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Green Transformation: Applying Statistical Data Analysis to a Systematic Literature Review

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Abstract: The main purpose of the paper was to identify the most frequently discussed directions of research on green transformation. In the article, both the significant similarities in the existing studies in this field, as well as the newly emerging topics of research, are presented. For this purpose, the authors used a systematic literature review with elements of statistical analyses. This kind of approach is not popularly used in literature review papers, as it differs from the research practices employed previously, which mostly concentrated on applying qualitative methods, alternatively supported by the analysis of the co-occurrence of keywords. In this paper, the authors decided to include selected methods of dimensional analysis in the systematic literature review, namely the log-linear and correspondence analyses. The main results of the presented analyses are a more detailed division of studies related to green transformations into groups focused on the areas more difficult to distinguish in terms of the traditionally conducted literature review.

Keywords: green transformation; green transition; green energy; systematic literature review; log-linear model; correspondence analysis

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1. Introduction

The development of the global economy has resulted in the excessive exploitation of the planet's natural resources, which is not compatible with the principle of sustainable growth. The situation is deteriorating along with the increase in the world's population, which is approaching the level of 8 billion. The strategy of fast growth and neglecting the environmental issues followed by many decision makers means that ecological problems have evolved into social and economic ones. The worsening condition of the natural environment, which has attracted increasing attention since around the 1950s, has directed the attention of governments worldwide toward matters related to increasing ecological awareness and counteracting environmental threats [1]. In the context of the growing awareness and interest in the global changes in the natural environment, such as climate change and the loss of biodiversity, the concept of green transformation has emerged and is defined in the subject literature in many different ways. Some researchers see it as a consequence of societal collapse and thus treat it as a negative result [2]. According to Feol [3], the term "transformation" is often used as a mere metaphor, whereas other authors view transformation as an effective way of promoting environmental sustainability and societal prosperity [4]. In line with Scoones et al. [5], in order that humanity could exist on the Earth in a sustainable way, there is a need for numerous "green transformations", which should be both "top-down" in their nature, involving elitist alliances between state and business, as well as "bottom-up", supported by grassroots innovators and entrepreneurs, and at the same time constituting an element of the wider mobilisation of civic society.

Over the last decade, green transformation gained popularity both in the scientific literature and also in political discourse [6]; however, there is scant research explaining the meaning of this phenomenon based on diverse viewpoints and using the method of multivariate statistical analysis in order to find connections between the terms related to green transformation. This article is a contribution to filling the research gap in this area.

The aim of the article was to identify the main directions of research on the green economy, including both the definition of the significant similarities in the existing studies in this field as well as the newly emerging topics of research. In order to realise this aim, the authors used a systematic literature review with elements of statistical analyses. The approach used by the authors differs from the research practices employed previously, which mostly concentrated on applying qualitative methods, alternatively supported by the analysis of the co-occurrence of keywords. It was also decided to include in the systematic literature review selected methods of dimensional analysis, namely the log-linear and correspondence analyses. The obtained effect was not only a map of the connections between the keywords most frequently used by authors but also a more detailed division of studies related to green transformations into groups focused on the areas more difficult to distinguish in terms of the traditionally conducted literature review.

The study consists of six sections. Following the introduction describing the research aim and the main motivations for the authors to address this subject, Section 2 presents a review of publications concerning the green economy and green transition, focusing on the main aspects discussed by their authors. Section 3 describes the methodology of the research, the data collection procedure and the description of the methods. Section 4 discusses the obtained results, while Section 5 compares the results with those obtained by other studies; Section 6 presents the conclusions.

2. Green Transformation—Research Overview

The green transformation has now become one of the more important areas of research, discussed by authors representing diverse disciplines of science. The publications in this area include both the theoretical issues linked with defining the term "green transformation", as well as present analyses of the current stage of the process of transformation. There are also some popular studies comprising the results of the literature review; however, these are usually limited to a quantitative presentation of the number of citations and number of works indexed in databases. It is far less frequently possible to find their listings of the analysed research subjects and analyses focused on, for example, examining the relations linking green transformation with other areas of research. The published papers mostly have the character of a survey, and the conducted studies in practice do not apply the methods of statistical data analysis. However, besides the knowledge, among others, of how to define green transformation or describe the stages and activities undertaken as part of the process of transition from the conventional economy to that with low or even zero emissions, one should also acquire information about the methods and models employed by scholars to expand the knowledge in this scope.

A starting point for more advanced statistical analyses is a review of the definitions of green transformation. At the same time, it is worth noting that the subject literature almost equally often uses the term "green transition", frequently treating them as interchangeable [7–9]. However, others [10] point out that the concept of green transformation refers to far more complex processes than green transition. According to Stirling [11], the term "transition" describes an ordered process realised "according to tightly disciplined technical knowledge and innovations", whereas "transformations imply more diverse, emergent and unruly political alignments, challenging incumbent structures, subject to incommensurable, tacit and embodied social knowledge and innovations".

Both these terms are defined in the subject literature in many different ways. For some, green transition means "the transition towards the achievement of the climate and environmental objectives primarily through policies and investments" [12], whilst the definitions of green transformation [5,13–15], in line with its original meaning, mostly highlight the environmental results (advantages) of the ongoing changes, the impact of the transformation saving natural resources available on the Earth, and the necessity of implementing such actions in conditions of the observed unfavourable climate change.

Thus green transformation is defined, for example, in [5], as "the restructuring of political, social, and economic systems to fit within the planetary boundaries". Newell [16] described it in a similar way, stressing that industrial societies should strive for the transformation into "a climate compatible, resource-conserving and sustainable world economic order". Some authors also focus on the very course of the transformation and the areas in which it takes place. Schmitz and Becker [17] point out that green transformation can be interpreted as "practices of radical economic, societal and institutional change that transcends sectors and levels". Table 1 presents an overview of selected definitions in the field of green transition and green transformation.

Table 1. Definition and description of green transition and green transformation.

Author (Year)	Definition
WBGU (2011) [18]	"Green transformations have the objective to be socially just, equitable, and balancing the ecological, economic, and social dimensions".
Scoones, I; Leach, M.; Newell, P. (2015) [5]	By prefacing the transformations with the word "green", our intention is to focus on the environmental dimensions of change, but these almost inevitably raise questions of social as well as environmental justice.
Lederer, M.; Wallbott, L.; Bauer, S. (2018) [19]	Green transformation is "a holistic and wide-ranging set of processes".
Nordic Council of Ministers (2021) [6]	Green transition is "the gradual and full transition to a fossil-fuel-free, low-carbon society".
Zhai, X; An, Y. (2021) [20]	"Green transformation emphasizes the change from an extensive development mode (with high input, high consumption, and high pollution) to an intensive development mode (with low input, low consumption, and zero pollution)".

At present, researchers also examine new aspects and/or areas that are strongly linked to the process of green transformation; among the keywords mentioned in these studies, one can find the following: security [21], including mainly energy security [22], fairness [18], understood, e.g., as a transparent and respecting diverse stages of socio-economic development, the transition towards a low or even zero-emissions economy [23]. Many authors also define green transformation in the context of technologies developing in line with the progressing greening of the economy [20,24]. However, it is worth noting that, according to Stern and Rydge [25], the development of environment-friendly technologies is not the factor that could significantly speed up the ecological transformation; there are also many other different conditions existing both in the economy as well as in societal awareness. Pertinent examples are the recent events connected with the actual geopolitical situation and the COVID-19 pandemic, whose effect is the drastic change in the existing conditions of the functioning of not just companies but also entire societies. The recent, unexpected and continuing growth of energy prices in the coming months will undoubtedly have a significant impact on changes in consumer behaviour. For this reason, the recently promoted technological solutions regarding the use of electricity-powered vehicles are becoming far less attractive commercially.

One should also note that, over the last decade, the concept of green transformation has been examined in many different studies [3,7,26–31]. The review of the literature available in the Web of Science (WoS) database suggests that in the period 2001–2022 (as of the end of September 2022), there were 871 indexed publications that referred to, in their title, abstract and/or keywords to the terms "green transformation" (524 publications) or "green transition" (382) (Table 2).

Table 2. Number of papers indexed in the WoS databases, including the indicated keywords.

Searched Terms	No. of Publications
“green transformation*”	524
“green transition*”	382
“green transformation*” OR “green transition*”	871

There has been a systematic increase in the number of publications in the analysed period starting already from 2017 when 51 such works were published. In 2021, the WoS database indexed 191 publications, and a further 270 appeared by the end of September 2022. In line with the growing number of publications, one could also observe an increase in the number of their citations, from 280 in 2017 to 2535 in 2021 and up to 2970 in the first three quarters of 2022 (Figure 1).

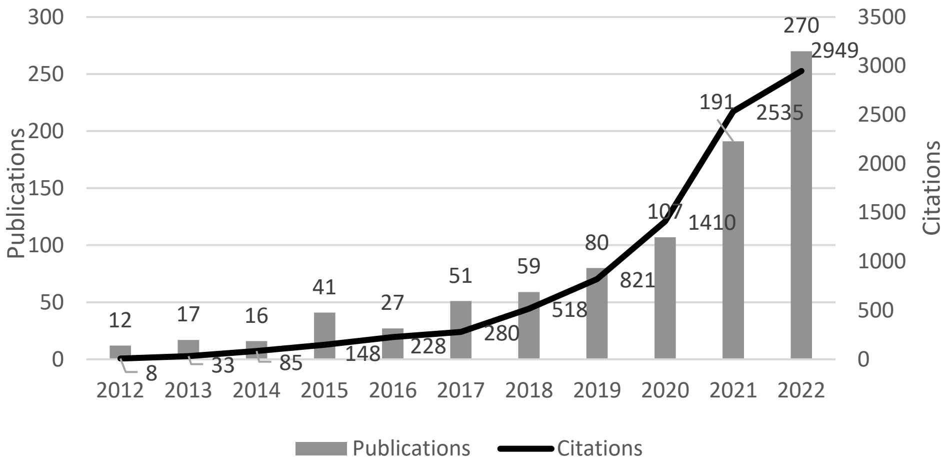

Figure 1. The evolution of publications and citations by year.

Despite the growing number of publications and their citations, the assembled database is not very impressive, which only confirms the limited exploration of issues in this area of research. The emergence of the literature devoted to green transformation (or green transition) should be viewed in the context of the growing knowledge and interest in global environmental change, such as climate change and loss of biodiversity. The most recent and widely publicised political agreements, for example, the one signed in Paris, and the declared aims of sustainable development (SDG) [32], have led to an ever greater interest in transformation on the part of society and academia. The growing interest in the analysed research subject in recent times is also a direct result of the already-mentioned current geopolitical situation and the energy crisis being its consequences.

The publications indexed in the WoS database mainly refer to all the issues corresponding with the scope of environmental science ecology (402 publications), science technology (222), business economics (179), engineering (118) and energy fuels (112). They were published mostly in such journals as *Sustainability* (84), *Journal of Cleaner Production* (36), *Environmental Science and Pollution Research* (34), *International Journal of Environmental Research and Public Health* (23) and *Energies* (21). The majority of their authors come from China (429 publications), the United Kingdom (78), Denmark (70), Italy (61), the USA (57) and Germany (51). Table 3 presents the bibliographical details of the top ten most cited articles.

These are mainly publications of a general nature, corresponding with the scope of theoretical considerations dedicated to green transformation. Singh et al. [33] examined the way in which the green management of human resources impacts the relations between green transformative leadership, green innovation and environmental effectiveness. The authors mostly used data from a questionnaire survey conducted in 309 small and medium enterprises in the production sector and verified the posed hypotheses by employing the covariate modelling of structural equations (SEM).

Table 3. The top ten most cited papers.

Title	Journal	Publications	Total Citations
Green innovation and environmental performance: The role of green transformational leadership and green human resource management	*Technological Forecasting and Social Change*, 150, 119762	[33]	325
The determinants of green product development performance: Green dynamic capabilities, green transformational leadership, and green creativity	*Journal of Business Ethics*, 116(1), 107–119	[34]	254
Aggregation-and leaching-resistant, reusable, and multifunctional Pd@ CeO2 as a robust nanocatalyst achieved by a hollow core-shell strategy	*Chemistry of Materials*, 25(9), 1979–1988	[35]	208
Sustainability transitions: A political coalition perspective	*Research Policy*, 43(2), 278–283	[36]	195
Green, Transition-Metal-Free Aerobic Oxidation of Alcohols Using a Highly Durable Supported Organocatalyst	*Angewandte Chemie International Edition*, 46(38), 7210–7213	[37]	174
The politics of green transformations	*Routledge*	[5]	166
Sensemaking and sustainable practicing: functional affordances of information systems in green transformations	*MIS quarterly*, 1275–1299	[38]	164
Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy	*Science of the Total Environment*, 665, 23–32	[39]	142
How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data	*Energy Policy*, 139, 111310	[40]	129
Effect of green transformational leadership on green creativity: A study of tourist hotels	*Tourism Management*, 57, 118–127	[41]	123

In turn, Chen and Chang [34] discussed the determinants of effectiveness in the development of ecological products. To this end, they conducted a questionnaire survey among the following: a) 12 CEOs, managers of environmental, marketing, manufacturing or R&D departments, and leaders and members of green product development projects in different electronics companies in Taiwan; b) 254 businesses. Similarly to Singh et al. [33], the study used SEM to verify the posed hypotheses.

Hess [36] examined the influence of political conditions on the speed of the process of green transformation in the United States, using mainly literature studies and a case study. The conducted research suggests that in industrialised countries, there are tensions between the need to change to low-emission energy sources and the desire to satisfy the fast increase in demand for energy with the continued exploitation of fossil fuels.

A case study was also used by Seidel et al. [38] to describe the implementation of environment-friendly business practices by a global supplier of operational software. The authors of that publication showed, among others, the way in which information systems can contribute to creating environmentally sustainable organisations.

The study by Cai et al. [39] presented a review of the current practices and the limitations of the applied energy-saving strategies and the strategies for reducing emissions

(ESER) in the manufacturing industry. Based on the case study, the authors outlined a new concept of the strategy aimed at improving energy efficiency and reducing waste emissions.

In the more advanced research presented by Ouyang et al. [40], the authors used a two-directional panel model with permanent effects to analyse the impact of environmental regulations on technological innovations; the study showed the existence of a U-shaped relationship between them. In the short-term, environmental regulations have a negative impact on the development of research and innovation capabilities of the industrial sector in China; however, along with the expanding environmental regulations, companies seek to reduce the costs of controlling pollution via the improvement of their capability for technological innovation.

In all these studies, the conducted literature review had the character of synthesis based on selected works published in the analysed scope, following the subjective choice of the authors. However, despite a fairly large number of the analysed works, none of those attempted to provide a comprehensive view of the issues linked with green transformation or green transition. The authors mostly focused on the presentation of their research results, which usually described individual strategies applied by the companies under study, for example, as a case study. The fragmentary character of the existing research on green transformation (or transition) was also confirmed by the results obtained from more advanced analyses of the contents of the publications on this subject, the outcomes of which are presented in the following sections of this paper.

3. Research Methodology

3.1. Stages of the Applied Research Procedure

To analyse the content of publications on the green transformation or green transitions, the authors employed a three-step research procedure whose stages are presented in Figure 2.

The first stage, based on the created database of 871 publications indexed in the WoS, identified keywords used in them to describe green transformation or green transition and their connections with other keywords describing these terms. The study used VOSviewer version 1.6.14, which allowed for the distinction of clusters containing the keywords most frequently creating such connections. In this stage of the research, publications presenting these issues using different types of models were sought. The results of the first stage were also visualised in a map showing the links between the terminology of green transformation and green transition models with other keywords identified in the conducted study (Figure 3).

The next stages of searching for relations between the selected keywords describing the results of quantitative or qualitative research presented in the analysed studies employed the methods of multivariate statistical analysis, namely the log-linear and correspondence analyses.

3.2. Statistical Methods

The methodology of a systematic literature review, through the use of a repetitive and precisely described research procedure, allows for searching, selecting and evaluating all the available scientific evidence in a given field of research [41]. Analysis of periodical publications, above all in the form of scientific articles, provides information on the current state of research, allows for posing research questions correctly, proposing hypotheses and then helping with the interpretation of the obtained empirical results [42].

Conducting a literature review constitutes an important part of every research project [43–48], helps to understand a given issue and identifies knowledge gaps that will have to be addressed in subsequent studies. Based on the review, the authors constructed a base of academic publications containing the appropriate keywords, which in turn led to the creation of variables used in the later stages of the research. The log-linear analysis allows for a detailed assessment of dependencies between any number of non-metric variables recorded in a multivariate contingency table, as well as including interactions occurring among them. It is used successfully in many fields of science, in particular in medicine [49–51], demographic studies [52,53] and economics [54–57].

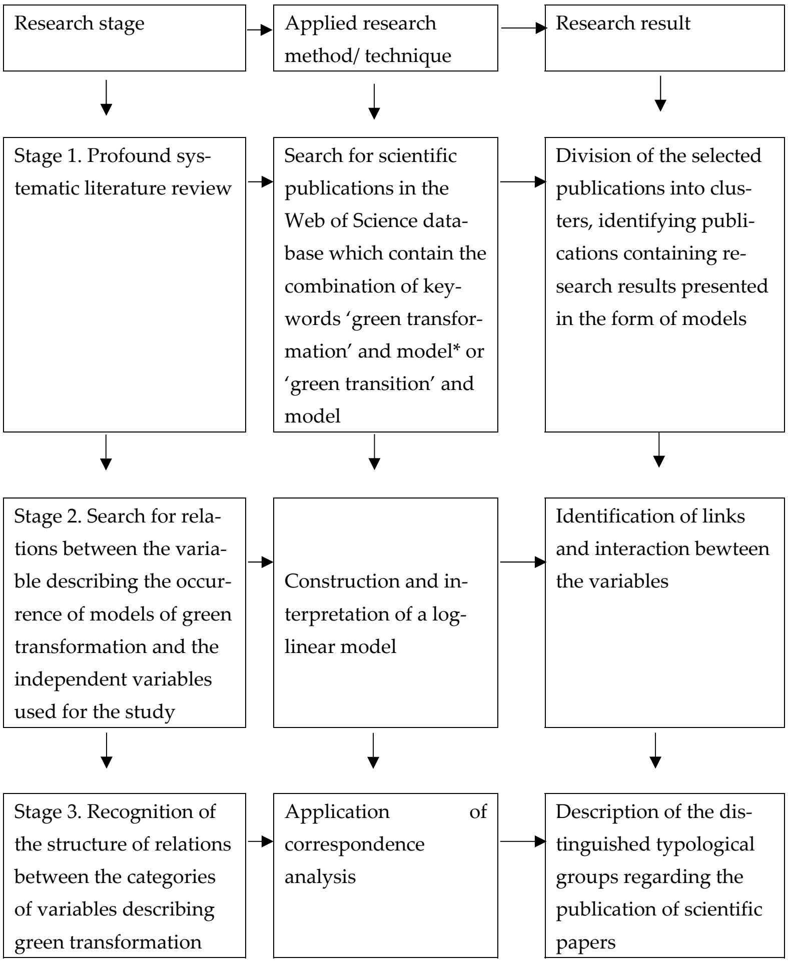

Figure 2. Research procedure chart, where * denotes the possibility of different inflectional forms of a word.

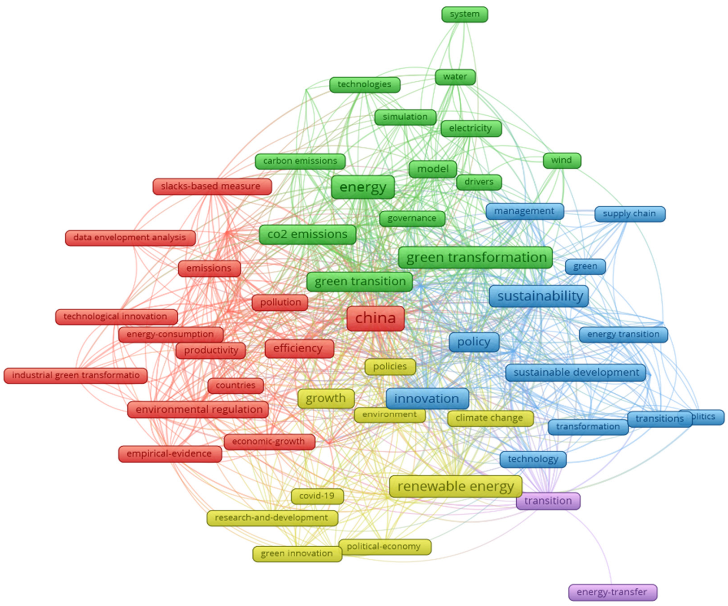

Figure 3. Map of links among keywords characterised by most frequent co-occurrence.

In the log-linear model, it is assumed that the natural logarithm of the numerosity expectation value per cell in the independencies table is a linear function of factors. The generalised form of the model is as follows:

$$ln\left(\hat{n}^{T\cdots}\right) = n + \sum \lambda_i^T + \ldots + \sum \lambda_{ij}^{TS} + \ldots + \sum \lambda_{ijk}^{TSQ} + \ldots \tag{1}$$

where $\hat{n}^{T\cdots}$ is vector $\left[\hat{n}_i^T \hat{n}_{ij}^{TS} \ldots\right]$, and $\hat{n}_i^T$ is the expected numerosity of i-th level of factor T, $\hat{n}_{ij}^{TS}$ is the expected numerosity regarding interactions of i-th level of factor T and j-th level of factor S, etc.; n is the mean of natural logarithms of all observed numerosities calculated on the basis of formula

$$n = \frac{1}{n} \sum_T \sum_i ln\left(n_i^T\right), \tag{2}$$

where $\sum_T$ is summation after all the factors; $\sum_i$ is summation after all the levels of the factors; λ_i^T is the indicator of i-th level of factor T; λ_{ij}^{TS} is the indicator of the interaction of the second order of i-th level of factor T and j-th level of factor S; λ_{ijk}^{TSQ} is the indicator of the interaction of third order between i-th level of factor T, j-th level of factor S and k-th level of factor Q, etc.

The measure of the model's fit to the results are the statistics of Pearson's χ^2 and χ^2 of the greatest reliability.

In order to provide the specification of a log-linear model, it is necessary to define the order of variable interactions, namely which interactions of a given order (among which variables) should be included in the model. To this end, one should carry out analyses of partial and boundary correlations. The former informs whether the respective interaction is statistically relevant when all the factors of the same level are already within the model, whereas the latter signals whether the respective correlation has an impact when the model does not yet have any interactions of the same order [49].

Correspondence analysis is often used for qualitative variables [58–61]. The starting point in this method is to record a complex contingency table, including numerosity of the occurrence of the individual categories of variables assumed to describe n objects; Burt's matrix is a very frequently used way of recording the values [62]. In the first stage, a complex matrix of markers **Z** is constructed, containing blocks (submatrices) corresponding to the following variables: $\mathbf{Z} = [\mathbf{Z}_1, \ldots, \mathbf{Z}_Q]$, where Q stands for the number of characteristics. The elements of this matrix only take on values of 0 and 1, depending on whether the given object does or does not have a distinct category of a variable.

Burt's matrix is given by $\mathbf{B} = \mathbf{Z}^{\mathbf{T}}\mathbf{Z}$. This provides a symmetrical block matrix, in which on the main diagonal, there are placed diagonal matrices containing the number of the occurrence of the characteristics, and outside the main diagonal, there are contingency tables for each pair of the studied variables. The total number for each submatrix equals the numerosity of the examined units n, while the total number for Burt's matrix amount to $n \cdot Q^2$. Since Burt's matrix is symmetrical ($b_{ij} = b_{ji}$), then the boundary numbers for lines and columns are identical and calculated as follows [63–65]:

$$\sum_{j=1}^{J} b_{ij} = b_{i\cdot} = b_{\cdot j=Q} = Q \cdot b_{ii}, \tag{3}$$

where b_{ij} is the elements of Burt's matrix, and J is the total number of categories of all the characteristics.

Marginal frequencies of lines and columns are equal and amount to

$$p_{i\bullet} = \frac{Q \cdot b_{ii}}{n \cdot Q^2} \tag{4}$$

Values $p_{i\bullet}$ are the elements of a diagonal matrix of boundary frequencies of the lines and hence also the columns; they are also the components of the vector of boundary frequencies **r**. The matrix of the observed frequencies is calculated as

$$P = \frac{1}{n \cdot Q^2} B \tag{5}$$

Matrix **B** is symmetrical and subject to decomposition according to its own values

$$A = D_r^{-1/2}\left(P - rr^T\right)D_r^{-1/2} = U\Gamma_B^2 U^T \tag{6}$$

where **U** is the matrix of vectors of matrix A, Γ_B^2 is the diagonal matrix containing squares of peculiar values $\gamma_{B,k}^2$ $\left(k = 1, 2, \ldots, K; K = \sum\limits_{q=1}^{Q}\left(J_q - 1\right)\right)$ of matrix **A**, J_q is the number of categories of characteristic q and $\mathbf{D}_r$ is the diagonal matrix of the observed boundary frequencies of the lines.

As $\Gamma_B^2 = \Lambda_B$, where $\lambda_{B,k}$, are the own values of matrix **A**, there follows decomposition of matrix **A** according to own values, and only one matrix contains the coordinates of the characteristics

$$\mathbf{F} = D_r^{-1/2} U \Gamma_B \tag{7}$$

The size of the actual space of the coexistence of answers to the questions is calculated based on the formula

$$K = \sum\nolimits_{q=1}^{Q}\left(J_q - 1\right). \tag{8}$$

According to Greenacre's criterion, the best choice is the dimension of projecting categories of variables in which the own values follow the condition $\lambda_{B,k} > \frac{1}{Q}$.

Greenacre added to the complex criterion of choosing the relevant own values ($\lambda_{B,k} > \frac{1}{Q}$) the way to "improve" the results of the analysis of variables given in the form of Burt's matrix [66–68]:

$$\tilde{\lambda}_k = \left(\frac{Q}{q-1}\right)^2 \cdot \left(\sqrt{\lambda_{B,k}} - \frac{1}{Q}\right)^2 \tag{9}$$

where Q is the number of variables, and $\lambda_{B,k}$ is the k-th own value.

When using the correction of Greenacre, new coordinates for the categories of characteristics are set according to the formula

$$\tilde{\mathbf{F}} = \mathbf{F}^* \cdot \mathbf{\Gamma}^{-1} \cdot \tilde{\mathbf{\Lambda}} \tag{10}$$

where $\tilde{\mathbf{F}}$ is the matrix of new coordinates for variable categories, $\mathbf{F}^*$ is the matrix of the primary values of coordinates for variable categories, $\mathbf{\Gamma}^{-1}$ is the diagonal reverse matrix of the peculiar values and $\tilde{\mathbf{\Lambda}}$ is the diagonal matrix of the modified own values.

4. Study Results

4.1. The Results of Systematic Literature Review

The outcome of the analyses carried out in the first stage of the study was the classification of keywords identified in the 871 collected works into clusters containing terms commonly used by their authors to describe the analysed phenomenon. Thanks to the VOSviewer software version 1.6.14, five clusters were identified using the following expressions:

1. Cluster 1: China, competitiveness, countries, data envelopment analysis, economic growth, efficiency, emissions, empirical evidence, energy efficiency, energy consumption, environmental regulation, industrial green transformation, pollution, productivity growth, slacks-based measure and technological innovation.
2. Cluster 2: carbon emissions, CO2 emissions, consumption, drivers, economy, electricity, energy, energy consumption, governance, green transformation, green transition,

energy transformation, governance, model, simulation, system, technologies, water and wind.
3. Cluster 3: climate change, energy policy, transition, energy transition, green, green economy, industry, innovation, management, policy, politics, supply chain, sustainability, sustainable development, systems, technology and transformation.
4. Cluster 4: climate change, COVID-19, environment, green innovation, growth, investment, perspective, policies, political economy, renewable energy, research and development.
5. Cluster 5: energy transfer and transition.

The results obtained in this stage were also visualised in a map presenting the connections of the terms green transformation and green transition with other keywords identified in the examined publications (Figure 3).

By taking into consideration the connections occurring among the keywords, it is possible to indicate a few recurrent elements characteristic of the research presented in the analysed publications concerning green transformation and green transition (Table 4).

Table 4. Characteristics typical of research on green transformation (or transition) in the analysed publications.

Characteristic	Examples of Publications
Studies describing the process of green transformation on country level (regarding economies of countries in the world)	[15,66–70]
Studies describing the process of green transformation on regional level (regarding the world's regions)	[69,71–74]
Studies describing the process of green transformation on the level of individual sectors/branches of industry: production, transport, energy, etc.	[75–79]
Studies describing the process of green transformation on the level of individual companies (qualitative research) or their groups (quantitative or qualitative research)	[80–84]
Studies presenting research on green transformation in systemic approach as an element of a greater whole linked with the current socio-economic realisations globally	[8,85–88]
Studies regarding issues linked with sustainable development, including economic, social and environmental	[86–92]
Studies presenting examples of technologies supporting the process of green transformation	[10,93–96]
Studies presenting examples of innovations supporting the process of green transformation	[97–100]
Studies addressing the issues linked with the policy of green transformation	[101–104]
Studies addressing the issues linked with green transformation, mainly in the context of changes related to abandoning traditional sources of energy, mostly coal, in favour of other green sources of energy	[105–107]
Studies presenting the results of modelling the process of green transformation	[108–113]

4.2. The Results of the Log-Linear Models

In the second stage, the authors established a binary dependent variable defining the occurrence of the models of green transformation, as well as dependent binary variables, identified based on the analysis of the keywords selected for the study of publications. These variables show whether the examined academic publications include the issues selected for this study. Next, a log-linear model was constructed, enabling the identification of connections and interactions among the variables.

Bearing in mind the aim of this article, the authors distinguished a dichotomous dependent variable (Y), describing the occurrence of green transformation models (1—yes, 0—no). The following variables were included in the set of independent variables:

X_1—research on the level of a country (1, 0);
X_2—technology (1, 0);
X_3—economy (1, 0);
X_4—environment (1, 0);
X_5—research on the level of a region (1, 0);
X_6—coal (1, 0);
X_7—systemic approach to green transformation (1, 0);
X_8—industry (1, 0);
X_9—companies (1, 0);
X_{10}—politics (1, 0);
X_{11}—social aspects (1, 0);
X_{12}—innovation (1, 0).

In the first step, the study examined which variables demonstrate significant relations with a dependent variable, using the independence test χ^2. Table 5 shows the values of testing statistics χ^2 and test probability p.

Table 5. Value of statistics χ^2 and test probability p.

Variable	**Value of Statistic χ^2**	**Value of Test Probability *p***
X_1	16.2181	0.0001
X_2	10.2082	0.0014
X_3	3.5961	0.0479
X_4	4.8745	0.0273
X_5	15.6281	0.0001
X_6	5.0912	0.0241
X_7	0.5540	0.4567
X_8	0.3649	0.5458
X_9	0.2306	0.6311
X_{10}	2.2785	0.1312
X_{11}	0.5394	0.4627
X_{12}	0.1416	0.7068

Based on the calculations, it can be stated that the variable describing the occurrence of green transformation models is not linked to the following variables: a systemic approach to green transformation (X_7), industry (X_8), enterprises (X_9), policy (X_{10}), social aspects (X_{11}) and innovation(X_{12}), which consequently were excluded from further research, whereas all the other variables (X_1–X_6) apart from variable Y qualified into the log-linear model. In order to provide the specification of the model, the study defined the order of interaction. The results of the tests of all the interactions are presented in Table 6, suggesting that the model that is to be analysed should include, besides the main factors, also interactions of, at most, second order. This is indicated by the values of test probabilities p corresponding to the values of test statistics χ^2 with the highest probability and Pearson's χ^2.

In order to assess which interactions should be included in the log-linear model, the authors used partial and boundary tests (Table 7). Due to the significant number of interactions possible for six factors, it was decided to present the interactions of the second order at most because none of the interactions of higher orders proved to be statistically relevant in terms of the partial and boundary tests. The interactions marked in bold in Table 6 are those for which partial and boundary dependencies are relevant.

Table 6. The results of variable interaction tests.

Degree of Interaction	Degree of Freedom	Value χ^2NW	Probability p	Pearson's χ^2Value	Probability p
1	7	183.9112	0.0000	338.8615	0.0000
2	21	121.1573	0.0000	213.3733	0.0000
3	35	28.8885	0.7571	33.2661	0.5520
4	35	26.7474	0.8402	24.9619	0.8956
5	21	8.9109	0.9899	9.1476	0.9880
6	7	3.9952	0.7803	4.2614	0.7492
7	1	0.3428	0.5582	0.3439	0.5576

Table 7. Excerpts from the results of partial and boundary tests between variables: Y, X_1, X_2, X_3 X_4, X_5, X_6.

Factors	Degree of Freedom	Partial Relationship χ^2	The p-Value in Partial Relationship	Boundary Relationship χ^2	The p-Value in Partial Relationship
Y	1	11.5732	0.0007	11.5732	0.0007
X_1	1	5.0497	0.0246	5.0497	0.0246
X_2	1	11.5732	0.0007	11.5732	0.0007
X_3	1	3.4608	0.0497	3.4608	0.0497
X_4	1	6.0358	0.0140	6.0358	0.0140
X_5	1	99.9059	0.0000	99.9059	0.0000
X_6	1	49.3135	0.0000	49.3135	0.0000
YX_1	1	5.9548	0.0147	13.7561	0.0002
YX_2	1	5.4859	0.0192	8.9260	0.0028
YX_3	1	0.0338	0.8542	3.0132	0.0826
YX_4	1	0.8958	0.3439	3.5874	0.0582
YX_5	1	7.5624	0.0060	13.4593	0.0002
YX_6	1	1.7404	0.1871	5.0030	0.0253
$X_{2\times 2}$	1	0.7855	0.3755	3.9828	0.0460
X_1X_3	1	8.6852	0.0032	17.6010	0.0000
X_1X_4	1	4.0025	0.0454	9.6944	0.0018
X_1X_5	1	9.5992	0.0019	17.7962	0.0000
X_2X_6	1	0.7717	0.3797	4.4377	0.0352
X_2X_3	1	2.2114	0.1370	4.6715	0.0307
X_2X_4	1	0.0022	0.9630	1.0709	0.3007
X_2X_5	1	0.1866	0.6658	2.1481	0.1427
X_2X_6	1	2.0430	0.1529	4.0412	0.0444
X_3X_4	1	8.1640	0.0043	13.1781	0.0003
X_3X_5	1	4.4063	0.0358	9.4064	0.0022
X_3X_6	1	0.2236	0.6363	2.8827	0.0895
X_4X_5	1	0.2867	0.5923	0.6307	0.4271
X_4X_6	1	11.3229	0.0008	15.1487	0.0001
X_5X_6	1	0.3207	0.5712	1.8738	0.1710

The results of the tests presented in Table 7 indicate that the model should include six main factors, as well as interactions of the second order, which occur between dependent variable Y and the independent variables. Moreover, the model should also contain the result representing all the interactions between the independent variables, which will help to avoid decreasing the degree of fit. Eventually, the study included dependencies between the occurrence of the models of green transformation and the following:

- Research at the national level (X_1);
- Technology (X_2);

- Research at the regional level (X_5).

The log-linear model takes on the following form:

$$ln\left(\hat{n}_{(ijklmno)}\right) = n + \lambda_i^Y + \lambda_j^{X_1} + \lambda_k^{X_2} + \lambda_l^{X_3} + \lambda_m^{X_4} + \lambda_n^{X_5} + \lambda_o^{X_6} + \lambda_{ij}^{YX_1} + \lambda_{ik}^{YX_2} + \lambda_{in}^{YX_5} + \lambda_{jklmno}^{X_1X_2X_3X_4X_5X_6}$$

The estimated model is well-fitted to the empirical data, as shown by the values of statistics χ^2 of the highest probability, which amounts to 75.637 (p = 0.994), and the statistics of Pearson's χ^2 which equal 80.095 (p = 0.969). The goodness-of-fit of the model is confirmed in Figure 4, which shows the shaping of the numerosity of those observed versus the fitted ones. The results presented in Table 7 clearly show that the models of green transformation, apart from the main factors, are also affected by interactions of second order for the following pairs of variables:

- Country and economy (X_1X_3);
- Country and environment (X_1X_4);
- Country and region (X_1X_5);
- Economy and environment (X_3X_4);
- Economy and region (X_3X_5);
- Environment and coal (X_4X_6).

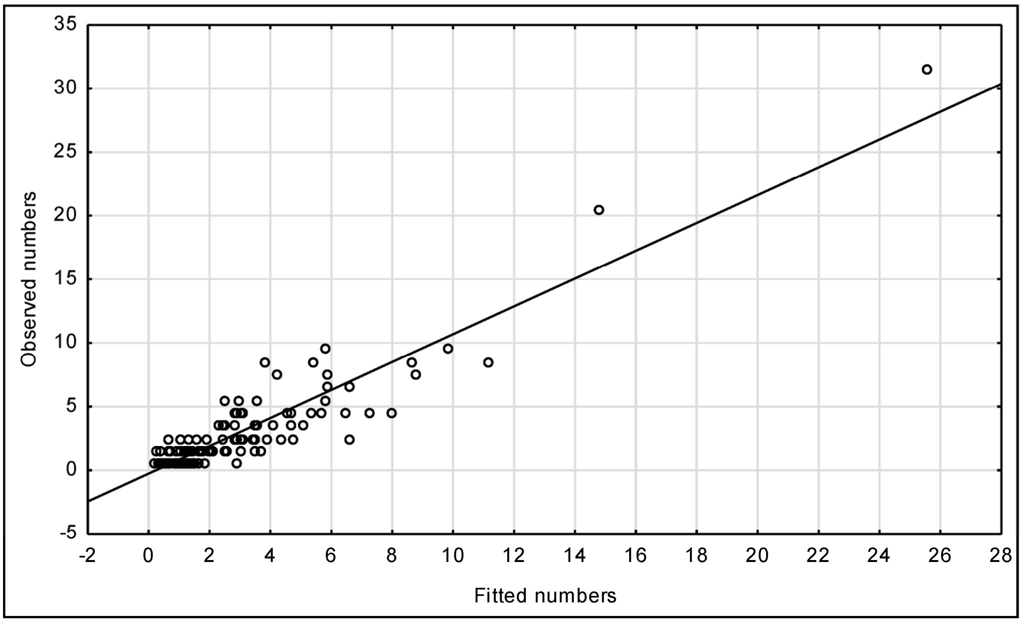

Figure 4. Distribution graph of observed frequencies versus fitted frequencies.

This also suggests that studies concerning models of green transformation are conducted at both national and regional levels and are usually linked to the economy and environment.

4.3. The Results of the Correspondence Analysis

The next stage of the study involved creating six categorising variables connected with the area of the conducted research and the issues addressed in scientific publications. They regarded sustainable development, technology and innovations applied in industry and in enterprises, policy and innovation, and also models and systems of green transformation. The study included the following variables and their categories:

- A–area (1–China, 2–Europe, 3–others);
- SD–sustainable development concerning three aspects: economic, social and environmental (1–no aspect of SD was considered; 2–at least two aspects of SD were considered; 3–all three aspects of SD were considered);

- TIE–technologies in industry and enterprises (1–technologies only in industry; 2–technologies only in enterprises; 3–technologies in industry and in enterprises);
- IIE–innovation in industry and in enterprises (1–innovation only in industry; 2–innovation only in enterprises; 3–innovation in industry and in enterprises);
- PI–policy and innovation (1–no reference to both categories; 2–including only one category; 3–including both categories together);
- MS–models and systems of green transformation (1–no reference to both categories; 2–including only one category; 3–including both categories together).

The first step involved creating a Burt's matrix sized 18 × 18 (number of categories accepted for the study). The size of the real space of the coexistence of variables calculated based on formula 8 amounted to 12. Next, it was checked to what degree the own values of spaces of a smaller size explain the total inertia (λ = 2.0000). By using Greenacre's criterion, it was found that inertias for K assumed at the most 6 because only the main inertias were higher than $\frac{1}{Q} = \frac{1}{8} = 0.1667$ were considered relevant for the study. For such dimensions, the authors set a share of inertia of a chosen size (λ_k) in total inertia (λ), designated as τ_k. In addition, a diagram showing its own values was prepared (Figure 5), and by using the "elbow" criterion, it was decided that the space of the presentation of the coexistence of the categories of the variables should be three-dimensional. The degree of explanation of the inertia in this space equals 4.43%, and after the modification of the own values, according to Greenacre, 66.94% (Table 8).

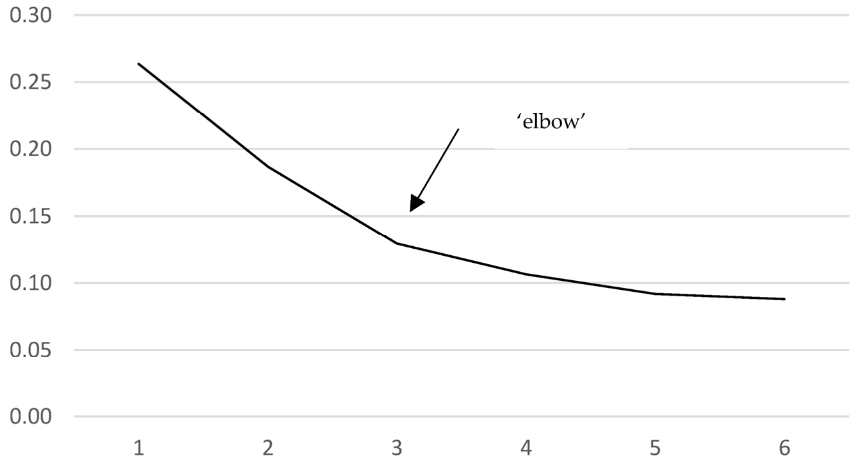

Figure 5. Eigenvalue—"elbow" criterion.

Table 8. Singular values and eigenvalues together with the degree of explanation of the total inertia in the original and modified versions.

K	Singular Values γ_k	Eigen Values λ_k	λ_k/λ	τ_k	$\tilde{\lambda}_k$	$\tilde{\lambda}_k/\tilde{\lambda}$	$\tilde{\tau}_k$
1	0.594550	0.353489	17.67446	17.6745	0.2636	0.3043	0.3043
2	0.526800	0.277518	13.87589	31.5503	0.1868	0.2156	0.5199
3	0.466530	0.217650	10.88251	42.4329	0.1295	0.1495	0.6694
4	0.438582	0.192354	9.61769	52.0505	0.1065	0.1229	0.7923
5	0.419355	0.175859	8.79294	60.8435	0.0919	0.1061	0.8984
6	0.413874	0.171291	8.56457	69.4081	0.0880	0.1016	1.0000
7	0.390395	0.152408	7.62042	77.0285	$\tilde{\lambda}_k = 0.8663$		

In order to clearly define the relations among the categories of variables in a three-dimensional space, the study used Ward's method with a Euclidean distance. The optimum number of clusters was determined based on the first notable increase in agglomeration distance for the subsequent stages of linkage.

Figure 6 shows linkages of categories into classes, where the horizontal line marks the stage when the linking of classes was interrupted.

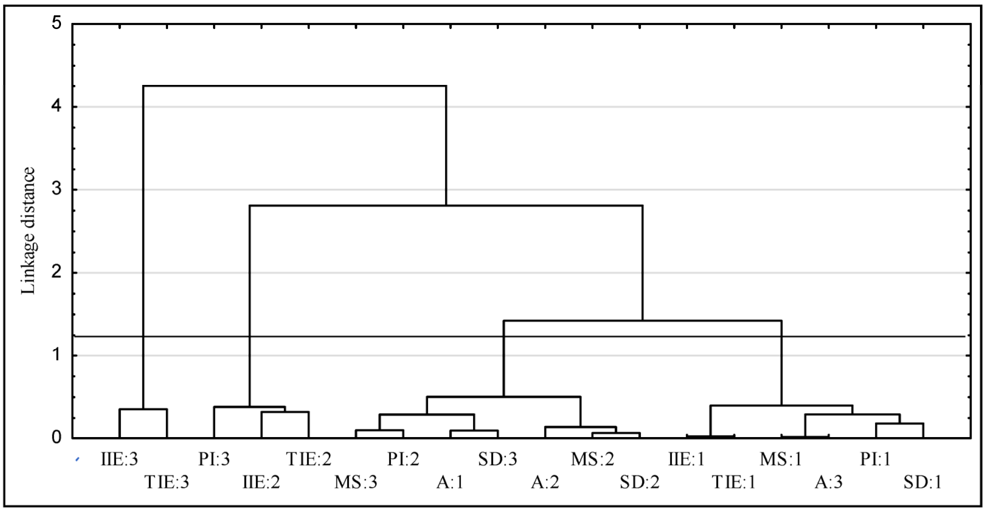

Figure 6. Hierarchical classification of variable categories performed with the use of Ward's method.

On the basis of this criterion, the dendrogram was cut at the level of 1.42, obtaining four homogenous clusters which can be characterised as follows:

- Group I (IIE3, TIE3) regards articles concerning innovation and technologies in industry and in enterprises;
- Group II (PI3, IIE2, IIE2) regards articles concerning problems of policy and innovation, as well as innovations and technologies connected with industry and enterprises;
- Group III (MS3, PI2, A1, SD3, A2, MS2, SD2) regards publications concerning China and Europe, which address problems connected with at least two aspects of SD, models and systems of green transformation, and also policy and/or innovation;
- Group IV (IIE1, TIE1, MS1, A3, PI1, SD1) regards publications from the world's areas other than China and Europe that refer to green transformation but do not address issues related to sustainable development (SD), technology and innovation in industry and in enterprises, policy and innovation, as well as models and systems of green transformation.

5. Discussion

Sustainable development goals (SDGs) aim at the integration of three aspects of development: social, economic and environmental, one of those being SDG7, which is meant to provide everyone with access to inexpensive, reliable and sustainable modern energy. In order to be able to achieve this aim, it is necessary to improve energy efficiency and speed up the transformation [114]. Green transformation relates to increased effectiveness of using resources of energy, reduced emission of pollutants, reduced impact on the environment, improved efficiency of work and increased ability for sustainable development, allowing for achieving a situation favourable both to the economy and to the environment [95]. In the opinion of Li and Lin [115], technological progress provides the basis for improving energy effectiveness and energy saving while, at the same time, it leads to stimulating green transformation. This view is shared by Söderholm [116], claiming that one of the significant elements of green transformation is the promotion of development based on sustainable technologies, i.e., such models of production and consumption, which have a far less negative effect on the natural environment, including climate change. According to Ngai and Pissarides [117], technological innovation is a constant source of sustainable development of the modern economy and plays a key role in improving the effectiveness of the use of resources and in the modernisation of industrial infrastructure. Innovations can encourage the effectiveness of the use of natural resources both in the traditional and emerging sectors of the economy [118] and, in this way, contribute to the development of a green economy. A completely different viewpoint was presented by Stern and Rydge [25], who suggested that new technologies aimed at reducing the negative impact of the economy on the environment are unable to speed up significant ecological transformation. This is also confirmed by the current geopolitical situation and the decidedly faster-than-expected increase in interest on the part of consumers in the highly eco-effective technologies caused by the drastic increase in prices of energy and the risk of limited access to its sources.

This was also confirmed by the research results of this study. In the log-linear model describing the occurrence of the models of green transformation in scientific publications, among the dependent variables, there were also found such variables as "technologies". However, it is worth confirming in line with Stern and Rydge [25] that the technological development itself may not be a sufficient factor to decide about the pace of the process of transformation as it is also important in what setting, system, or even environment these technologies are developing. In the more developed economies, one can observe a greater willingness on the part of society to invest in this type of solution, whereas energy transformation in countries that are just catching up with the leaders may, for a variety of reasons, proceed more slowly. Hence the recent popularity of publications on the so-called just transition draws attention to the fact that the process of transition from a high-emission to a zero-emission economy should consider the level of wealth of the local population [119]. This concept is also linked with the term "co-creation", pointing out that energy transformation is the work of not only governments, introducing appropriate regulations; inventors, creating new technological solutions; and entrepreneurs, launching their production, as well as being affected by the local community, directly interested in introducing them into their homes [120].

During the analyses of the progress towards green transformation, researchers also indicate the need to consider the socio-economic context. According to Crespi [8], not only the environmental aims should be reached without harming economic competitiveness, productivity and economic growth, but also the policy framework created in order to promote environmental sustainability should be able to support economic recovery and increased employment.

These considerations highlight the complexity of the discussed issues and the need to prepare a broad analytical and political framework regulating the transition to a green economy through attaining both environmental and economic goals. This is also confirmed by the systematic literature review undertaken in this study and the modelling based on it. It was found that the models of green transformation in the elaborated log-linear model were influenced by the main factors as well as the interactions for the variables "economy" and "environment".

Energy transformation is also increasingly often addressed in the context of the security of energy supply [121], political security [122] and even the sense of security among the inhabitants of individual countries [123]. There is also an increased number of publications that, more than ever before, concentrate on access to energy as one of the factors that guarantee the functioning of entire economies and that are now becoming increasingly common [124–126].

The subject literature also indicates the necessity of conducting research and monitoring green transformation at the level of both countries and regions [127,128]. According to Barbier [129], this applies in particular to rural areas, where the facilitating wider popularisation and reception of renewable energy and the improved technologies related to energy effectiveness depends on overcoming key obstacles such as lack of long-term systems of financing, weak participation of the private sector, inadequate institutional infrastructure, lack of coordination between local and national governments and weak purchasing power of rural communities.

The scope of the conducted research is very wide—from fairly general terminological divagations directed at, among others, recognising the barriers slowing down the process of green transformation [130,131] to more detailed studies aimed at technological solutions, which can speed up energy transformation such as those related to [132].

In the coming years, one can expect a significant increase in the number of publications on green transition and energy transition. Due to the current energy crisis and the need to find urgent systemic solutions to accelerate energy transition, this will become even more than now the subject of research on the part of scientists and entrepreneurs representing different scientific disciplines and economic sectors.

6. Conclusions

Alongside the ever more visible problems of the global consumption of resources and the pollution of the environment, the green transformation has become one of the requirements in the world's development, as well as a key concept in research on climate change and sustainable development. This is based on the understanding that the challenges resulting from climate change are so far-reaching that the current graduał approach to these challenges is insufficient. The subject is also becoming increasingly popular in scientific literature and in political discourse, yet there is still a shortage of empirical studies that examine the functioning of this concept and its linkages with other areas. This article, via the analysis of scientific articles and using methods of multivariate statistical analysis, has contributed to filling this gap.

As demonstrated by the authors' research, over the last decade, there were numerous publications devoted to the matter of green transformation, which confirms the growing knowledge and interest in global changes in the environment, such as climate change, loss of biodiversity and energy security. At the same time, this increased interest has led to the emergence of various conceptualisations of this idea.

The conducted systematic literature review, and the statistical analyses (log-linear analysis) based on it, suggest that studies concerning models of green transformation are conducted both at national and regional levels and are usually connected with the economy and the environment. Employing the multivariate correspondence analysis allowed for distinguishing a group of scientific articles that are similar due to the analysed issues. It was found that publications regarding China and Europe most frequently address problems related to at least two aspects of sustainable development in different configurations encompassing economic, environmental and social problems, as well as models and systems of green transformation, policy and innovation. Although publications concerning other geographic regions also include the concept of green transformation, they do not address issues related to sustainable development, technologies and innovation in industry and in enterprises, policy and innovation, as well as models and systems of green transformation.

This article, being a continuation of the earlier studies by the authors on the subject of green energy transition [1], provides a very detailed review of the subject literature. Its purpose was to recognise the existing directions of research and indicate new potentially emerging fields of study. In forthcoming articles, the authors are planning to carry out a review of publications that will appear in bibliographic databases in the next few years and already during the current energy crisis. A limitation of this kind of consideration is the necessity to establish a certain framework for the search for keywords that could be used to conduct a systematic literature review. In this case, the knowledge and experience of the authors may prove to be both an asset and a factor limiting the scope of this search.

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