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Directions of green transformation of the European Union countries

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ABSTRACT

Green transformation has become one of the most important directions in the further development of the world. It involves the development of green technologies and the creation of legal regulations enforcing, for example, saving energy or reducing the emissions of greenhouse gases, as well as any other activities aimed at changing society's attitude towards the acceptance of – frequently more expensive but more environment-friendly – technological solutions and legal norms. Thus green transformation can be defined as combining economic growth with caring about the environment in order to guarantee a high quality of life for present and future generations at the level which is attainable due to civilisational development, as well as to an effective and rational use of the available resources. Still, there is no single globally accepted way to this transformation. It is proceeding in a variety of ways and depends on many different factors. The main purpose of the paper is a comparative analysis of the directions of changes occurring in the process of green transformation in EU countries. The added value of the research presented in the paper and its novelty is the analysis of the current patterns of green transformation in EU countries. The paper concentrated on recognizing them and drawing attention to the unfavourable directions of this transformation as well as to its positive aspects. The changes in the process of green transformation were analysed based on data used by the OECD to describe green growth in two periods: 2004 or 2005 as initial data and the last available data (usually 2018 or 2019). For this purpose the TOPSIS method was applied. The EU countries were divided into groups according to their way of applying green transformation. The provided research allows to better understand the course of this transformation in various EU countries.

1. Introduction

Successive crises (economic, social, natural and the most recent ongoing epidemiological crisis), which systematically affect the economies of many countries globally, have drawn attention to the need for urgent and, above all, real implementation of structural changes in the economy. One of these changes is the so-called green transformation which aims to transform national economies into modern and competitive economic systems with minimal environmental impact, and it covers many different aspects, starting from evident changes related to the way available natural resources are used, through the development of environmentally friendly technologies, to transformations in the area of competencies and social awareness, including the necessity of development towards the so-called green skills.

The changes related to the green transformation are a long-term process and strongly linked to the active environmental protection policy, which creates demand for new environmentally friendly products, services and technologies and at the same time has a strong influence on changes in social attitudes in this area. The result is the creation of new green markets, which are slowly becoming the basis of modern business competition. The so-called global eco-market is currently estimated to be worth many billions of euros. According to the Research Institute of Organic Agriculture (FIBL), the market for organic food alone is worth over 106 billion euros. It is also expected to grow dynamically in the coming years, strongly conditioned by the growing demand for environmental technologies, goods and services.

However, it is worth noting that despite the enormous benefits, green transformation is not an easy task, and many countries are already struggling with problems that, despite the implementation of green solutions in one area of the market, generate problems in others. An example can be Norway, where the dynamic growth in the sale of electric cars is observed. Over 54% of all cars sold in this country in 2020

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did not have a combustion engine, yet the very high cost of repairing these cars is the problem, limiting interest in repairing them. As a result, the number of scrapped electric cars that could be suitable for further use after the repair is growing exponentially. A similar problem may soon arise with used photovoltaic panels, which, given the growing interest in this method of generating electricity, will also be a source of very hazardous waste.

According to the Green Growth Knowledge Platform, an organization bringing together institutions such as the World Bank, OECD, and UNEP supporting activities for the transition of the global economy to the path of sustainable development, green growth means combining the promotion of economic growth with ensuring that the environment provides the resources and services necessary for the prosperity of humanity in the future. It is, therefore, a vision of the future that highlights the positive effects of a green transition.

According to Hallegatte et al. (2017), "green growth is about making growth processes resource-efficient, cleaner and more resilient without necessarily slowing them". Since the transition from a growth-based economy towards green growth is not easy and does not proceed in the same way in different countries, this paper focuses on analysing the changes in its progress so far. There are many reasons that lead to conducting a research in the field of green transformation. The article addressed the literature gap in terms of the study of the main directions of the green transformation in EU economies, taking into account the various dimensions of this transformation and the impact of socio-economic conditions in the individual EU countries on the direction of changes in this process. There is a lack of comprehensive research on this matter in the literature. Green transformation has been the subject of numerous scientific papers, but was usually addressed in terms of the individual dimensions of such a transformation or even the analysis of changes of singular indicators used to monitor this process. A review of the literature on green transition shows that the main emphasis is on analysing the current situation and predicting future possible directions of change in this area. However, few publications show how the transformation proceeded in the past. The ways and directions of this transformation occurring earlier were described to a lesser extent. Meanwhile, the consolidation of specific patterns may both positively and negatively influence the course of this process in the following years.

An analysis of the course of the green transformation in various countries to date will make it possible to identify the directions of changes that should be avoided before the world becomes trapped in set patterns, the modification of which could be excessively costly and complicated. Research in this scope also complements the new directions of research on green transformation, which apart from changes of technological nature (the development of green technologies), also considers specific conditions existing in individual economies.

The added value of the research presented in the paper and its novelty, is the analysis of the current patterns of green transformation in EU countries. The paper concentrated on recognizing them and drew attention to the unfavourable directions of this transformation as well as its positive aspects. In the already published papers, it is usually argued that most highly developed countries have better opportunities and prospects for the faster transformation of their economy and social awareness towards green behavioural patterns. The results presented in the paper show that it is not as obvious as it might seem.

Therefore, the aim of this paper was a comparative analysis of the directions of the changes occurring in the process of green transformation, and these changes were analysed based on data used by the OECD to describe green growth in the European Union countries. The statistics describing the situation in this area at two points in time were taken into account: in 2004 or 2005 (depending on the availability and frequency of data) and based on information from the most recent year available (the most common was 2019). The United Kingdom, which was still a member of the European Union during the period analysed, was included in the analyses. The purpose of comparing these two moments in time was to examine the direction of change in the studied EU countries in terms of green transformation. Green growth indicators were compared with the performance of the studied economies in terms of the indicators used as standard in economic growth analyses, including GDP per capita and social changes such as total fertility rate.

The research used a three-stage procedure. First, the preparation of data for analysis was provided (stage 1), next the results of the EU countries were analysed separately for each year under consideration, which were then compared in different combinations. Advanced multivariate statistical analysis methods were used for this purpose (stage 2), as well as the methods allowing for the determination of the strength and directions of dependencies between the obtained results (stage 3).

The following research questions were addressed in the study:

1. How is the green transformation progressing in the countries of the European Union? What directions of changes are observed in this regard based on the analysed data?
2. Is it possible to identify patterns (reference models) of green transformation in EU countries?
3. Are the observed directions of change related to general changes and socio-economic conditions in the analysed countries?

The paper is divided into five subsections. After the introduction, which outlines the purpose of the study and the main research questions, a literature review is presented which discusses the current research directions in the field of green transformation and indicates the research gap resulting therefrom. In the empirical part, which includes two subchapters, the applied research procedure is presented, the statistical data and the applied research method are discussed, as well as the obtained results. The paper ends with conclusions and recommendations for possible future research directions.

2. Green transformation – the origin and state of the art?

In the past, economic growth often depended on the consumption of natural resources as if their resources were limitless. The consequence of this is the current crisis regarding natural resources with the threat of a shortage of raw materials and ever-increasing prices. Today, more and more societies/countries and economists are turning to other models of the economy, according to which wealth can be created without destroying the environment. There is an ever-growing need for a transition to green economy – through better resource management, using economic instruments that favour environmental protection, supporting innovative projects, conducting more effective water and waste management policies, and making efforts to develop sustainable consumption and production. Such activities constitute the pursuit of green transformation.

The subject literature dedicates significant space to matters related to green transformation. Nowadays, it has become one of the most frequently addressed subjects, both in the political debate and in scientific papers. The Web of Science database identified more than 25 thousand publications which refer to the term 'green transformation' in the title, abstract and/or keywords. A growing interest in the research on this subject has been observed in particular during the last ten years (see: Gibbs and O'Neill, 2014, Sun et al., 2017; Liu et al., 2019; Mets et al. 2021; Zeng et al., 2021), which results from the present negative global changes of the natural environment, linked with e.g. climate change and loss of biodiversity.

The first published papers which included the phrase 'green transformation', also in the context of sustainable development and green growth were at the beginning of this century. Luttropp and Karlsson (2001) in their study started to analyse the green transformation movement in terms of industrial products with better performance and business opportunities. They touched on the topic of EcoDesign which brings benefits to the economy, performance and the environment. Their paper concluded with the statement that the information society and knowledge about the environment had reached a particular level of development and that there were new opportunities to make use of environmental guidelines. From then on, green transformation within the scope of economic and environmental issues started to be an interesting topic to discuss for scholars around the world.

The year of 2011 was crucial in terms of published articles regarding the green transformation, and in the following years the concept has been developed and discussed all over the world by many scholars and practitioners. There has been an increasing number of scientific publications regarding this issue, however most of them considered the regional point of view, especially regarding China (Luo, 2013; Lo and Yi, 2013; Kennedy et al., 2016; Mathews and Tan, 2017; Zhang et al., 2017; Liu et al., 2019; Xie et al., 2020; Wang and Li, 2020 and many others). There were also papers concerning Indonesia (Soejachmoen, 2017), Denmark (Albrecht and Nguyen, 2020), Ghana and Nigeria (Efobi et al., 2019), the United Kingdom (Oyedokun et al., 2015), Norway (Haugseth, 2019), Taiwan (Chou et al., 2019) and France (Hermwille et al., 2017). Apart from regional observations regarding specific countries and their way to green transformation, by analysing individual published works one can also distinguish approaches related to the industry perspective, specific fields of science and the general approach to green transformation.

In the industry context, there were publications related to the green transformation in the manufacturing sector (Shen et al., 2020; Li et al., 2021); construction and buildings (Wang et al, 2012; Guo and Lin, 2012), the cement industry (Lu et al., 2015), the maritime industry (Sjotun, 2020; Anwar et al., 2020; Luo, 2020) and the fashion industry (Da Giau et al., 2020).

When it comes to science, one can distinguish the managerial point of view (Johnson et al., 2014; Uygun and Dede, 2016); financial (Epstein, 2014; Soejachmoen, 2017); policy issues (Messner, 2015; Kuai et al., 2015; Crespi, 2016; Hanna, 2016; Pei, 2017; Schmitz et al., 2015; Mrozowska and Hintz, 2020; Bisson, 2020; Chiengkul, 2018; Barbier, 2020) and logistics (Poulsen and Lema, 2017) and green transformation as a business model (Duarte and Cruz-Machado, 2013; Wang et al., 2012; Wang, 2012; Cui and Yang, 2017).

In general, within those few years, authors discussed the determinants of implementing green transformation strategies (Schmitz, 2015), transformation imperatives (Leach, 2015), urban informal economy, local inclusion and achieving a global green transformation (Brown and McGranahan, 2016), macroeconomic aspects (Hooke, 2017), evaluation of enterprise green growth ability (Zhao et al., 2017), developing a 'greenometer' as a green transformation assessment (Salem and Deif, 2017) and green transformation within the context of circular economy and ecological environment protection (Luo et al., 2018).

In the first half of 2021, 40 papers were published regarding green transformation. Mostly however, they related again to the regional point of view and explain the determinants of implementing green transformation strategies (Mets et al., 2021; Yang et al., 2021) in particular countries like Norway (Karlsson and Hovelsrud, 2021), Italy (Alekseenkova, 2021) or specific industries, e.g. the maritime (Alekseenkova, 2021), the energy sector (Palmie et al., 2021) and the steel industry (Branca et al., 2020). Most common are still the papers regarding the road to green transformation in China as well as the status quo and prospects (Zeng et al., 2021; Zhai and An, 2021; Yang et al., 2021; Zhang and Fang, 2021; Hu et al., 2021; Liu et al., 2021), Chinese provinces (Cui and Lui, 2021) or industries (Xu et al., 2021; Du et al., 2021; Li et al., 2021; Gao et al., 2021).

The term 'green transformation' in these research papers (see: Albernhe et al., 2011; Berger, 2011; Gu et al., 2018) is defined in many different ways. In the narrow sense, it is linked with the concept of green growth, i.e. development oriented towards a green transformation of the economy (Berger, 2011). In a wider sense, it coexists with the idea of sustainable development, which apart from the 'greening' of the economy also refers to changes in the social and environmental spheres (Gu et al., 2018). In the subject literature, this term is mostly defined as actions aimed at creating equilibrium (agreement) between the economic growth and care for the environment, aimed at guaranteeing the high quality of life for both present and future generations at the level allowed by the civilisational development, and at the same time an effective and rational use of the available resources. Huan (2010) analysed the political issues linked with eco-socialism as red-green politics. He wrote that "the eco-socialism can't function as a more convincing political discourse and influential practical movement for the green transformation until it effectively overcomes the enormous difficulties brought about by a capitalist globalization." He also suggested that we need to "improve a coherent and convincing interpretation of the ongoing process of globalization, make efforts to assimilate the essence of ecologism and pay more attention to the political potential of non and/or anti-capitalist ideas and practices". Just in 2011, there were 23 publications addressing the "green transformation" concept. Macdonald (2011) wrote about financial grants to companies that would seek to modernise their manufacturing activity to make their plants less dependent on traditional energy sources. Hader et al. (2011) suggested that in the coming decades, renewable energy would account for a higher share of the energy generation structure. They argued that investing in renewable energy not only helps the environment but also enables countries to boost their economies. Berger (2011) addressed green business – with enormous growth potential and driven by megatrends: climate and demographic change and urbanisation that drives the transformation of existing businesses in terms of the way suppliers and customers operate, forcing them to rethink their business strategy towards sustainable development. Stäglich et al. (2011) pointed out the importance of electric mobility which is seen as one of the keys to reducing the world's greenhouse gas emissions.

It is also worth stressing that, according to some authors (see: Schmitz, 2015), this term should be identified above all with changes occurring in the natural environment, such as "the process of structural change which brings the economy within the planetary boundaries", or as the "system (of decisions, policies and directions of growth), which emphasizes the use of renewable sources of energy and prudent management of green areas for a sustainable future". In contrast to definitions focused on the need to observe environmental restrictions, others (see: Amundsen and Hermansen, 2021) combine 'greening' with many other aspects concentrated on technological, environmental and possibly also political issues. By introducing the word 'green' before 'transformation', the intention is to focus on the environmental dimension of changes, even though – as was indicated in the paper – the results of these changes are also relevant, including their societal considerations (Blythe et al., 2018). This implies the need to extend the original term 'green transformation' directed at counteracting the unfavourable changes occurring in the natural environment of the human species, by issues which also consider the economic, social, institutional and political context. The present state of knowledge regarding the progress so far in the realisation of the assumptions of green economy shows clearly that its success depends on many diverse factors. The structure of 'green' changes differs depending on the environment in which they take place. In many countries, and it is worth stressing that this does not apply just to developing countries, it is highly unlikely that any significant and notable changes can occur when only taking into consideration the technological and environmental effects of the transformation. Hence the studies whose results are presented in this paper place particular attention on the linkages between groups of factors which directly describe the process of green transformation and the socio-economic factors existing in individual EU countries. Regarding the state of the art on green transformation it is also clear that there is a huge research gap in terms of analysing the green transformation, not only in the regional-industrial perspective, but also finding out what are the most often applied solutions in this term, and in which directions this green transformation is developing in different countries. This research method is in line with the studies (see: Bąk and Cheba, 2021), which

Table 1
Statistical database, descriptive characteristics of indicators analysed in the paper, EU countries and the United Kingdom, 2004/2005 and the last available year.

Symbol	Description	Descriptive statistics $\bar{x}$ initial data	$\bar{x}$ final data	V_s (%) initial data	V_s (%) final data	A_s initial data	A_s final data
Group 1. Environmental and resource productivity							
$X_{1.1S}$	Production-based CO2 productivity, GDP per unit of energy-related CO2 emissions	4.35	7.48	29.82	37.05	0.50	1.28
$X_{1.2D}$	Production-based CO2 intensity, energy-related CO2 per capita	8.26	6.03	48.34	39.97	2.67	1.84
$X_{1.3S}$	Demand based CO2 productivity GDP per unit of energy-related CO2 emissions	3.51	4.55	17.28	19.84	−0.33	−0.16
$X_{1.4D}$	Demand based CO2 intensity, energy-related CO2 per capita	9.88	7.61	42.87	35.62	1.73	1.01
$X_{1.5S}$	Energy intensity, TPES per capita	3.69	3.19	44.11	37.57	1.87	1.17
$X_{1.6D}$	Total primary energy supply	64.14	56.46	134.76	131.78	1.98	2.02
$X_{1.7S}$	Renewable energy supply, % TPES	9.53	17.66	87.79	58.52	1.35	1.08
$X_{1.8S}$	Renewable electricity, % total electricity generation	18.68	37.88	104.15	56.16	1.43	0.56
$X_{1.9D}$	Energy consumption in agriculture, % total energy consumption	2.79	2.65	60.50	50.98	1.01	1.15
$X_{1.10D}$	Energy consumption in industry, % total energy consumption	24.99	22.93	27.90	29.48	0.74	0.87
$X_{1.11D}$	Energy consumption in transport, % total energy consumption	27.62	30.94	32.57	26.70	1.51	0.90
Group 2. Natural asset base							
$X_{2.1S}$	Natural and semi-natural vegetated land, % of total	50.32	50.50	37.82	36.96	−0.08	−0.17
$X_{2.2S}$	Bare land, % of total	1.33	1.22	241.18	235.61	3.63	3.58
$X_{2.3D}$	Cropland, % of total	42.38	41.89	40.39	39.43	−0.55	−0.50
$X_{2.4D}$	Artificial surfaces, % of total	3.83	4.25	116.51	114.59	2.86	3.19
$X_{2.5S}$	Water, % of total	2.19	2.18	114.72	114.82	2.15	2.17
$X_{2.6D}$	Loss of natural and semi-natural vegetated land, % since 1992	3.38	4.74	49.13	77.75	0.85	3.58
$X_{2.7S}$	Gain of natural and semi-natural vegetated land, % since 1992	3.01	4.62	73.70	69.53	0.61	0.62
$X_{2.8D}$	Conversion from natural and semi-natural land to cropland, % since 1992	2.66	3.24	60.21	58.83	0.68	0.79
$X_{2.9D}$	Conversion from natural and semi-natural land to artificial surfaces, % since 1992	0.58	3.39	138.43	56.78	2.37	0.76
$X_{2.10D}$	Conversion from cropland to artificial surfaces, % since 1992	2.62	3.17	95.77	78.15	1.31	1.30
$X_{2.11D}$	Built up area, % of total land	4.02	4.45	115.26	110.26	2.60	2.41
$X_{2.12D}$	Built up area per capita	243.40	263.86	29.56	25.10	0.67	0.57
$X_{2.13D}$	New built up area, % since 1990	17.72	33.38	50.55	31.74	2.49	0.73
Group 3. Environmental dimensions of quality of life							
$X_{3.1D}$	Mean population exposure to PM 2.5, micrograms per cubic metre	16.37	12.89	30.94	33.55	0.03	0.22
$X_{3.2D}$	Percentage of population exposed to more than 10 Âµg/ m3	82.48	73.25	38.41	43.41	−1.94	−1.17
$X_{3.3D}$	Mortality from exposure to ambient PM 2.5, per 1,000,000 inhabitants	538.63	401.66	57.53	68.15	1.33	1.31
$X_{3.4D}$	Welfare costs of premature mortalities from exposure to ambient PM 2.5, GDP equivalent, %	5.66	4.15	62.09	72.42	1.42	1.32
$X_{3.5D}$	Mortality from exposure to ambient ozone, per 1,000,000 inhabitants	23.37	25.06	44.28	62.97	0.54	0.55
$X_{3.6D}$	Welfare costs of premature deaths from exposure to ambient ozone, GDP equivalent, %	0.24	0.25	44.77	64.70	0.52	0.61
$X_{3.7D}$	Mortality from exposure to lead, per 1,000,000 inhabitants	91.94	85.51	64.71	69.75	1.52	1.50
$X_{3.8D}$	Welfare costs of premature deaths from exposure to lead, GDP equivalent, %	0.96	0.87	68.87	72.49	1.61	1.50
$X_{3.9S}$	Population with access to improved drinking water sources, % total population	92.77	96.84	10.35	4.28	−2.61	−2.07
$X_{3.10S}$	Population with access to improved sanitation, % total population	83.62	89.30	17.65	11.34	−1.16	−1.62
Group 4. Economic opportunities and policy responses							
$X_{4.1S}$	Development of environment-related technologies, % of technologies	8.91	10.82	34.16	51.61	0.57	0.78
$X_{4.2S}$	Relative advantage in environment-related technology, ratio	1.17	1.19	34.17	51.72	0.57	0.80
$X_{4.3S}$	Development of environment-related technologies, % inventions worldwide	1.18	0.94	231.98	222.57	4.14	3.95
$X_{4.4S}$	Development of environment-related technologies, inventions per capita	10.34	13.49	112.80	116.23	1.09	1.79
$X_{4.5S}$	Net ODA provided, % GNI	0.32	0.33	83.88	82.39	0.94	1.33
$X_{4.6D}$	Environment-related taxes, % GDP	2.79	2.47	22.30	33.08	1.85	−0.13
$X_{4.7D}$	Environmentally related taxes, % total tax revenue	7.95	6.87	19.04	32.64	0.25	−0.26
$X_{4.8D}$	Energy related tax revenue, % total environmental tax revenue	72.33	75.03	20.03	16.50	−0.38	−0.70
$X_{4.9D}$	Road transport-related tax revenue, % total environmental tax revenue	22.86	22.82	64.08	74.52	0.47	1.53
$X_{4.10D}$	Petrol end-user price, USD per litre	2.11	2.14	27.90	21.52	0.63	0.25
$X_{4.11D}$	Diesel tax, USD per litre	0.65	0.67	31.17	20.27	0.97	−0.45
$X_{4.12D}$	Diesel end-user price, USD per litre	1.95	2.03	32.08	24.57	0.86	0.51
Group 5. Socio-economic context							
$X_{5.1S}$	Real GDP per capita, USD Dollar	34651.00	42697.57	48.27	41.43	2.01	2.21
$X_{5.2S}$	Labour tax revenue, % GDP	18.91	18.91	27.16	27.16	−0.13	−0.13
$X_{5.3S}$	Labour tax revenue, % total tax revenue	17.98	51.32	29.17	17.62	0.25	−1.20
$X_{5.4S}$	Total fertility rate, children per woman	1.53	1.57	13.63	10.57	0.82	−0.06
$X_{5.5S}$	Life expectancy at birth	77.34	80.39	3.92	3.20	−0.76	−0.82
$X_{5.6S}$	Population, ages 0–14, % total	16.43	15.61	11.05	10.39	0.36	1.25
$X_{5.7D}$	Population, ages 65 and above, % total	15.63	19.51	13.98	11.72	−0.75	−1.16

Source: own calculations, where: $\bar{x}$ —mean, V_S—coefficient of variation, A_s—*asymmetry, S – stimulants and D – destimulants.*

highlight the multidimensionality of this process. The success of green transformation is also increasingly discussed in the context of the so-called co-creation, which involves including in this process its many different actors: local residents, authorities and businesses. In this context, green transformation should be defined in a broader way as a socially inclusive process in which various actors such as local communities, local governments and companies, have a representative voice in planning and redevelopment (Feola, 2015). Such an approach is connected with the need to carry out comprehensive research on the conditions and progress of green transformation in different economies. On such basis it will be possible to, among others, design various tools for monitoring advancements in terms of green transformation, which will also contribute to promoting this kind of structural approach to it.

3. Data and methodology

3.1. Research procedure

The article uses a three-stage research procedure: 1. Preparation of data for analysis; 2. Construction of synthetic measures using the TOPSIS method, 3. Analysis of the relationship between the synthetic measures. A graphical presentation of the analytical framework covers Figure A in Appendix A.

3.2. Statistical database description

In this paper, statistical data used by the OECD to monitor the progress of the green growth strategy were studied to examine the directions of green transformation of the European Union countries. OECD indicators regarding green transformation now constitute one of the most comprehensive databases in this scope, providing information accessible to all EU countries. Due to the fact that these indicators were elaborated in order to monitor changes in the realisation of the strategy aimed at green transformation, it was decided that the study was to be based on all the available data. The indicators available in the OECD database were assigned to four groups: environmental and resource productivity, natural asset base, the environmental dimension of quality of life, economic opportunities and policy responses. Changes in the green growth strategy implementation were analysed against the background of the general socio-economic situation in individual countries. In order to determine the directions of green transformation of the EU countries (including the United Kingdom), indicators describing all groups distinguished in the Green Growth Strategy were taken into account in this study. Statistics covering two periods (depending on data availability) were analysed: 2004–2005 (initial data) and data from the last available year, usually 2019 (final data). In total, 53 indicators were analysed. Table 1 presents their detailed list and information on basic descriptive characteristics.

The information presented in Table 1 shows that most of the analysed indicators are characterised by a significant level of variation (Vs > 15%). It is particularly relevant to note the following indicators: $X_{1.6D}$ (total primary energy supply), $X_{1.8S}$ (renewable electricity), $X_{2.2S}$ (bare land), $X_{2.4D}$ (artificial surfaces), $X_{2.5D}$ (water), $X_{2.11D}$ (built up area per capita), $X_{4.3S}$ (development of environment-related technologies, % inventions worldwide), $X_{4.4S}$ (development of environment-related technologies, inventions per capita), for which coefficients of variation were at a level exceeding 100%, indicating considerable differences between the results obtained by individual European countries. In most cases, the identified high level of variation applies to both analysed years. However, for indicator $X_{1.8S}$ – renewable electricity (% of total electricity generation), the level was almost half lower in the last analysed year in relation to the first year (respectively: 104.15 and 56.16). The level of asymmetry (right-hand side) of this indicator is also significantly lower (1.43 and 0.56 respectively), which, given the almost twofold increase of the average value, is a favourable phenomenon and proves that its values are equalising in individual countries (more countries are reaching a similar level).

When analysing the first group of indicators (environmental and resource productivity), it is also worth noting the relatively favourable changes involving an increase in the average value of the indicators: $X_{1.1S}$ – production-based CO2 productivity (GDP per unit of energy-related CO2 emissions) and $X_{1.3S}$ – demand based CO2 productivity (GDP per unit of energy-related CO2 emissions), while the values of the indicators decreased: $X_{1.2D}$ – production-based CO2 intensity, energy-related CO2 per capita and $X_{1.4D}$ – demand based CO2 intensity, energy-related CO2 per capita. There is also an increase in the average value of indicators: $X_{1.7S}$ – renewable energy supply (% of TPES) and $X_{1.8S}$ – renewable electricity (% total electricity generation). The highest values were identified in the northern European countries: Denmark, Finland, Latvia and Sweden. High values also relate to Austria, Croatia, Portugal and Romania.

There is a large differentiation among the indicators from the second group (natural asset base), which mostly describe the available natural resources in individual countries and the ways there are processed by the population, in particular it is worth noting indicator $X_{2.2S}$ which describes the share of bare land in total of land in particular countries. Its minimal value was identified in the case of Luxembourg (0% in both analysed years), and maximal for Malta (respectively: 15.32% and 13.68%). These differences are mostly connected with the natural conditions existing in these countries, and are also largely affected by the surface area of a given country.

The third group (environmental dimensions of quality of life) contains indicators characterised by a lower level of their differentiation than the previous groups, among which the lowest level of differentiation is shown for the indicators describing access of population to improved drinking water ($X_{3.9S}$) and to improved sanitation ($X_{3.10S}$). In their case there is also visible a reduction in this differentiation in the last analysed year as compared to the first one. One can observe a different situation for all the other indicators which would imply a deepening of the differences between some countries, which applies mostly to: $X_{3.5D}$ (mortality from exposure to ambient ozone, per 1,000,000 inhabitants) and $X_{3.6D}$ (welfare costs of premature deaths from exposure to ambient ozone, GDP equivalent, %). In 2005 the lowest values for both indicators were identified for Estonia (respectively: 5.18 per 1,000,000 inhabitants and 0.06%), and the highest for Spain (respectively: 51.78 per 10,000,000 inhabitants and 0.53%). In 2009 the lowest values regarded Ireland (respectively: 3.22 1,000,000 inhabitants and 0.23%), while the highest again for Spain (respectively: 61.91 per 10,000,000 inhabitants and 0.62%).

The fourth group (economic opportunities and policy responses) comprises indicators showing the level of green technological advancement in the EU countries ($X_{4.1S} – X_{4.4S}$) and the policy directions in these countries including the level of engagement in aid for the developing countries ($X_{4.5S}$, net ODA provided, % GNI), as well as the current levels of environmental taxes ($X_{4.6D}$ – $X_{4.9D}$) and prices of fuel ($X_{4.9D}$ – $X_{4.12D}$).

The last, fifth group (socio-economic context) is made up with indicators used to describe the current socio-economic situation in the examined countries, which show the lowest level of differentiation out of all the analysed groups. Additionally, this differentiation is lower in the last year under analysis in comparison to the first year, which confirms the levelling-off in the socio-economic development of the EU countries. The decidedly smallest differences concern indicator $X_{4.6D}$ (life expectancy at birth), which during the analysed years had the average level of 77.34 and 80.39, respectively.

3.3. Research method

In the next stage the results of the EU countries were analysed separately for each year under consideration, which were then compared in different combinations. Advanced multivariate statistical analysis methods were used for this purpose (stage 2), as well as the methods allowing for the determination of strength and directions of dependencies between the obtained results (stage 3). At stage 2, synthetic measures for each considered group of indicators were calculated. For this purpose the TOPSIS method was used. It allowed ordering the EU countries in terms of their performance in green transformation. The subject literature (Triantaphyllou, 2000; Kersten, 2001; Mendoza and Martins 2006; Buchholz et al. 2009; Huang et al. 2011) describes many diverse methods which can be used in ordering socio-economic subjects (in this case – EU countries). The advantage of the TOPSIS method selected by the authors of this study, was the possibility of ordering objects both according to their similarity to the most preferable object, as well as to the one with the least desirable characteristics (values selected for the study of indicators). This similarity is determined based on the minimisation of the distance of the object to that most desirable,

Table 2
Results of the ranking of EU countries in terms of green economy areas and socio-economic situation 2004/2005.

Country	GG		I		II		III		IV		V	
	1	2	1	2	1	2	1	2	1	2	1	2
Austria	0.5598	4	0.6956	3	0.5541	9	0.6841	12	0.4094	6	0.7288	7
Belgium	0.4164	28	0.5052	16	0.3509	28	0.5775	18	0.3505	10	0.7478	6
Bulgaria	0.4569	24	0.5255	13	0.5670	7	0.2478	28	0.2639	24	0.2262	28
Croatia	0.5092	15	0.6787	4	0.5348	16	0.5257	24	0.2902	22	0.3709	23
Cyprus	0.5380	5	0.4991	18	0.6485	1	0.6395	14	0.3365	13	0.4312	19
Czech Republic	0.4753	22	0.4998	17	0.5237	21	0.6104	16	0.2941	19	0.5374	13
Denmark	0.4888	16	0.5527	11	0.5257	20	0.7026	11	0.2019	28	0.7879	2
Estonia	0.5246	10	0.5082	15	0.5670	6	0.8995	2	0.2841	23	0.4184	20
Finland	0.5733	3	0.6335	5	0.6155	3	0.9462	1	0.2936	20	0.7483	5
France	0.5172	13	0.4567	25	0.5319	19	0.7453	7	0.4352	5	0.7784	3
Germany	0.4540	25	0.4214	28	0.4782	24	0.7262	9	0.2981	17	0.6165	9
Greece	0.5289	8	0.4865	20	0.6039	4	0.5665	20	0.3977	7	0.3564	24
Hungary	0.5184	12	0.5470	12	0.5376	15	0.4997	25	0.4459	4	0.4795	18
Ireland	0.6117	1	0.4952	19	0.5660	8	0.8245	4	0.7587	1	0.5452	12
Italy	0.4835	18	0.4765	21	0.5427	14	0.5586	22	0.3498	11	0.6032	10
Latvia	0.5374	6	0.7249	2	0.5532	10	0.6317	15	0.2598	25	0.3283	25
Lithuania	0.5327	7	0.5750	9	0.5787	5	0.7104	10	0.2917	21	0.4068	21
Luxembourg	0.4752	23	0.4683	23	0.4625	25	0.7627	6	0.3247	15	0.7543	4
Malta	0.4401	26	0.5150	14	0.3810	27	0.4966	26	0.4492	3	0.2680	26
Netherlands	0.4227	27	0.4585	24	0.3983	26	0.7373	8	0.2458	26	0.6609	8
Poland	0.4793	21	0.4453	26	0.5509	11	0.5662	21	0.3336	14	0.4861	16
Portugal	0.5170	14	0.5777	8	0.5123	22	0.5423	23	0.4707	2	0.3729	22
Romania	0.5222	11	0.6167	6	0.5508	12	0.4249	27	0.3951	8	0.2667	27
Slovak Republic	0.4838	17	0.5572	10	0.5333	17	0.5928	17	0.2371	27	0.4804	17
Slovenia	0.5272	9	0.5894	7	0.5323	18	0.6705	13	0.3806	9	0.5930	11
Spain	0.4821	19	0.4755	22	0.5439	13	0.5718	19	0.2955	18	0.5278	14
Sweden	0.5868	2	0.7436	1	0.6176	2	0.8846	3	0.3045	16	0.7895	1
United Kingdom	0.4799	20	0.4380	27	0.5005	23	0.7782	5	0.3426	12	0.5048	15

Source: own elaboration.

and the maximisation of the distance to that least desirable. Other advantages of this method in the subject literature (Hung and Chen, 2009) include:

- simple, rational, comprehensible concept,
- intuitive and clear logic that represents the rationale of human choice,
- ease of computation and good computational efficiency,
- a scalar value that accounts for both the best and worst alternatives ability to measure the relative performance for each alternative in a simple mathematical form,
- possibility for visualisation.

TOPSIS is used in the subject literature to put in order the objects (countries, regions, towns, companies, etc.) taking into consideration many different research areas, and one of its fairly frequent uses is, for example, study of customer preferences. Bąk and Cheba (2021) applied this method in their regional studies involving, among others, a general assessment of socio-economic development and also an evaluation of the progress in the realisation of the postulates of the Green Growth Strategy. A description of the individual steps of this method and the principles of creating a synthetic measure can be found in many publications: Shih et al. (2007), Behzadian et al. (2012), Soufi et al. (2015), Cao et al. (2021). The TOPSIS method, as opposed to other multi-criteria methods, allows to establish a distance between the examined objects in terms of the so-called pattern and anti-pattern. Based on such distances, next a synthetic measure is calculated, which creates a ranking of the analysed objects (in this case, EU countries). First place in the constructed ranking goes to the country with the shortest distance from the pattern and the longest from the anti-pattern. The next steps of TOPSIS are as follows (Bąk and Cheba, 2021):

1 First, a normalisation of indicators is carried out according to the formula:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{1}$$

2. The next step involves setting the coordinates of the z_{0j}^{+} pattern and the distance of objects from it d_{i0}^{+} (formulas 2 and 3), and the coordinates of the z_{0j}^{-} anti-pattern and the distance of objects from it d_{i0}^{-} (formulas 4 and 5):

$$z_{0j}^{+} = \begin{cases} \underbrace{max}_{i}\{z_{ij}\} \text{ for stimulant variables} \\ \underbrace{min}_{i}\{z_{ij}\} \textit{ for destimulant variables} \end{cases} \tag{2}$$

$$d_{i0}^{+} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{ij}^{+})^2} \tag{3}$$

$$z_{0j}^{-} = \begin{cases} \underbrace{min}_{i}\{z_{ij}\} \text{ } f\text{or stimulant variables} \\ \underbrace{max}_{i}\{z_{ij}\} \textit{ for destimulant variables} \end{cases} \tag{4}$$

$$d_{i0}^{-} = \sqrt{\sum_{j=1}^{m} (z_{ij} - z_{ij}^{-})^2} \tag{5}$$

4 The final result of TOPSIS is a synthetic measure:

$$q_i = \frac{d_{i0}^{-}}{d_{i0}^{+} + d_{i0}^{-}} \tag{6}$$

with: $q_i \in [0; 1]$, $\underbrace{max}_{i}\{q_i\}$ - best object, $\underbrace{min}_{i}\{q_i\}$ - worst object.

The synthetic measures were set separately for each group of indicators used to examine progress in the realisation of the green growth strategy (groups 1 to 5), and additionally to all the analysed objects treated as a single set (GG).

The objects ordered according to decreasing values of the synthetic measure can also be divided into typological groups in regard of their distance from the mean value (using the arithmetic mean $\bar{q}$ and standard deviation S_q as follows (formula 7):

Table 3
Descriptive characteristics of taxonomic measures in the areas of green economy and socio-economic situation 2004/2005.

Descriptive statistics	GG	I area	II area	III area	IV area	V area
Arithmetic mean	0.505	0.542	0.531	0.647	0.348	0.529
Coefficient of variation (%)	9,118	16,09	12.508	22.980	29.959	32.159
Minimum	0.416	0.421	0.351	0.248	0.202	0.226
Maximum	0.612	0.744	0.649	0.946	0.759	0.790
Asymmetry	0.182	0.900	−1.089	−0.218	2.209	0.041

Source: own elaboration.

- Group I: $q_i \geq \overline{q} + S_q$, comprises countries with the highest values of the synthetic measure;
- Group II: $\overline{q} + S_q > q_i \geq \overline{q}$;
- Group III: $\overline{q} > q_i \geq \overline{q} - S_q$
- Group IV: $q_i < \overline{q} - S_q$, comprises countries with the lowest values of the synthetic measure.

The aim of the next stage (stage 3) in the research procedure used in the study was to find dependencies between the established synthetic measures. To this end the following correlation coefficients were applied: r Pearson (for the value of synthetic measures) and τ Kendall (for the positions occupied by the studied countries). At this stage the authors also analysed the directions of changes in each of the distinguished groups of indicators during the final year under analysis compared to data from the beginning of the analysed period (depending on the availability of data: 2004 or 2005).

4. Study results

The diagnostic features presented above were used to construct taxonomic measures describing: the level of the green economy in four areas in general (GG) for each separate area of the green economy (environmental and resource productivity, natural asset base, the environmental dimension of quality of life, economic opportunities and policy responses) and in the fifth area concerning the socio-economic situation of the EU countries. The results obtained in the first research period (initial data) are presented in Table 2.

As shown in Table 2, the best situation in terms of the green economy in 2005 occurred in three northern European countries: Ireland, Sweden and Finland. In fact, Ireland's top position was influenced by the fourth green economy area, which was the highest in the EU. This high position was influenced by the highest indicators among the EU countries for: $X_{4.3S}$ (development of environment-related technologies, % inventions worldwide) and $X_{4.4S}$ (development of environment-related technologies, inventions per capita), as well as low levels of the indicators: $X_{4.6D}$ (environmentally related taxes, % GDP), $X_{4.10D}$ (petrol end-user price, USD per litre), $X_{4.12D}$ (diesel end-user price, USD per litre). Ireland's position for the other areas was significantly lower, ranging from 4th for area III to 20th for area I. The socio-economic situation of this country, due to the diagnostic characteristics adopted for the survey, was ranked in 12th position.

Sweden's second position regarding GG is a consequence of its high rankings for the first three areas of GG, i.e. environmental and resource productivity (3rd position), natural asset base (2nd position) and environmental dimension of quality of life (3rd position). However, due to area IV, the country ranked 16th in the ranking. Sweden's first position related to its socio-economic situation should also be stressed.

Finland ranked third for all GG areas and was the leader for the environmental dimension of quality of life, achieving the lowest air pollution-related indicators and their impacts in the EU ($X_{3.1D}$ – mean population exposure to PM2.5 per cubic metre, $X_{3.2D}$ – percentage of population exposed to more than 10 μg/m^3, $X_{3.3D}$ – mortality from exposure to ambient PM2.5 per 1,000,000 inhabitants, $X_{3.4D}$ – welfare costs of premature mortalities from exposure to ambient PM2.5, GDP equivalent %, $X_{3.7D}$ – mortality from exposure to lead per 1,000,000 inhabitants, $X_{3.8D}$ – welfare costs of premature deaths from exposure to lead, GDP equivalent, %) and the highest indicator for $X_{3.10S}$ (population with access to improved sanitation, % total population). The indicators related to the socio-economic situation of Finland ranked the country high, in fifth place.

At the end of the ranking according to GG were Belgium, the Netherlands and Malta. These countries finished last in most areas, except area IV (Belgium – 10th position, Malta – 3rd position) and area III for the Netherlands (8th position). The positions occupied by individual EU countries in all areas of the green economy often show significant discrepancies. This is also indicated by the selected descriptive characteristics presented in Table 3, determined for the taxonomic measures estimated based on the diagnostic characteristics adopted for the study.

The coefficients of variation only for the whole GG were below 10% (9.12%). For individual areas of the GG, they exceeded 12%, and the highest variation concerned the socio-economic situation of the EU countries and the fourth area of the green economy. The strength and sign of the asymmetry coefficients should also be noted. Left-handed asymmetry was identified in areas II and III (natural asset base and environmental dimension of quality of life), yet for area III, the strength of this asymmetry was small, but it means that in 2005 a greater number of countries reached values of taxonomic measures above the average. The opposite was true for GG and areas I (environmental and resource productivity) and IV (economic opportunities and policy responses) of the green economy, with the high strength of this asymmetry. Despite the high taxonomic differentiation of the measure in the case of the socio-economic situation, its distribution is close to symmetric, meaning that for about 50% of the countries the taxonomic measure takes a value below the average and for the rest above the average.

The rankings of the EU countries in each area are not the same, as already mentioned, and in some cases differ quite significantly. In order to determine which area has the most significant influence on the taxonomic measure for all four areas combined (GG), Pearson's r and Kendall's τ correlation coefficients were determined (Tables B and C in Appendix A). Their analysis indicates that there is a strong and positive correlation between the taxonomic measure of GG and area II (natural asset base) and a moderate correlation with: area I on environmental production efficiency, area III on the environmental quality of life, and area IV related to economic policies and their consequences. No correlation was found between the GG for all areas and area V on the socio-economic situation of EU countries. A strong relation between area V is only visible with area III on the green economy (environmental dimension of quality of life). Table 4 presents the taxonomic measures for 2019.

When analysing all GG areas together, it should be noted that both the top three EU countries in the ranking, and the last one, have been slightly modified. Sweden and Finland continue to top the ranking, with Sweden moving up one position (from 2 to 1). Ireland, first in the 2005 ranking, fourteen years later has dropped to fifth position, and Denmark has entered the top three (in the third position), having risen from 16th position in 2005. Belgium (one position up compared to 2005) and Malta (down two positions) are again in the last positions in the 2019 ranking. The Netherlands improved its position considerably, rising from 27th place in 2005 to 16th in 2019, while Bulgaria, which ranked 24th fourteen years earlier, came in third from bottom.

Sweden's rise to the top of the ranking is due to its high positions in all green economy areas. The situation is similar with Finland, which only for area IV was ranked 10th, while for the other areas it was respectively: 8th, 2nd and 1st. Denmark, in 3rd place, only ranked a relatively low 21st position for its natural asset base (area II), while in the other areas, it ranged from 2nd (economic opportunities and policy responses) to 7th (environmental dimension of quality).

As was the case in 2005, the positions taken by individual EU

Table 4
Results of the ranking of EU countries in terms of green economy areas and socio-economic situation (the last available year).

Country	GG		I		II		III		IV		V	
	1	2	1	2	1	2	1	2	1	2	1	2
Austria	0.5359	6	0.6769	4	0.5539	8	0.7053	11	0.3398	14	0.5221	4
Belgium	0.4369	27	0.5563	20	0.3927	27	0.6303	15	0.5109	3	0.4854	8
Bulgaria	0.4607	26	0.5773	16	0.5554	7	0.2616	28	0.3344	16	0.1726	27
Croatia	0.4642	24	0.6786	3	0.5032	20	0.4687	26	0.3015	20	0.2123	26
Cyprus	0.5088	11	0.5571	19	0.6348	1	0.5980	18	0.2336	28	0.2737	22
Czech Republic	0.4691	22	0.5405	21	0.5057	19	0.5929	19	0.3440	13	0.3804	12
Denmark	0.5554	3	0.6683	6	0.4957	21	0.7688	7	0.5339	2	0.5051	5
Estonia	0.5282	9	0.5741	17	0.5215	13	0.9297	3	0.3599	11	0.3208	19
Finland	0.5829	2	0.6358	8	0.5997	2	0.9816	1	0.3848	10	0.4451	10
France	0.5132	10	0.4541	26	0.5213	14	0.7668	9	0.4179	7	0.4850	9
Germany	0.5487	4	0.3921	28	0.4893	23	0.7031	12	0.6610	1	0.4908	7
Greece	0.4970	13	0.5984	14	0.5912	4	0.4687	25	0.3063	19	0.1303	28
Hungary	0.4702	21	0.5855	15	0.5259	11	0.4909	23	0.2639	26	0.2946	20
Ireland	0.5437	5	0.6226	10	0.5668	5	0.9236	4	0.2674	25	0.6209	2
Italy	0.4620	25	0.5380	22	0.5125	18	0.5145	22	0.3494	12	0.3954	11
Latvia	0.4930	14	0.6748	5	0.5174	15	0.6923	13	0.2801	23	0.2923	21
Lithuania	0.5304	8	0.7161	2	0.5600	6	0.7681	8	0.2880	22	0.3311	17
Luxembourg	0.5086	12	0.5724	18	0.4669	26	0.8118	6	0.4094	8	0.7707	1
Malta	0.4338	28	0.6101	12	0.3798	28	0.4878	24	0.4204	6	0.2295	25
Netherlands	0.4849	16	0.4729	25	0.4798	25	0.7277	10	0.3947	9	0.4914	6
Poland	0.4682	23	0.4524	27	0.5381	9	0.5399	21	0.3014	21	0.3279	18
Portugal	0.4865	15	0.6474	7	0.4811	24	0.6258	16	0.2637	27	0.2551	23
Romania	0.4715	20	0.6317	9	0.5357	10	0.4655	27	0.2744	24	0.2309	24
Slovak Republic	0.4844	17	0.6044	13	0.5168	16	0.6123	17	0.3350	15	0.3490	16
Slovenia	0.4787	19	0.6184	11	0.4936	22	0.6499	14	0.3135	18	0.3778	13
Spain	0.4804	18	0.5358	23	0.5229	12	0.5790	20	0.3299	17	0.3744	14
Sweden	0.6049	1	0.7672	1	0.5989	3	0.9339	2	0.4547	4	0.5344	3
United Kingdom	0.5333	7	0.5222	24	0.5161	17	0.8473	5	0.4413	5	0.3627	15

Source: own elaboration.

Table 5
Descriptive characteristics of taxonomic measures in the areas of green economy and socio-economic situation (the last available year).

Descriptive statistics	GG	I	II	III	IV	V
Arithmetic mean	0.501	0.589	0.521	0.662	0.361	0.381
Coefficient of variation (%)	8,213	14,053	10.411	25.616	26.011	36.867
Minimum	0.434	0,392	0.380	0.262	0.234	0.130
Maximum	0.605	0.767	0.635	0.982	0.661	0.771
Asymmetry	0.653	−0.271	−0.517	−0.001	1.374	0.619

Source: own elaboration.

Table 6
Comparison of EU countries' ranking results for green economy areas and socio-economic situation, 2004/2005 and the last available year.

Country	GG	I	II	III	IV	V
Austria	−2	−1	1	1	−8	3
Belgium	1	−4	1	3	7	−2
Bulgaria	−2	−3	0	0	8	1
Croatia	−9	1	−4	−2	2	−3
Cyprus	−6	−1	0	−4	−15	−3
Czech Republic	0	−4	2	−3	6	1
Denmark	13	5	−1	4	26	−3
Estonia	1	−2	−7	−1	12	1
Finland	1	−3	1	0	10	−5
France	3	−1	5	−2	−2	−6
Germany	21	0	1	−3	16	2
Greece	−5	6	0	−5	−12	−4
Hungary	−9	−3	4	2	−22	−2
Ireland	−4	9	3	0	−24	10
Italy	−7	−1	−4	0	−1	−1
Latvia	−8	−3	−5	2	2	4
Lithuania	−1	7	−1	2	−1	4
Luxembourg	11	5	−1	0	7	3
Malta	−2	2	−1	2	−3	1
Netherlands	11	−1	1	−2	17	2
Poland	−2	−1	2	0	−7	−2
Portugal	−1	1	−2	7	−25	−1
Romania	−9	−3	2	0	−16	3
Slovak Republic	0	−3	1	0	12	1
Slovenia	−10	−4	−4	−1	−9	−2
Spain	1	−1	1	−1	1	0
Sweden	1	0	−1	1	12	−2
United Kingdom	13	3	6	0	7	0

Source: own elaboration.

countries in all areas of the green economy show significant divergences, as indicated by the selected descriptive characteristics determined for the taxonomic measures presented in Table 5. For all GG areas, the variation was around 8%, while for individual GG areas it exceeded 10%, with the highest variation in the socio-economic situation of EU countries and areas IV and III of the green economy. Strong and moderate left-handed asymmetry was identified in areas IV and II (economic opportunities and policy responses, natural asset base), meaning that in 2019, just as fourteen years earlier, a more significant number of countries reached values of the taxonomic measures above the average.

The opposite situation can be observed for GG and area IV (economic opportunities and policy responses) of the green economy, with the strength of this asymmetry varying considerably. For area IV GG, it is very high, and for all areas together it is strongly moderate. Despite the high taxonomic variation of the measure for the area III situation, its distribution is close to symmetrical, meaning that for about 50% of the countries the taxonomic measure takes a value below average and for the remaining countries above average.

The distribution of the taxonomic measure for the socio-economic situation was characterised by high variation and quite strong right-hand asymmetry.

In order to determine which of the GG areas in 2019 has the most significant impact on the taxonomic measure for all four areas, Pearson's r and Kendall's τ correlation coefficients were calculated (Tables C and D in Appendix A). Their analysis indicates a strong and positive correlation between the taxonomic measure GG and area III (environmental dimension of quality of life). A moderate positive correlation was also

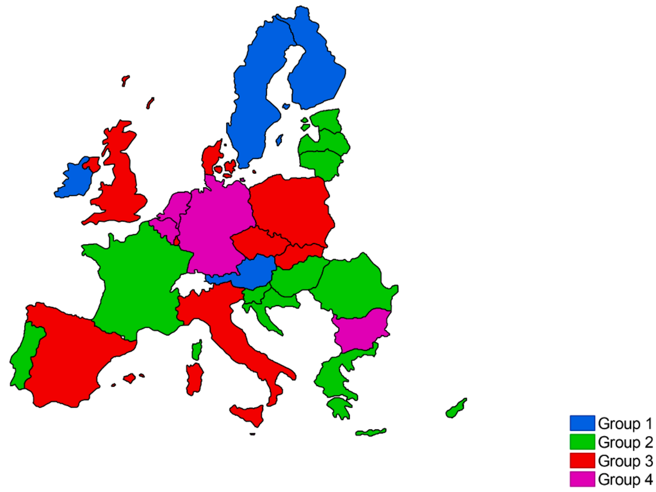

Fig. 1. Division of EU countries based on initial data and every analysed indicator (GG) *Source: own elaboration.*

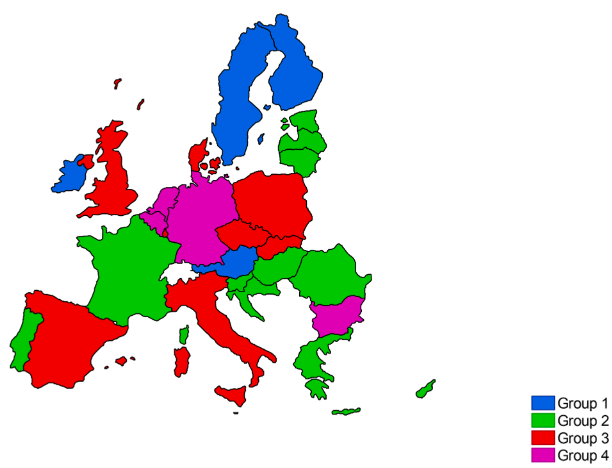

Fig. 2. Division of EU countries based on final data and every analysed indicator (GG) *Source: own elaboration.*

found between GG for all areas and area V concerning the socio-economic situation of EU countries. In addition, a moderate relation between area V and areas III and IV of the green economy was observed.

Table 6 shows the change in the position of EU countries in the examined areas over the two periods. A plus sign indicates an improvement in position, a minus sign a deterioration. The stability of position in both periods (value 0) occasionally occurs, except for area III, for which nine countries in the examined periods remained in the same places. Three countries are worth noting, as they did not change their positions in the ranking for two of the areas studied:

- Bulgaria was in 7th position in area II (natural asset base) and last in area III (environmental dimension of quality of life);
- The Slovak Republic was in 17th position for all GG areas and area III (environmental dimension of quality of life);
- The United Kingdom was 5th in area III (environmental dimension of quality of life) and 15th in area V on the socio-economic situation.

An in-depth analysis of the individual areas examined reveals some interesting developments:

1. The most remarkable improvement in all GG areas concerned Germany, which moved from 25th position in the first study period to 4th in the last study period. That was undoubtedly influenced by the improvement of indicators in GG area IV (economic opportunities and policy responses). Indicators for the development of environment-related technologies have improved considerably, with impressive improvements in indicator $X_{4.4S}$ (development of environment-related technologies, inventions per capita), which increased 56-fold, and indicator $X_{4.1S}$ (development of environment-related technologies, % of technologies), which doubled in value. Denmark's position in GG improved by 13 places, which was also influenced by an improvement in area IV of 26 positions. Similarly to Germany, indicators for the development of environmental technologies improved.
2. Some countries worsened their indicators and thus their ranking in the GG ranking. Slovenia, for example, dropped ten places in the ranking and basically worsened its positions in all areas examined, with the greatest deterioration in area IV.
3. The smallest change is seen in area III, related to the environmental dimension of quality of life, while the most changes are in area IV, where 15 countries improved their positions, and 13 deteriorated. Moreover, area IV showed the most remarkable differences in the positions of countries; for eight of them, the change in plus or minus was at least 15 places, and for four of them, between 22 and 24. Such a large discrepancy was not found in any other considered area.

The results of analyses conducted in workplaces for the set of typological groups created based on formula 7 for all the analysed indicators (GG), are visualised in maps (see Figs. 1 and 2), detailed results are also presented in Table E (Appendix A).

5. Discussion and conclusions

The conducted analyses suggest that green transformation takes a different form in the individual countries. A spectacular improvement of the position allocated in the ranking, based on all the analysed indicators, applies mostly to Germany (by 21 places, from 25th place to 4th). This is a result of very significant changes in the fourth area under analysis – economic opportunities to policy responses (by 16 positions, from 17th to 1st place). The positive changes also mostly relate to the development of environment-friendly technologies – which constitute as much as 10.76% of inventions worldwide (most of them in the EU). However, Germany still occupies last place in the EU in terms of indicators from the first group (environmental and resource productivity) as well as the second (natural asset base). In the case of the first group, unfavourable changes (increase in value of the indicators considered as factors weakening development) were observed e.g. for indicators describing energy consumption in agriculture ($X_{1.9D}$), in industry ($X_{1.10D}$) and in transport ($X_{1.11D}$). The growing use of energy was also observed in other EU countries, but in the case of Germany it was decidedly largest for agriculture (by 1769% in 2018 compared to 2005). With a decrease in the average value by 5% in the entire EU. Germany is also one of the four EU countries (together with Hungary, Latvia and Poland), which reported an increase in the use of energy in all sectors of their economies. As for the second group of indicators, one can also see a significant growth of indicator $X_{2.9D}$ (conversion from natural and semi-natural land to artificial surfaces, % since 1992) from 1.31% in 2004 to 2.40% in 2015, and more than a double increase in the New built-up area, % since 1990 ($X_{2.13D}$), from 12.61% in 2004 up to 25.12% in 2014. The observed changes show that green transformation in Germany is mostly directed at the development in terms of green economy, i.e. it mainly concerns changes in the economy. Hence the relatively high position of Germany in the final ranking, obtained on the basis of all the analysed variables, results from only a partly green transformation. Similar changes were also noted for the Netherlands, which during the first analysed year gained 27th place in the general ranking, and then improved it by 11 places (up to 16th), and in the final year, also mainly due to the positive changes in area IV (by 17 positions, from 26 to 9). Changes of this kind (improvement in the area of economy, with no change or even an increased negative pressure on the natural environment) were also observed during analyses regarding the progress in the realisation of the sustainable development strategy (Cheba et al. 2020). In this case, Germany serves as an example of a country oriented at green transformation, mainly in the economy. Yergin (2011) pointed out that this kind of transformation is risky and allows for some justification of the increased pressure on the natural environment from positive changes in the development of environment-friendly technologies. The changes occurring in the individual groups of indicators, in respect of the synthetic measures set for Germany, are presented in Appendix A (Figure B).

Green transformation takes a different course in some Nordic countries in the EU. An improved position in the final ranking (in the case of Sweden from 2nd to 1st place, and for Finland – from 3rd to 2nd) results from the positive changes related to the majority of the analysed groups of indicators, and in particular those from group IV (economic opportunities and policy responses). It is also worth noting Denmark and its spectacular improvement from last to 2nd place in area IV, which led to the improved position in the final ranking (from 16th to 3rd). These countries for many years have been implementing technological solutions aimed at combating the degradation of the natural environment. As was pointed out by many authors (Sachs, 2015) these are actually the only countries in Europe which have managed to separate permanently their economic growth from the negative pressure exerted on the natural environment. Such dependencies are also visible in the analyses carried out for his study, and the changes for Sweden are visualised in Appendix A (Figure C).

It is also worth drawing attention to the countries placed last in the constructed rankings. Whereas the distant position of Bulgaria in the ranking based on all the analysed indicators comes as no particular surprise (24th and 26th, respectively), yet one may ponder the distant positions occupied by, for example, Belgium (28th and 27th) and Malta (26th and 28th). Bulgaria and Romania regularly take last places in various rankings examining the level of socio-economic development in the EU (Surubaru, 2021), just as in the case of these analyses. A much slower socio-economic growth compared to countries in Western and Northern Europe is accompanied there by much lower pressure exerted on the natural environment (see also: Brodny and Tutak, 2021). The continued monitoring of their further development is vital in this case. A detailed analysis of the results suggests that despite the relatively high place of Bulgaria in area II (natural asset base) there is , among others, a growing conversion from natural and semi-natural land to artificial surfaces ($X_{2.9D}$, % since 1992) from 0.06% to 2.51%; conversion from cropland to artificial surfaces ($X_{2.10D}$, % since 1992) from 0.05% to 1.10%. Almost a double increase also concerns indicator 13 – new built-up area ($X_{2.9D}$, % since 1992) from 12.97% to 24.19%, while the percentage of the area is still lower that the average in the EU (33.38%). A graphic presentation of changes in the individual groups of indicators under analysis for Bulgaria is shown in Appendix (Figure D).

It is worth emphasising here that even though all countries are aware that the climate change and degradation of the natural environment now constitute a major threat, and green transformation is one of the directions which should at least allow for a certain slowing down of the negative changes in Nature, yet the related improvement occurs in a different way in individual countries. The Nordic model, even if with some limitations, can be acknowledged as the approach which allows to separate economic growth from the negative pressure imposed on the environment. Despite its obvious advantages and positive changes, not only in respect of the development of the environment-friendly technologies as well as caring for the available resources, and the appropriate organisation of the tax system with the inbuilt solutions supporting environmental protection, this model has not been widely copied by other EU countries. One could use an example of some West European countries, like Germany, which with their significant development of environment-friendly technologies, pay less attention to the care for economic growth which will protect available resources and reduce the negative impact of human activity on the natural environment (Bekun et al., 2019).

To face the challenges related to the protection of the environment in Europe, a plan called the European Green Deal was created, intended to help transforming the EU into a modern, sustainable and competitive economy. The agreement is focused on three goals:

- zero-level net emissions of greenhouse gases by 2050, which is linked with increasing the share of renewable energy in the energy mix of the EU. Moreover, compared to the base year (1990), by 2030 greenhouse gas emissions in the EU are to be reduced by 55%, instead of the 40% planned previously (https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en);
- separation of economic growth from using-up natural resources, which is connected with, among others, the acceleration of technological progress;
- support for inclusive green transformation aided by the mechanism of fair transformation, which will provide from 65 to 75 bn euros during the period 2021–2027 to alleviate the socio-economic consequences of the transformation – this means that no region will be left behind (WEF, 2021).

The effect of these actions will be changes not only in the energy sector but in all other areas of the economy. The European Green Deal is also meant to help in overcoming the COVID-19 pandemic. It will be financed from financial means constituting one-third of the amount of 1.8 bn euros allocated for investment in the reconstruction plan Next Generation EU together with the funds from the seven-year EU budget.

The analysis of the literature (Berger, 2011; Zhao et al., 2017; OECD, 2019) and reports by the largest international organisations suggest that the concept of green growth is a development opportunity for many countries and that it has a crucial importance for resolving global threats linked to climate change and extinction of natural resources. What is more, the 'ecologisation' of the economy favours the realisation of the majority of the aims of sustainable development. It can contribute to the increased well-being and social equality of future generations, at the same time ensuring the correct proportions between the economy and ecosystems. The change of thinking in the direction of green economy can be observed not only in highly developed countries, but also in developing ones (Bąk and Cheba, 2021). As green growth has the potential to stimulate vital and transformative changes in the direction of sustainable development, the more important the active and proactive role of governments in facing to the challenges of restructuring ecologically sustainable and ecologically alive ecosystem and economy, generally referred to as green transformation (Altenburg and Pegels, 2012; Borel-Saladin and Turok, 2013; Abuzeinab et al., 2016; Mets et al., 2021).

It should be clearly pointed out that without the engagement of individual countries it would not be possible to progress in terms of implementing the elements of the Green Deal, hence the importance of monitoring the changes of indicators connected with green economy, as was the case in this study. The comparison of the values of these indicators in two research periods allowed to verify both the carried out and the abandoned actions aimed at the environment-friendly solutions and thus bringing benefits in the form of improved living standards for the population.

As suggested by the results of this research, many EU countries have not succeeded in achieving desirable changes linked with green growth. These are the consequences of, among others, continuing with the existing business practices, ineffectiveness of some of the applied instruments, the lack of exactly specified economic policies, as well as subsidising sectors harmful to the natural environment. At the same time, such practices clearly confirm the necessity for a comprehensive approach to change, especially if individual countries wish to aim at creating the New Green Deal (Tarabusi and Guarini, 2018). The scope and nature of the challenges emerging as a result of climatic and environmental threats are complex and have many aspects. The transformation into a green ecological economy should be based on research addressing diverse assessments of the impact by important base trends, e.g. digitalisation and automation, globalisation, nationalisation, etc., on the environmental and distributive results, as well as the prospects for collaboration in the scope of green innovation and diverse business models inspired by a circular economy. Such evaluations may be particularly important for the understanding of the possible future paths of greening – and decarbonising – key sectors of manufacturing industry. It is also important to better assess the policy instruments (Söderholm, 2020). Research connected with green economy and its transformation requires not merely a large volume of data but also the appropriate classification of problems. The correct diagnosis employs the taxonomic methods owing to which it is possible to define the diversity of objects (such as EU countries) and select those which are leading or lagging due to the level of the examined phenomenon. The empirical results and findings regarding green economy may lead to identifying several conclusions regarding e.g. the measurement of the studied phenomena, comparison of the obtained results and identification of causal effects. The information obtained in this way can be a valuable clue to undertaking specific practical activities aimed at the transformation of national economies into modern and competitive business systems with a minimal impact on the environment.

A significant limitation of the research on green energy transformation is the access to reliable and comparable statistical data. Public statistics databases do not always provide complete and up-to-date information. It is a typical limitation of research using data from official statistics. The final result is also the effect of the applied data analysis method. For this reason, in this type of research, it is important to look for regularities, the confirmation of which can be found in the studies by other authors. This type of approach was used in this paper.

As for the directions of subsequent studies, it will be necessary to expand the set of indicators describing both green growth and socio-economic development of EU countries. These indicators will allow for an even better understanding of the causes of the green energy transformation in individual countries.

The novelty of the presented research is based on the analysis of the directions of changes occurring in the process of green transformation in individual EU countries, whereas up till now the subject literature evaluated mainly changes in individual indicators over some years. This paper provided comprehensive analyses which involved multidimensional approach to green transformation. When comparing two fairly distant periods of research (2005 and 2019), it was possible to identify the direction in which green transformation is proceeding in the examined countries. The authors considered both the positive and negative aspects of the transformation. In order to determine directions of green transformation of countries, the study included indicators describing all the groups distinguished in the Green Growth Strategy (Environmental and resource productivity, Natural asset base, Environmental dimensions of quality of life, Economic opportunities and policy responses), linking them to the general socio-economic situation in individual countries. In this way it became possible to indicate certain regularities, and then assess for which countries achieving climate neutrality postulated in the Green Deal will be a greater challenge than for others, and what importance should be given to environmental, social and economic priorities in aiming for green transformation.

Further research on the process of green transformation conducted by the authors will involve the issues linked with, e.g. co-creation, namely the role of residents and local authorities in the process of energy transition. Currently, analyses in this scope, which also concentrate on less obvious conditions in the process of green transformation, constitute an important research direction. The research findings presented in this study can be used as the basis for designing solutions which take into consideration the varied pace of changes regarding green transformation in EU countries. The multidimensionality of the examined phenomenon means that it is also necessary to include analyses of the pace of transitional changes towards green economy in individual countries, which is highly diversified depending on the level of their economic development.

The future problems that we want to deal with will also concern the construction of the green transformation referential model which will be prepared from the perspective of various actors of the sustainable transitions process. It will also be important to predict the pace of green transitions, as it strongly varies depending on the level of economic development of individual countries. These are just some of the challenges that will guide our future research.

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CRediT authorship contribution statement

Katarzyna Cheba: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Iwona Bąk:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Katarzyna Szopik-Depczyńska:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Giuseppe Ioppolo:** Writing – original draft, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

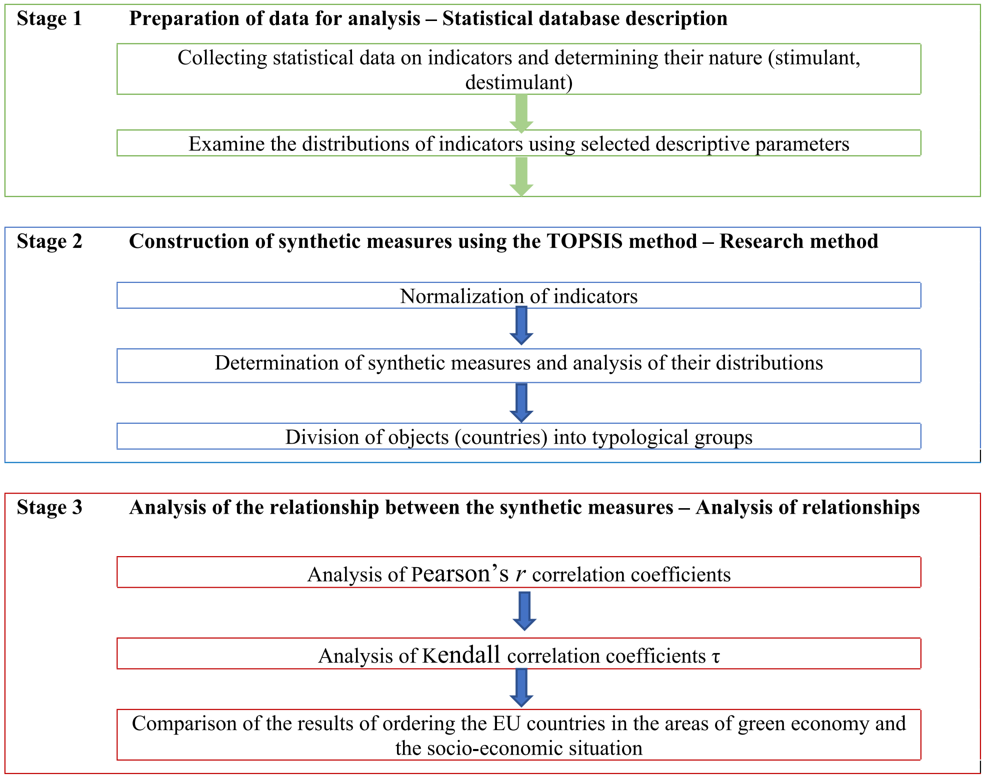

Fig. A1. The graphical presentation of the analytical framework used in the research.

Table A1
Pearson's r correlation coefficients calculated for the EU countries according to the taxonomic measures of development obtained for the study areas 2004/2005.

	GG	I	II	III	IV	V
GG	1.0000	0.5520	0.7717	0.4325	0.4247	0.0596
I	0.5520	1.0000	0.3488	0.0475	−0.1100	−0.0400
II	0.7717	0.3488	1.0000	0.1557	0.0063	−0.1406
III	0.4325	0.0475	0.1557	1.0000	0.0261	0.6311
IV	0.4247	−0.1100	0.0063	0.0261	1.0000	−0.0785
V	0.0596	−0.0400	−0.1406	0.6311	−0.0785	1.0000

Table B1
Kendall's correlation coefficients τ calculated for the ranks of EU countries according to the taxonomic measures of development obtained for the study areas 2004/2005.

	GG	I	II	III	IV	V
GG	1.0000	0.4074	0.6085	0.2169	0.1217	−0.0317
I	0.4074	1.0000	0.2593	−0.0794	−0.0688	−0.1587
II	0.6085	0.2593	1.0000	0.0794	−0.0370	−0.1693
III	0.2169	−0.0794	0.0794	1.0000	−0.1323	0.4868
IV	0.1217	−0.0688	−0.0370	−0.1323	1.0000	−0.0106
V	−0.0317	−0.1587	−0.1693	0.4868	−0.0106	1.0000

Table C1
Pearson's r correlation coefficients calculated for the EU countries according to the taxonomic development measures obtained for the study areas (the last available year)

	GG	I	II	III	IV	V
GG	1.0000	0.2740	0.5526	0.7975	0.3060	0.4754
I	0.2740	1.0000	0.2329	0.1469	−0.3274	−0.0969
II	0.5526	0.2329	1.0000	0.1710	−0.4181	−0.1200
III	0.7975	0.1469	0.1710	1.0000	0.3043	0.6714
IV	0.3060	−0.3274	−0.4181	0.3043	1.0000	0.4609
V	0.4754	−0.0969	−0.1200	0.6714	0.4609	1.0000

Table D1
Kendall's correlation coefficients τ calculated for the ranks of EU countries according to the taxonomic measures of development obtained for the study areas (the last available year).

	GG	I	II	III	IV	V
GG	1.0000	0.1534	0.2593	0.6243	0.1429	0.3439
I	0.1534	1.0000	0.1746	0.0952	−0.1958	−0.0794
II	0.2593	0.1746	1.0000	0.0529	−0.3122	−0.1323
III	0.6243	0.0952	0.0529	1.0000	0.2751	0.5291
IV	0.1429	−0.1958	−0.3122	0.2751	1.0000	0.4074
V	0.3439	−0.0794	−0.1323	0.5291	0.4074	1.0000

Table E1
Typological division of EU countries during the first and last analysed year – GG.

Typological group	Number of countries	GG based on initial data	Number of countries	GG based on final data
I	4	Ireland, Sweden, Finland, Austria	5	Sweden, Finland, Denmark, Germany, Ireland,
II	11	Cyprus, Latvia, Lithuania, Greece, Slovenia, Estonia, Romania, Hungary, France, Portugal, Croatia	7	Austria, United Kingdom, Lithuania, Estonia, France, Cyprus, Luxembourg
III	8	Denmark, Slovak Republic, Italy, Spain, United Kingdom, Poland, Czech Republic, Luxembourg	14	Greece, Latvia, Portugal, Netherlands, Slovak Republic, Spain, Slovenia, Romania, Hungary, Czech Republic, Poland, Croatia, Italy, Bulgaria
IV	5	Bulgaria, Germany, Malta, Netherlands, Belgium	2	Belgium, Malta

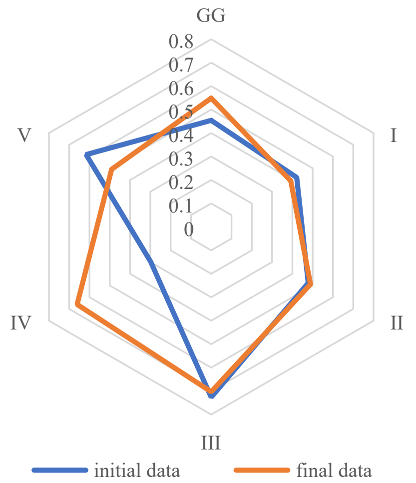

Fig. B1. Values of synthetic variables set for individual groups of indicators (groups 1 to 5) and for all indicators considered as a single data set (GG) – Germany.

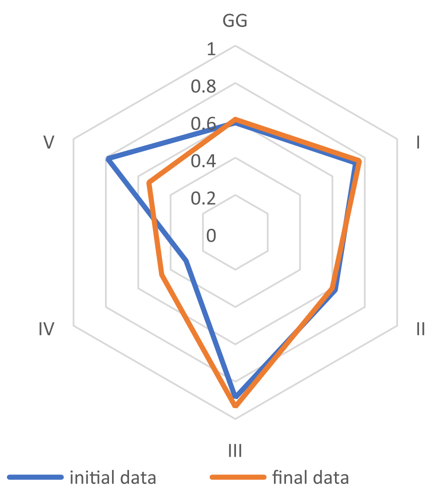

Fig. C1. The values of synthetic variables set for the individual groups of indicators (groups 1 to 5) and for all the indicators considered as a single data set (GG) – Sweden.

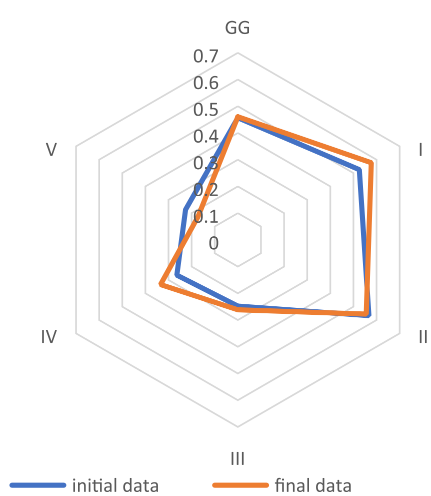

Fig. D1. The values of synthetic variables set for the individual groups of indicators (groups 1 to 5) and for all the indicators considered as a single data set (GG) – Bulgaria.

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