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Review

Exploring the Research Regarding Energy–Economic Growth Relationship

Claudiu Cicea, Carmen Nadia Ciocoiu * and Corina Marinescu

Faculty of Management, Bucharest University of Economic Studies, 010374 Bucharest, Romania; claudiu.cicea@man.ase.ro (C.C.); corina.marinescu@man.ase.ro (C.M.)
* Correspondence: nadia.ciocoiu@man.ase.ro

Abstract: The purpose of this study is to analyze the evolution of the scientific research regarding the relationship between energy and economic growth, in order to reveal preferred topics and less approached themes. We conducted an occurrence and cluster analysis, followed by a correspondence analysis using articles published between 1979 and 2019 in journals indexed in the Web of Science. The analysis was split into three periods taking into account the major economic and energetic milestones. The analysis focused on distribution of the topics studied both by years and by journals. The research revealed some major trends: there has been an explosive increase in studies based on Asian countries over the three periods as concerns for sustainable development intensified, and environmental issues were associated with research on the relationship between energy and economic growth. Even if the journals cover different scientific areas, during the last 10 years they contain articles with very similar topics.

Keywords: economic growth; energy; research agenda; correspondence analysis; text mining

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1. Introduction

There is no doubt that the relationship between economic growth and energy is strong, with deep roots in the history of human civilization. Studying this relationship from the earliest times, we can say that energy has been a vital source for providing food, for the survival and development of human society. Moreover, the success of this attempt has increased the world's population exponentially in the last millennium [1]. Gradually, as energy consumption increased, there was an improvement in living conditions for the population (daily food, health, safety, etc.) [2].

In the modern era, this relationship between energy and economic growth is an ambivalent relationship, in the sense that each of the two variables influences the other [3,4]. On the one hand, energy has been an engine for the development of human society [5], influencing its distinct areas—economic, social, cultural, etc. [6]. On the other hand, economic development has allowed an increase in the volume of energy production (and, implicitly, energy consumption) as well as a diversification of its sources—from fossil fuels to renewable energy, green energy, etc. [7–9]. The analysis further demonstrated that energy is one of the determinant vectors that influence economic growth, especially gross domestic product [10–13]. At the same time, the reciprocal is true, in the sense that economic development (characterized mainly by increase of GDP per capita) leads to an increase in energy demand (implicitly, energy production) and a diversification of its sources [14], triggering effective public policies [15,16].

Statistics [17,18] also demonstrate the strong interdependence between energy and economic growth, recorded in the last fifty years. According to the World Bank [17,18], the growth of gross domestic product per capita was constant between 1970 and 2015, starting from a value of 870 USD (year 1971) and reaching a value of 10,935 USD (for the year 2015). Even if not in the same manner, the increase in the level of energy consumption

accompanied economic growth, starting from a value of 1337 kg of oil equivalent per capita (for the year 1971) and reaching a value of 1922 kg for year 2014.

The aim of this study is to survey the scientific research dealing with the relationship between energy consumption and economic growth in order to reveal how these two concepts evolved together in almost four decades of research. The question arising from this analysis is: which topics related to energy–economic growth nexus are preferred in the scientific world and which themes are less approached? By revealing such findings, this research tries to fill this gap and transform the less studied themes into paths that deserve further attention of researchers.

This paper is organized as follows: Section 2 presents the literature review, Section 3 gives an overview of the methodology used, Section 4 contains the main findings, and Section 5 concludes the analysis.

2. Literature Review

The literature on the relationship between economic growth and energy consumption has grown exponentially in recent years. Research has gradually been linked to environmental quality as it has become aware that it can generate positive or negative externalities. Past research has been governed by the study of the relationship between GDP and energy production and consumption using quantitative methods.

The idea of causal relationship between energy consumption and economic growth was first introduced in the paper of Kraft and Kraft [19]. The authors examined Granger causality between these variables for USA using data from period 1947–1974. In the following year, two articles were published in *Energy Policy* journal. The first tracks economic growth and energy consumption in the UK using data from 1700 to 1975 [20]. The second analyses the relationship between economic growth, employment, and energy in the USA using data from 1900 to 1973 in order to forecast how much energy is necessary to achieve social progress in the year 2000 [21]. In fact, this journal has the most constant evolution over time in terms of the chosen topic.

The debates focused on two approaches: neoclassical views of economic growth, which refer to the fact that increases in energy efficiency might result in increases in energy consumption based on rebound effect, and ecological economic worldviews that see the economy as an open subsystem of the global system governed by the laws of thermodynamics [22].

The last two decades have brought to the attention of researchers the issue of pollution, gas emissions, and environmental protection. The analysis of causality between energy, the environment, and economic growth was intensified at the beginning of the new millennium after the World Summit on Sustainable Development, held in Johannesburg in 2002 [23]. The development of the information economy and, more recently, of the digital economy also influences research in the field of energy consumption. The explosive growth of information technology, after 1990, brought to attention both the influence in terms of increasing consumption and the positive effects of reducing pollution. Moreover, the development of innovation in economically developed countries facilitates the introduction of energy-saving technologies. As a result of using such technologies, economic growth may occur and, at the same time, a reduction in energy consumption [24,25]. In developed EU countries, economic growth occurs with a decrease in energy consumption [26] However, growth ratios of energy consumption are inferior to those of gross domestic product in the early stage of a country's development [27], while afterwards they become superior in an attempt of the country to develop more rapidly [28].

The issue of the relationship between economic growth and energy has been studied by many authors, on several levels. Some of them tried to explain a causal link between the two variables [29], others had a descriptive approach [20], and others tried to explain the link based on diverse econometric models [30,31].

Energy intensity has also generated much debate among researchers because the results were different depending on the method used, the horizon of analysis and the sample of countries [32]. They show that either the energy intensity declines with increasing GDP,

or the energy intensity increases; in different situations it follows an inverted U-shaped curve [33,34]. An extensive study published in 2013 [35] examines how energy consumption and economic development have evolved in Europe. The study shows that, although the modern economic development after 1970 has increased energy consumption, the energy intensity of European countries has decreased, but the quality of the mix of energy sources has improved. Comparisons between the situation of developed and developing countries, and between the use of traditional and modern energy sources, respectively, have led to contradictory results. Some studies show that energy demand growth rates decline to higher levels of economic growth [34,36].

Making a brief chronology in the field, we can identify some reference papers regarding the relationship between energy and economic growth, over the last 40 years, presented in Table 1.

Table 1. Representative papers that focus on the energy–economic growth relationship.

No.	Authors	Year/Country	Topic
1	Humphrey and Stanislaw [20]	1979/UK	The authors study the relationship between energy consumption and economic growth over the period of 1700–1975. The analysis is performed over two large periods of time: the first period pre-1800 (when the energy source was mainly coal) and the second period 1800–1975 (when other forms of energy emerge).
2	Samouilidis and Mitropoulos [37]	1984/Greece	The work analyzes the link between economic growth and energy demand, using different econometric models. The authors analyze the case of Greece and conclude that energy policies are less effective if they are not accompanied by major changes in the economy.
3	Gilland [38]	1988/UK	The paper aims to estimate global energy demand at the level of 2000 and 2020, based on assumptions about population growth, economic growth, and elasticity of energy demand.
4	Hefner [39]	1995/USA	The paper emphasizes that sustainable development involves an increasingly efficient and lower cost energy system, in accordance with environmental protection rules; the paper also analyzes energy sources that, in the author's opinion, are in solid or gaseous form (liquid form is considered an intermediate form).
5	Howarth [40]	1997/USA	The author analyzes the hypothesis that an increase in energy demand may be accompanied by an increase in productivity in this area.
6	Wolde-Rufael [41]	2005/UK	The author analyzes the long-term relationship between energy consumption per capita and the level of Gross Domestic Product per capita, for a sample of 19 African countries, during 1971–2001, based on an econometric approach (cointegration and causality tests).
7	Ayres, Turton, and Casten [42]	2007/Austria	The authors analyze two important aspects related to the role of energy in economic development and potential sources for improving energy efficiency in the context of reducing greenhouse gas emissions.
8	Zhang and Cheng [43]	2009/China	The paper examines the Granger causal link between economic growth, carbon emissions, and energy consumption in China during 1960–2007; among the main results is that neither carbon emissions nor energy consumption directly contributes to economic growth.
9	Apergis and Payne [44]	2010/Greece	The authors analyze the relationship between economic growth and renewable energy consumption for a panel of 20 OECD member countries, based on an econometric instrument.
10	Pirlogea and Cicea [27]	2012/Romania	The authors analyze the relationship between energy consumption (by type of fuel) and economic growth; the analysis is performed using econometric methods, starting from a comparison between Spain, Romania, and the European Union.
11	Kasman and Duman [45]	2015/Turkey	The paper analyzes the causal relationship between energy consumption, economic growth, carbon dioxide emissions, trade openness, and urbanization for new members of the European Union, for 1992–2010; therefore, the authors use an econometric instrumentation consisting of unit root tests, panel causality tests, and panel cointegration methods.
12	Cai, Sam, and Chang [46]	2018/Taiwan	The authors analyze the relationship between clean energy consumption, CO_2 emissions, and economic growth, based on cointegration and causality tests for the group of G7 countries; the paper shows that there is no integration between GDP per capita, CO_2 emissions, and clean energy consumption in France, Canada, Italy, USA, and UK; at the same time, there is a cointegration between these variables for Germany.

Analyzing the data in Table 1 (which presents important papers in the field over time), it is observed that if at the beginning (until 2000) the authors focused on descriptive aspects when analyzing the relationship between economic growth and energy, gradually (after year 2000) they focused their attention on the econometric aspects of this relationship,

trying to identify particularities for certain economies, countries, or geographical areas. At the same time, if at the beginning the emphasis was on classical energy sources (oil, gas, coal), lately the emphasis has been on the use of renewable energy and environmental protection. This has been observed by other authors who have reviewed the literature on the topic [47].

A first analysis of the empirical literature on the nexus between energy and economic growth, for the period between 1978 and 2009 (in the Web of Science database), belongs to Ozturk [48]. He observed that most empirical studies focus either on testing the role of energy (electricity) in stimulating economic growth or examining the direction of causality between these two variables. There is also no consensus on the existence or direction of causation between energy consumption (electricity consumption) and economic growth.

Eight years later, Jakovac [49] finds that although the number of studies in the field and the econometric methods has increased greatly, there is an inconsistency of the results regarding the link between energy and GDP growth. Studies conducted for the same country lead to different results depending on the method of investigation used and the period in which the research is realized. Thus, if Kraft and Kraft [19] study for the United States in 1947–1978 shows that GDP influences economic consumption, Cheng [50] finds no connection between the two variables using data from 1947–1990. Furthermore, in the studies of Wang et al. [51] and Wang et al. [52] for China, in the first situation there is a bidirectional causality between energy consumption and GDP, and in the second study the causality runs from energy consumption to economic growth.

Many studies favor the neutrality hypothesis, claiming that policies intended to reduce energy consumption have no effect on economic growth [53–57]. More recent studies broaden the field of research by introducing the topic of pollution and environmental protection in the relationship between energy and economic growth [23,58–60]. One of the first studies analyzing the relationship between the three variables is that of Roca et al. [61] for Spain, using a time series analysis with data from 1973–1996. The research does not highlight any evidence of environmental Kuznets curve hypotheses. The recent study of Waheed, Sarwar, and Wei [58] investigates the literature for last two decades in domain of economic growth, energy consumption, and carbon emission. The causal relationships among the three variables grouped in pairs were analyzed both from the point of view of single-country-based and multicountry-based studies. The authors of this study conclude that economic growth might affect the carbon emission of countries, but its magnitude may be different for different levels of economic development for each country. Similar studies are presented by Chontanawat [62] for Southeast Asian countries, by Leitao and Lorente [63] for European countries, by Rahman et al. [64] for BRICS members, and by Kahia et al. [65] for Saudi Arabia.

3. Methodology of Research

The research methodology was constructed sequentially following the steps described by other authors [66–71]. It has the advantage of providing a logical set of phases able to ensure the reliability of the outcomes. They are briefly further described.

Phase 1. Planning the Review

The selection of articles followed a two-step process. The first step applied a search of the keywords "energy, economic growth" unified by Boolean AND to find articles that contain both words in a title, during the time from 1979 to 2019. The search was performed in the Web of Science database due to the fact that it contains quality papers written by top reputed scholars in the field and in order to ensure the comparability over time of the results. This search resulted in 663 articles published in 104 journals. As a second step, the articles from the journals containing less than five publications on the topic were eliminated. This step entailed the removal of more than 42.84% of the articles initially identified.

Phase 2. Building the Dictionary of Descriptors

The objective of this step was to build a dictionary containing main descriptors used by scholars within the field. These descriptors were derived from the analysis realized

both manually by the authors extracting key content from the articles' titles, abstracts, and keywords, and using QDA Miner, a software for content analysis. This tool was chosen from several possible ones, Computer Assisted Qualitative Data AnalysiS (CAQDAS) packages. QDA Miner, designed by Provalis Research, is very useful for textual and image analysis, which includes searching for keywords in context, searching for sections, querying by example search, and a cluster extraction and coding tool [72,73]. Compared to other CAQDAS packages, QDA Miner has a "geotagging" function that allows the user to connect data to the corresponding geographical locations and time dimensions [74]. Although in the case of Nvivo, which has a much more comprehensible interface [75], QDA Miner is more powerful and more complex.

The software is used to obtain the list of frequency of nouns, verbs, and compound forms extracted from article content. They can be thematically grouped.

Phase 3. Rationale for the Time Span

This phase refers to deciding how to split the time frame of the analysis, by reporting to major economic and energetic milestones of last decades. In order to study stability and change over time, the division of the analysis into stages is recommended in the situation where major events have influenced the research.

Phase 4. Frequency of Descriptor Occurrences

The frequency of keywords or descriptors occurrence is presented in various forms, both statistical and graphical, for the entire period of time. The evolution of descriptor occurrence over the three periods is observed in order to highlight discrepancies among periods for different keywords.

Phase 5. Cluster Analysis

Clustering is the process of grouping similar observations into different groups, or more precisely, the partitioning of a data set into subsets according to some defined distance measure. Agglomerative algorithms begin with each element as a separate cluster and merge them in successively larger clusters [76]. The result of grouping on clusters with the QDA Miner using the Jaccard similarity coefficient is presented within a dendrogram, which allows an exploratory analysis to see how the descriptors group together based on similarity of features [77].

Phase 6. Link and Topic Analysis

Link analysis allows for visualizing the connection between categories, descriptors, or keywords using a network graph. Qualitative content analysis with QDA Miner is useful to find the most common topics of phrases based on eigenvalues as a goodness-of-fit index.

Phase 7. Correspondence Analysis

For a more specific analysis of how different elements of existing energy–economic growth research relate to each other, we conducted a correspondence analysis (CA). CA is a version of factor analysis designed for categorical variables [78–82]. It allows for detecting systematic patterns of similarities and differences between cases (energy–economic growth publications) in a statistically inductive manner and identifying elements that best describe these differences.

The method is used in various literature review articles: Exadaktylos and Radaelli [83] to review research design issues in the literature on Europeanization; Dabic, González-Loureiro, and Furrer [66] in the field of expatriates; Furrer, Thomas, and Goussevskaia [68] in the field of strategic management; González-Loureiro, Kiessling, and Dabic [68] for review of migrant acculturation; and González-Loureiro, Dabic and Kiessling [69] to analyze the intersection of two literature streams, that of strategy and supply chain management. López-Duarte et al. [70] analyze the role of national culture and cultural distance (NC/CD) in international strategic alliances features, management, and evolution, etc.

3.1. Planning the Review

The selection of articles as presented within the methodology brought together 379 articles from 16 journals (Table 2).

Table 2. Breakdown of identified articles by source journal.

No.	Journal (Year of the First Issue/First Issue in WoS)	Acronym	Number of Articles	Percent
1	*Energy Policy* (1973/1975)	EP	77	20.32%
2	*Renewable and Sustainable Energy Reviews* (1997/1999)	RSER	69	18.21%
3	*Energy Economics* (1979/1981)	EnE	53	13.98%
4	*Energy* (1976/ 1980)	E	40	10.55%
5	*Applied Energy* (1975/1977)	AE	13	3.43%
6	*Ecological Economics* (1989/1990)	EcE	7	1.85%
7	*Ecological Indicators* (2001/2002)	EI	6	1.58%
8	*Economic Modelling* (1984/1984)	EM	10	2.64%
9	*Journal of Policy Modeling* (1979/1980)	JPM	5	1.32%
10	*Energy Sources* (1973/1977)	ES	30	7.92%
11	*Environmental Science and Pollution Research* (1994/ 1995)	ESPR	21	5.54%
12	*Natural Hazards* (1988/ 1994)	NH	8	2.11%
13	*Quality & Quantity* (1967/1975)	QQ	7	1.85%
14	*Energies* (2008/2008)	Ens	5	2.11%
15	*Sustainability* (2009/2011)	Sust	16	4.22%
16	*Journal of Cleaner Production* (1993/2002)	JCP	9	2.37%
	Total		379	

The temporal distribution of articles shows that until 2008 only 16 papers had been published on the topic, with an average of two articles per year. There were also years when the search did not produce any results in the Web of Science (1982, 1988, 1989, 1991–1994, 1997).

After 2008, there was an increase in the number of articles published per year with the highest value in 2016 (Figure 1). This increase was partly due to the energy and economic crises that have manifested in various places around the globe.

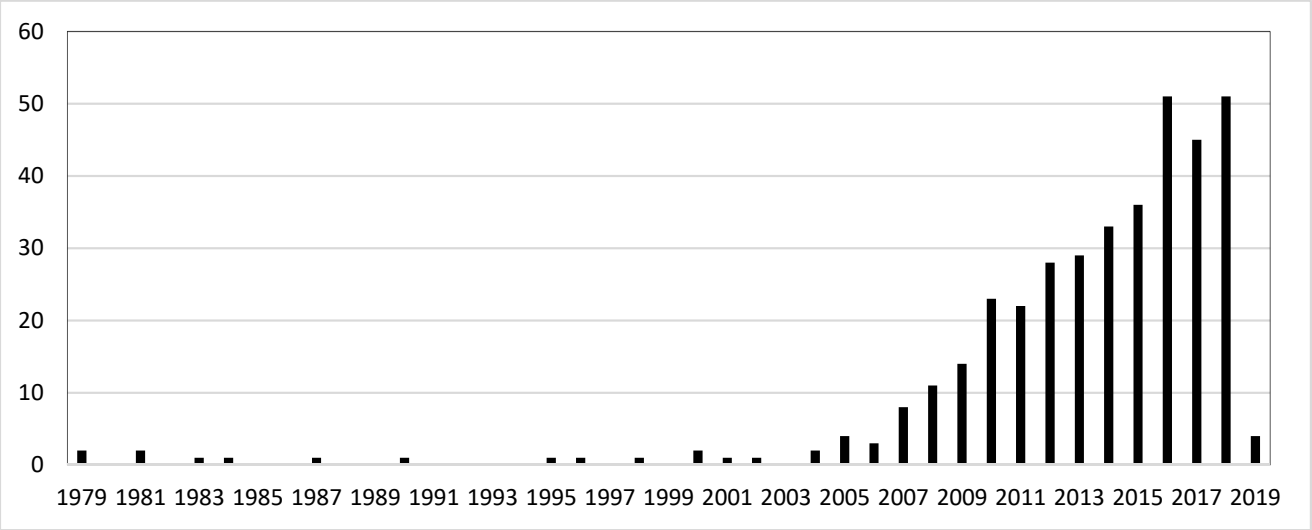


Figure 1. Distribution of articles during 1979–2019.

3.2. Dictionary of Descriptors

A number of 218 different keywords were retained from the analyzed articles. Words that had a frequency of occurrence less than 10 were removed. The authors analyzed the words in order to group them thematically and to eliminate the insignificant words. Some descriptors were joined by the research team into similar thematic families. The final list contained 29 descriptors grouped in eight categories (Table 3).

Table 3. List of keywords and descriptors.

Descriptors (Acronym)	Key Words
Category 1: Research design	
Panel (PNL)	panel data, panel unit, panel causality, panel analysis
Studies (STD)	country stud*, econometric study, comparative study, case stud*, economic studies, empirical studies, panel studies
Empirical research (EMR)	empirical analysis, empirical evidence, empirical investigation, empirical research, empirical literature, empirical study
Category 2: Results	
Equilibrium (EQL)	long run equilibrium, short run equilibrium, long run elasticity
Relationship (RLS)	causal relationship*, causality relationship, long run relationship, short run relationship, dynamic relationship, economic growth relationship
Category 3: Methodologies for causality analysis	
Granger Causality (GRC)	Granger causality, Granger coefficient, panel Granger
Causality analysis (CAN)	causality analysis, causality approach, unidirectional causality, direction* of causality, evidence of causality, result* of causality, absence of causality, nature of causality, lack of causality, long run causality, short run causality, bidirectional causality, cointegration and causality, panel causality, no causality, noncausality, GDP causality, causality test*, causality result*
Cointegration (CON)	cointegration relationship, cointegrating relationship, cointegration test*, panel cointegration, cointegration analysis, cointegration approach, Johansen cointegration, cointegration analysis
Category 4: Methods of analysis	
Mathematical and statistical tests (MST)	Wald test*, F test*, integration test*, test* result*, test* statistic*, empirical result*, regression result*, error correction model, null hypothesis, EKC hypothesis, hypothesis of no cointegration, multivariate approach, unit root*, root test*
Forecasting data and models (FDM)	ARDL model, ARDL approach, regression model, regression analysis, decomposition analysis, time series, series analysis, series data
Quantitative Analysis (QA)	data analysis, econometric analysis, integration analysis, variables, time period*, testing approach, data approach, modeling approach, comparative analysis, statistical analysis, annual data, energy data, energy consumption data
Category 5: Characteristics of development	
GDP (GDP)	GDP, GDP per capita
Income (INC)	middle income, low income, high income, real income, consumption income, income level*, income countries, income economies, income inequality
Type of development (TOD)	financial development, economic development, sustainable developmentworld development, human development, social development, national development, development indicators, economic analysis, economic production, production function, green economy
Energy and electricity generation and consumption (EPC)	oil consumption, oil price*, crude oil, oil production, coal production, heat production, electricity consumption, electricity production, electricity generation, electricity demand, energy production, electricity production, energy consumption per capita, electricity consumption per capita, biomass consumption per capita
Capital (CPT)	capital formation, capital and labor, capital labor, capital investment, consumption capital, human capital, physical capital
Category 6: Policies focus (contents and features)	
Economy sectors (EST)	energy sector, transport sector, industrial sector, financial sector, private sector, agricultural sector, service sector, banking sector, electricity sector, manufacturing sector, commercial sector, tourism sector, production sector
Impact (IMP)	impact of energy, impact of urbanization, impact of electricity, impact of trade, impact of emission*, environmental impacts
Policy (PLC)	energy policy, planning and policy, policy makers, policy implications, policy model, policy modeling, policy recommendations, policy analysis
Country/economic groupings (CEG)	industrialized countries, developed countries, developing countries, BRIC* countries, OECD countries, G countries, GCC countries, groups of countries, panel of countries, number of countries, sample of countries, set of countries, emerging countries, world economy, global economy, country analysis
Category 7: Geographical area	
Asia (ASI)	Asian countries, China, Chinese economy, Japanese economy, Turkish economy
Europe (EURP	European countries, EU countries, Greek economy, Portuguese economy, Italian economy
America (AME)	American countries, USA economy
Africa (AFR)	African countries, African economy

Table 3. *Cont.*

Descriptors (Acronym)	Key Words
Category 8: Environmental impact and protection	
Gases emissions (GSE)	CO emission*, carbon emission*, dioxide emission*, gas emission*, GHG emission*, gases emission*, carbon dioxide, carbon intensity, air emission*
Emissions per capita (EPC)	per capita emission*, emission* per capita
Pollution (POL)	environmental degradation, environmental pollution, pollutant emission*, pollution emission*
Environmental protection (EVP)	carbon tax, environmental quality, environmental protection, environmental Kuznets curve
Renewable sources and energy (RSE)	impact of renewable energy, renewable energy, renewable source*, renewable resource*

3.3. Rationale for the Time Span

The time frame of the study was split into three different stages: a first period from 1979 to 1999, a second from 2000 to 2009, and the last from 2010 to 2019. The year 2000 and 2010 were used for splitting the sample as a consequence of the energy and financial crises manifested globally. Although we found that very few articles were published, the first split is year 2000. The period before includes the 1973 oil crisis and other oil shocks as a result of the Iranian revolution in the fall of 1978, Iraq's invasion of Iran in September 1980, and Iraq's invasion of Kuwait in August 1990 [84]. On the other hand, after 1990, the development of information and communication technology generated concerns for the study of their implications on economic growth and energy consumption.

Between 2000 and 2010, humanity went through one of the most severe financial crises since the Great Depression of the 1930s, namely the global financial crisis of 2007–2008. That crisis resulted in price fluctuations and intense volatility for oil and natural gas.

During the ten years, there had been numerous energy crises in various parts of the world: the 2000–2001 Western energy crisis and California electricity crisis, 2000–2008 North American natural gas crisis, and the 2004 energy crisis in Argentina.

After 2010, the concerns for nuclear and renewable energy were renewed all over the world, as a result of the increasing pollution. In 2010, the European Union's actions culminated in the approval of the Europe 2020 strategy, which set targets for reducing greenhouse gas emissions by 20% compared to 1990 levels, reaching 20% of energy from renewable sources and increasing energy efficiency 20% by year 2020 [85].

4. Findings

4.1. Frequency of Descriptor Occurrences

Table 4 presents the frequency and share of the descriptors for the entire period of analysis (1979–2019) and also for three subperiods (Period 1: 1979–1999; Period 2: 2000–2009; Period 3: 2010–2019).

In terms of frequency, the top keywords addressed in the literature that stream from 1979 to 2019 are GDP and GDP per capita, which appear in 368 cases that are part of the sample. The situation is similar for all three periods. This result is confirmed by other previous studies based on literature reviews that analyze the relationship between energy and economic growth [23,48,49].

After GDP, the top keywords addressed in the literature are those that belong to the following groups of descriptors: quantitative analysis, mathematical and statistical tests, renewable sources and energy, Asia, and gases emissions.

Table 4. Frequency of descriptors.

	Category\Descriptor	Frequency, Total	Frequency P1, 1979–1999	Frequency P2, 2000–2009	Frequency P3, 2010–2019	Total 1979–2019, % Total (n = 379)	P1, % Total (n = 11)	P2, % Total (n = 46)	P3, % Total (n = 322)
1	Characteristics of Development\GDP	13,705	272	1215	12,218	97.10	100.00	97.83	82.32
2	Methods of Analysis\QA	8997	82	832	8083	94.72	81.82	91.30	81.27
3	Methods of Analysis\MST	8494	34	922	7538	84.70	27.27	73.91	74.93
4	Environmental_Impact and Protection\RSE	6662	6	216	6440	70.45	27.27	39.13	64.91
5	Geographical_Area\ASI	6446	19	481	5946	83.91	27.27	76.09	73.88
6	Methodologies for Causality Analysis\CAN	5199	10	472	4717	77.31	9.09	71.74	68.34
7	Environmental_Impact and Protection\GSE	5013	3	197	4813	79.68	9.09	63.04	71.77
8	Characteristics of Development\EPC	4996	134	448	4414	89.45	100.00	86.96	75.99
9	Methodologies for Causality Analysis\GRC	4291	2	437	3852	72.56	9.09	63.04	64.64
10	Results\RLT	4105	13	426	3666	81.27	36.36	76.09	70.98
11	Policies_Focus\CEG	3800	101	362	3337	91.56	81.82	93.48	77.84
12	Methodologies for Causality Analysis\CON	2959	5	287	2667	73.35	9.09	67.39	64.91
13	Characteristics of Development\TOD	2942	44	192	2706	87.60	54.55	89.13	75.20
14	Methods of Analysis\FDM	2783	27	292	2464	89.18	63.64	80.43	77.57
15	Research Design\Panel	2365	0	186	2179	68.34	0.00	45.65	62.80
16	Characteristics of Development\Income	1887	49	93	1745	64.12	45.45	71.74	54.09
17	Environmental_Impact and Protection\EVP	1627	11	43	1573	49.87	18.18	32.61	45.38
18	Characteristics of Development\CPT	1354	28	168	1158	53.30	63.64	54.35	44.85
19	Policies_Focus\PLC	1339	5	156	1178	83.64	36.36	73.91	73.61
20	Policies_Focus\EST	1288	41	135	1112	56.46	63.64	50.00	48.55
21	Research Design\EMR	1087	5	110	972	75.73	18.18	69.57	66.75
22	Environmental_Impact and Protection\POL	817	7	33	777	48.81	27.27	32.61	44.06
23	Research Design\STD	744	5	69	670	72.30	36.36	63.04	63.59
24	Policies_Focus\IMP	660	23	48	589	55.94	81.82	45.65	48.02
25	Geographical Area\AFR	612	1	70	541	40.37	9.09	21.74	37.47
26	Geographical Area\EUR	419	8	14	397	30.87	18.18	10.87	29.02
27	Environmental Impact and Protection\EPC	228	1	5	222	14.78	9.09	4.35	13.98
28	Geographical_Area\AME	160	0	11	149	20.58	0	10.87	19.26
29	Results\EQL	90	2	3	85	10.55	9.09	6.52	9.50

These terms are often used together as they are related. The relationship between energy and economic growth is analyzed based on the causality direction among GDP as output growth and the energy use variables, between economic growth and environment, and between the three variables concurrently.

Regarding the frequency of the keywords related to renewable energy, it is observed that over 18% of the selected articles are published in *Renewable and Sustainable Energy Reviews*, which may explain the high occurrence.

There are imbalances in the countries included in the samples of previous research. The *Asia* descriptor has 6446 appearances in the 40 years, with China in 76 cases, followed by Turkey in 48 cases, Taiwan (25), Malaysia (20), and Pakistan (15). These are the countries with the highest frequency of occurrences; the other countries record less than 20 occurrences in total cases, except Tunisia (25).

The high frequency recorded by the *gases emissions* descriptor is explained by the fact that over 10% of the totality of the analyzed articles come from journals that have explicitly pollution as the main theme (*Journal of Cleaner Production*, *Natural Hazards*, *Environmental Science and Pollution Research*).

In order to improve the analysis, due to the large differences between the numbers of cases over the three periods, the more prevalently occurring descriptors are represented as a percentage of occurrences in the total number of articles analyzed for each period.

In relation to the number of articles analyzed, the hierarchy is changed: the highest share after GDP (97.10%) and quantitative analysis (94.72%) is held by the economic grouping (91.56%), and energy and electricity production and consumption (89.45%).

Regarding the evolution of the descriptors occurrence over the three periods, the largest discrepancies are observed for the descriptor *panel* with no appearance in articles from period 1, but the descriptor reaches a frequency of over 60% in period 3. Neither does America appear in pre-2000 articles. A similar situation occurs in the case of the descriptors *causality analysis, Granger causality, cointegration,* and *gases emissions,* which evolve from a frequency of 9% in the first period to over 60% in the next periods. The descriptors whose occurrence decreases from the first to the last period are *capital*, *impact, economy sectors, energy and electricity production, and consumption.* In the case of *GDP*, the decrease cannot be considered significant.

In the case of Europe, the frequency of European countries mentioned in the articles decreases from 18.18% in the first period to 10.87% in the second, and then increases to 29.02% after 2010.

4.2. Cluster Analysis

The result of grouping keywords on clusters using the Jaccard similarity coefficient is presented in the dendrogram depicted in Figure 2.

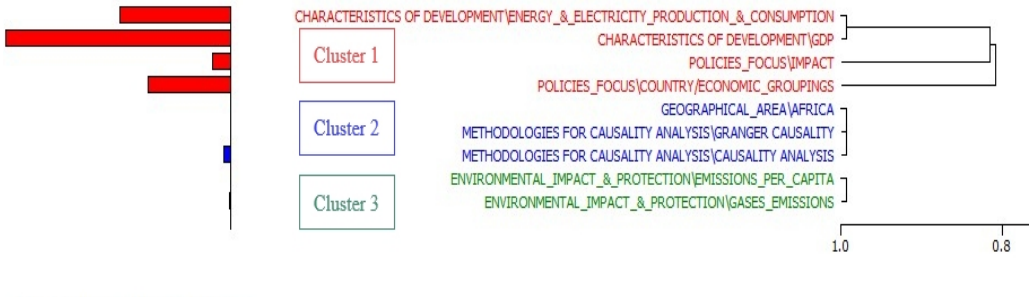
Out of the 29 descriptors, 18 were eliminated from the analysis, and the clusters were constructed based on the similarity between 11 descriptors that have a similarity index greater than 0.8.

A first observation is that two clusters were built. The first cluster is the largest in the number of descriptors and has the most factors with a higher similarity index close to one.

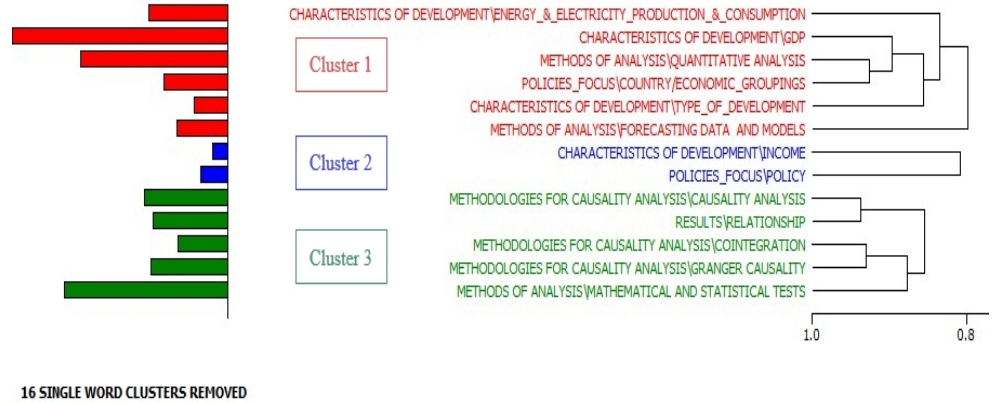
There is a very strong similarity between GDP and quantitative analysis, followed by relationship and analysis causality. In turn, GDP and quantitative analysis show high similarity with the economic grouping of countries. The Jaccard index has the same value for causality analysis and relationship. This situation is generated by the fact that in these situations both items occur in the same time in a large number of cases.

The evolution of the clusters over the three periods is presented in Figure 3. Thus, in the first two periods the appearance of three clusters is observed.

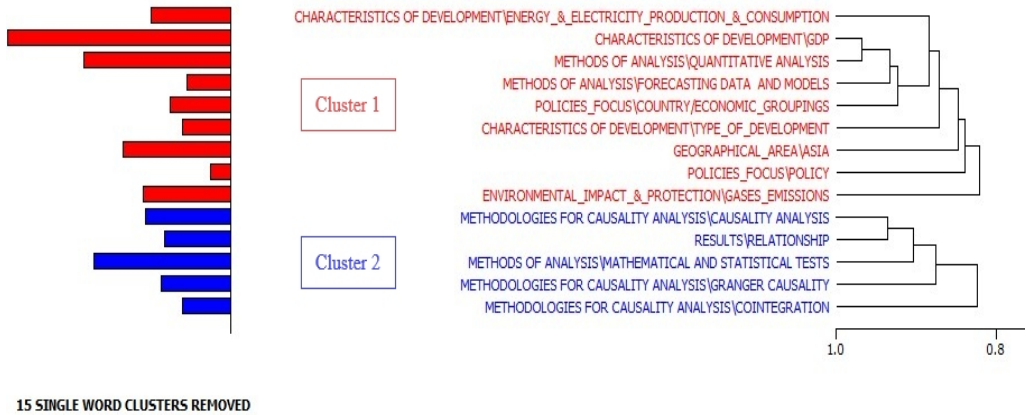
Figure 2. Dendrogram of the similarities between descriptors for the entire period (1979–2019).



(**a**) Period 1 (1979–1999).



(**b**) Period 2 (2000–2009).



(**c**) Period 3 (2010–2019).

Figure 3. Dendrogram of the similarities between descriptors for each period.

For the period 2010–2019, the clusters are similar to those for the entire period, and this can be explained by the large number of articles published in the last 10 years.

As observed, in period 1 the first cluster contains four descriptors, but only two, respectively, *energy and electricity production and consumption* and *characteristic of development*, have the similarity index equal with one. In the second and third clusters, all the descriptors have the similarity equal with one.

In the second period, none of the three clusters contains descriptors with such a high similarity and their distribution on the three clusters is different. The descriptor Africa, which has the highest frequency of occurrence in period 2, is no longer included in any cluster from period 3, being replaced by Asia. The countries of America and Europe, due to the lower frequency of occurrence, are not included in any cluster.

4.3. Link and Topic Analysis

Regarding the connection between categories, it is observed in Figure 4 that the strongest connection is between the *methods of analysis* and *policies focus*, followed by the one between the *characteristic of development* and the *methods of analysis.* The link between *research design* and *method of analysis*, *environmental impact and protection*, and *policies focus* is also relevant.

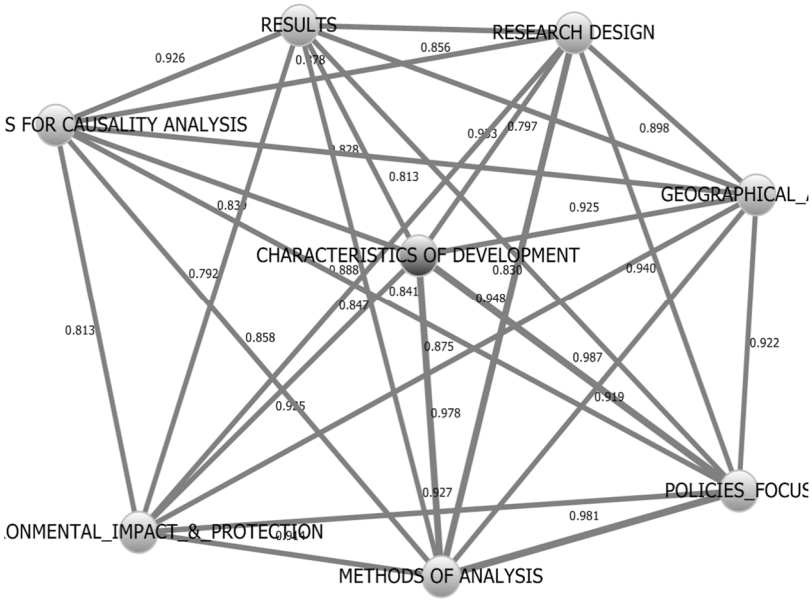


Figure 4. The link between the eight categories for the entire period.

There are some minor changes in the analysis over the three periods; the three categories stated maintain their strongest connection.

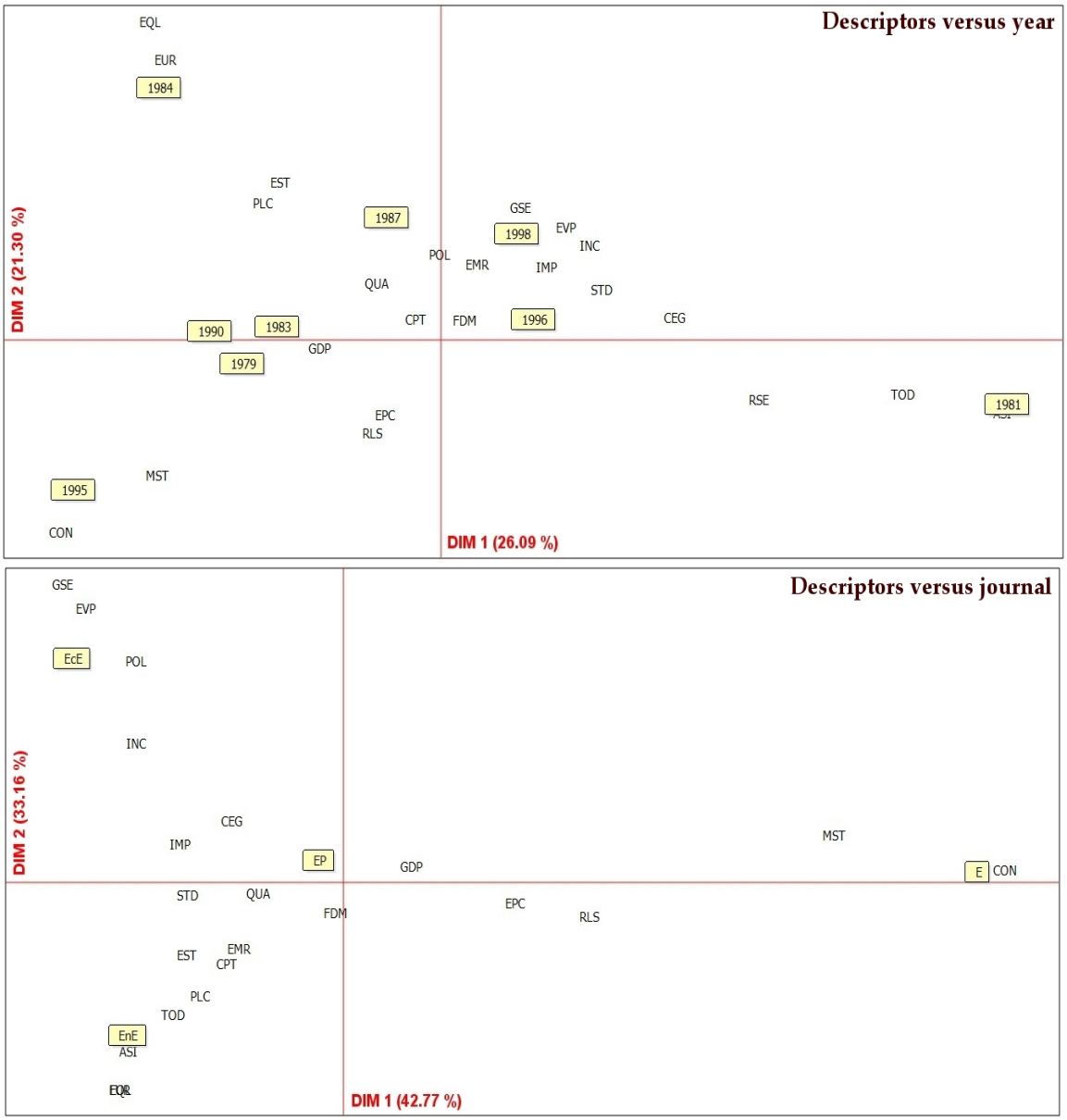
As shown in Table 5, five topics are dominant, with eigenvalues between 7 and 1.35. The first topic named *Analysis\Causality* indicates a strength link between descriptors related with causality, relationship and cointegration, quantitative analysis and mathematical and statistical tests, panel, income, and Africa. The items of these topics occur in 93.37% of articles, with a total frequency of all descriptors equal with 778 during the entire period. Other important topics are *Forecasting and Pollution*.

Table 5. Important topics for the period 1979–2019.

Topic	Descriptors	Eigen Value	% Var	Freq	Cases	Cases %
1. Analysis; Analysis\Causality	Methodologies for Causality Analysis\CAN; Methodologies for Causality Analysis\GRC; Results\RLS; Methods of Analysis\MST; Methodologies for Causality Analysis\CON; Research Design\PNL; Geographical Area\AFR; Research Design\EMR; Characteristics of Development\INC; Methods of Analysis\FDM; Policies Focus\PLC; Research Design\STD; Methods of Analysis\QA	7.00	19.05	778	352	93.37%
2. Analysis; Analysis\Forecasting	Methods of Analysis\QA; Characteristics of Development\GDP; Methods of Analysis\FDM; Policies Focus\CEG;Characteristics of Development\TOD; Characteristics of Development\EPC; Geographical Area\ASI	2.29	9.81	665	365	96.82%
3. Environmental Impact and Protection\Environmental Protection; Environmental Impact and Protection\Pollution	Environmental_Impact and Protection\EVP; Environmental_Impact and Protection\POL; Environmental Impact and Protection\EPC; Policies Focus\IMP; Environmental_Impact and Protection\GSE	2.21	7.69	944	344	91.25%
4. Characteristics; Development\Capital	Geographical Area\EUR; Geographical Area\AME; Geographical Area\AFR; Characteristics of Development\CPT	1.41	6.27	348	216	57.29%

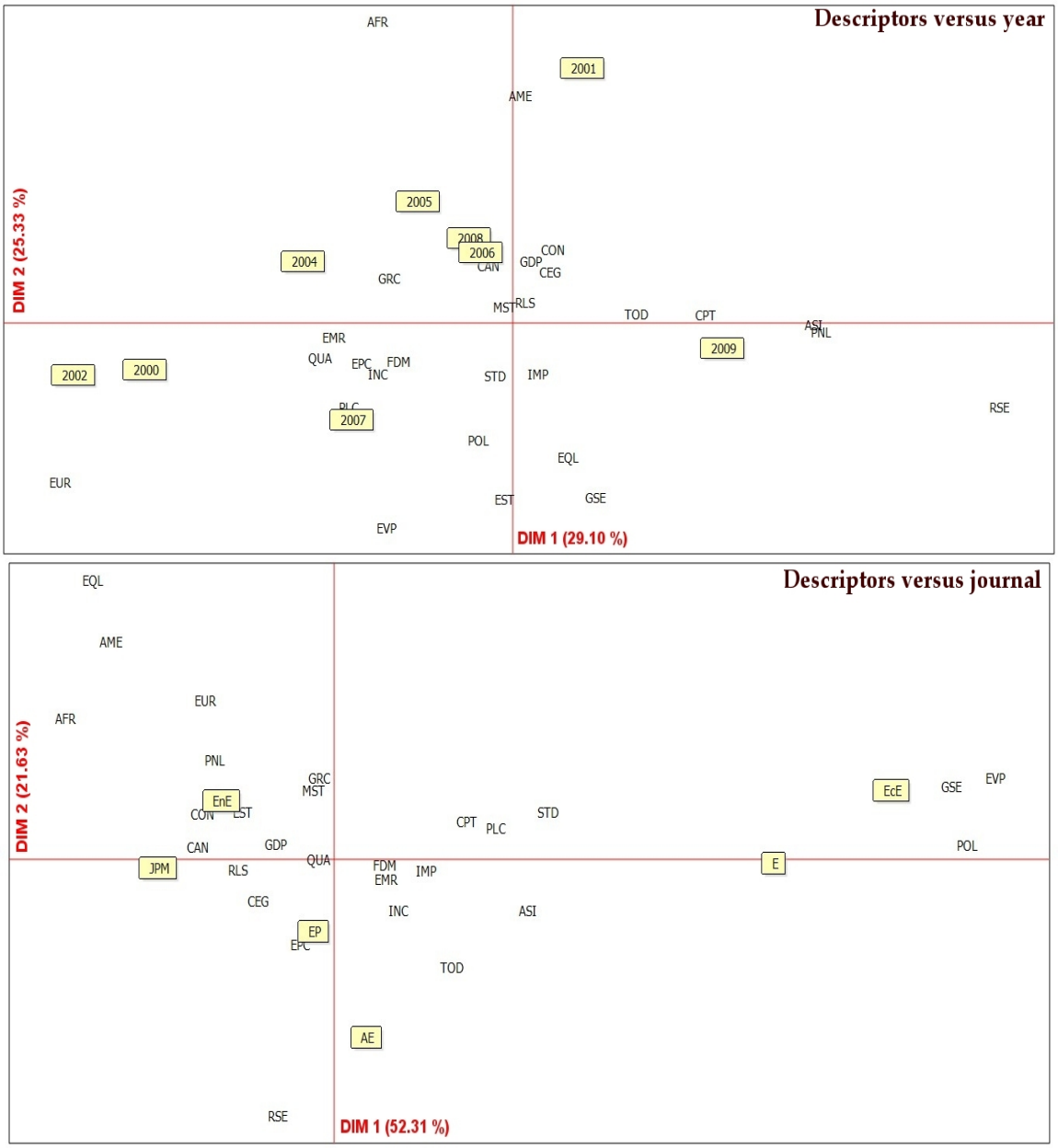
4.4. Correspondence Analysis

The results of this step are two proximity maps where keywords are depicted along two axes (descriptors versus year of the articles' publication; descriptors versus journals) for the analyzed periods (Figure 5). If two descriptors appear closer in the map, it means that the pairs of keywords are jointly associated in a significant portion of articles [71]. In the horizontal dimension, we found the most common issues investigated in this area.



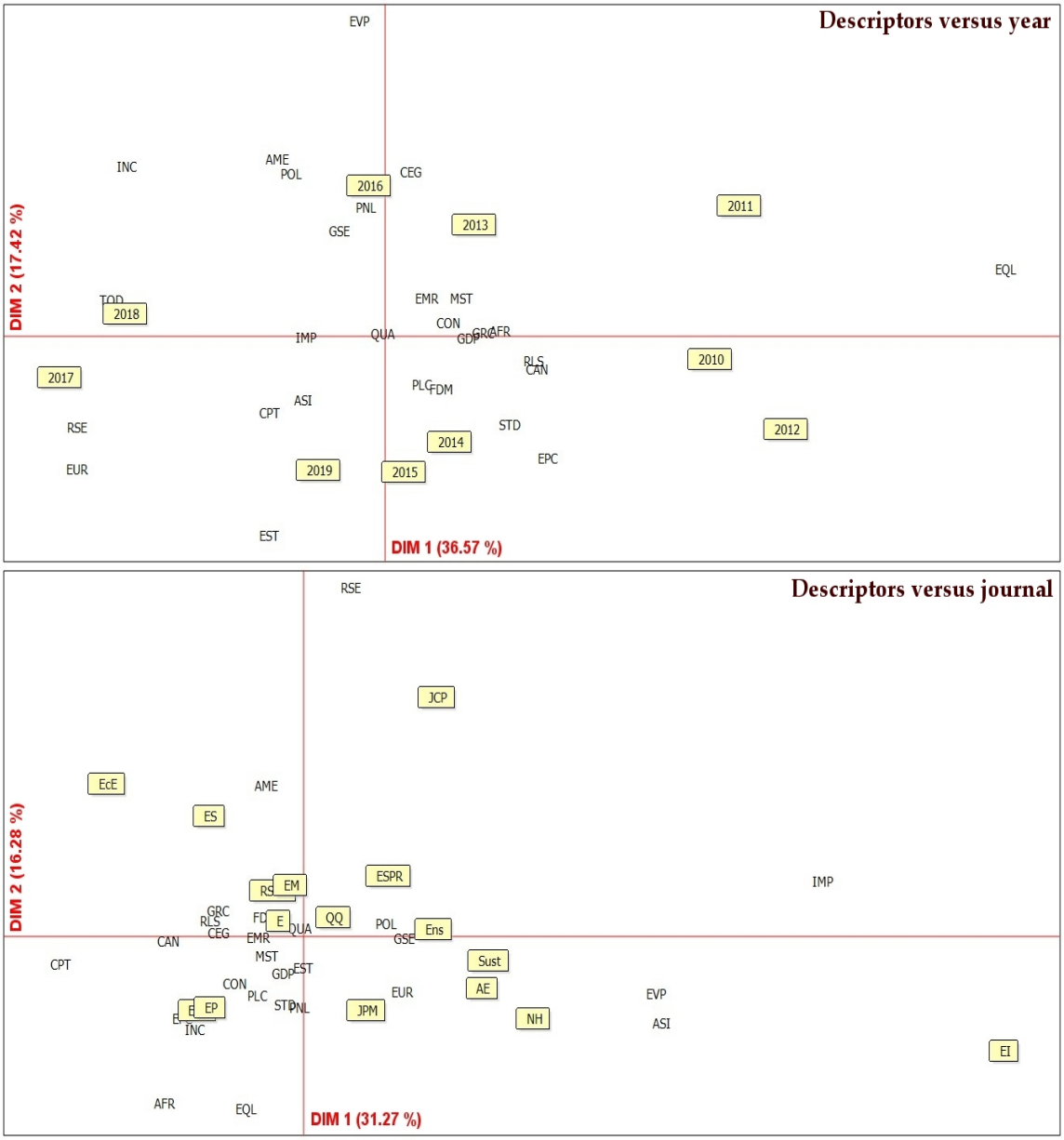
(**a**) Period 1 (1979–1999)

Figure 5. *Cont.*



(**b**) Period 2 (2000–2009)

Figure 5. *Cont*.



(**c**) Period 3 (2010–2019)

Figure 5. Maps of the field for three periods.

The correspondence maps showing descriptors versus years have the advantage of presenting evidence regarding (1) the spread of descriptors along the two axes, (2) the proximity of a descriptor to a specific year, and (3) the movement of a descriptor from one period to another within the three maps.

In the first period 1979–1999, descriptors such as EUR and EQL are characteristic to research conducted and published around 1984, while ASI and TOD are located near each other in the right half of the map, and both close to 1981. Many descriptors are plotted above the intersection of the two dimensions described by the map, in proximity to 1996 and 1998 years. This states the fact that such descriptors are more characteristic to research specific to 1996 and 1998, than others. For instance, the location of ASI and TOD shows a smaller frequency of utilization in articles from 1996 and 1998.

Moving forward to the 2000–2009 period, one can observe that the spread of the descriptors changes. There are some concentrating near the centroid, as they were in the previous period, but moving from the upper half of the map to the lower half (the case of

QUA, FDM, POL, EMR, IMP, INC, STD, PLC) and vice versa (the case of GDP, RLS, TOD). Period 2006–2008 seems to be dominated by descriptors belonging to category "methodology for causality analysis" (GRC, CAN, CON), while 2000–2002 is a period characterized by publications concerning the causal relationship between energy consumption and economic growth in Europe (EUR descriptor).

As for the 2010–2019 period, the map shows a clear separation of descriptors on the right side of the map and on the left side of the map, as the time shifts from 2010 to 2015 (right) and from 2016 to 2019 (left). Years 2013, 2014, and 2016 each have in their proximity at least four descriptors associated to research related to the economic growth–energy consumption relationship. A highly discriminating descriptor is EQL, as it lies farther from the origin (Figure 5c). This descriptor also has an interesting movement within the maps, from the upper left half in 1979–1999 to lower right half of the map in the second period, and to the upper right half of the map in the last period.

The correspondence maps showing descriptors versus journals have similar advantages as the ones regarding descriptors versus years. They are able to provide evidence on (1) the spread of descriptors along the two axes, (2) the proximity of a descriptor to a specific journal, and (3) the movement of a descriptor from one period to another within the three maps.

If comparing the map for the first period to the map for the third period, one can observe a major discrepancy concerning the number of journals appearing within the maps. Less "inhabited" by journals, the first map reveals strong associations between CON descriptor and *Energy* journal; between *Ecological Economics* journal and EVP, POL, and GSE descriptors; and between *Energy Economics* journal and ASI, TOD, and EQL descriptors. More "populated" with journals, the third map reveals a greater concern for the economic growth–energy consumption relationship in the last decade. For 2010–2019 period of time, the fact that the majority of journals are located relatively near each other indicates that they have very similar subjects treated in their articles. However, within this period, the *Ecological Economics* journal focuses on environmental protection (EVP descriptor) and on policies impact (IMP descriptor) regarding countries from Asia (ASI descriptors).

Studying the map designed for the 2000–2009 period, a closeness or "clustering" degree for a majority of descriptors at the intersection point can be observed. More distant from the general tendency, GSE, POL, and EVP are descriptors that plotted farther from the centroid, identified as being more characteristic for some journals (*Energy and Ecological Economics*).

Within the three maps concerning descriptors versus journals, there are descriptors that always remain close to the map centroid: GDP, QUA, FDM, and CEG, while others migrate from one quadrant to another when changing periods of time for analysis.

5. Discussion

Following the presentation of all results obtained after performing the steps of the proposed methodology, we find it useful to clarify some aspects of novelty regarding our research, which, on some points, do not have a term of comparison in the research field of energy, and specifically on this theme of the relationship between energy and economic growth. A similar research has been done before but for the innovation–development relationship [86] revealing salient facets of this theme and also the changing interest of researchers along time.

First of all, the present research combines systematic review with text mining, using bibliographic data from Web of Science. As compared to bibliometric studies (where mainly bibliographic data related to authors, title, abstract, keywords and references are used), for instance, our research utilizes the entire text of the studies downloaded after being reported in the Web of Science search. The software used for conducting the analysis, QDA Miner, searches for keywords in the entire content of a paper, being able to provide the so-called descriptors (or keywords with the highest frequency).

Second, the clusters or the network graphs, and also the dendrograms are designed using these descriptors, while in bibliometric studies such representations are made using

only keywords provided by authors in their papers or keywords Plus, a specific category of keywords generated from the cited references of papers. To be more specific, here we found that keywords from categories such as: Characteristics of Development (GDP), Methods of Analysis (Quantitative analysis and Mathematical and statistical tests), Environmental Impact and Protection and Geographical Area (Asia), have the highest frequency in articles based on the relationship between energy and economic growth. We wanted to compare our findings with other results generated in bibliometric studies of the relationship between energy and economic growth but we were not able to find one as specific as we needed. However, we did find bibliometric studies focusing on different aspects regarding energy. Within a bibliometric analysis of energy performance contracting literature, Zhang and Yuan [87] revealed keywords that have been in the researchers' center of attention, such as energy performance contract, energy service company, energy efficiency, and building energy efficiency. A similar study [88], on the energy efficiency literature, revealed that among the top 20 most frequent Keywords Plus are: system, performance, energy, design, model, energy efficiency, consumption, optimization, emissions. In another bibliometric analysis, the authors [89] study a collection of papers on the environmental Kuznets curve and reveal that the highest occurring keywords are: China, economic growth, evidence, environmental Kuznets curve, CO_2 emission, energy consumption relationship, impact, environment and environmental quality.

Third, revealing the main influential journal publishing research papers on the theme of interest in relation with the most specific keywords is another characteristic of such type of analyses as the one developed within this paper. By observing the correspondence maps with descriptors versus journals, one found that strong associations exist (in the first studied period 1979-1999) between Cointegration category of descriptors and Energy journal, between *Ecological Economics* journal and EVP, POL and GSE categories of descriptors and between *Energy Economics* journal and Asia, Type of Development and Equilibrium categories of descriptors. And the examples can go on as well for the other two periods. On the contrary, bibliometric analyses only provide top journals which have published articles containing specific keywords. *Energy Procedia, Applied Energy, Energy Policy, Journal of Cleaner Production* and *Energy* are the first five journals reported in a bibliometric study on research regarding energy in urban areas [90], while in another one [91] referring to energy economics in Islamic countries, *Energy Economics, International Journal of Energy Economics and Policy* and *Renewable and Sustainable Energy Reviews* are the most important contributors, with papers treating the main keywords related to the studied subject.

However, both types of analyses have advantages and disadvantages. For instance, almost all methodologies used in bibliometric studies also have a citation analysis part, trying to measure the impact that studies published on a specific theme have in the scientific world by referring mainly to the number of received citations and most cited articles [92,93]. Relevant in this regard is the study of Anwar et al. [94] which explores the research on energy crisis and economic growth. The analysis benefits from the facilities offered by CiteSpace, respectively "article co-citation analysis" (which analyzes the existing links between citations in the analyzed field), "citation burst" (to identify the works that record a large number of citations per unit of time) and the collaboration of the authors/institutions/countries of origin of the authors with reference to citations.

6. Conclusions

The authors' attempt to analyze the scientific research on the relationship between energy and economic growth in order to observe the evolution of the topic over time is based on the use of qualitative data analysis methods. Through this method, the main trends in the field were mapped and the gaps identified. A total of 379 articles divided into three periods and indexed in the Web of Science were analyzed. Some gaps in the research were found and discussed using the results of qualitative analysis with QDA Miner.

Regarding the spread of topics in journals, there are significant differences in the 40 years of analysis. In the period 1979–1999, 10 out of the 16 journals were indexed in

the Web of Science, and only 4 journals published papers dealing with the relationship between energy and economic growth. Although only two journals were indexed after year 2007, the accelerated growth of publications on the subject began from that moment.

In 1998, following the 1997 financial crisis in Asia, a single article was published in *Ecological Economics* journal. Most studies of Asian countries grouped by type of economic development were published in the *Energy Economics*. A significant number of studies published in 1991 investigated Asian countries grouped by type of economic development.

The period 2007–2009 was representative for Asia and the Pacific in terms of energy security and sustainable development, resulting from increased investment in clean energy development, including renewable energy, energy efficiency, and access to new forms of energy [95].

The period 2010–2019 marked a boom in terms of population growth, but also economic growth and energy consumption for Asia. During this period, scholars intensified research that analyzes the impact of capital and finding renewable energy sources. This can be seen in Figure 5b, which shows the CA with descriptors versus years for the last period, the year 2009 being the one with the most articles dedicated to renewable energy urges in Asian countries. The *Energy Economics* journal includes the most studies based on samples of Asian countries in all three periods. The key trends for the field research are best seen in the results for the period 2010–2019.

On the whole, it appears that scholars have investigated the relationship between energy and economic growth using as the main indicator GDP with quantitative data processing. Additionally, it seems that most of these articles measure the relationship based on the data that reflect the energy consumption and production from different countries, grouped according to various criteria, such as industrialized countries, developing countries, or belonging to different organizations. Quantitative analysis of the causality between energy production and consumption and GDP is the one frequently analyzed in studies published in *Renewable and Sustainable Energy Reviews*, along with gas emissions and renewable energy sources.

The main limitation of this study could be the selection of reviewed journals from a single database, although the subject is also treated in nonindexed conferences and journals. Another limitation of the research may be the fact that articles from journals in the economic field that may contain papers dealing with the subject were not included in the sample, but this shortfall was reduced by searching in the title and not in the topic. In addition, using similar keywords to search for "economic growth" could increase the number of selected articles.

The relationship between energy consumption and economic growth has always been of great importance for policy purposes and also gained the attention of economists and researchers, as there is a body of literature dealing with this topic. One of the research findings of this paper reveals that the strongest connection between the categories of the keywords is between *methods of analysis* and *policies focus*. This strengthens the idea that energetic and economic policy development depend on reliable results provided after applying relevant methods. Moreover, the four descriptors belonging to this category, Policies Focus, have an interesting movement within the proximity or correspondence maps, from the upper left half in the 1979–1999 period to the lower right half of the map in the second and third periods, and to the upper right half of the map in the last period. According to the dimensions of the maps, this means that the topic regarding policies moved from a point with low importance from the analyzed theme to emerging themes in terms of experts' interest and, in the end, to an area with vital research themes for the development and structuring of the analyzed field.

This research has allowed us to analyze a particular part of a field born where energy meets economic growth. The added value of the paper consists in providing and mapping the structure of the scientific knowledge related to this field, in terms of concepts, theoretical and methodological approaches, topics, and links among topics, and in allowing research gaps to be identified. For instance, when dealing with geographical distribution of research,

Europe and North and South America remain underexploited territories in terms of the topic investigation. The lack of concern, which is obvious for research on equilibrium conditions of energy consumption and economic growth, constitutes another research gap; the examples could go on. Overall, our research has implications for researchers and scholars. They can gain an in-depth understanding of the evolution of concerns for studying the energy–growth relationship, and can better select both journals and the topic of the study. They can also choose new methods of analysis that can lead to better results.

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