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Derleme / Review

A Bibliometric Study: General Equilibrium Models on Energy Economics*

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Abstract

General equilibrium (GE) models are commonly used for economic impact analysis. They offer a benchmark for analyzing changes in the overall economy due to new policies, shocks, or technological improvements, using the data from the social accounting matrices and input-output tables. GE models are widely used for analyzing the areas of energy economics, as the focus on energy-related issues has become critical throughout the years. Therefore, a broad literature focuses on the GE models and energy economics. This study uses bibliometric analysis to examine the networks between the existing literature between 1990-2020. No other paper uses this method to focus on the selected literature. The data for the bibliometric analysis is subtracted from the Web of Science. The keywords are "computable general equilibrium, dynamic stochastic general equilibrium, and energy." Dynamic Stochastic Models are added to expand the scope of the dataset. In addition, the paper reviews the ten most cited articles based on the data retrieved from the Web of Science. The main results of the bibliometric analysis show that the GE models were highly used after 2005, with the introduction of international energy agreements. The focus of these models is usually renewable energy and mitigation policies.

Keywords: *General Equilibrium Models, CGE, DSGE, Energy.*

Enerji Ekonomisinde Genel Denge Modelleri Üzerine Bibliyometrik Çalışma

Öz

Genel denge (GD) modelleri, ekonomik etki analizi için yaygın olarak kullanılmaktadır. Bu modeller sosyal muhasebe matrislerinden ve girdi-çıktı tablolarından elde edilen verileri kullanarak, yeni politikalar, şoklar veya teknolojik gelişmeler nedeniyle oluşan değişiklikleri analiz etmek için bir kıyaslama sunarlar. GD modelleri, enerji ile ilgili konuların yıllar içinde daha kritik hale gelmesiyle, bu alanların analizi için yaygın olarak kullanılmaktadır. Bu nedenle, geniş bir literatür GD modellerine ve enerji ekonomisine odaklanmaktadır. Bu çalışma, 1990-2020 yılları arasındaki mevcut literatür arasındaki ağları incelemek için bibliyometrik analizi kullanmaktadır. Daha önceki hiçbir çalışmada, seçilen literatüre odaklanmak için bu yöntem kullanılmamıştır. Bibliyometrik analiz için veriler Web of Science'tan alınmıştır. Anahtar kelimeler "hesaplanabilir genel denge, dinamik stokastik genel denge ve enerji"dir. Dinamik Stokastik Modeller veri setinin dahil ettiği alanı genişletmek amacıyla eklenmiştir. Çalışma ayrıca Web of Science'tan alınan verileri kullanarak en çok atıf yapılan on makaleyi de gözden geçirmektedir. Bibliyometrik analizin ana sonuçları, 2005 yılından itibaren, uluslararası enerji anlaşmalarının yürürlüğe girmesinin de etkisiyle GD modellerinin yüksek oranda kullanıldığını göstermektedir. Analiz GD modellerinin odak noktasının genellikle yenilenebilir enerji ve karbon azaltma politikaları olduğunu göstermektedir.

Anahtar Kelimeler: *Genel Denge Modelleri, CGE, DSGE, Enerji.*

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INTRODUCTION

This paper aims to conduct a bibliometric analysis of general equilibrium models and investigate how these models are used in the energy sector. Since energy is one of the main driving forces of the economies, it is essential to analyze the methods used to evaluate the energy sector. Many studies use these models to investigate countries' energy policies, renewable energy resources, carbon emissions, environmental taxes, and climate. Bibliometric analysis is appropriate for focusing on such a broad field since it provides a quantitative literature review of the selected research subject. With bibliometric analysis, one can get a comprehensive understanding of the subject and identify the field's gaps and the possible contributions that can be made to the area. (Donthu et al.,2021)

General equilibrium (GE) models are widely preferable for the energy sector. They are based on equations and assumptions, such as the outcome of the agents, budget limitations, or technological restrictions. Bhattacharyya (1996, p.146) pointed out the common aim of the general equilibrium models: "to measure overall economic impacts in any economy due to changes in the energy sector." General equilibrium models can provide information about all economic variables separately. Therefore, studying the individual effects of the economic factors contributes to the development of energy policies focusing on different aspects of the economy, such as the price, income, or agent's behavior.

GE models usually use the data from the social accounting matrix (SAM) and run this data to reach equilibrium and investigate the effects of energy or environmental policies. Using the primary equilibrium obtained with the SAM, how the variables change due to the changes in different exogenous factors "either price-based (taxes and subsidies) or quantity-based (constraints on demand or supply)" is observed, and a new equilibrium is reached. (Wing, 2009, p.27). Therefore, GE models are helpful for the large-scale and multi-sectoral energy market since there is a comparison between the status quo and the potential energy policies, helping policy-makers evaluate. For example, Fan et al. (2018) established a recursive dynamic CGE model to examine the synergetic effects of water fees and energy-related climate policy. Moreover, Shobande and Shodipe (2019) used a dynamic stochastic general equilibrium model to investigate energy policy in China, the United States, and Nigeria.

Dynamic stochastic general equilibrium models are similar to computable general equilibrium models with slight differences. DSGE models take uncertainties about the decision-making environment into account. The intertemporal decision-making process in the DSGE models helps investigate how the behavior of the economic agents changes as a response to future uncertainties (Burns et al.,2018). These uncertainties can be related to price and wage frictions or monopolistic market structure. Dynamics and uncertainty are vital factors to be considered while focusing on energy-related issues, especially for climate change, which make DSGE models appropriate tools for the area. (Hassler & Krusell, 2018) Therefore, instead of focusing solely on GE models, the paper divides GE models into CGE and DSGE models. Although these two pieces of literature will converge based on their setup and computations (Hassler & Krusell, 2018), combining them into just GE models will limit the research's database, as it can exclude papers using DSGE.

The GE models cannot be considered separately from the Input-Output tables and their modeling structure, which present the transactions within a country's or region's economy.

They are one of the most used methods to work on energy economics. For example, He et al. (2019) composed an input-output linear programming model to study the energy resilience of a multi-region economy, and Xing et al. (2018) used an environmentally extended input-output analysis for China. The input-output tables are commonly used with the other energy economics methods, which is the case for the GE models. While input-output tables present a snapshot of the economy for a given period, GE models allow various analyses and comparisons of different scenarios.

Also, econometrics methods such as time series applications, VAR models, and forecasting are highly preferable and expand the study of the interconnected energy markets by providing quantitative arguments related to all actors in the sector, like companies, consumers, governments, and international organizations. (Chevalier, 2007) For example, Wu et al. (2020) used panel data from the Chinese provinces for 16 years and obtained a stochastic frontier model to measure agricultural energy efficiency at the provincial level. However, econometric models do not provide an optimizing behavior as they are based on conditions of uncertainty. On the other hand, optimizing is possible for the GE models as they mainly assume perfect knowledge, making them suitable tools for focusing on the optimal allocation of resources and related policies. (Pollitt et al.,2019) They are better for making "ex-ante predictions" about the various policies' impact on the economy, welfare, and the environment. (Carbone et al.,2020)

Considering the main methods used in energy economics demonstrates that naming a model "better" is not easy, as one method can be more suitable than the other, depending on the intended research question. The mentioned models can be used in the same context in energy economics, as they do not entirely differ. However, GE models are more dominant as they allow the analysis of all the economic agents and how they react to specific shocks. For instance, SAM and IO analysis usually focus on sectoral interactions and do not include behavioral aspects of the economy. They present static analysis and do not touch upon how a change in one variable channels through the rest of the economy and changes the actions of an actor, as in the case of GE.

Similarly, the econometric models present the relationship between the variables and provide quantitative arguments related to these interrelations. However, they lack optimization and are more suitable for forecasting. Therefore, as these models can be suitable for touching upon various subjects in energy economics, GE models are better for policy analysis, which is critical for discussing any energy-related area.

The chosen methods for the bibliometric analysis are GE models, including CGE and DSGE, since GE models are more insightful for scenario analyses and policy implications. The aim is to understand how these models are conducted in the energy literature and provide a starting point for those who wish to build a similar model.

GE models are the leading method of analyzing energy economics, and the related literature is examined from different aspects. For instance, a systematic review by Babatunde et al. (2017) investigated the literature for applying CGE models to climate mitigation measures and policy interventions. Bardazzi and Bosello (2021) presented how CGE models treat the water-energy-food nexus with the same method. Although the systematic review articles review the GE literature, they focus on one aspect of energy economics and try to answer specific questions. The paper aims to focus on a broader part and provide more quantitative results using bibliometric analysis. No standing-out bibliometric analysis focuses solely on the general

equilibrium models. The paper contributes to this gap in the literature and macroeconomic analysis of the energy sector.

The bibliometric analysis follows a quantitative approach to analyze, evaluate, and monitor published research with related data. (Zupic & Čater, 2015). It is beneficial because it can show the relationship between publications, authors, journals, and related information. With bibliometric analysis, one can combine different subjects. The chosen issues are computable general equilibrium models, dynamic stochastic general equilibrium models, and energy for this paper, and various tools like Vosviewer and Histcite are used for analysis. In addition, the most cited ten publications are reviewed to expand the analysis and gain insight into how the GE models are used.

The rest of the paper is organized as follows: the following section explains the study's methodology. The analysis results are presented, followed by a review of the most cited articles and the conclusion.

1. METHODOLOGY

Bibliometric analysis is a highly used tool for investigating different aspects of energy since it provides comprehensive information about the literature on the chosen area. Therefore, various publications use bibliometric methods to work on numerous aspects of energy. Alternative energy supplies for sustainable energy development were investigated by Mao et al. (2015). Hache and Palle's work (2019) was about electrical system modeling to integrate renewable energy sources into power networks. Mao et al. (2018) analyzed the interaction of biomass energy with the environment. Tsay (2008) worked on the hydrogen energy literature. Du et al. (2013) studied the characteristics of the energy efficiency literature. Chen et al. (2016) summarized the research on Chinese energy and fuels. These examples demonstrate that bibliometric analysis is beneficial in many fields of energy.

The bibliometric analysis links almost all aspects of the selected subject, such as authors, documents, journals, and keywords. It helps one understand the extensive relationship between the publications. Also, Durieux and Gevenois (2010) stated that bibliometric analysis is essential for researchers since it allows objective measurement of the articles' diffusion and impact. Therefore, it is appropriate to understand a broad range of subjects, such as energy markets and general equilibrium models.

The search for the paper is conducted through the Web of Science under the topic section. The topic section includes titles, abstracts, keywords, and keywords plus publications. The search includes all Web of Science core collections, SCIE, SSCI, AHCI, and ESCI. The type of documents is limited only to articles. The results are obtained using the data retrieved from the Web of Science on 05.05.2021. The bibliometric analysis includes a network of publications' citations, a co-citation map, and a bibliographical coupling map. It also presents the field's top journals, institutions, and authors. While the bibliometric figures are obtained using VosViewer, Histcite is used to create tables.

As explained, the search query for general equilibrium is divided into CGE and DSGE models. The search query used for this paper is as follows:

TS=(((“computable-general-equilibrium’’ OR “dynamic-stochastic-general-equilibrium’’)) AND (“energy’’)).

The search was conducted from 1990 to 2020, and there are 715 publications on the subject.

Table 1: Document Type

Document Type	Recs	Percent	LCS	GCS
Article	675	94.4	2119	12955
Article; Proceedings Paper	24	3.4	91	621
Article; Book Chapter	10	1.4	7	40
Article; Early Access	5	0.7	0	2
Article; Data Paper	1	0.1	0	1

Recs: Number of records, LCS: Local Citation Score, GCS: Global Citation Score

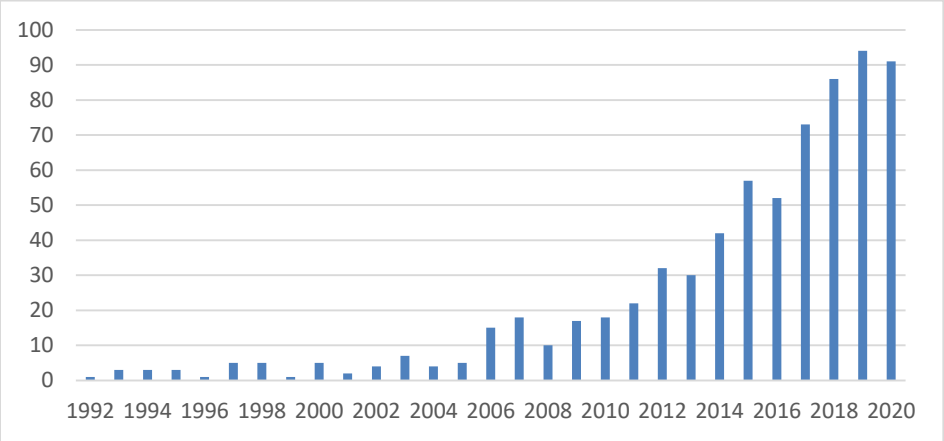
Table 1 shows the document types of these 715 publications; 94.4% of the documents are articles, 3.4% are proceeding papers, 1.4% are book chapters, and the rest are data papers. The local citation score shows the total citations of a paper within the searched group. In contrast, the global citation score presents the total number of citations in the Web of Science collection. Table 1 shows articles have the highest scores compared to other document types.

2. RESULTS

This section will give the results of the bibliometric analysis related to general equilibrium models and energy. As mentioned, the data related only to general equilibrium models and energy left out some highly cited papers using dynamic stochastic models. Therefore, the selected keywords for the study are computable general equilibrium, dynamic stochastic general equilibrium, and energy, which provide a better scope than searching only for general equilibrium models.

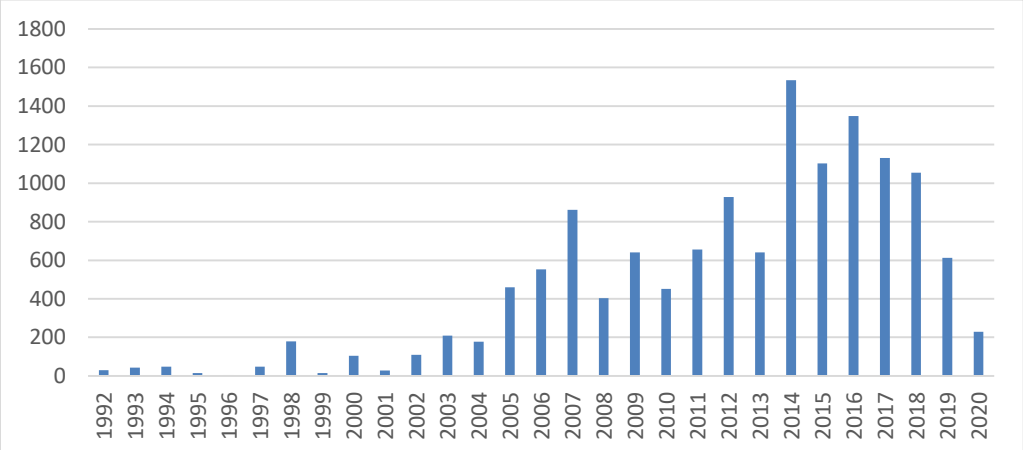
The data from the Web of Science is used to create tabulations and figures using VosViewer and Histcite, presented below.

Figure 1: Number of Studies Per Year



As Figure 1 shows, the number of studies per year has an increasing trend with minor fluctuations. The number increased primarily after 2005, which was the year that the Kyoto Protocol entered into force. Therefore, the implications of the Kyoto Protocol can explain the increase after 2005. The number of publications increased even more after 2015, with a slight decrease in 2016. The adaptation of the Paris Agreement in 2015 may explain this trend since the focus on energy analysis is increasing. The number of studies reached its peak in 2019, with 96 publications. Similar to the Kyoto Protocol and the Paris Agreement, the formation of the European Green Deal in 2019 may explain the peak. The mentioned agreements mainly focus on carbon mitigation, climate change, pollution, and similar environmental problems, which GE models can analyze.

Figure 2: Number of Global Citations Per Year



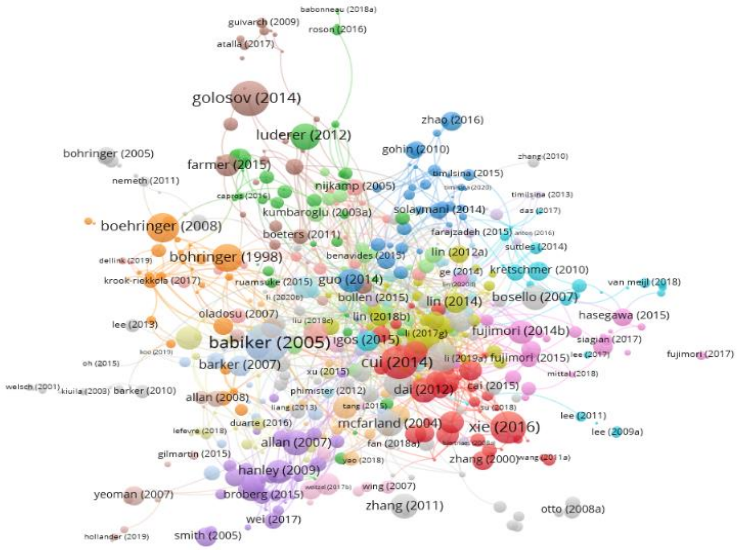
The number of global citations reached its peak in 2014. Since the number of publications increased, especially after 2005, so did the global citations. Out of all publication records, two of the highly-cited articles were published in 2014.

The first article was published by Golosov et al. (2014), and the paper was cited 212 times. The authors analyzed a DSGE model for using fossil energy. In this model, an externality comes from emitting carbon dioxide. The model gives a formula for the marginal externality damage of

emissions proportional to the current GDP. This formula depends on the discounting rate, expected damage elasticity, and structure of carbon deprecation in the atmosphere. Thus, it provides a new argument for the optimal taxes on fossil fuels; optimal tax does not necessitate any information about the availability of fossil fuels, technology, or population growth.

The second article (Cui et al., 2014) focused on the effects of carbon emissions trading in China using a CGE model, and the paper was cited 191 times. The authors concentrated on the cost-savings impacts of carbon emissions trading in China by using a CGE model with the emission trading scheme (ETS), a mechanism to control carbon emissions. They estimated the marginal abatement cost (MAC) at the provincial level using the coordinate translation technique (CTT). Three policy scenarios are analyzed after the local and national levels of MACs are obtained. There are no emission trading schemes among provinces, emission trading schemes only contain the seven pilot provinces and unified national emission trading market.

Figure 3: Document Citation Network



Source: Data retrieved from Web of Science on 05.05.2021 with the search query

Figure 3 shows the network of citations and documents in the field. The minimum number of documents is one out of 715; 664 documents meet the criteria. There are 26 clusters in the network. The authors in the network are close to the central nodes; the data has no outliers.

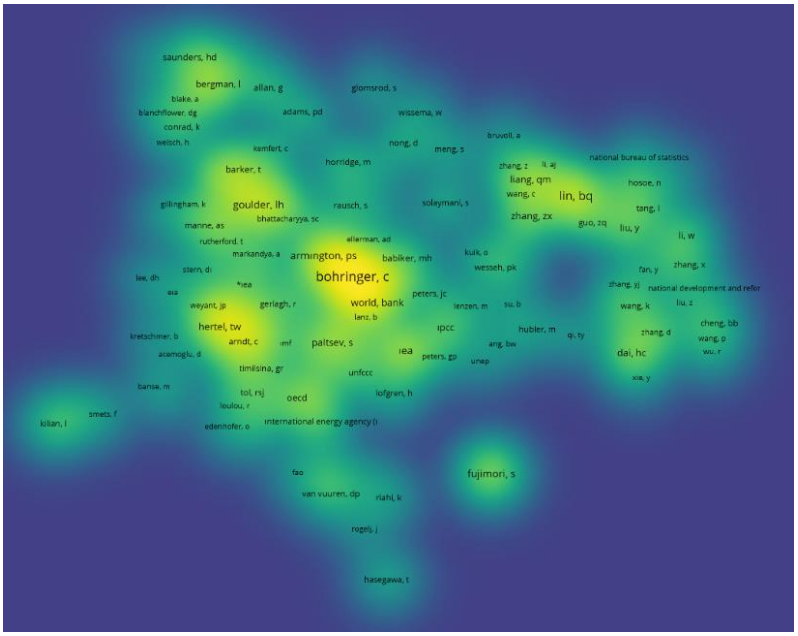
The most crowded cluster is the first one, with 43 documents. It includes the different authors' work, and the main focus of this cluster's publications is China's policies on climate change, focusing on carbon emissions. The document with the highest number of links and citations in the first cluster is Cui et al. (2014). The authors used a dynamic-single region CGE model to analyze the cost-saving effects of carbon emission trading in China. The following node is Xie et al. (2016), in which PM2.5 pollution-related impacts are analyzed with a computable general model. Another apparent publication is Dai et al. (2016); the authors investigated the effects of household consumption on energy demand and emission in China from 2005 to 2050

using a hybrid recursive dynamic computable general equilibrium model. It is important to note that these papers and authors are the most cited and productive ones in the selected field.

There are 38 documents in the second cluster, and the main focus of these documents is climate change, mitigation, and targets. In the second cluster, Luderer et al. (2012) attract attention. This paper differs from the mentioned ones because it compares three existing climate models and captures the outcomes of mitigation policies on the economy and technology. These three models are IMACLIM-R (Sassi et al. 2010; Waisman et al. 2011), ReMIND-R (Leimbach et al. 2010; Baueret al. 2011), and WITCH (Bosetti et al. 2006; De Cian et al. 2011). Between these models, IMACLIM-R is a recursive CGE model. This paper is also on the list of the most cited articles.

The documents in the other clusters have more or less the same number of citations and links. There are some outstanding papers, such as Golosov (2014), Bohringer (1998 & 2008), and Babiker (2005). These are on the list of the most cited articles; more details will be given in the following sections.

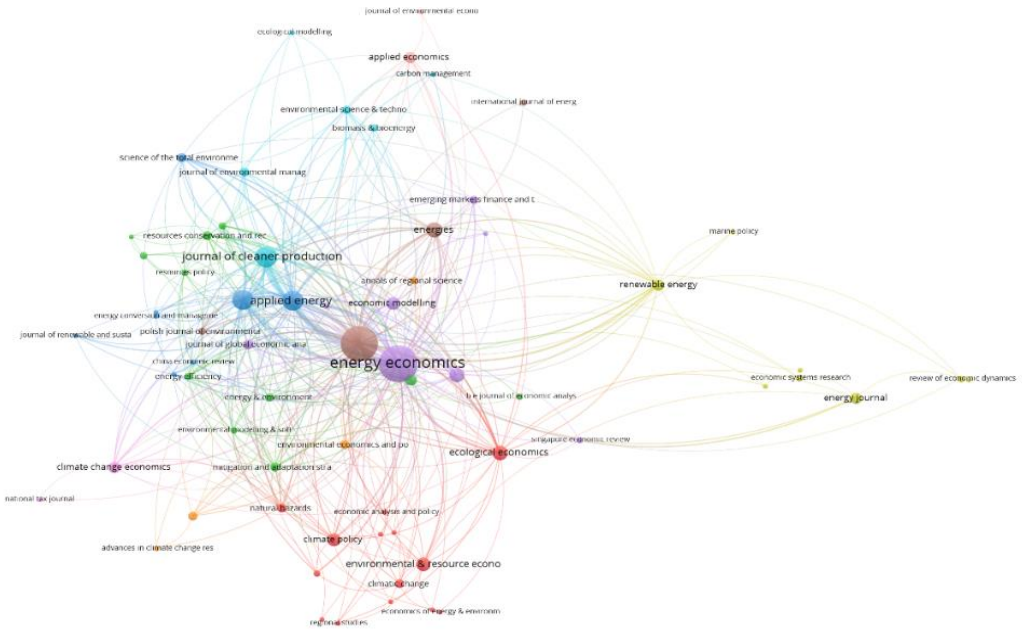
Figure 4: Author Co-Citation Map



Source: Data retrieved from Web of Science on 05.05.2021 with the search query

Figure 4 shows the co-citation map of the network, indicating the authors who are cited together. The authors with more publications, such as Christoph Bohringer, Fujimori Shinichiro, and Lin Boqiang, are cited in the data.

Figure 5: Journal Citation Map



Source: Data retrieved from Web of Science on 05.05.2021 with the search query

Figure 5 shows the journal citation map of the network; the minimum number of documents is 2. Journals such as Energy Policy, Energy Economics, Applied Energy, and Journal of Cleaner Production seem like the central nodes in the network. There are no high outliers from these nodes. The linkages between the journals are prominent; moreover, these are the top journals in the field.

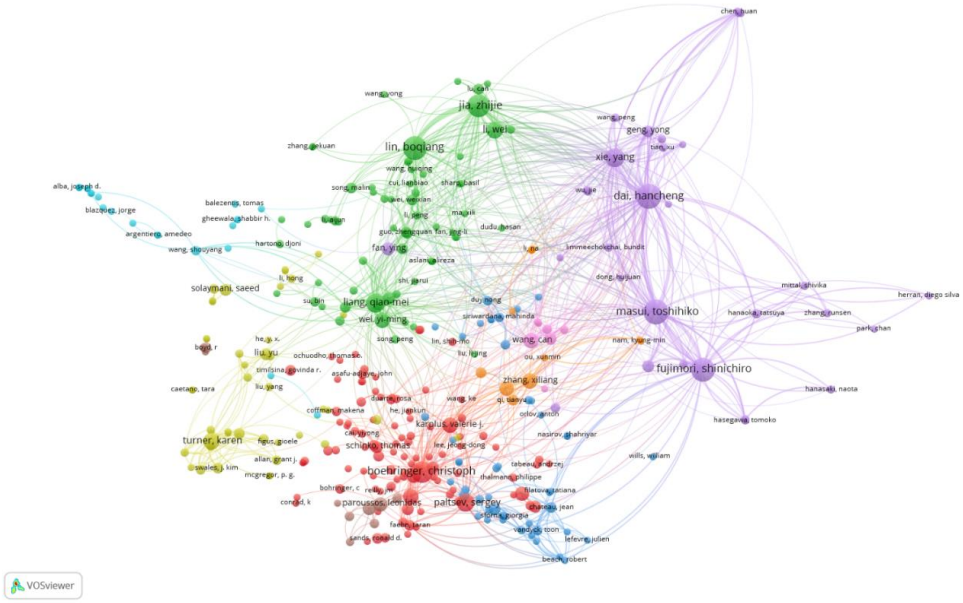
Table 2 shows the top 15 journals in the field. The results are consistent with the outstanding journals in the Journal Citation Map, indicating that the citation scores increase with the number of publications. Energy Economics and Energy Policy have the highest record compared to the other journals. Journal of Cleaner Production, Applied Energy, and Energy followed the two top journals with similar publications. The citation scores are consistent with the journal's publication records.

Table 2: Top 15 Journals

	Journal	Recs	Percent	LCS	LCS/t	GCS	GCS/t	LCR
1	Energy Economics	97	13.6	522	55.26	2872	315.99	217
2	Energy Policy	91	12.7	418	52.60	2172	286.26	267
3	Journal Of Cleaner Production	31	4.3	78	18.45	394	106.38	215
4	Applied Energy	29	4.1	258	42.87	1294	227.68	208
5	Energy	29	4.1	175	29.13	722	121.06	136
6	Energies	18	2.5	25	3.36	175	34.63	75
7	Sustainability	16	2.2	8	1.02	62	12.54	55
8	Ecological Economics	15	2.1	103	9.13	524	56.34	29
9	Environmental & Resource Economics	14	2	28	2.59	409	45.53	11
10	Economic Modelling	13	1.8	26	3.65	158	16.98	17
11	Climate Policy	12	1.7	20	3.63	122	22.97	20
12	Applied Economics	10	1.4	14	1.73	61	9.18	24
13	Climate Change Economics	10	1.4	0	0.00	30	7.83	45
14	Energy Journal	9	1.3	15	1.23	110	12.17	15
15	Journal Of Policy Modeling	9	1.3	66	4.27	262	17.11	5

Recs: Number of records, LCS: Local Citation Score, LCS/t: Local Citation Score per year, GCS: Global Citation Score, GCS/t: Global Citation Score per year, LCR: Local Cited References.

Figure 6: Bibliographical Coupling



Source: Data retrieved from Web of Science on 05.05.2021 with the search query

Bibliographical coupling gives the third joint work cited by the two others. Figure 6 shows the authors' bibliographical coupling; the minimum number of documents is two, and the maximum number of documents is 25.

Out of the 1542 authors, 338 meet the threshold. There are 10 clusters in the network. The largest cluster includes 101 authors, such as Christoph Bohringer, Sergey Paltsev, and Ian Sue Wing. Other clusters have similar records, and authors more apparent in the network are Masui Toshihiko, Dai Hancheng, Xie Yang, and Lin Boqiang. It is important to note that these are the most productive authors on the research subject. Also, most of the authors have joint publications together.

Table 3: Top 15 Authors

	Author	Recs	Percent	LCS	LCS/t	LCSx	GCS	GCS/t	LCR	LCSb	LCSe
1	Masui Toshihiko	26	3.6	228	31.04458	115	1090	161.5393	125	85	30
2	Dai Hancheng	25	3.5	199	31.19394	110	988	164.6595	174	72	22
3	Bohringer Christoph	23	3.2	145	11.0127	127	912	74.21486	28	5	28
4	Fujimori Shinichiro	23	3.2	200	25.80227	98	724	104.7683	122	60	17
5	Lin Boqiang	23	3.2	124	25.775	58	494	116.6917	201	10	1
6	Jia Zhijie	20	2.8	136	30.3	58	454	119.1667	238	9	1
7	Liang Qiao-Mei	15	2.1	97	9.74536	49	342	37.66712	91	20	22
8	Xie Yang	14	2	83	15.91667	55	520	98.75	117	39	10
9	Paltsev Sergey	12	1.7	26	2.99816	17	237	25.60716	28	4	2
10	Reilly John M.	12	1.7	56	3.744192	43	340	28.39684	11	10	3
11	Turner Karen	12	1.7	108	8.133496	78	512	40.56227	40	16	23
12	Zhang Xi-Liang	12	1.7	61	9.027778	47	400	64.2873	42	8	4
13	Li Wei	11	1.5	73	12.94762	36	276	51.83571	86	12	14
14	Liu Yu	11	1.5	34	7.283333	31	170	35.86984	65	0	-6
15	Wang Can	11	1.5	53	7.660256	36	207	39.35256	74	8	-4

Recs: Number of records, LCS: Local Citation Score, LCS/t: Local Citation Score per year,

LCSx: Local Citation Score, excluding self-citation, GCS: Global Citation Score, GCS/t: Global Citation Score per year, LCR: Local Cited References, LCSb: Local Citations at the beginning, LCSe: Local Citations at the end

Table 3 shows the most productive 15 authors in the subject. Masui Toshihiko and Dai Hancheng publish more articles than the other authors. Masui Toshihiko mainly focused on Asian countries like Japan, China, Taiwan, Thailand, and Vietnam and focused on these countries' GHG emissions, sustainability, mitigation costs, and emission trading systems using dynamic and static general equilibrium models. Similarly, Dai Hancheng used general equilibrium models to analyze the pollution, climate change mitigation, carbon emission, and taxes of Asian countries, especially China. These authors are followed by Christoph Bohringer, Fujimori Shinichiro, Lin Boqiang, and Jia Zhijie, who have similar records. The rest of the scores are consistent with the list as well. The highest citation scores belong to the most productive authors. Local citation references show the citations to other articles in the collection, which are relatively high for almost all papers.

Table 4: Most Used Words

	1990-2004	Records		2005-2020	Records
1	EQUILIBRIUM	14	**1**	ENERGY	215
2	GENERAL	14	**2**	CHINA	170
3	ENERGY	13	**3**	CARBON	163
4	EFFECTS	12	**4**	ANALYSIS	129
5	MODEL	10	**5**	ECONOMIC	118
6	CARBON	9	**6**	MODEL	115
7	ANALYSIS	8	**7**	EQUILIBRIUM	113
8	COMPUTABLE	8	**8**	GENERAL	111
9	ECONOMY	8	**9**	IMPACTS	110
10	TAX	8	**10**	CGE	104
11	ECONOMIC	6	**11**	CLIMATE	96
12	MACROECONOMIC	5	**12**	POLICY	88
13	POLICY	5	**13**	ECONOMY	84
14	BOTTOM	4	**14**	IMPACT	74
15	CO2	4	**15**	TAX	71

The data is divided into two periods: 1990-2004 and 2005-2020. Table 4 shows the most used words for these two periods. The division started in 2005 because the number of publications increased, especially after this year. The aim is to see whether there is a new focus on the second period. As can be seen, there are no significant word differences between the two periods. Equilibrium, energy, carbon, analysis, policy, tax, and economy dominate both periods. The main difference between the two periods is that "China" became a dominant word for the second period because many articles focus on analyzing energy in China in this period.

Table 5: Top 15 Institutions

	Institution	Recs	Percent	LCS	GCS
1	Natl Inst Environm Studies	37	5.2	316	1429
2	MIT	33	4.6	158	1135
3	Chinese Acad Sci	29	4.1	216	990
4	Tsinghua Univ	27	3.8	115	685
5	Xiamen Univ	26	3.6	130	541
6	North China Elect Power Univ	23	3.2	129	446
7	Carl von Ossietzky Univ Oldenburg	22	3.1	82	687
8	Beijing Inst Technol	20	2.8	84	325
9	Univ Strathclyde	19	2.7	125	599
10	Peking Univ	17	2.4	38	217
11	Kyoto Univ	14	2	137	417
12	World Bank	14	2	20	131
13	European Commission	13	1.8	29	184
14	Beihang Univ	12	1.7	7	91
15	Univ Chinese Acad Sci	11	1.5	47	233

When Table 5 shows the top 15 institutions observed, it is seen that a high portion of the institutions is from Asian countries. The National Institute of Environmental Studies, Japan, is the top institution with 37 publications, followed by MIT. Most of the other institutions on the list are in China. Carl von Ossietzky University Oldenburg is in Germany.

Figure 7: Distribution of publications across countries

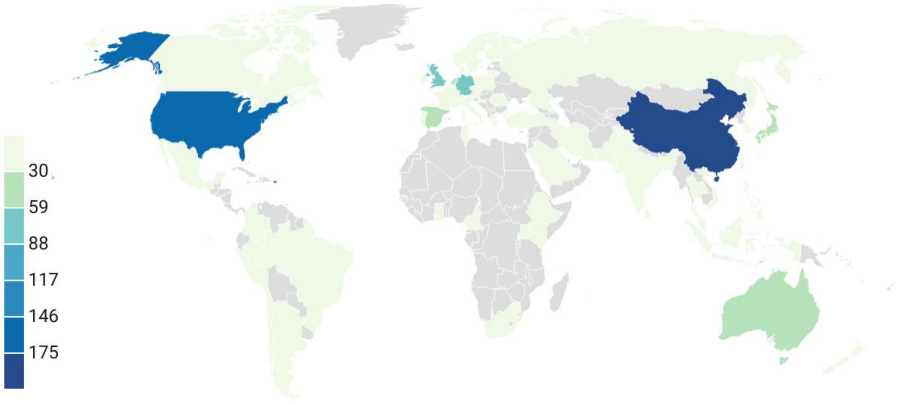
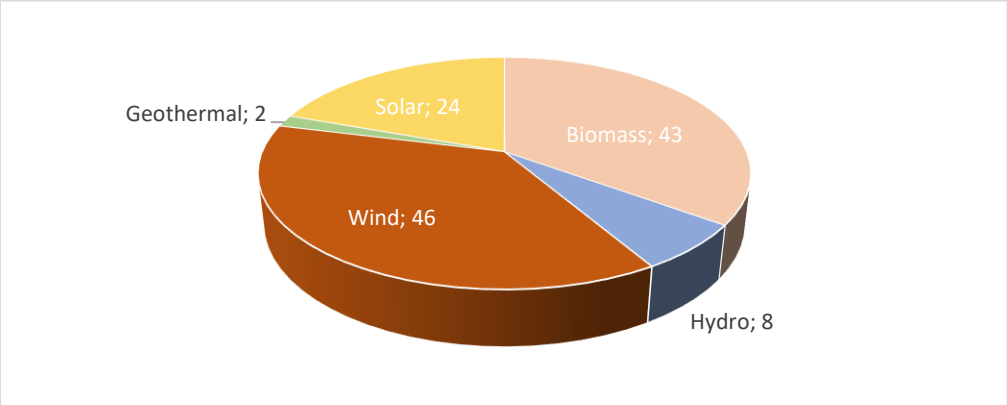


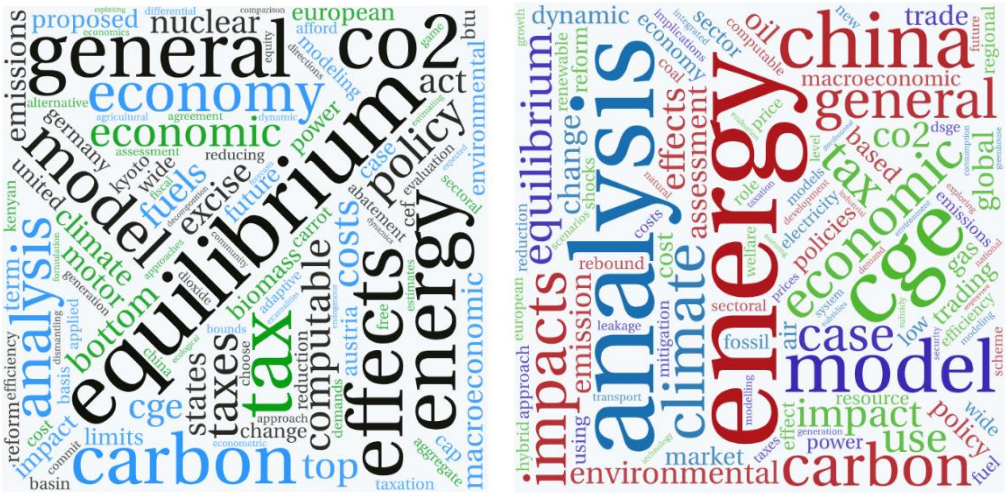
Figure 7 shows the distribution of publications across countries. China and the USA have the highest records since the top institutions are in these countries. Some European countries like Germany, the United Kingdom, and Spain have high publication records similar to those of Japan and Australia.

Figure 8: Number of Studies With Renewable Energy Keywords



The research is repeated for renewable energy resources to focus on the publications in this area alone. CGE or DSGE with solar, biomass, hydro, wind, and geothermal are searched separately. The records can be seen in Figure 8. Wind energy has the highest records, followed by biomass. The number of publications about solar energy is close to these two, whereas few papers are about geothermal and hydro energy.

Figure 9: Word Clouds



1990-2004 2005-2020

Following a similar approach as Table 4, the period is divided into two: 1990-2004 & 2005-2020. Two-word clouds with 100 words are created to see whether there are shifts of focus in the subject. There is no significant difference between the two periods. Words like energy, analysis, tax, general, model, and economy stand out for both periods. The only different word is China for 2005-2020, which can be explained by the increasing focus on China on the subject.

3. REVIEW OF THE MOST CITED ARTICLES

The results of the bibliometric analysis show that there are 715 articles using CGE and DSGE models to focus on energy economics from 1990 to 2020. In this section, there will be a review of the top 10 most cited articles, out of 715. The aim is to provide more insight into the general equilibrium models and observe how they are used in the energy sector. Table 6 shows the authors, titles, and citations of the top 10 most cited articles.

Table 6: TheTop 10 Most Cited Articles

	Authors	Article Title	Times Cited, WoS Core	Times Cited, All Databases
1	Babiker, MH	Climate change policy, market structure, and carbon leakage	263	272
2	Golosov, M; Hassler, J; Krusell, P; Tsyvinski, A	Optimal taxes on fossil fuel in general equilibrium	212	212
3	Cui, LB; Fan, Y; Zhu, L; Bi, QH	How will the emissions trading scheme save costs for achieving China's 2020 carbon intensity reduction target?	191	201
4	Xie, Y; Dai, HC; Dong, HJ; Hanaoka, T; Masui, T	Economic Impacts from PM2.5 Pollution-Related Health Effects in China: A Provincial-Level Analysis	172	191
5	Bohringer, C; Rutherford, TF	Combining bottom-up and top-down	149	150
6	Dai, HC; Xie, XX; Xie, Y; Liu, J; Masui, T	Green growth: The economic impacts of large-scale renewable energy development in China	146	154
7	Bohringer, C	The synthesis of bottom-up and top-down in energy policy modeling	132	141
8	Liang, QM; Fan, Y; Wei, YM	Carbon taxation policy in China: How to protect energy- and trade-intensive sectors?	123	136
9	Bohringer, C; Loschel, A; Moslener, U; Rutherford, TF	EU climate policy up to 2020: An economic impact assessment	121	124
10	Luderer, G; Bosetti, V; Jakob, M; Leimbach, M; Steckel, JC; Waisman, H; Edenhofer, O	The economics of decarbonizing the energy system-results and insights from the RECIPE model intercomparison	117	118

The top 10 most cited articles show variations of CGE and DSGE models that can analyze various factors in the energy sector. These articles investigate carbon emissions, environmental taxes, mitigation costs, emission trading schemes, and the economic consequences of different energy policies. In the top 10 list, the CGE models are dominant, starting with the most cited article on the subject. " Climate change policy, market structure, and carbon leakage," by Babiker (2005), cited 263 times. Babiker (2005) focused on the greenhouse (GHG) emission control policies that the developed countries' Kyoto Protocol necessitates. Although several models analyze similar issues, Babiker (2005, p.422) stated that "these models treat the first channel relatively well; they fall short of adequately representing the industry relocation channel." Therefore, the model used in the paper focused on how the market structure affects the

geographical distribution of energy-intensive production, trade, and leakage that similar models may neglect. The article points out that the reallocation of industries will offset the decrease in emissions. Böhringer et al. (2009) followed a similar approach using a CGE model. The authors tried to see whether policies to decrease greenhouse gas emissions may create an excess cost. If the focus is solely on the climate policy target, segmenting emission markets with differential emission pricing and using multiple climate policies results in excess costs. The fact that there may be adverse effects of shifting renewable energy resources can explain the increase in publications throughout the years. In addition, the shift of industries to China, India, and dynamic Asian economies can be one of the reasons why almost half of the papers in the top-10 list are about China and why the publication records of institutions in the Asian countries are higher compared to the rest of the world.

As mentioned, the articles focus on China being dominant in the top-10 list. Each of these articles works on a different aspect of environmental issues in China. For instance, two articles stand out as they discuss the policy tools for carbon emission. Cui et al. (2014) analyzed the cost-saving effects of carbon emission trading in China at the province level for 2020 following China's intention to decrease carbon emissions after the 2009 Copenhagen Submit, using a dynamic, single-region CGE model. Kyoto Protocol necessitates China to take measures related to its CO2 emission, and carbon tax could be an appropriate tool for this issue. Liang et al. (2017) used a recursive dynamic CGE model to analyze the effects of carbon tax schemes and their impact on energy-intensive, trade-intensive sectors and the overall economy in China. These articles take different aspects of the carbon emission policy of China by using different approaches since Cui et al. (2014) analyzed the issue at the provincial level. Like Babiker's (2005) approach, Dai et al. (2016) considered the possibility of adverse effects of promoting renewable energy. They analyzed the impact of China's renewable energy development toward 2050 by using a dynamic, multi-sectoral, and recursive CGE model. They try to answer several questions about whether renewable energy development causes adverse shocks in China's economy and how these developments affect other sectors, employment, and carbon emissions. They focus on the neglected factors in similar studies, such as economic and sectoral impacts. Different than the other publications about China, Xie et al. (2016) focused on the effects of PM2.5 pollution-related health impact on the sub-national scale using a computable general model and assessed the mitigation cost and China's regional disparity; they focused on all provinces, as in Cui et al. (2014). Health problems caused by PM2.5 pollution may also cause economic problems for the government, such as increased health expenditures, more workday loss, or decreased labor supply. Although these articles present the environmental issues in China, each highlights a different aspect.

There is only one publication using the DSGE model in the top-10 list, Golosov et al. (2014, p.82). However, this is the second most cited article. This article used a DSGE model with an externality from fossil energy. Externality comes from emitting carbon dioxide," a by-product of using fossil fuel as an energy input into production." Through this model, the authors reached a closed-form formula for the marginal externality damage of emissions, proportional to the current GDP depending on discounting, expected damage elasticity, and structure of carbon depreciation in the atmosphere. The formula also shows the optimal tax on carbon emission if a tax introduced makes the user internalize the externality. Thus, this paper provides a new argument for the optimal taxes on fossil fuels; optimal tax does not necessitate any information about the availability of fossil fuels, technology, or population growth. Although the paper has

a dynamic approach, it focuses on a subject similar to the previously mentioned ones; carbon tax.

Luderer et al. (2012) have a different approach than the other articles in the top 10 list. The authors used three existing energy-economy-climate models to see the economic and technological outcomes of the climate mitigation policies. These three models are IMACLIM-R (Sassi et al. 2010; Waisman et al. 2011), ReMIND-R (Leimbach et al. 2010; Baueret al. 2011), and WITCH (Bosetti et al. 2006; De Cian et al. 2011). Among these models, IMACLIM-R is a recursive-dynamic CGE model. Macroeconomic processes have top-down representations with bottom-up representative technologies for all these models. These three models are harmonized with some assumptions related to the characteristics of the models, such as socio-economic developments, the availability of fossil fuels, etc. Luderer et al. (2012) used these models to compare and analyze decarbonization scenarios.

Unlike the above-explained papers based on concrete examples of different general equilibrium models, some articles focus on the theoretical side, mainly top-down and bottom-up approaches. The bottom-up approach estimates how energy parameters such as efficiency, fuel, emission, and infrastructure changes affect the environment. In contrast, the top-down approach provides a series of equations linking outputs and inputs related to energy and estimates the parameters econometrically. (Jaccard, 2009). Böhringer and Rutherford (2017) focused on directly integrating bottom-up analysis into a top-down representation of the broader economy in a complementarity format. First, they explain the integration and complementarity of economic equilibria and a concrete example in both static and dynamic environments. Also, they formulated the equilibrium as a mixed complementarity problem. Then, after the integration is fully explained, they analyze three different energy policy agendas for developed countries using the described hybrid model: nuclear phase-out, green quotas, environmental tax reform, which combines the advantages of the bottom-up and top-down models.

Similarly, Böhringer (1998) explained a synthesis of bottom-up and top-down approaches for the models for energy policies. He showed how to formulate general equilibrium as a complementarity problem in which energy sectors are explained with a hybrid description, bottom-up analysis. In contrast, other sectors have a regular top-down representation. He aimed to increase the credibility of the CGE for energy policy simulations and improve the sector-specific measures in the energy sector.

5. CONCLUSION

This paper uses bibliometric analysis to analyze how general equilibrium models are used in the energy sector. By dividing the general equilibrium models into CGE and DSGE, the paper examines a broad literature that contributes to analyzing energy markets.

The bibliometric methods provide a general framework and give the most productive authors, journals, and institutions and their connections. In addition to the bibliometric analysis, a review of the top 10 most cited articles shows the diversity of the general equilibrium models for the different factors in the energy sector. The study also indicates that the publications about bottom-up and top-down models are striking for the subject.

The most outstanding results of the bibliometric analysis of general equilibrium models and energy can be summarized as follows;

1. The number of publications has significantly increased since 2005, affected by the Kyoto Protocol. The number of studies peaked in 2019, with 96 publications resulting from the formation of the European Green Deal. The number of global citations peaked in 2014; out of all publication records, two of the highly-cited articles were published in 2014. These results show the importance of cooperation between countries, incentivizing more research on the subject.

2. The top five journals in the fields are Energy Economics, Energy Policy, Journal of Cleaner Production, Applied Energy, and Energy, followed by similar journals focusing on different aspects of energy, showing the general equilibrium models' wide usage area.

3. The top five authors, the most productive, in the field are Masui Toshihiko, Dai Hancheng, Christoph Bohringer, Fujimori Shinichiro, and Lin Boqiang.

4. The top five institutions that have publications in the field are the National Institute for Environmental Studies, MIT, University of China Academy of Sciences, Tsinghua University, and Xiamen University. Except for MIT, the rest of the top five institutions are in Asia.

5. China and the USA have the highest records of publications. Some countries in Europe, Germany, the United Kingdom, and Spain have high publication records similar to those of Japan and Australia.

6. There are no significant word differences throughout the period. Words such as "equilibrium," "analysis," "policy", and "tax" are dominant. The one crucial difference is that the word "China" has increased significantly, showing that publications focusing on China had a high share among the publications.

7. According to the field's top 10 most cited articles, most papers do not include uncertainties in models except one. The articles mainly focus on similar environmental policy subjects, resulting in GE models appropriate for evaluating policy measures. Almost half of the articles in the list are about China, analyzing the renewable energy policy and its effects. China is one of the top countries with the highest carbon emission rates, and its climate policy offers a significant research area. Also, combining the bottom-up approach and the top-down models outstands in the top-10 list, using the advantages of both methods, in other words, hybrid models, provide a better view for the economic analysis.

These results show that the GE models have a wide range of usage in different aspects of the energy sector. More specifically, various authors have discussed recent environmental topics such as renewable energy, mitigation policies, carbon tax, and positive and negative effects in different countries. The possible adverse effects of various energy policies come forward in the most cited top-10 list. One of the main focuses of the authors is that the downside of these policies is as vital as their positive effects. China is one of the countries where negative issues are highly debated; many publications focus on China and its energy policy. Discussing all energy sector outcomes provides a more realistic and persistent point of view for the energy policy. The linkages and networks between the publications are high, showing that the selected subject is interrelated, covering all possible factors for the energy sector. Therefore, the general equilibrium models are appropriate tools for analyzing similar issues.

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AUTHOR STATEMENT

Statement of Research and Publication Ethics

This study has been prepared in accordance with scientific research and publication ethics.

Author Contributions

Ezgi İpek (60%)

Pınar Derin Güre (40%)

Conflict of Interest

There is no conflict of interest for the authors or third parties arising from the study.

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