval (0,1).

Table 5. Standardized partial efficiency matrix E for 2020

	o_1 (BEL)	o_2 (CZE)	o_3 (DEN)	o_4 (EST)	o_5 (LAT)	o_6 (LIT)	o_7 (HUN)	o_8 (NET)	o_9 (AUT)	o_{10} (SLO)	o_{11} (FIN)	o_{12} (SWE)
e_1^*	0.415	0.765	0.506	1.000	0.000	0.222	0.266	0.290	0.453	0.010	0.449	0.808
e_2^*	0.034	0.735	0.205	1.000	0.602	0.489	0.357	0.156	0.000	0.539	0.156	0.390
e_3^*	0.178	1.000	0.479	0.700	0.069	0.325	0.280	0.276	0.191	0.000	0.390	0.430
e_4^*	0.320	0.046	0.858	0.202	0.035	0.037	0.000	0.775	0.464	0.001	0.682	1.000
e_5^*	0.019	1.000	0.100	0.774	0.592	0.021	0.790	0.000	0.286	0.811	0.096	0.312
e_6^*	0.065	0.306	0.000	0.809	0.961	1.000	0.345	0.353	0.164	0.380	0.134	0.210
e_7^*	0.000	0.626	0.229	1.000	0.708	0.590	0.349	0.374	0.043	0.436	0.169	0.343

The reference vector will consist of values of 1.00 in each of the partial efficiencies (standardized) and the anti-reference vector will consist of 0.00 values alone.

Step 7. Determination of SEI-EG for each country

Table 6 shows the SEI-EG values for all countries analyzed in 2020.

Table 6. SEI-EG index values for all countries analyzed 2020

	σ_1 (BEL)	σ_2 (CZE)	σ_3 (DEN)	σ_4 (EST)	σ_5 (LAT)	σ_6 (LIT)	σ_7 (HUN)	σ_8 (NET)	σ_9 (AUT)	σ_{10} (SLO)	σ_{11} (FIN)	σ_{12} (SWE)
SEI-EG	0.012	0.338	0.116	0.633	0.188	0.146	0.097	0.078	0.042	0.069	0.082	0.234

SEI-EG, Synthetic Efficiency Indicator for Economic Growth.

Table 7, meanwhile, shows the SEI-EG values for all countries analyzed for 2016–2020.

Table 7. SEI-EG index values for all countries analyzed for 2016–2020

	σ_1 (BEL)	σ_2 (CZE)	σ_3 (DEN)	σ_4 (EST)	σ_5 (LAT)	σ_6 (LIT)	σ_7 (HUN)	σ_8 (NET)	σ_9 (AUT)	σ_{10} (SLO)	σ_{11} (FIN)	σ_{12} (SWE)
SEI-EG ₂₀₂₀	0.012	0.338	0.116	0.633	0.188	0.146	0.097	0.078	0.042	0.069	0.082	0.234
SEI-EG ₂₀₁₉	0.005	0.261	0.115	0.714	0.149	0.122	0.062	0.057	0.028	0.054	0.055	0.162
SEI-EG ₂₀₁₈	0.006	0.262	0.127	0.758	0.147	0.146	0.059	0.058	0.028	0.053	0.062	0.141
SEI-EG ₂₀₁₇	0.006	0.255	0.126	0.781	0.142	0.124	0.058	0.057	0.025	0.065	0.070	0.118
SEI-EG ₂₀₁₆	0.008	0.236	0.139	0.754	0.146	0.136	0.050	0.055	0.024	0.063	0.078	0.119

SEI-EG, Synthetic Efficiency Indicator for Economic Growth.

Table 8 shows the ranking in relation to the value of the SEI-EG index for the countries analyzed between 2016 and 2020.

The average values of the SEI-EG coefficient for countries entering the EU in 2004 by year were as follows: 0.228 (2016), 0.229 (2017), 0.231 (2018), 0.212 (2019), and 0.215 (2020). In contrast, the average values of this indicator for the other countries included in the analysis were 0.295 (2016), 0.283 (2017), 0.296 (2018), 0.260 (2019), and 0.267 (2020).

In 2020, Estonia had the highest efficiency in converting inputs resulting from economic growth into sustainability effects (0.633). The value of the SEI-EG index for Estonia is illustrated in Figure 1 (2020 data).

Estonia was followed by the Czech Republic (0.338) and Sweden (0.234) with a large loss. The worst countries in relation to the SEI-EG index in 2020 were Belgium (0.012), Austria (0.042), and Slovakia (0.069). In the first 3 years analyzed, the top three in respect of the SEI-EG index were invariably Estonia, the Czech Republic, and Latvia. Sweden has overtaken Latvia in 2019–2020. Throughout the period analyzed, Belgium and Austria had the lowest efficiency of converting inputs resulting from economic growth into sustainability effects. It is evident from the research results presented that the small countries joining the EU in 2004 were more effective in their sustainable development efforts during the study period than the small highly developed countries in the EU. Estonia was the clear leader in sustainability efforts between 2016 and 2020.

5 Findings

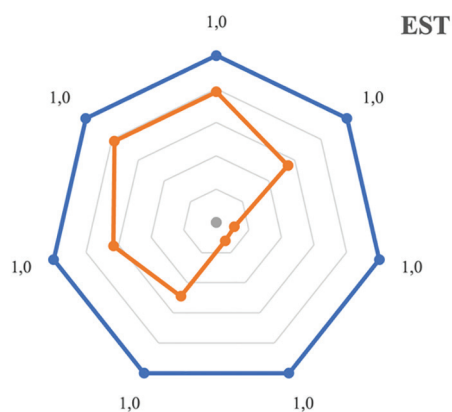
The article determines the values of the author's SEI-EG for selected small countries in the EU. The countries were represented by two groups. The first were the most developed countries in the EU (among the small countries) and the second were the small countries that joined the EU in 2004. Through the research conducted, it was revealed that countries joining the EU in 2004 were characterized by a higher efficiency of transforming growth-related inputs into sustainable development outcomes. Estonia and the Czech Republic were characterized by the highest values of the indicator throughout the analyzed period, i.e., 2016–2020. The lowest ranked countries in each of the years analyzed were Belgium and Austria. This may constitute a kind of convergence process, encompassing the elements of considering the impact of European funds on combating climate change, maintaining the trend of actions aimed at sustainability in conso-

Table 8. Ranking of all countries analyzed for 2016–2020 according to the SEI-EG index

2016			2017			2018		
1	Estonia	0.754	1	Estonia	0.781	1	Estonia	0.758
2	Czech Rep.	0.236	2	Czech Rep.	0.255	2	Czech Rep.	0.262
3	Latvia	0.146	3	Latvia	0.142	3	Latvia	0.147
4	Denmark	0.139	4	Denmark	0.126	4	Lithuania	0.146
5	Lithuania	0.136	5	Lithuania	0.124	5	Sweden	0.141
6	Sweden	0.119	6	Sweden	0.118	6	Denmark	0.127
7	Finland	0.078	7	Finland	0.070	7	Finland	0.062
8	Slovakia	0.063	8	Slovakia	0.065	8	Hungary	0.059
9	Netherlands	0.055	9	Hungary	0.058	9	Netherlands	0.058
10	Hungary	0.050	10	Netherlands	0.057	10	Slovakia	0.053
11	Austria	0.024	11	Austria	0.025	11	Austria	0.028
12	Belgium	0.008	12	Belgium	0.006	12	Belgium	0.006

2019			2020		
1	Estonia	0.714	1	Estonia	0.633
2	Czech Rep.	0.261	2	Czech Rep.	0.338
3	Sweden	0.162	3	Sweden	0.234
4	Latvia	0.149	4	Latvia	0.188
5	Lithuania	0.122	5	Lithuania	0.146
6	Denmark	0.115	6	Denmark	0.116
7	Hungary	0.062	7	Hungary	0.097
8	Netherlands	0.057	8	Finland	0.082
9	Finland	0.055	9	Netherlands	0.078
10	Slovakia	0.054	10	Slovakia	0.069
11	Austria	0.028	11	Austria	0.042
12	Belgium	0.005	12	Belgium	0.012

SEI-EG, Synthetic Efficiency Indicator for Economic Growth.

**Figure 1.** Graphic presentation of the SEI-EG index for Estonia (2020).

SEI-EG, Synthetic Efficiency Indicator for Economic Growth.

the objective of achieving a higher level of these actions earlier in richer countries, raising awareness of these actions in companies, etc. The implementation of climate goals is to be supported by the EU budget, which is why the current one already allocates 20% of expenditure to climate-related activities (climate mainstreaming). The EC wants to increase this share to 25% of the total budget (around €212 billion) in the negotiated multi-annual financial framework for 2021–2027. This increase would be particularly visible in agricultural policy (the largest budget program), but also in the area of research. The Commission intends to allocate 35% of the €100 billion under Horizon Europe to climate projects [https://europapnews.pap.pl, 2022]. The findings may find practical implications in the implementation of economic policies by EU countries. It appears that small countries, where the capitalist economy has only been operating for about 30 years, achieve better results in regard to sustainable development than countries in the so-called “old Union.” The indicator developed can at the same time provide a measure of the effectiveness of achieving sustainability outcomes in the European dimension. A limitation of the method developed is the relative nature of the indicator. The object of further research could be, on the one hand, to improve the developed indicator by extending the list of inputs or effects and making it dynamic.

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