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Carbon Pricing Mechanism for the Energy Industry: A Bibliometric Study of Optimal Pricing Policies

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Abstract

The carbon market can guide the optimal allocation of carbon emission reduction resources through price signals, and it can reduce the cost of emission reduction in the entire society, promote investment in green and low-carbon industries, and then guide the capital flow. Therefore, the carbon pricing mechanism has encouraged the energy transition and effectively mitigating climate change. Additionally, the primary source of carbon emissions is the rapid growth of energy use, such as coal and crude oil. Therefore, carbon pricing plays a vital role in promoting energy transitions, such as the transition from high-carbon energy (coal and oil) to low-carbon energy (natural gas) and clean energy (nuclear and renewable resources). Our study is devoted to investigating the impact of carbon pricing on the energy industry using bibliometric analysis and visual investigation. We analyze existing research trends on the impact of carbon pricing on the energy industry from different angles and review the effect of carbon pricing on various energy industries. We search for optimal carbon pricing models and pricing policies that impact the energy industry. Our study contributes to the literature by discussing the challenges and future study recommendations.

Keywords

Carbon pricing, Energy industry, Bibliometric analysis, Paris Agreement, Energy transition

Introduction

Energy is an essential material foundation for economic and social development. In most developing countries, their energy output has been dominated for a long time. Oil and gas are highly dependent on foreign countries, the main source of global carbon emissions. In recent years, carbon emissions have caused various international climate change issues, including climatic anomalies, glaciers and eastern soils melting, sea level rising, threatening people's food supply and habitat, and are suffering. Therefore, carbon pricing has been the European Union (EU)'s most important climate change mitigation policy since the launch of the Emissions Trading System (ETS) in 2005 (Elkerbout, 2020), (Hepburn, 2006), (Hepburn and Schwarz, 2020). Additionally, as the key to the most significant development, China has launched the national carbon trading market (limited to the thermal power industry) in mid-2021. Key sectors such as petrochemical, chemical, building materials, iron and steel, nonferrous metals, paper production, and aviation will gradually be included in the carbon trading system.

The global economy is consistently concerned with the price of carbon allowance forecasting (Adekoya, 2021). Therefore, as an essential policy to reduce carbon emissions (Elkerbout, 2020), the carbon pricing mechanism has been proven to be an effective measure to promote the energy revolution and mitigate climate change (Fu et al., 2020), and the main methods of carbon pricing include the carbon tax and the carbon trading market system. For example, the role of carbon pricing was highlighted, and the authors discussed how carbon pricing could be used in the EU climate policy mix to help achieve modest targets under the Kyoto Protocol (Elkerbout, 2020). Furthermore, the carbon pricing policy is a means to address the negative externalities of the economic impacts of climate change and correct market failures. Therefore, it is mainly implemented in two forms, including a carbon tax and a carbon trading mechanism (Lili et al., 2015).

The primary source of carbon emissions is the rapid growth of energy use such as coal and crude oil. In 2017, coal was still the most used energy source and represented about 44% of global carbon dioxide emissions from fuel combustion 2017 (Li et al., 2020a). Therefore, carbon pricing plays a vital role in promoting energy transitions, such as the transition from high-carbon energy (coal and oil) to low-carbon energy (natural gas) and clean energy (nuclear and renewable resources). Furthermore, optimization of the industrial and energy consumption structure is the key to reducing carbon emissions, and optimization of the industrial system helps reduce the intensity of carbon emissions (Li et al., 2018). Therefore, it is necessary to investigate the impact of carbon pricing on the energy industry to understand the driving force of carbon pricing, how to implement different carbon emission control, and energy transition policies to move away from fossil fuels as soon as possible.

The work of this paper is devoted to analyzing the impact of carbon pricing on the energy industry by reviewing the research status of existing publications. Bibliometric analysis is a comprehensive knowledge system that encompasses mathematics, statistics, and philology. In recent years, there has been much research that discussed carbon pricing (Maestre-Andres et al., 2019; Mintz-Woo et al., 2020; Nelson et al., 2012; Streimikiene, 2010), or energy industry (Gebreslassie, 2021; Kumar et al., 2021; Liu & Lu, 2021; Mo et al., 2021; Zeng et al., 2021; Zhang et al., 2021), from a certain point of view, such as carbon pricing and COVID-19 (Mintz-Woo et al., 2020), the perceived fairness and public acceptability of carbon pricing (Maestre-Andres et al., 2019), the feasibility assessment of renewable energy resources (Kumar et al., 2021). However, the bibliometric analysis of the impact of carbon pricing on the energy industry has not yet been addressed in existing research. To fill this gap, our study summarizes the research status and explores potential research directions through bibliometric analysis.

Here, we investigate the following research topics.

(1) Existing research trends on the impact of carbon pricing on the energy industry are analyzed and concluded from different angles.

(2) The impact of carbon pricing on different energy industries, some models for optimal carbon pricing, carbon pricing policies, and their implications on the energy industry are reviewed. Then some discussions are summarized.

(3) Some challenges are discussed, and future research on carbon pricing is introduced on the impact on the energy industry.

The remainder of this paper is organized as follows. Section 2 proposes the bibliometric analysis methodology used in this paper. Section 3 concludes the existing research trends on the impact of carbon pricing on the energy industry from different angles. Section 4 discusses the implications of carbon pricing on various energy industries in detail. Section 5 introduces some challenges and future research. Finally, the conclusions of this paper are given in Section 6.

Material and Methods

Generally, in the process of bibliometric analysis, scholars usually choose some common publication databases as data sources, such as Web of Science (WoS), Scopus, and Google Scholar. The bibliometric analysis methods include overall publication output analysis, overall publication citations analysis, publication countries/regions analysis, institutions analysis, highly cited publication analysis, keyword co-occurrence analysis, etc. (Qin et al., 2021; Wang et al., 2020; Yu et al., 2017). This paper selects bibliometric analysis tools, such as Citespace and VOS Viewer, to monitor and evaluate the given research topics. The methodology framework is shown in Fig. 1.

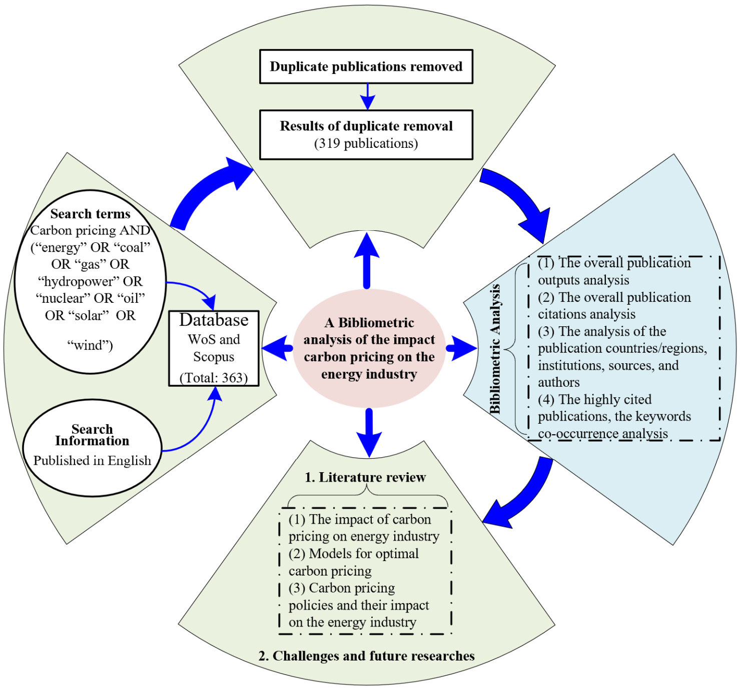

Fig. 1. The methodology framework

Based on the databases WoS and Scopus, and setting search terms with carbon pricing (OR carbon price) AND ("energy" OR "coal" OR "gas" OR "hydropower" OR "nuclear" OR "oil" OR "solar" OR "wind"), 301 terms from WOS, and 62 terms from Scopus are selected. After removing duplicate publications, the final sample includes 319 publications. The percentage of existing publications involving different energy types is shown in Fig. 2.

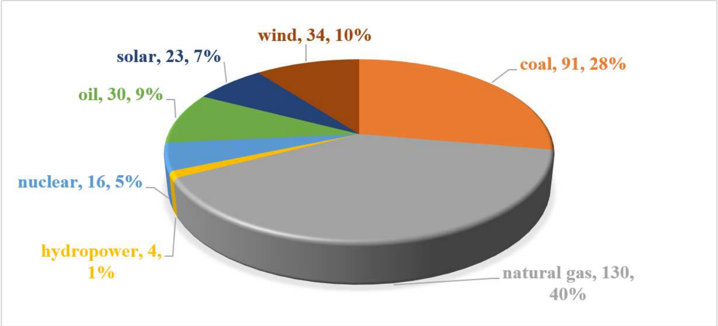

Fig. 2. The percentage of existing publications involving different types of energy

This section summarizes existing research trends on the impact of carbon pricing on the energy industry. They are analyzed from the angles of the overall publication outputs analysis, the comprehensive publication citations analysis, the publication countries/regions, institutions, sources, and authors analysis, the highly cited publications analysis, and the keywords co-occurrence analysis. In these processes, some coding errors are corrected, such as synonym substitution (e.g., the People R China and China), the expression of the expert's name (Zaman, Khalid, and Zaman, K.), singular and plural substitution (e.g., price and prices), and abbreviation substitution (e.g., carbon emissions trading and CET, carbon, and C).

Firstly, the analysis of the overall publication output consists of the publication type, the publication year, and the citation of existing publications.

(1) *Types of publications*

Fig. 3 is drawn to show the distribution of the existing publication types. We can find nine types, in which articles account for 81% of the total publications. Additionally, the remaining types of current publications are proceedings paper, early access, editorial material, review article, book review, corrections, book chapters, and books.

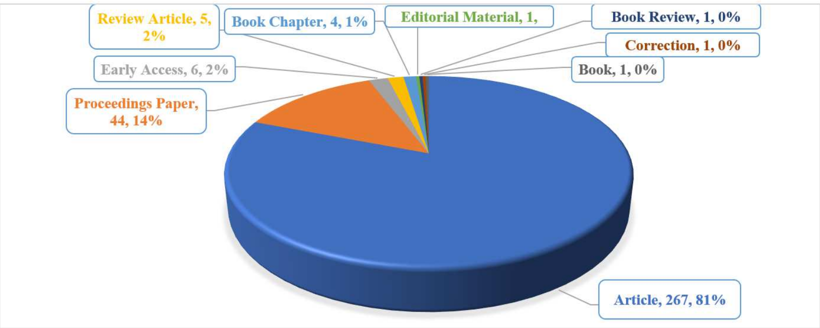

Fig. 3. The types of existing publications

(2) *The years of publications*

The distribution of the years of the selected publications is shown in Fig. 4. From the histogram of documents about the domain of carbon pricing from 1984 to 2021, few studies have been done in the field before 2006, and the related research began to show an increasing trend since 2006. What cannot be ignored is that with global carbon emissions increasing year by year, especially under the influence of China's efforts to achieve carbon neutrality and carbon peak, carbon pricing will increasingly become the focus of global scholars' research. In other words, the study of carbon pricing and its effects on energy industries will go a long way.

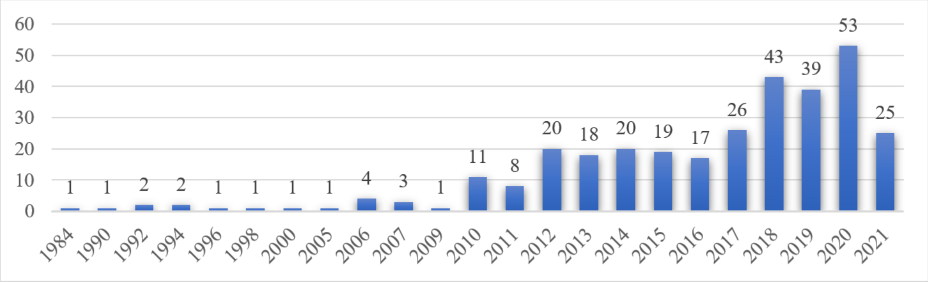

Fig. 4. The years of the existing publications

(3) *The annual number of citations*

The number of citations for existing publications is shown in Fig. 5. The total number of citations for selected publications has reached 3,811 times, and the average number of citations per publication is 11.95. The number of citations has shown an increasing trend since 2005, consistent with the beginning of the growth trend in publications. Furthermore, as more and more industries worldwide are closely related to carbon pricing, such as the power industry and supply chain, carbon pricing articles gain more attention. In addition, current research on carbon pricing involving the energy industry is a hot topic worldwide because carbon pricing is becoming more and more relevant to the energy industry, especially in the current climate of advocacy for carbon reduction and focusing on the development of other clean energy sources.

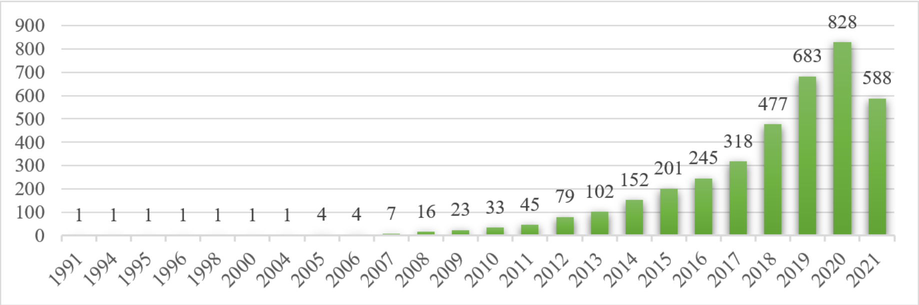

Fig. 5. The annual number of citations for existing publications

Secondly, this subsection provides analyses of publication countries/regions, institutions, sources, and authors.

(1) *Countries/Regions Level*

The number of countries/regions covered by the selected publications is 49. In Table 1, the top 10 countries/regions are selected by ranking the total link strengths of each country/region in descending order. Firstly, the complete publication (TP) expresses the total number of publications, and we find that China published the most significant number of publications, that is, 109 publications. The remaining countries/regions belonging to the top 10 prolific countries/regions are the USA (TP: 68), Australia (38), Japan (19), Germany (16), England (14), Canada (14), France (13), Netherlands (10), and Spain (9). Second, the fourth column expresses the number of citations of publications belonging to each country/region, and the USA has the highest citations, 1,064 times. Third, the fifth column expresses the different clusters for countries/regions. The links of each country/region represent the number of countries/regions having collaborative research networks, and there are 119 links among all countries/regions. The total strength of the link refers to the times of cooperation between these countries/regions, and the total strength of the link is 200. With the VOS viewer, Fig. 6 is drawn to show the collaboration network of all countries/regions with publications. The right graph in Fig. 6 expresses the overall collaboration network of countries/regions with publications, and the left figure represents the maximum subnetwork.

In Fig. 6, 49 countries/regions are clustered into 12 clusters, in which different colors represent different clusters. Additionally, the bigger the size of the point, the more significant the number of publications that belong to this country/region. All elements are clustered into nine groups, ignoring those clustered with fewer than two elements. For example, the first group consists of 9 items, such as Canada, Indonesia, Iran, Malaysia, Nigeria, Pakistan, Saudi Arabia, Syria, and Vietnam; the second group contains seven items, including Ethiopia, Finland, Germany, Lithuania, Norway, Sweden, and Switzerland. Additionally, the remaining 7 clusters have less than seven items.

Furthermore, the maximum subnetwork (making the USA or China central) consists of 46 items. Therefore, all the top 10 prolific countries/regions shown in Table 1 are concluded in the maximum sub-network. However, three countries do not yet cooperate with others: Mexico, Lebanon, and South Africa.

Tab. 1. Top 10 prolific countries/regions and detailed information on their collaboration network

Rank	Countries/regions	TP	Citations	Cluster	Links	Total link strength
1	China	109	898	5	21	57
2	USA	68	1064	8	22	43
3	Australia	38	540	9	11	24
4	Japan	19	290	7	11	23
5	Germany	16	156	2	10	13
6	England	14	155	5	6	12
7	Canada	14	85	1	5	7
8	France	13	189	3	8	10
9	The Netherlands	10	110	4	10	23
10	Spain	9	186	4	6	15

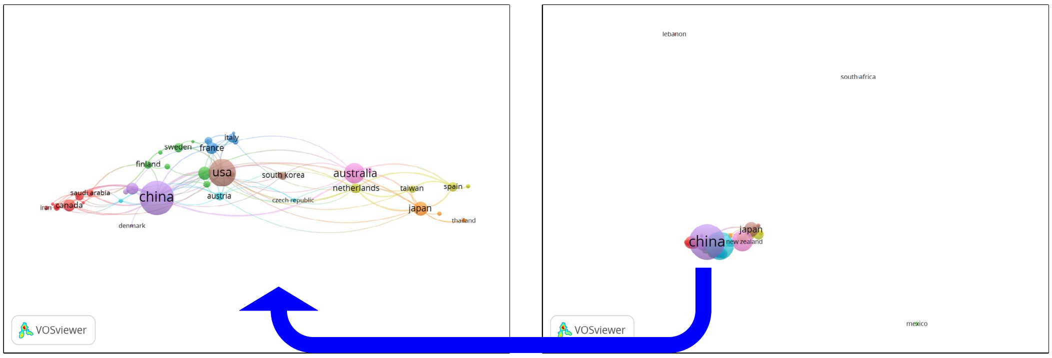

Fig. 6. The collaboration network of publication countries/regions

(2) *Institution level*

This subsection analyzes the institutions with publications involving carbon pricing's impact on the energy industry. The top 10 institutions and their complex cooperative network are shown in Table 2, and the institutions' network is shown in Fig. 7, respectively.

Firstly, in Table 2, it can be found that North China Electric Power University has the most significant number of publications, i.e., 10 publications. Furthermore, seven of the top 10 institutions are from China, including North China Electric Power University, Beijing Institute of Technology, University of Chinese Academy of Sciences, Chinese Academy of Sciences, Xi'an University of Architecture & Technology, Tsinghua University, and Beihang University, and the remaining institutions are from the United States and Australia. Second, the publications of the Massachusetts Institute of Technology have the highest citations, i.e., 180 times, and the remaining institutions are Beijing Institute of Technology (95), University of Chinese Academy of Sciences (93), and Tsinghua University (62), etc. Third, in the fifth column of Table 2, the top 10 institutions are classified into 8 groups. University of Chinese Academy of Sciences, Chinese Academy of Sciences, and Beihang University belong to the same cluster. Finally, the sixth (links) and seventh columns (total link strength) in Table 2 show different ranks from the TP rank. North China Electric Power University scores low in links and full link strength even though it published the most articles. In other words, there is no significant correlation between the number of institutional publications and the results of institutional collaboration (links and total link strength).

Tab. 2. The top 10 institutions and the complex cooperative network of them

Rank	Institutions	TP	Citations	Cluster	Links	Total link strength
1	North China Electric Power University	10	32	5	9	9
2	University of Sydney	8	57	3	9	12
3	Beijing Institute of Technology	7	95	2	21	25
4	University of Chinese Academy of Sciences	7	93	7	13	16
5	Chinese Academy of Sciences	6	34	7	11	16
6	Massachusetts Institute of Technology	6	180	11	7	7
7	Xi'an University of Architecture & Technology	5	12	4	13	21
8	Tsinghua University	5	62	10	12	12
9	Beihang University	5	17	7	10	11
10	Macquarie University	5	46	9	4	4

To analyze the cooperation relationship among all institutions, the cooperation network is drawn by the VOS viewer and shown in Fig. 7, where the upper right subgraph represents the overall cooperation network among all institutions. The lower left subgraph expresses the maximum subnetwork of the broad cooperation network. First, 460 institutions belong to the general cooperation network, and all of them are classified into 155 clusters. Additionally, the discrete points to the far right in Fig. 7 mean that these institutions do not cooperate with others. Second, the maximum subnetwork consists of 101 institutions and is classified into 13 clusters. For example, for 12 items in cluster 1 (color in red), the representative institution is Beihang University. 11 items in cluster 2 (color in green), the representative institution is Tsinghua University.

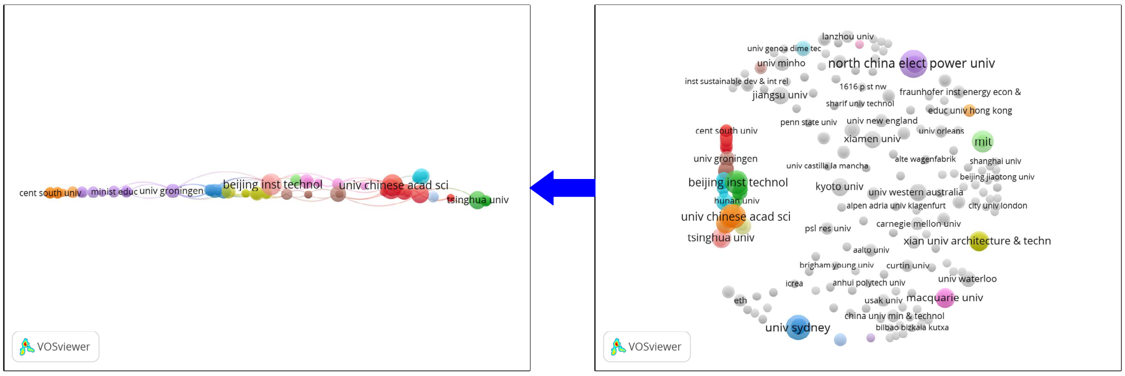

Fig. 7. The cooperative network of publishing institutions.

(3) *Influential publication sources coupling analysis*

In this subsection, the influential publication sources coupling is analyzed to discover research trends in the sources of publications. The same as before, we list the top 10 influential publication sources shown in Table 3, consisting of 10 journals according to the number of publications. The network among all influential publication sources is shown in Fig. 8.

In Table 3, we find that almost all sources belong to the energy field, including Economics, Energy & Fuels, Environmental Sciences, Green & Sustainable Science & Technology, etc. Additionally, Energy Policy published the most significant number of publications, that is, 24 publications. The journals with more than ten publications are Energy Economics (20), Energy (17), Journal of Cleaner Production (13), Applied Energy (12), and Energy Journal (10), and the remaining journals published fewer than ten papers. Furthermore, the JCR partition represents the corresponding partition of the journal related to the categories in the Journal Citation Reports. IF2020 meant the impact factor of each journal in 2020, and Applied Energy has the highest impact factor at 9.746.

In Fig. 8, the right subgraph represents the overall cooperation network among all sources, and the left subgraph expresses the maximum subnetwork of the overall cooperation network. First, the comprehensive cooperation network consists of 157 sources, and there are 40 clusters. Additionally, the far-right discrete points in Fig. 8 mean that these sources have no relation to others. Secondly, the maximum subnetwork consists of 130 sources, and it is classified into 13 clusters. For example, the first cluster contains eight items (color in red), and the representative source is Energy Policy.

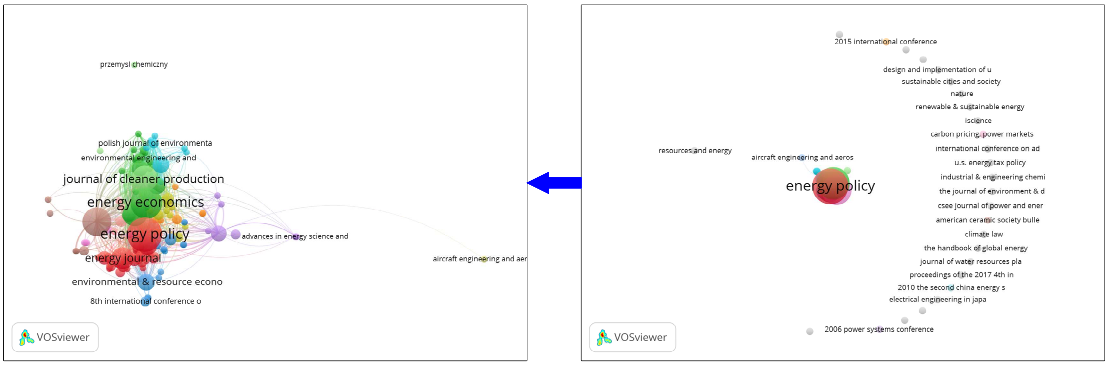

Fig. 8. The cooperative network of the publication sources

Tab. 3. Detailed information on influential journals

Rank	Institutions	TP	Citations	Links	Total link strength	Categories	JCR partition	IF$_{2020}$
1	*Energy Policy*	24	499	88	637	Economics; Energy & Fuels; Environmental Sciences	Q1; Q2; Q1	6.142
2	*Energy Economics*	20	650	85	1596	Economics	Q1	7.042
3	*Energy*	17	347	66	466	Energy & Fuels; Thermodynamics	Q1; Q1	7.147
4	*Journal of Cleaner Production*	13	200	73	1042	Engineering, Environmental; Environmental Sciences; Green & Sustainable Science & Technology	Q1; Q1; Q1	9.297
5	*Applied Energy*	12	285	76	1078	Energy & Fuels; Engineering, Chemical	Q1; Q1	9.746
6	*Energy Journal*	10	126	38	111	Economics; Energy & Fuels; Environmental Studies	Q2; Q3; Q3	2.414
7	*Climate Policy*	7	55	47	158	Environmental Studies; Public Administration	Q1; Q1	5.085
8	*Sustainability*	6	31	51	473	Environmental Sciences; Environmental Studies; Green & Sustainable Science & Technology	Q2; Q2; Q3	3.251
9	*Energies*	6	50	44	304	Energy & Fuels	Q3	3.004
10	*Environmental & Resource Economics*	6	102	43	165	Economics; Environmental Studies	Q2; Q4	2.181

(4) *Contributing authors and cooperative network*

In this subsection, the authors who published more than three publications are selected to analyze the cooperation network among the authors, and the related information is listed in Table 4. We find that Zaman, K. published the most significant number of publications, i.e., five publications, and the publications of the remaining authors are less than 5. Furthermore, Fan, J. obtained the most important number of citations from the profession, 72 times.

Table 4. The authors who published more than three publications and their information about their cooperation network

Rank	Authors	TP	Citations	Cluster	Links	Total link strength
1	Zaman, K.	5	12	1	19	29
2	Anser, M. K.	4	12	1	14	24
3	Nassani, A. A.	4	12	1	14	24
4	Fan, J.	4	72	16	6	14
5	Behnia, M.	4	38	63	3	8
6	Meybodi, M. A.	4	38	63	3	8
7	Lin, B.Q.	4	41	53	4	4
8	Wu, Y. R.	3	66	16	5	11
9	Zhao, D. T.	3	66	16	5	11
10	Li, J.	3	55	16	5	11

The cooperative network of all contributing authors is shown in Fig. 9. The left subfigure represents the overall collaborative network of 869 authors classified into 259 clusters. The discrete points mean that the authors cooperate in a specific scope. Additionally, the right sub-figure expresses the maximum sub-network of the cooperative network, in which 33 authors are involved and classified into 6 clusters. We can realize the collaborative network among authors more clearly.

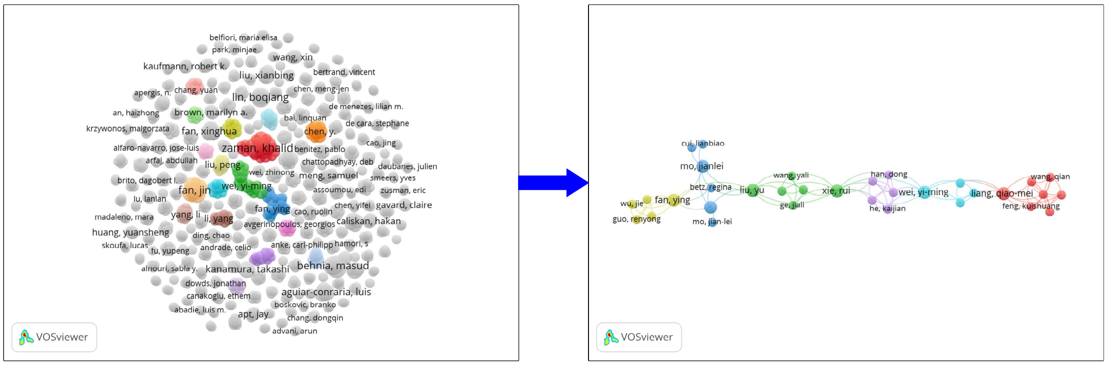

Fig. 9. The cooperative network of contributing authors

Thirdly, this subsection analyzes the citations among publications, sources, authors, institutions, and countries, the co-citations among references, sources, and authors, and highly cited publications.

(1) *Citation level*

The citation situation at the publication level is shown in Fig. 10, where the larger the size of the circle, the more extensive the citations the publication has. For example, we investigated 913 publications, and the top three cited publications are Kumar (2012) (Kumar et al., 2012) with 170 times citations, Abadie (2008) (Abadie & Chamorro, 2008) with 140 times citations, and Lee (2012) (Lee & Zhang, 2012) with 124 times citations. The number of citations for the remaining publications is less than 100.

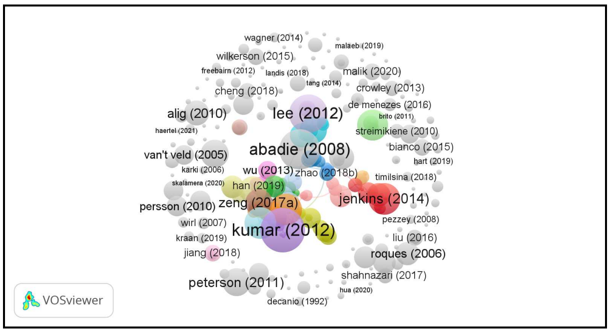

Fig. 10. The citation situation at the publication level.

By analyzing 157 sources, the citation situation at the source level is shown in Fig. 11. Additionally, the top five sources are Energy Economics (650 times), Energy Policy (499 times), Energy (347 times), Applied Energy (285 times), and Journal of Cleaner Production (200 times).

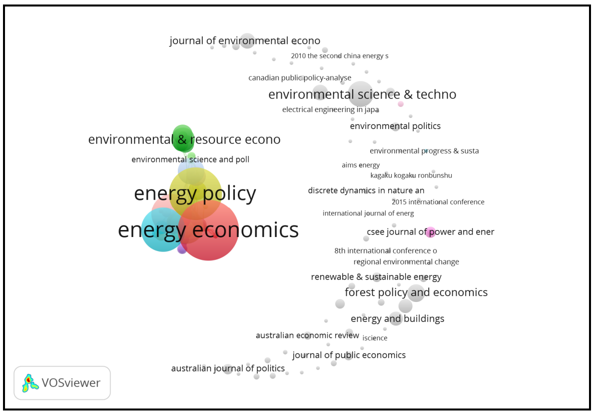

Fig. 11. Citation situation at the source level

The citation situation at the author level is shown in Fig. 12, in which the authors with the top five highest citations are Managi S. (172 times), Kumar S. (170 times), Matsuda A. (170 times), Abadie L. M. (140 times), and Chamorro J. M. (140 times).

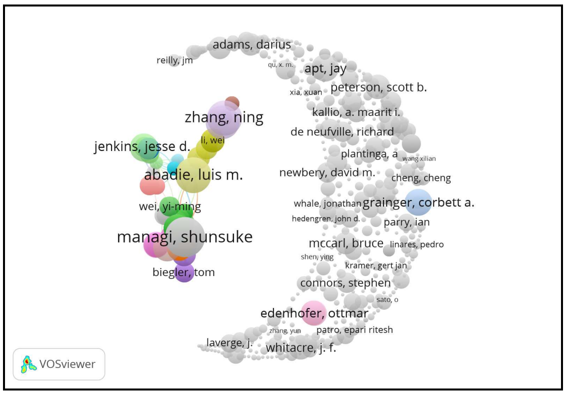

Fig. 12. The citation situation at the author level

The citation situation at the institution level is shown in Fig. 13. The right subfigure represents the overall citation network, and the left subfigure expresses the maximum citation subnetwork among institutions. Additionally, the institutions with the top five highest citations are Massachusetts Institute of Technology (180 times), Tohoku University (172 times), Nomura Securities Co., Ltd., University of Delhi, and the University of Tokyo, which have the same number of citations, that is, 170 times.

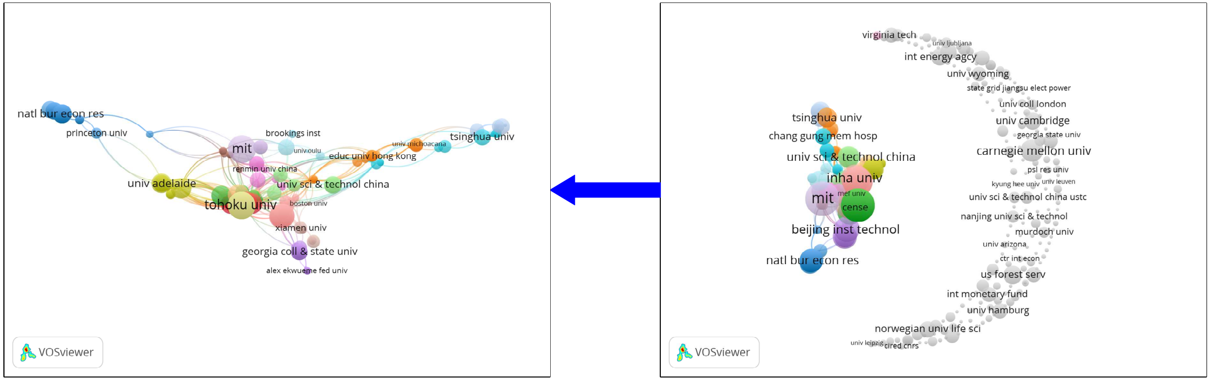

Fig. 13. Citation situation at the institution level

The citation situation at the country level is shown in Fig. 14. The right sub-figure represents the overall citation network, and the left sub-figure expresses the maximum citation sub-network among countries. Furthermore, the countries with the top five highest citations are the USA (1064 times), China (898 times), Australia (540 times), Japan (290 times), and South Korea (191 times).

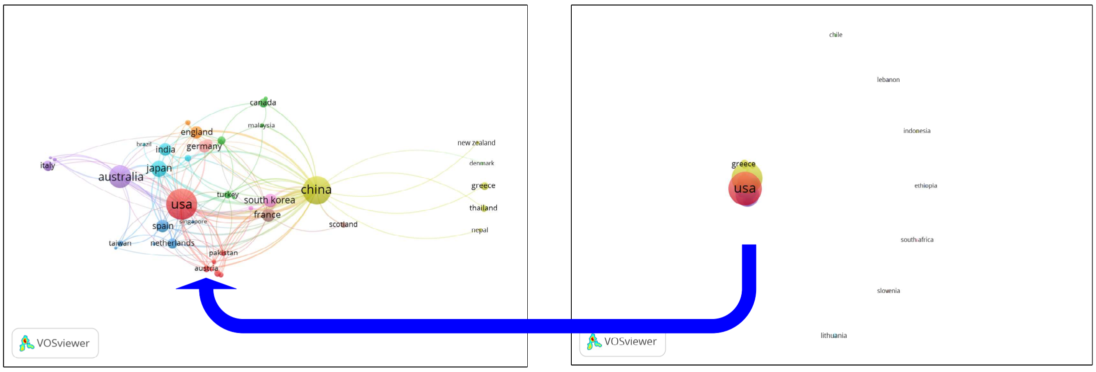

Fig. 14. The citation situation at the country level

(2) *Cocitation level*

In this subsection, the level of co-citation among the selected publications is investigated and involves the co-cited references, the co-cited sources, and the co-cited authors.

There are 20 references cited when ten is set as the minimum number of citations for a cited reference. Then the total strength of the co-citation links with other cited references is calculated, and the overall co-citation network on the cited references is shown in Fig. 15. We obtain that Alberola et al. (2008) with 29 times citations and the total link strength is 153; Creti et al. (2012) with 24 times citations and the entire link strength is 145; and Aatola et al. (2013) with 23 times citations and the total link strength is 152.

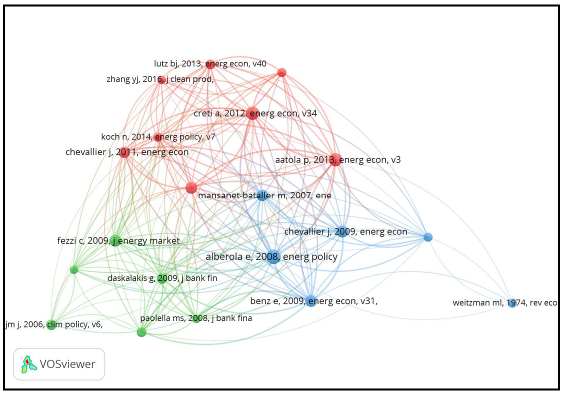

Fig. 15. The overall co-citation network on the co-cited references

We also set 10 as the minimum number of citations of a cited source, and there are 124 co-cited sources. The top 3 sources are Energy Policy with 994 times co-citations. The total link strength is 28,543, Energy Economics with 787 times co-citations, and the entire link strength is 24,280, Applied Energy with 398 times co-citations, and the link as the whole strength is 12,465. The overall co-citation network on all co-cited sources is shown in Fig. 16.

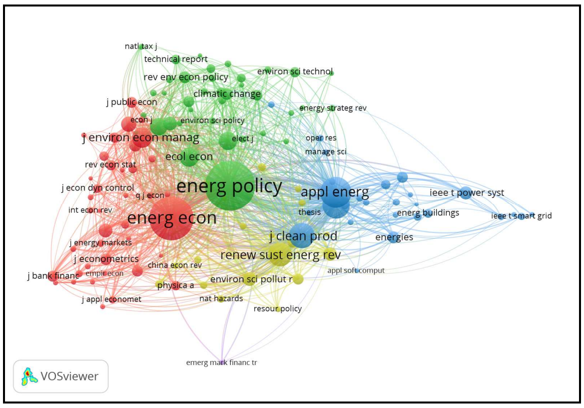

Fig. 16. The overall co-citation network on the cocited sources

By setting the minimum number of citations as 10, 119 authors are selected to show the overall co-citation network. We can also obtain the total strength of the co-citation links for each author with the other authors. The comprehensive co-citation network of the 119 co-cited authors is shown in Fig. 17. Chevallier, J. with 90 times co-citations and the total link strength is 1,372. International Energy Agency (IEA) with 54 times co-citations and the entire link strength is 431. European Commission with 49 times co-citations and the total link strength is 371.

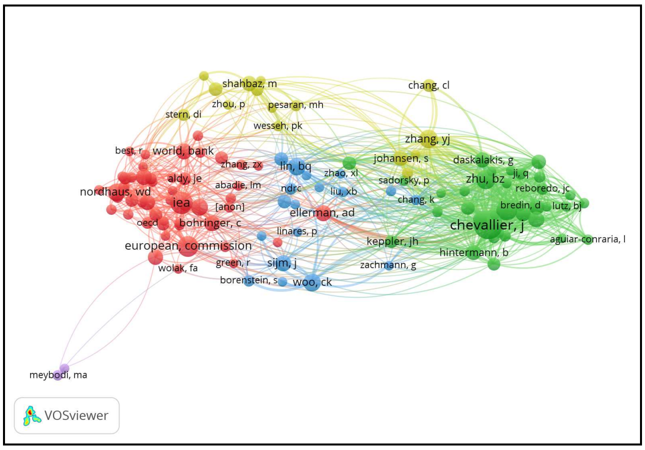

Fig. 17. The overall co-citation network on the cited authors.

Fourthly, the co-occurrence analyses of all keywords, author keywords, and critical words plus are developed.

(1) There are 1,452 keywords included in all selected publications, and we select 98 keywords that occur more than five times. Then the co-occurrence network of all keywords is shown in Fig. 18. The top ten keywords are Carbon pricing (Occurrences: 36 times), Carbon price (35), Energy (34), Emissions (33), China (32), Policy (31), Carbon tax (30), Impact (28), EU ETS (25) and Electricity (22). We find that keywords related to carbon pricing directly, such as carbon pricing, carbon price, emissions, and carbon tax, appear more frequently. Additionally, keywords closely related to carbon pricing mainly involve Impact, Policy, Energy, Market, EU ETS, Climate, etc.

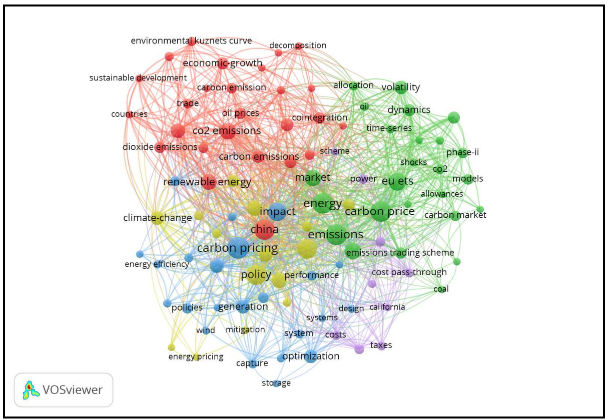

Fig. 18. The co-occurrence network of all keywords.

(2) According to the keywords given by the authors, the co-occurrence of author keywords is analyzed, and the co-occurrence network is drawn and shown in Fig. 19. From the selected publications, the keywords given by authors are 872, of which 22 keywords are set as they meet the threshold that the minimum number of occurrences of keyword is more than 5. In Fig. 19, the top ten keywords are Carbon price (35), Carbon pricing (34), Carbon tax (30), Climate change (16), China (15), EU ETS (14), Carbon emissions (12), Energy price (12), Emissions trading (10) and Carbon policy (10).

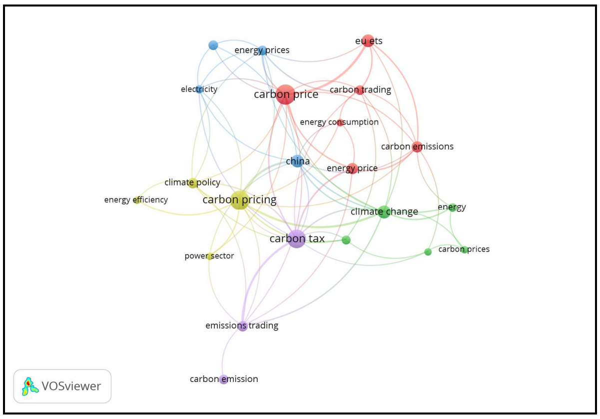

Fig. 19. *The co-occurrence network of all author keywords.*

(3) Keywords plus, generated by an automatic computer algorithm, are words or phrases that frequently appear in the titles of an article's references and not necessarily in the title of the article or as author keywords. This paper also analyzes the co-occurrence of keywords plus, and we obtain 692 keywords, in which 67 meet the threshold that the minimum number of occurrences of keywords is more than 5. The co-occurrence network of keywords plus is contracted and shown in Fig. 20. Additionally, the top 10 keywords are Policy (30), Energy (29), Emissions (29), Impact (28), Market (21), Co2 emissions (19), China (19), Model (19), Consumption (16) and Electricity (16).

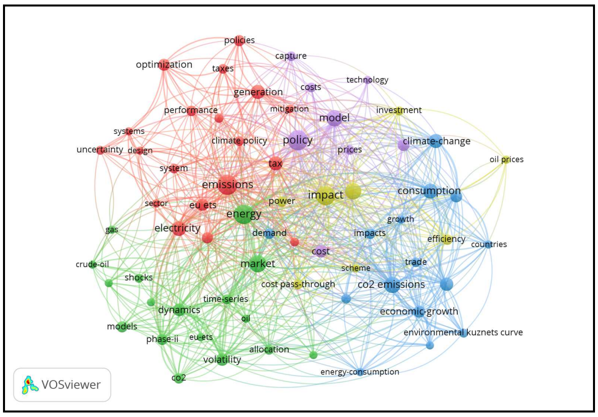

Fig. 20. *The co-occurrence network of keywords plus.*

Based on the above three kinds of co-occurrence analysis of keywords, we clearly understand the research hotspots on carbon pricing impact on the energy industry in existing publications, and these hot words are also the subject of future research. We will discuss this topic in detail in the next section.

Results

This section reviews the impact of carbon pricing on different energy industries and discusses it.

(1) *Impact of carbon pricing on different energy industries*

Along with the development of the carbon market and the setting of carbon reduction and carbon peaking targets, the effect of carbon pricing on the energy industry has become increasingly prominent in recent years, such as the investment in renewable energy and advanced technologies and the energy structure (Ji et al., 2019). Furthermore, many researchers studied that change and global warming are significantly affected by carbon emissions from fossil fuel burning, particularly coal, oil, and gas (Chang & McAleer, 2019), and then proposed that carbon price is crucial in the management and risk decision making of activities related to fossil fuel combustion (Aguiar-Conraria et al., 2018; Chang et al., 2018; Chang & McAleer, 2019; Scholtens & van der Goot, 2015; Sousa & Aguiar-Conraria, 2015). Some reviews involving the impact of carbon pricing on different energy industries are summarized below.

As a kind of fossil energy, oil is widely used worldwide, and it is also the most crucial element affecting global carbon emissions. Therefore, a growing number of countries are developing strategies to address carbon emissions from energy sources such as oil. These strategies also affect the development of the oil industry. Zheng et al. (2021) investigated the asymmetric relationship between oil shocks and China's carbon emission trading market. They proposed that oil shocks have a long-term asymmetric effect on carbon allowance prices.

For a similar reason, Ullah et al. (2020) suggested that more fossil fuel taxes and clean energy subsidies are needed for significant carbon-emitting economies. Additionally, some scholars also studied the impact of oil price fluctuations on carbon integration network design (Malaeb et al., 2019), the effectiveness of crude oil-linked carbon pricing (Kanamura, 2019), the impact of oil market uncertainty on emissions price fluctuations (Dutta, 2018), and the interaction between oil prices, carbon emissions, and GDP (Zou, 2018), etc. Furthermore, much-existing research confirmed that high carbon prices and oil prices had prompted the development of the economy, but reducing carbon emissions while ensuring growth is still the focus of future research (Belfiori, 2017; Lin & Tan, 2021; Nwani, 2017).

As we know, coal has existed as a fuel for a long time and is now the primary fuel for generating electricity in power plants worldwide. Therefore, reducing coal use is critical to reducing carbon dioxide emissions. Similarly, in promoting carbon reduction, a lot of research discussed the relations between the coal industry and carbon price strategies. Firstly, some results are discovered by building models (Jie et al., 2021; Zhang et al., 2020b), such as non-fossil fuel development and carbon pricing strategies (Jie et al., 2021), as well as the carbon price and income floors support scheme (Zhang et al., 2020b), etc. Furthermore, some studies have found that switching from coal to gas is the most cost-effective way to reduce carbon dioxide emissions (Bianco et al., 2015; Lyseng et al., 2016; Scheller et al., 2019; Wagner et al., 2014; Wu et al., 2020b). Furthermore, Zhao et al. (2018a) proposed that coal is the best predictor of a carbon price and is superior to predictions and actual carbon price trends based on raw petroleum. Zhao et al. (2017) studied the carbon price of China's carbon emission trading pilot and its influencing variables, including coal price, economy, and temperature. They found that almost all variables have significant impacts on the carbon price, among which the coal price is the critical factor. Finally, unlike the EU market, the main driver of carbon prices in China appears to be coal prices instead of oil and gas prices because the main component of China's energy mix is coal (Fan et al., 2019a).

Compared to "dirty" coal plants, "cleaner" gas plants are more environmentally friendly, and a modest carbon price can achieve significant reductions in emissions at low costs in a short period (Gugler et al., 2021). Furthermore, the research discussed the marginal effects of energy prices on carbon price varies with the distributions of carbon-energy price in EU ETS and proposed that the impact of oil and coal prices is much more significant than that of gas price (Duan et al., 2021). At present, Britain's energy policy is mainly aimed at reducing carbon emissions. They are considering raising the price of carbon that households face and facilitating changes in the carbon prices for gas and electricity use. However, the above policy does not protect all low-income families (Advani & Stoye, 2017).

As one of the clean energies, nuclear power is being developed and used in more and more countries, although the proportion is still deficient. The Paris Agreement (COP21) highlighted the need for progress in the use of low-carbon energy technologies, including nuclear power. Alternative and atomic energy needs are optimized solutions to reduce carbon damage and work better with carbon taxes on polluters. Although alternative and nuclear energies initially increase carbon damage, they will decrease in the later stages of atomic expansion. Therefore, the development of nuclear power will effectively reduce the cost of carbon pollution (Anser et al., 2021). Some studies have found that high fossil fuel prices have rekindled interest in nuclear energy. However, some specific characteristics make nuclear energy unattractive to competitive merchant generators in liberalized electricity markets (Roques et al., 2006). Therefore, there are still many obstacles to overcome in developing nuclear energy.

Wind power is a renewable, clean energy source, and it is abundant and widely distributed. Under certain technical conditions, wind power can be an essential energy source. Currently, wind energy is a comprehensive engineering technology that converts the kinetic energy of the wind into mechanical energy, electric energy, and heat energy through wind turbines. Wind power is energy-saving and environmentally protective, so the full utilization of wind power will significantly reduce fossil energy consumption and thus reduce carbon emissions. Forbes and Zampelli (2019) concluded that higher levels of wind penetration significantly reduce carbon emissions and reduce emissions by 14.6% with wind power. Furthermore, when investigating the ability of carbon pricing policies to support offshore wind power investment in China, a sensitivity analysis of the effect of carbon pricing policy shows that the impact of carbon pricing policy on wind power investment seems to be more significant when the investment risk is higher. Wind curtailment is more meaningful (Tu et al., 2018). Feed-in tariff policies that promote wind power to replace thermal power and a well-functioning carbon price mechanism significantly impact carbon dioxide reduction. They can be coordinated to achieve emission reduction (Lin & Chen, 2018). Furthermore, Petitet et al. (2016) proposed that market-driven development of wind power seems to be possible only based on stable and high carbon prices. In addition to the above research and technical level, some experts have made the carbon price level a condition for wind deployment, giving it an edge over fossil fuel technologies and an effective wind support policy (Gavard, 2016).

With the decrease in fossil fuels, solar power, as new renewable energy, has become an essential part of human energy use and has been continuously developed. Solar power can be used in the photothermal and photoelectric conversion. In recent years, studies are developed that involve solar energy policy, such as the economic profitability of solar photovoltaic systems (Huuki et al., 2021), (Kruitwagen et al., 2021), the relationship between the time-of-use electricity price and solar panels (Liang et al., 2020), boosting the demand for photovoltaic projects (Chen & Bi, 2018), etc. Additionally, Best and Burke (2018) analyzed the role of policies and preferences in the national adoption of solar and wind technologies. They proposed that countries with a carbon price and a higher proportion of people concerned about climate change have a higher proportion of solar energy.

(2) *Models for optimal carbon pricing*

In this subsection, some constructed models for optimal carbon pricing are summarized in Table 5 to show the impact of carbon policies on the energy structure (An & Zhai, 2020; Chu et al., 2020; Galinis et al., 2020; Han et al., 2019; Li et al., 2021; Li et al., 2020a; Meng et al., 2020; Mo et al., 2021; Tsao et al., 2021; Wilkerson et al., 2015; Zeng et al., 2021; Zhang et al., 2019; Zhang et al., 2021; Zhu et al., 2019). For example, integrated assessment models (IAM) were used to assess the impact of carbon policies on the energy structure (Wilkerson et al., 2015), and the ARMA-GARCH model was used to discuss the characteristics of carbon price fluctuation in seven regions of China (Zeng et al., 2021), the MRSVD-MFO-ELM model was used to make carbon price forecasts in the European Union (EU) and China (Zhang et al., 2019). Established models are advantageous in redefining the carbon price and optimizing the energy structure.

Tab. 5. Some modes constructed for optimal carbon pricing.

References	model	Description
(Wilkerson et al., 2015)	Integrated assessment models (IAM)	Assess the impact of carbon policies on the energy structure
(Zeng et al., 2021)	ARMA-GARCH model	Discuss the characteristics of the fluctuation of carbon prices in seven regions of China.
(Zhang et al., 2019)	MRSVD-MFO-ELM model	Carbon price forecast in the European Union (EU) and China
(Zhang et al., 2021)	An optimal configuration planning and dispatch model	Compare the performance of the three heating modes
(Mo et al., 2021)	A Real Options-Based Model	Quantify the implied risk for newly built coal plants to become stranded assets by carbon pricing.
(Li et al., 2021)	Time-varying parameter vector autoregressive (TVP-VAR) model	Analyze the impacts of different drivers on the pricing of EU carbon futures in various periods
(Tsao et al., 2021)	Sustainable ADMS (SADMS)	Provide demand response programs with various energy pricing schemes that correspond to different customers and energy consumption loads.
(An & Zhai, 2020)	SVR-DEA model	Calculate the prices of increasing block carbon tax (IBCT) and flat carbon tax (FCT).
(Galinis et al., 2020)	Energy System Optimization Model	Assess the resilience of the planned energy system to possible disruptions.
(Chu et al., 2020)	Semiparametric Quantile Regression Model	Explore the effects of energy prices and macroeconomic drivers on carbon prices in different quantiles.
(Li et al., 2020a)	BP neural network model	Simulate the long-term trends of carbon futures prices in six scenarios.
(Meng et al., 2020)	GTAP-E model	Simulates the effect of a national ETS in China
(Han et al., 2019)	Combination-mixed data sampling regression model and backpropagation neural network	Perform real-time forecasting of weekly carbon prices in China's Shenzhen carbon market
(Zhu et al., 2019)	Multiscale analysis model	Explore and identify the carbon price drivers at different timescales

(3) *Carbon pricing policies and their impact on the energy industry*

Carbon pricing can internalize the negative externalities caused by environmental pollution that the commodity market cannot solve within the scope of the market to maximize social benefits (Stern and Stiglitz, 2021), (Klenert et al., 2018). In order to do this, greenhouse gas emitters should pay for the right to emit emissions to compensate the rest of the economy for lost benefits. This process can be known as carbon pricing. The carbon pricing mechanism is generally divided into carbon tax and carbon emission trading systems (Lili et al., 2015).

A carbon tax is a tax on carbon dioxide emissions. More specifically, a carbon tax is levied on fossil fuels according to their carbon content or carbon emissions to reduce carbon dioxide emissions. In recent years, many experts have studied carbon taxes, including the effect of expected energy prices on carbon taxes (Kaufmann, 1994), the decisive role of a carbon tax in limiting polluting industries and reducing carbon emissions (Zaman et al., 2021), the carbon tax pricing in China's thermal power industry (An & Zhai, 2020), the carbon tax has accelerated the spread of cogeneration systems (Zhang et al., 2020a), the optimal carbon tax rates of countries under noncooperative and cooperative scenarios (Chan, 2020), the impact of carbon tax policy on energy price decline (Guo et al., 2019), etc. A carbon tax combined with strong energy efficiency policies will produce synergies to achieve deep decarbonization targets (Brown & Li, 2019). However, there are some gaps in the carbon tax. First, even though the carbon tax reduced carbon dioxide emissions by a small amount from oil and gas use, this was offset by an increase in emissions from increased electricity consumption by some companies (Hyland & Haller, 2018). Second, under recent technology and cost projections, Palmer et al. (2018) found that a carbon tax would lead to a shift in power generation from coal and gas to renewables rather than coal to gas and renewables. Furthermore, the rational design of climate mitigation policies, such as carbon taxes, can face many challenges, including the strategic behavior of fossil fuel producers and the vast uncertainties surrounding the climate system (Zhang & Zhu, 2017).

As an effective economic tool to deal with climate change, carbon emission trading has received a great deal of attention in recent years (Chiu et al., 2015; Diaz-Trujillo et al., 2019; Fan et al., 2019b; Hua, 2020; Qi & Choi, 2020; Zhou & Li, 2018). For example, Qi and Choi (2020) analyzed the trading mechanism of China's carbon emission trading pilot market, suggesting that policymakers should levy a carbon tax or carbon emission quota to adjust the market price to stimulate coal enterprises' willingness to reduce carbon dioxide emissions. The carbon tax policy plays a vital role in curbing carbon dioxide emissions but has no apparent effect on optimizing the energy structure in the short term. Therefore, it is suggested to adopt the carbon tax and carbon emission trading policy to significantly reduce carbon dioxide emissions and optimize the energy structure (Zhao et al., 2018). Furthermore, Chiu et al. (2015) estimated the energy price equivalence of carbon taxes and emissions trading in energy markets. They proposed that the price effect of a carbon tax and carbon emission trading depends on the energy market structure in an imperfectly competitive market. On the contrary, the price effect of a carbon tax and carbon emission trading is lower than that of carbon emission trading.

Discussion

On the basis of the above analyses, some discussions are summarized as follows.

(1) For research on the influence of carbon price on the fuel conversion strategy of power generation companies, the switch from coal to gas in power generation companies is significant in tackling air pollution and mitigating climate change (Zhao et al., 2021). Additionally, the energy transition movement must place social and economic justice at the center of its struggle to gain broad appeal (Eaton, 2021). Therefore, with the increasing maturity of clean power generation technologies, enhancing their emission reduction capabilities and carbon trading management capabilities will enable power generation companies to occupy a more favorable position in the future low carbon energy market.

(2) Energy prices are a critical factor in reducing carbon emissions. The relationship between industrial energy prices and carbon emissions is generally non-linear, and energy prices have a significant negative impact on carbon emissions. When energy prices exceed the threshold, the negative effect on carbon emissions in energy-intensive industries is more significant (Tian & Yang, 2020). Furthermore, Ji et al. (2021) expressed that the price of oil is positively correlated with the price of carbon, the price of coal is negatively correlated with the price of carbon, and the price of carbon-intensive products will also affect the price of carbon. Therefore, for different fossil fuels, such as coal, oil, and natural gas, it will be increasingly worthwhile to study their impact on carbon pricing, such as degree, duration, and differences of impact.

(3) Overall emission levels can be further reduced by diversifying the energy mix, increasing renewable/clean energy sources, and developing policies that favor the industrial and residential use of renewable energy sources such as solar power (Malik et al., 2020). Furthermore, if a carbon pricing mechanism is in place, renewable energy policies will increase the economic cost of reducing greenhouse gas emissions and lead to a lower carbon price level (Wu et al., 2020a). In response to current pandemic developments, renewable energy generation, such as solar and wind power, has increased in the context of reduced global electricity demand due to the spread of COVID-19. Meanwhile, renewable energy power generation requires less staff, which has obvious advantages in preventing and controlling epidemics. Therefore, ambitious renewable energy policies must be matched with stronger climate policies and the realities of the COVID-19 response to achieve a reasonable carbon price.

Additionally, some challenges are discussed as follows:

(1) From research on the impact of zero-carbon investment, it is evident that the effectiveness of carbon pricing in stimulating innovation and zero-carbon investment remains a matter of theoretical debate (Lilliestam et al., 2021). For example, the influence of carbon pricing on the dispatch of the power system and the wholesale spot market price is related to a series of system conditions, operating procedures, and investment incentives, so it is not easy to minimize the actual cost per tonne of carbon reduction achieved while minimizing carbon emissions.

(2) As China's carbon market officially launches this year, one of the most critical challenges is its impact on the arid and semi-arid regions' social and economic development (Li et al., 2020a). Furthermore, carbon policies will increase the price of fossil fuels. Therefore, coordinating the relationship between carbon pricing

and traditional fossil energy subsidies is crucial. Furthermore, there is a need to have more strategic coordination of energy resources, power grid operation, and climate policy and take into account all parties' interests. Meanwhile, it is necessary to mitigate the adverse impact carbon policies can have on different industries.

(3) Although the carbon price appears to stimulate research and development intensity (innovation input), an increase in research and development intensity does not lead to a rise in industry sales and profits (innovation output) (Lin & Wesseh, 2020). Therefore, research on the relationship between carbon emissions, R&D expenditure, and carbon trading prices for different industries is also challenging research content.

(4) Some scholars argue that the energy market alone will not incentivize investors to provide fully renewable, reliable, and affordable energy systems even with a substantial carbon price. Therefore, it is necessary to find more secure measures to balance a carbon price with an efficient energy system in addition to the energy market.

(5) People pay great attention to the effect of distribution, especially the impact of policies on the poor population, thus reducing the acceptability of policies. There is also a lack of trust in governments' ability to make good use of carbon pricing revenues (Maestre-Andres et al., 2019). How can the government improve public confidence in its ability to generate revenue from carbon pricing, which is an essential step in developing a carbon pricing mechanism?

(6) Different carbon tax policies should be proposed for different industries. For example, subsidies and price changes have had little impact on energy investment and carbon intensity in the iron and steel industries. However, subsidies and fuel prices have driven investment in the chemicals sector, improving carbon emissions and energy intensity. Therefore, policymakers must adjust the rate of carbon taxes and tax recovery provisions according to the characteristics of the industry to stimulate the reduction of carbon dioxide.

Finally, we introduce future research on carbon pricing on the energy industry's impact.

According to reviews of the literature and the challenges summarized above, some future research guidelines on carbon pricing involving the energy industry are set up as follows:

(1) For the policies on carbon pricing, some future research can be listed: First, even though the carbon price appears to stimulate the intensity of R&D (Lin & Wesseh, 2020), the increased R&D does not lead to increased sales and profits for the energy industry. Therefore, to better achieve the economics of carbon pricing in a potentially risk-averse competitive world, it is necessary to implement some policies that encourage innovation in energy-intensive industries at the production stage. Additionally, considering that there is no incentive for investors to provide fully renewable, reliable, and affordable energy systems even with a substantial carbon price (Kraan et al., 2019), policymakers should focus on improving renewable energy management mechanisms, as well as combining with market incentives to achieve fully renewable, reliable and affordable power systems. Moreover, a clear policy direction for participating companies is to establish a positive and stable carbon price. Therefore, we encourage companies to adopt advanced pollution reduction technologies. Most importantly, public acceptance of carbon pricing is a prerequisite for the steady development of carbon pricing policy (Maestre-Andres et al., 2019). Therefore, the redistribution of income to vulnerable groups must be effectively combined with the funding of environmental projects such as renewable energy. Additionally, Minimum Energy Performance Standards (MEPS) can improve the energy efficiency of appliances and reduce carbon dioxide emissions. Therefore, the study on the dependency and difference between minimum energy performance standards and the carbon pricing mechanism can provide better policy suggestions to policymakers.

(2) Carbon pricing has drastically reduced carbon emissions. In the current international situation, carbon pricing incentivizes companies to find innovative ways to reduce carbon emissions (Anser et al., 2020). Therefore, converting non-renewable fuels to renewable fuels can achieve energy efficiency more efficiently, conserving natural resources through fuel burning. Furthermore, carbon pricing, food production indices, FDI inflows, and a broad money supply will reduce fossil fuel emissions over the next decade.

(3) Economists generally agree that carbon pricing is an effective policy to address externalities of energy use, but political feasibility is likely to be a persistent problem. For this issue, careful consideration of the potential factors influencing the range of carbon pricing, including environmental, social, political, and economic variables, is vital for future research.

(4) To guide investors to rational carbon trading, carbon price prediction plays a vital role in promoting carbon market management (Sun et al., 2020; Sun & Zhang, 2020). Therefore, the establishment of carbon price forecasting methods and models is also a critical research area in future research.

(5) The reduction in carbon emissions was achieved mainly by reducing coal inputs and emissions leaks rather than switching from coal to natural gas or from fossil fuels to non-fossil fuels (Huang et al., 2019). Therefore, it will be an exciting research topic in the future to discuss whether the shift from fossil to non-fossil fuels can reduce carbon emissions. Furthermore, improving energy efficiency reduces carbon emissions and has a positive economic impact but increases public and external debt. On the contrary, carbon taxes that reduce carbon emissions have positively impacted public and external debt. Therefore, these two strategies are fundamental to reducing carbon emissions and increasing growth.

(6) As we know, an emissions trading scheme (ETS) could be an effective way to combat global warming. In contrast, studies of the impact of ETS prices on energy consumption, carbon dioxide emissions, and the economy are essential prerequisites for implementing the scheme. In addition, the carbon tax is another economic measure that internalizes the cost of carbon emissions. However, it does not guarantee that emissions are kept within a specific limit, and a fixed tax may impose an unnecessary burden on the economy in the event of a recession. Therefore, it is essential to properly deal with the relationship between carbon trading opportunities and carbon taxes in future research.

Conclusions

This article investigates the impact of carbon pricing on the energy industry based on bibliometric analysis and visual study. First, we summarize existing research trends on the impact of carbon pricing on the energy industry from various social points of view. Then, we review the impact of carbon pricing on various energy industries, models for optimal carbon pricing, carbon pricing policies and their effect on the energy industry, and some discussions. Finally, some challenges were discussed, and future research on carbon pricing on the energy industry's impact was introduced.

Based on the bibliometric analysis and discussion above, carbon pricing has had a noticeable impact on the energy industry, especially in recent years of low-carbon and emission reduction. In the future, more research, such as carbon pricing policies, energy transformation, carbon price forecasting methods, and models, can be analyzed to coordinate the relationship between carbon pricing and the energy industry.

References

Aatola, P., Ollikainen, M., and Toppinen, A. (2013). Price determination in the EU ETS market: Theory and econometric analysis with market fundamentals. *Energy Economics*, 36: 380-395.

Abadie, L.M., and Chamorro, J.M. (2008). European CO2 prices and carbon capture investments. *Energy Economic*s, 30(6): 2992-3015.

Adekoya, O.B. (2021). Predicting carbon allowance prices with energy prices: A new approach. *Journal of Cleaner Production*, 282: 124519.

Advani, A., and Stoye, G. (2017). Cheaper, greener, and more efficient: rationalising UK carbon prices. *Fiscal Studies*, 38(2): 269-299.

Aguiar-Conraria, L., Soares, M.J., and Sousa, R. (2018). California's carbon market and energy prices: a wavelet analysis. *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences*, 376(2126): 20170256.

Alberola, E., Chevallier, J., and Cheze, B. (2008). Price drivers and structural breaks in European carbon prices 2005-2007. *Energy Policy*, 36(2): 787-797.

An, Y.F., and Zhai, X.Q. (2020). SVR-DEA model of carbon tax pricing for China's thermal power industry. *Science of the Total Environment*, 734: 139438.

Anser, M.K., Ahmad, M., Khan, M.A., Nassani, A.A., Askar, S.E., Zaman, K., Abro, M.M.Q., and Kabbani, A. (2021). Progress in nuclear energy with carbon pricing to achieve environmental sustainability agenda: on the edge of one's seat. *Environmental Science and Pollution Research*, 28(26): 34328-34343.

Anser, M.K., Yousaf, Z., Hishan, S.S., Nassani, A.A., Sheikh, A.Z., Vo, X.V., Zaman, K., and Abro, M.M.Q. (2020). Dynamic linkages between transportation, waste management, and carbon pricing: Evidence from the Arab World. *Journal of Cleaner Production*, 269: 122151.

Belfiori, M.E. (2017). Carbon pricing, carbon sequestration and social discounting. *European Economic Review*, 96: 1-17.

Best, R., and Burke, P.J. (2018). Adoption of solar and wind energy: The roles of carbon pricing and aggregate policy support. *Energy Policy*, 118: 404-417.

Bianco, V., Scarpa, F., and Tagliafico, L.A. (2015). Long term outlook of primary energy consumption of the Italian thermoelectric sector: Impact of fuel and carbon prices. *Energy*, 87: 153-164.

Brown, M.A., and Li, Y.F. (2019). Carbon pricing and energy efficiency: pathways to deep decarbonization of the US electric sector. *Energy Efficiency*, 12(2): 463-481.

Chan, Y.T. (2020). Collaborative optimal carbon tax rate under economic and energy price shocks: A dynamic stochastic general equilibrium model approach. *Journal of Cleaner Production*, 256: 120452.

Chang, C.L., Mai, T.K., and McAleer, M. (2018). Pricing carbon emissions in China. *Annals of Financial Economics*, 13(3): 1850014.

Chang, C.L., and McAleer, M. (2019). Modeling latent carbon emission prices for Japan: Theory and practice. *Energies*, 12(21): 1-21.

Chen, W.D., and Bi, Y.J. (2018). Electricity price subsidy or carbon-trading subsidy: which is more efficient to develop photovoltaic power generation from a government perspective? *Mitigation and Adaptation Strategies for Global Change*, 23(5): 667-683.

Chiu, F.P., Kuo, H.I., Chen, C.C., and Hsu, C.S. (2015). The energy price equivalence of carbon taxes and emissions trading-Theory and evidence. *Applied Energy*, 160: 164-171.

Chu, W.J., Chai, S.L., Chen, X., and Du, M. (2020). Does the impact of carbon price determinants change with the different quantiles of carbon prices? Evidence from China ETS pilots. *Sustainability*, 12(14): 1-19.

Creti, A., Jouvet, P.A., and Mignon, V. (2012). Carbon price drivers: Phase I versus Phase II equilibrium? *Energy Economics*, 34(1): 327-334.

Diaz-Trujillo, L.A., Tovar-Facio, J., Napoles-Rivera, F., and Ponce-Ortega, J.M. (2019). Effective use of carbon pricing on climate change mitigation projects: Analysis of the biogas supply chain to substitute liquefied-petroleum gas in Mexico. *Processes*, 7(10): 668.

Duan, K., Ren, X.H., Shi, Y.K., Mishra, T., and Yan, C. (2021). The marginal impacts of energy prices on carbon price variations: Evidence from a quantile-on-quantile approach. *Energy Economics*, 95: 105131.

Dutta, A. (2018). Modeling and forecasting the volatility of carbon emission market: The role of outliers, time-varying jumps and oil price risk. *Journal of Cleaner Production*, 172: 2773-2781.

Eaton, E. (2021). Approaches to energy transitions: Carbon pricing, managed decline, and/or green new deal? *Geography Compass*, 15(2): 12554.

Elkerbout, M. (2020). The changing role of carbon pricing in the EU. *National Institute Economic Review*, 251: R13-R24.

Fan, X.H., Li, X.X., and Yin, J.L. (2019a). Dynamic relationship between carbon price and coal price: perspective based on Detrended Cross-Correlation Analysis. *Energy Procedia*, 158(1): 3470-3475(6).

Fan, X.H., Zhang, Y., and Yin, J.L. (2019b). Evolutionary analysis of a three-dimensional carbon price dynamic system. *Sustainability*, 11(1): 116.

Forbes, K.F., and Zampelli, E.M. (2019). Wind energy, the price of carbon allowances, and CO2 emissions: Evidence from Ireland. *Energy Policy*, 133: 110871.

Fu, Y.P., Huang, G.H., Xie, Y.L., Liao, R.F., and Yin, J.N. (2020). Planning electric power system under carbon-price mechanism considering multiple uncertainties - A case study of Tianjin. *Journal of Environmental Management*, 269: 110721.

Galinis, A., Martisauskas, L., Jaaskelainen, J., Olkkonen, V., Syri, S., Avgerinopoulos, G., and Lekavicius, V. (2020). Implications of carbon price paths on energy security in four Baltic region countries. *Energy Strategy Reviews*, 30: 100509.

Gavard, C. (2016). Carbon price and wind power support in Denmark. *Energy Policy*, 92: 455-467.

Gebreslassie, M.G. (2021). Comparative assessment of the challenges faced by the solar energy industry in Ethiopia before and during the COVID-19 pandemic. *Wiley Interdisciplinary Reviews-Energy and Environment*, e418.

Gugler, K., Haxhimusa, A., and Liebensteiner, M. (2021). Effectiveness of climate policies: Carbon pricing vs. subsidizing renewables. *Journal of Environmental Economics and Management*, 106: 102405.

Guo, Z.Q., Zhang, X.P., Wang, D.J., and Zhao, X.N. (2019). The impacts of an energy price decline associated with a carbon tax on the energy-economy-environment system in China. *Emerging Markets Finance and Trade*, 55(12): 2689-2702.

Hepburn, C. (2006). Regulation by Prices, Quantities, or Both: A Review of Instrument Choice. *Oxford Review of Economic Policy*, 22(2): 226-247, https://doi.org/10.1093/oxrep/grj014.

Hepburn, C. and Schwarz, M. (2020). Climate Change: Answer to Common Questions, Oxford Smith School of Enterprise and the Environment, Pictet group.

Hepburn, C., Adlen, E., Beddington, J., Carter, E.A., Fuss, S., Mac Dowell, Minx, J.C., Smith, P., and Williams, C.K. (2019). The technological and economic prospects for CO2 utilization and removal. *Nature*, 575: 87-97. https://doi.org/10.1038/s41586-019-1681-6.

Han, M., Ding, L.L., Zhao, X., and Kang, W.L. (2019). Forecasting carbon prices in the Shenzhen market, China: The role of mixed-frequency factors. *Energy*, 171: 69-76.

Hua, H. (2020). Considering price competition in enterprise decisions under a low carbon economy background. Environmental Engineering and Management Journal, 19(9): 1507-1518.

Huang, L., and Zhou, Y.S. (2019). Carbon prices and fuel switching: A quasi-experiment in electricity markets. *Environmental and Resource Economics*, 74(1): 53-98.

Huuki, H., Karhinen, S., Book, H., Ding, C., and Ruokamo, E. (2021). Residential solar power profitability with thermal energy storage and carbon-corrected electricity prices. *Utilities Policy*, 68: 101157.

Hyland, M., and Haller, S. (2018). Firm-level estimates of fuel substitution: An application to carbon pricing. *Energy Journal*, 39(6): 71-97.

Ji, C.J., Hu, Y.J., Tang, B.J., and Qu, S. (2021). Price drivers in the carbon emissions trading scheme: Evidence from Chinese emissions trading scheme pilots. *Journal of Cleaner Production*, 278: 123469.

Ji, C.J., Li, X.Y., Hu, Y.J., Wang, X.Y., and Tang, B.J. (2019). Research on carbon price in emissions trading scheme: a bibliometric analysis. *Natural Hazards*, 99(3): 1381-1396.

Jie, D.F., Xu, X.Y., and Guo, F. (2021). The future of coal supply in China based on non-fossil energy development and carbon price strategies. *Energy*, 220: 119644.

Kanamura, T. (2019). Supply-side perspective for carbon pricing. *Quantitative finance and economics*, 3(1): 109-123.

Kaufmann, R.K. (1994). The effect of expected energy prices on energy demand-implications for energy-conservation and carbon taxes. *Resource and Energy Economics*, 16(2): 167-188.

Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., and Stern, N. (2018). Making carbon pricing work for citizens. *Nature Clim Change*, 8: 669-677, https://doi.org/10.1038/s41558-018-0201-2

Kraan, O., Kramer, G.J., Nikolic, I., Chappin, E., and Koning, V. (2019). Why fully liberalised electricity markets will fail to meet deep decarbonisation targets even with strong carbon pricing. *Energy Policy*, 131: 99-110.

Kruitwagen, L., Story, K.T., Friedrich, J., Byers, L., Skilman, S. and Hepburn, C. (2021). A global inventory of photovoltaic solar energy generating units. *Nature*, 598: 604-610.

Kumar, K.R., Dashora, K., Krishnan, N., Sanyal, S., Chandra, H., Dharmaraja, S., and Kumari, V. (2021). Feasibility assessment of renewable energy resources for tea plantation and industry in India-A review. *Renewable and Sustainable Energy Reviews*, 145: 111083.

Kumar, S., Managi, S., and Matsuda, A. (2012). Stock prices of clean energy firms, oil and carbon markets: A vector autoregressive analysis. *Energy Economics*, 34(1): 215-226.

Lee, M., and Zhang, N. (2012). Technical efficiency, shadow price of carbon dioxide emissions, and substitutability for energy in the Chinese manufacturing industries. *Energy Economics*, 34(5): 1492-1497.

Li, P., Zhang, H., Yuan, Y.N., and Hao, A.M. (2021). Time-varying impacts of carbon price drivers in the EU ETS: A TVP-VAR Analysis. *Frontiers in Environmental Science*, 9: 651791.

Li, W., Sun, W., Li, G.M., Jin, B.H., Wu, W., Cui, P.F., and Zhao, G.H. (2018). Transmission mechanism between energy prices and carbon emissions using geographically weighted regression. *Energy Policy*, 115: 434-442.

Li, Z.P., Yang, L., Li, S.R., and Yuan, X.L. (2020a). The long-term trend analysis and scenario simulation of the carbon price based on the energy-economic regulation. *International Journal of Climate Change Strategies and Management*, 12(5): 653-668.

Li, Z.P., Yang, L., Zhou, Y.N., Zhao, K., and Yuan, X.L. (2020b). Scenario simulation of the EU carbon price and its enlightenment to China. *Science of the Total Environment*, 723: 137982.

Liang, J., Liu, P.F., Qiu, Y.M., Wang, Y.D., and Xing, B. (2020). Time-of-use electricity pricing and residential low-carbon energy technology adoption. *Energy Journal*, 41(3): 1-37.

Lili, C., Li, H., Feng, H., and Yuting, H. (2015). The comparative study on carbon taxes and carbon trading mechanisms under conditions of uncertainty. In: 2015 International Conference on Logistics, Informatics and Service Sciences (LISS). doi:10.1109/liss.2015.7369647

Lilliestam, J., Patt, A., and Bersalli, G. (2021). The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical ex-post evidence. *Wiley Interdisciplinary Reviews-Climate Change*, 12(1): e681.

Lin, B.Q., and Chen, Y.F. (2018). Carbon price in China: A CO2 abatement cost of wind power perspective. *Emerging Markets Finance and Trade*, 54(7): 1653-1671.

Lin, B.Q., and Tan, Z.Z. (2021). How much impact will low oil price and carbon trading mechanism have on the value of carbon capture utilization and storage (CCUS) project? Analysis based on real option method. *Journal of Cleaner Production*, 298: 126768.

Lin, B.Q., and Wesseh, P.K. (2020). On the economics of carbon pricing: Insights from econometric modeling with industry-level data. Energy Economics, 86: 104678.

Liu, P.K., and Lu, C.Y. (2021). Strategic analysis and development plan design on digital transformation in the energy industry: A global perspective. *International Journal of Energy Research*, doi:10.1002/er.7032

Lyseng, B., Rowe, A., Wild, P., English, J., Niet, T., and Pitt, L. (2016). Decarbonising the Alberta power system with carbon pricing. *Energy Strategy Reviews*, 10: 40-52.

Maestre-Andres, S., Drews, S., and van den Bergh, J. (2019). Perceived fairness and public acceptability of carbon pricing: a review of the literature. *Climate Policy*, 19(9): 1186-1204.

Malaeb, R., Tarhini, H., and Alnouri, S.Y. (2019). Capturing the Effects of Oil Price Uncertainty in Carbon Integration Network Design. *Industrial and Engineering Chemistry Research*, 58(8): 3131-3145.

Malik, M.Y., Latif, K., Khan, Z., Butt, H.D., Hussain, M., and Nadeem, M.A. (2020). Symmetric and asymmetric impact of oil price, FDI and economic growth on carbon emission in Pakistan: Evidence from ARDL and non-linear ARDL approach. *Science of the Total Environment*, 726: 138421.

Meng, S.M., Siriwardana, M., and Shen, Y. (2020). The impact of a national carbon price on China. *Journal of the Asia Pacific Economy*, 18: 1777757.

Mintz-Woo, K., Dennig, F., Liu, H.X., and Schinko, T. (2020). Carbon pricing and COVID-19. *Climate Policy*, 9: 1831432.

Mo, J.L., Cui, L.B.A., and Duan, H.B. (2021). Quantifying the implied risk for newly-built coal plant to become stranded asset by carbon pricing. *Energy Economics*, 99: 105286.

Nelson, T., Kelley, S., and Orton, F. (2012). A literature review of economic studies on carbon pricing and Australian wholesale electricity markets. *Energy Policy*, 49: 217-224.

Nwani, C. (2017). Causal relationship between crude oil price, energy consumption and carbon dioxide (CO2) emissions in Ecuador. *Opec Energy Review*, 41(3): 201-225.

Palmer, K., Paul, A., and Keyes, A. (2018). Changing baselines, shifting margins: How predicted impacts of pricing carbon in the electricity sector have evolved over time. *Energy Economics*, 73: 371-379.

Petitet, M., Finon, D., and Janssen, T. (2016). Carbon price instead of support schemes: Wind power investments by the electricity market. *Energy Journal*, 37(4): 109-140.

Qi, C., and Choi, Y. (2020). A study on the CO2 marginal abatement cost of coal-fueled power plants: is the current price of China pilot carbon emission trading market rational? *Carbon Management*, 11(3): 303-314.

Qin, Y., Wang, X.X., Xu, Z.S., Skare, M. (2021). The impact of poverty cycles on economic research: Evidence from econometric analysis. *Economic Research-Ekonomska Istraživanja*, 34(1): 152-171.

Roques, F.A., Nuttall, W.J., Newbery, D.M., de Neufville, R., and Connors, S. (2006). Nuclear power: A hedge against uncertain gas and carbon prices? *Energy Journal*, 27(4): 1-23.

Scheller, F., Alkhatib, H., Kondziella, H., Graupner, S., Bruckner, T., and Ieee. (2019). Future merit order dynamics: A model-based impact analysis of ambitious carbon prices on the electricity spot market in Germany. In: 16th International Conference on the European Energy Market.

Scholtens, B., and van der Goot, F. (2015). Carbon prices and firms' financial performance: an industry perspective. *Carbon Management*, 5(5-6): 491-505.

Sousa, R., and Aguiar-Conraria, L. (2015). Energy and carbon prices: a comparison of interactions in the European Union Emissions Trading Scheme and the Western Climate Initiative market. *Carbon Management*, 6(3-4): 129-140.

Stern, N., and Stiglitz, J.E. (2021). The Social Cost of Carbon, Risk, Distribution, Market Failures: An Alternative Approach, NBER Working Papers 28472, National Bureau of Economic Research.

Streimikiene, D. (2010). Comparative assessment of future power generation technologies based on carbon price development. *Renewable and Sustainable Energy Reviews*, 14(4): 1283-1292.

Sun, W., Sun, C.P., and Li, Z.Q. (2020). A hybrid carbon price forecasting model with external and internal influencing factors considered comprehensively: A case study from China. *Polish Journal of Environmental Studies*, 29(5): 3305-3316.

Sun, W., and Zhang, J.J. (2020). Carbon price prediction based on ensemble empirical mode decomposition and extreme learning machine optimized by improved bat algorithm considering energy price factors. *Energies*, 13(13): 1-22.

Tian, Y.X., and Yang, X.M. (2020). Asymmetric effects of industrial energy prices on carbon productivity. *Environmental Science and Pollution Research*, 27(33): 42133-42149.

Tsao, Y.C., Thanh, V.V., and Lu, J.C. (2021). Sustainable advanced distribution management system design considering differential pricing schemes and carbon emissions. *Energy*, 219: 119596.

Tu, Q., Betz, R., Mo, J.L., Fan, Y., and Liu, Y. (2018). Can carbon pricing support onshore wind power development in China? An assessment based on a large sample project dataset. *Journal of Cleaner Production*, 198: 24-36.

Ullah, S., Chishti, M.Z., and Majeed, M.T. (2020). The asymmetric effects of oil price changes on environmental pollution: evidence from the top ten carbon emitters. *Environmental Science and Pollution Research*, 27(23): 29623-29635.

Wagner, L., Molyneaux, L., and Foster, J. (2014). The magnitude of the impact of a shift from coal to gas under a Carbon Price. *Energy Policy*, 66: 280-291.

Wang, X.X., Chang, Y.R., Xu, Z.S., Wang, Z.D., Kadirkamanathan, V. (2020). 50th anniversary of International Journal of Systems Science: A comprehensive bibliometric analysis. *International Journal of Systems* Science, doi.org/10.1080/00207721.2020.1862937.

Wilkerson, J.T., Leibowicz, B.D., Turner, D.D., and Weyant, J.P. (2015). Comparison of integrated assessment models: Carbon price impacts on US energy. *Energy Policy*, 76: 18-31.

Wu, J., Fan, Y., Timilsina, G., Xia, Y., and Guo, R.Y. (2020a). Understanding the economic impact of interacting carbon pricing and renewable energy policy in China. *Regional Environmental Change*, 20(3): 74.

Wu, Q., Wang, M.G., and Tian, L.X. (2020b). The market-linkage of the volatility spillover between traditional energy price and carbon price on the realization of carbon value of emission reduction behavior. *Journal of Cleaner Production*, 245: 118682.

Yu, D.J., Xu, Z.S., Pedrycz, W, Wang, WR. (2017). Information Sciences 1968-2016: A retrospective analysis with text mining and bibliometric. *Information Sciences*, 418: 619-634.

Zaman, K., Aziz, A. R.A., Sriyanto, S., Sasmoko, Indrianti, Y., and Jambari, H. (2021). The role of solar energy demand in the relationship between carbon pricing and environmental degradation: A blessing in disguise. *Journal of Public Affairs*, doi:10.1002/pa.2702

Zeng, S., Zhang, H., Qu, Y.W., and Zeng, B.Y. (2021). Study on price fluctuation and influencing factors of regional carbon emission trading in China under the background of high-quality economic development. *International Energy Journal*, 21(2): 201-211.

Zhang, L.T., Gao, W.J., Yang, Y.W., and Qian, F.Y. (2020a). Impacts of investment cost, energy prices and carbon tax on promoting the combined cooling, heating and power (CCHP) system of an amusement park resort in Shanghai. *Energies*, 13(16): 4252.

Zhang, X., Zhang, C.C., and Wei, Z.Q. (2019). Carbon price forecasting based on multi-resolution singular value decomposition and extreme learning machine optimized by the moth-flame optimization algorithm considering energy and economic factors. *Energies*, 12(22): 4283.

Zhang, X.B., and Zhu, L. (2017). Strategic carbon taxation and energy pricing under the threat of climate tipping. *Economic Modelling*, 60: 352-363.

Zhang, X.H., Gan, D.M., Wang, Y.L., Liu, Y., Ge, J.L., and Xie, R. (2020b). The impact of price and revenue floors on carbon emission reduction investment by coal-fired power plants. *Technological Forecasting and Social Change*, 154: 119961.

Zhang, Y.J., Hao, J.H., Ge, Z.H., Zhang, F.X., and Du, X.Z. (2021). Optimal clean heating mode of the integrated electricity and heat energy system considering the comprehensive energy-carbon price. *Energy*, 231: 120919.

Zhao, X., Han, M., Ding, L.L., and Kang, W.L. (2018a). Usefulness of economic and energy data at different frequencies for carbon price forecasting in the EU ETS. *Applied Energy*, 216: 132-141.

Zhao, X.G., Zhang, W.B., Wang, H., Zhou, Y., and Zhao, Y.Z. (2021). The influence of carbon price on fuel conversion strategy of power generation enterprises-A perspective of Guangdong province. *Journal of Cleaner Production*, 305: 126749.

Zhao, X.L., Zou, Y., Yin, J.L., and Fan, X.H. (2017). Cointegration relationship between carbon price and its factors: evidence from structural breaks analysis. *Energy Procedia*, 142: 2503-2510.

Zhao, Y.H., Li, H., Xiao, Y.L., Liu, Y., Cao, Y., Zhang, Z.H., Wang, S., Zhang, Y.F., and Ahmad, A. (2018b). Scenario analysis of the carbon pricing policy in China's power sector through 2050: Based on an improved CGE model. *Ecological Indicators*, 85: 352-366.

Zheng, Y., Zhou, M., and Wen, F.H. (2021). Asymmetric effects of oil shocks on carbon allowance price: Evidence from China. *Energy Economics*, 97: 105183.

Zhou, K.L., and Li, Y.W. (2018). An empirical analysis of carbon emission price in China. *Energy Procedia*, 152(1): 823-828.

Zhu, B.Z., Ye, S.X., Han, D., Wang, P., He, K.J., Wei, Y.M., and Xie, R. (2019). A multiscale analysis for carbon price drivers. *Energy Economics*, 78: 202-216.

Zou, X.H. (2018). VECM model analysis of carbon emissions, GDP, and international crude oil prices. *Discrete Dynamics in Nature and Society*, 2018: 1-11.