

Article

Research on the Policy Analysis of Sustainable Energy Based on Policy Knowledge Graph Technology—A Case Study in China

Yuechi Sun ¹, Haiyan Liu ^{1,*}, Yu Gao ¹ and Minrui Zheng ²¹ School of Economics and Management, China University of Geosciences (Beijing), Beijing 100083, China² School of Public Administration and Policy, Renmin University of China, Beijing 100872, China

* Correspondence: liuhy@cugb.edu.cn; Tel.: +86-010-82321343

Abstract: Nowadays, geopolitical, extreme weather and other emergencies have exacerbated the global energy crisis, and thus, have increased the urgency of the world's transition to sustainable energy. Sustainable energy policies play an important role in the process of sustainable energy transformation. The research on sustainable energy policy is mainly carried out through conventional qualitative and quantitative methods, in which bibliometrics and meta-analysis methods are paid attention to; however, the mining and analysis of the semantics of the relationships between policies are ignored. This paper uses knowledge graph technology to build a knowledge graph of China's sustainable energy policy by using 10,815 open official documents of sustainable energy policy issued by China from 1981 to 2022. It forms the relevant policy archive storage and details related organizations. The legal source can be traced through the graph database, where the powerful synergy can be seen, and the policy focus can be monitored. In terms of structural data, this paper uses graph algorithms to identify key policy nodes at different stages, to identify the key government departments for policy issuance and cluster policy issuance departments, and it investigates China's policy evolution in the issue of sustainable energy policies, the evolution of policy issuance departments, and the power co-evolution process between policy issuance departments. The research found that: (1) China's sustainable energy policy was initiated in environmental protection, and the relevant policies on collecting pollution charges has continued to play an important policy node. Additionally, the three versions of the *Environmental Protection Law of the People's Republic of China* have successively become the main legal source of other sustainable energy transformation policies. (2) The prominent feature of China's sustainable energy policy transformation has involved transforming the process where the issuance of policies came from a single department to the joint issuance of documents by multiple departments. The joint exercise of government functions and powers by multiple departments jointly promotes sustainable energy policies' implementation and play. (3) In the future, when formulating sustainable energy policies, the Chinese government should focus on the strategic and systematic aspects of the policies, so that the sustainable energy policies can meet both short-term and long-term development goals. At the same time, the synergy of various policies and measures should be fully played in implementing sustainable energy policies. The establishment of the policy knowledge graph based on publicly-open official documents can facilitate the analysis and visualization of sustainable energy policies, providing new ideas for policy research. This paper introduces the knowledge graph, graph machine learning algorithms and big data technology, which can deepen the depth and breadth of people's research on sustainable energy policy. This study will help the public policy formulation work in the future and has a positive reference value for the evaluation of the implementation effect of policy objectives.



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Keywords: sustainable energy policy; knowledge graph; graph algorithms; policy evolution

1. Introduction

With the rapid increase in the human demand for energy, a large number of greenhouse gases and polluting gases are produced in the process of energy consumption [1–3].

At the same time, global warming is intensifying. It is estimated that the global temperature will rise by 1.5 °C from 2030 to 2052 [4]. In order to cope with extreme weather (e.g., high temperatures, drought and other extreme weather and climate events) and serious environmental pollution, and also achieve green and low-carbon sustainable development, this has become one of the most challenging issues in the process of sustainable human development in the 21st century. Fossil energy plays an important role in the global economy. It will be very difficult to reduce the proportion of fossil energy used to mitigate climate change [5]. In recent years, various countries and regions around the world have made unremitting efforts to save energy, reduce emissions and protect the ecological environment [6,7]. Renewable energy has great potential to reduce fossil energy consumption and carbon dioxide emissions [8,9]. Globally, renewable and fossil energy are highly replaceable [10]; consequently, both developing and developed economies are now focused on developing and using renewable energy [10]. In order to achieve clean and sustainable economic growth, the use of renewable energy is also conducive to reducing carbon emissions and improving the climate environment [11]. China's energy consumption structure, which has been dominated by fossil energy for a long time, has supported the rapid development of China's society and economy on the one hand, and has also caused the problem of ecological environment pollution on the other [12]. In 2019, China's oil imports ranked first in the world, and its dependence on foreign oil exceeded 70% [13]. According to the 2021 World Energy Statistical Review released by BP, China was the largest coal energy consumer and the largest carbon dioxide emitter in 2020 [14]. Therefore, scholars [15–17] have pointed out that increasing the proportion of renewable energy in the energy structure, and promoting the transformation of China's energy structure [18] and improving its energy use efficiency [19], are important measures to achieve high-quality economic growth and sustainable development goals [20]. The renewable energy policy has great potential and a boosting effect in solving the energy shortage problem, cultivating new economic growth points, protecting the ecological environment and other aspects [21]. In order to achieve clean energy and green development, China's energy revolution needs to be promoted to ensure energy security. China's central government and local government departments have successively introduced a series of sustainable energy policies [22–24]. Measuring and evaluating the effect of these renewable energy policies and the role of the policy issuing departments is conducive to providing a reference for the formulation of future renewable energy policies.

Currently, the research methods on renewable energy policy are mainly divided into qualitative and quantitative research methods. The analysis of renewable energy policies initially focused on qualitative analysis, including the combination research of different policies [25], the comparative analysis of renewable energy policies for different countries [26], and research on the effectiveness of policies through case analysis [27]. Quantitative research methods of renewable energy policy include: (1) A network construction method based on bibliometrics, for example, Huang et al. [28] used bibliometrics to conduct a co-word analysis and network analysis of science and technology policies, while De Paulo [29] built an open innovation network through "cooperation" and "collaboration" mapping. (2) Based on the content analysis method, Huang et al. [30] used the natural language method to mine the theme of China's science and technology policy, and McWilliam et al. [31] used the content analysis method to analyze the core content of the policy. (3) Based on the method of combining a semantic analysis with network analysis, Yang et al. [32] proposed a research idea for mining the core content of policies through a text analysis, and building a policy target network. The above qualitative research methods for renewable energy policies mainly focus on the policies of multiple policy-issuing departments and fields and policies with a long time span, which have certain limitations, and where it is difficult to mine and extract the characteristic information of the policy network. The network construction method based on traditional bibliometrics can fully build the relationship between the relevant elements of policies, but this ignores the mining and analysis of text semantics. The content analysis method can mine the semantic infor-

mation of policy texts, but it cannot study the relationship between policies. A knowledge graph, therefore, can make up for the shortcomings of the above methods. In the face of massive, complex and cumbersome policy documents, a policy knowledge graph will effectively improve the organization and utilization of policies, especially in the face of unstructured data.

The main contribution of this paper is to use knowledge graph technology to build a knowledge graph of sustainable energy policy based on open official documents, and to introduce knowledge graph technology, graph machine learning algorithms and big data technology to carry out graph mining tasks on graph data, thus providing new ideas and methods for policy research. The purpose of this paper is to extract the relationships between policies, departments and policies in the policy text through the relationship extraction method in the process of building the knowledge graph, and use the Neo4j diagram database for storage and visualization. Then, this paper analyzes China's sustainable energy policy through the construction of related organizations and knowledge graphs to realize the effective path of an intelligent analysis of the policy knowledge graphs. This study combines the knowledge graph with the graph algorithms, uses the graph algorithms to mine the information of the points, edges and subgraphs in the graph on the constructed structured data (i.e., graph data), and then further investigates the evolution of China's policies in the issue of sustainable energy policies, the evolution of the policy issuing departments and the power co-evolution process between the policy issuing departments. This study provides a reference basis for government departments to formulate policies, optimize policies and evaluate the implementation effect of policy objectives in the future. The chapters of this paper are arranged as follows: Section 1 is the background of this study; Section 2 introduces the data collection process, policy evolution analysis method and research realization process of the sustainable energy policy text of this paper; Section 3 analyzes and discusses the research results of China's sustainable energy policy and draws conclusions; finally, in Section 4, the summary of the research conclusions and recommendations for future sustainable energy policy formulation are carried out.

2. Materials and Methods

2.1. Data Source and Preprocessing

This paper builds a policy knowledge graph using public-oriented sustainable energy policy documents. The policy documents are mainly from the PKULAW.COM laws and regulations library (<http://www.pkulaw.cn> (accessed on 30 June 2022)), which contains China's national and local policy documents. At present, different countries and organizations have different definitions of new energy. According to the definition of the United Nations, "new energy is a pollution-free and renewable energy based on new technologies and materials, which replaces conventional energy, mainly including solar energy, wind energy, biomass energy, nuclear energy, geothermal energy, ocean energy and other energy sources" [33]. Sustainable energy is defined as a sustainable energy supply to meet the current needs without harming future generations and meeting their needs. It includes renewable energy sources such as hydropower, solar, wind energy, wave energy, geothermal energy and tidal energy, as well as strong support for developing technologies that improve energy efficiency. Compared with traditional energy, renewable energy has the advantages of causing less pollution and being a renewable energy source. Renewable energy development is an important measure to solve the current environmental protection problems, climate deterioration and energy shortage crisis, and it has become the focus of the world [34].

According to the definition of sustainable energy given by Obrecht and Denac [33], this paper searched the keywords used in the relevant policy text on the PKULAW.COM laws and regulations library: "wind power", "solar PV", "hydropower", "wave energy", "geothermal energy", "renewable energy", "sulfur dioxide", "sulfur dioxide", "carbon dioxide", "greenhouse gas", "low carbon", "carbon emissions" or "pollutant discharge fee". As a result, this paper collected 1215 policies issued by the central government

and 6938 policies issued by local governments, making a total of 8153 policies. The data collection period was from 1 January 1981 to 30 June 2022. Figure 1 shows the number of sustainable energy policies issued by the central government departments and local government departments. In this paper, the policy data included not only 8153 sustainable energy policy documents issued by the central and local government departments, but also included policies with an “implementation/reference to” relationship with the above sustainable energy policies. The data collection period for this part was from 1 January 1981 to 30 June 2022. After completing this part of the data collection, the number of policy documents increased. After the data preprocessing processes, such as eliminating those policies with missing information, deleting duplicate policies, discarding policies irrelevant to the content, and deleting expired policies, this paper finally obtained 1752 policies issued by the central government and 9063 policies issued by local governments, totaling 10,815 policies. The data collection time was 30 June 2022. The effectiveness level of the sustainable energy policy involved 20 types of administrative documents such as departmental working documents, local normative documents, departmental normative documents and normative documents of the State Council. Table 1 presents statistics on the effectiveness level of the sustainable energy policy.

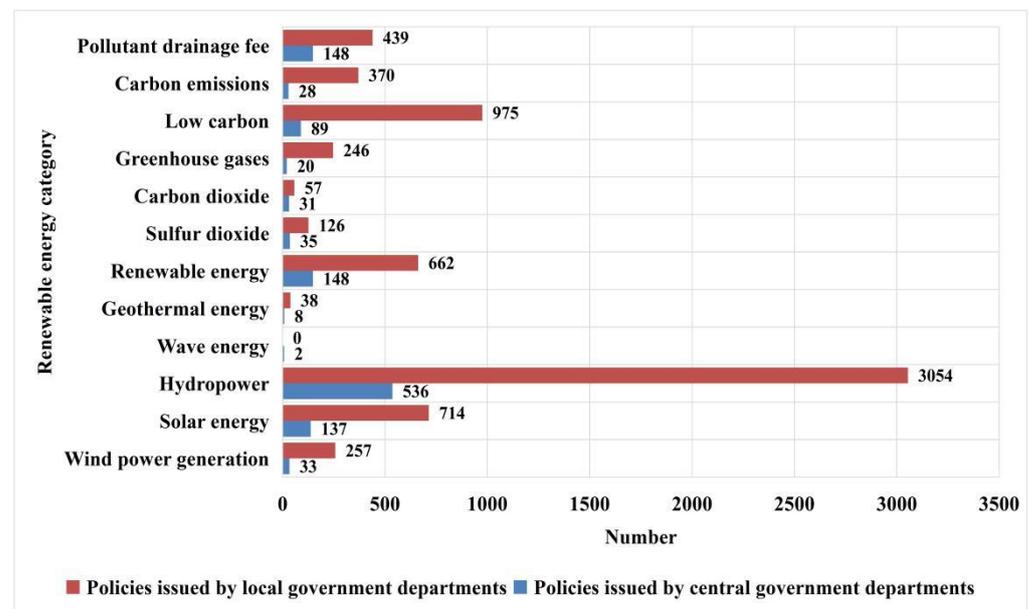


Figure 1. The number of sustainable energy policies issued by central and local government departments. Data source: PKULAW.COM laws and regulations library (<http://www.pkulaw.cn>). Accessed on 30 June 2022.

2.2. Construction of Policy Knowledge Graph

As a simple and practical knowledge representation method, the triple is composed of entity nodes, entity attributes and entity relationships [35]. It exists in the structured form of “entity-relationship-entity” or “entity-relationship-attribute value”, and can intuitively display the relationships between information [36]. The construction of the knowledge graph of sustainable energy policy was a process of establishing the relationship between the policy entities based on the triplet of sustainable energy policy. In view of the characteristics of a unified entity structure, diversified information content and semantic relevance in the field of sustainable energy policy, this paper selected a combination of from top-to-bottom and from bottom-to-top methods to build a knowledge graph of sustainable energy policy (Figure 2). That is, the pattern layer follows the above entity structure design, it designs the hierarchy, attributes and semantic associations of the various entities from the top to bottom, and it guides the design of the knowledge extraction algorithm. The data

layer is from the bottom to top, based on the sustainable energy policy text, it extracts the entity information and its semantic association, and it establishes the sustainable energy policy knowledge network according to the structural design of the model layer. This paper used the technical means of multi-knowledge fusion to eliminate the triplet redundancy of sustainable energy policy caused by multi-source data, and used the knowledge reasoning algorithm [37] to enrich the semantic relationship between the sustainable energy policy information, forming a knowledge graph of sustainable energy policy, and storing it in the form of the Neo4j graph database [38].

Table 1. Statistics of the effectiveness level of sustainable energy policy.

Effectiveness Level	Quantity	Effectiveness Level	Quantity
Local working paper	5122	Administrative regulations	12
Local normative documents	2843	Autonomous regulations and special regulations	9
Administrative license reply	995	Local regulations of cities divided into districts	8
Departmental working paper	748	Inner party laws and regulations	5
Departmental normative documents	683	Documents of judicial interpretation nature	4
Local government regulations	139	Law	3
Departmental regulations	71	Special Economic Zone regulations	2
Provincial local regulations	58	Group regulation	2
Normative documents of the State Council	44	Two high level working documents	1
Industry regulations	40	Local judicial documents	1
Working paper	24	Work reply	1
	Total		10,815

Data source: PKULAW.COM laws and regulations library (<http://www.pkulaw.cn>). Accessed on 30 June 2022.

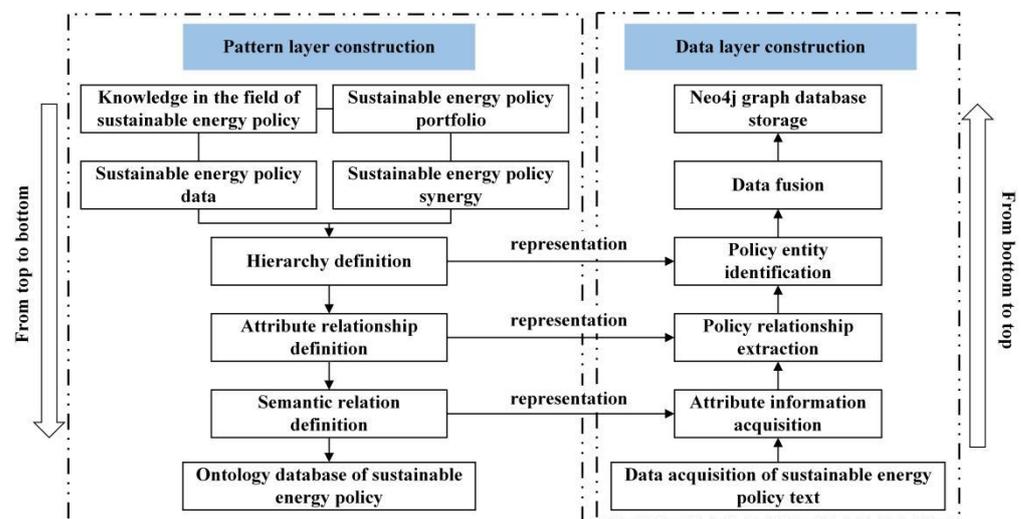


Figure 2. Construction process of knowledge graph of sustainable energy policy.

In this paper, the software used to perform the research included: Anaconda3 (<https://www.anaconda.com/> (accessed on 10 April 2022)), Neo4j-community-4.3.7 (<https://neo4j.com/download-center/> (accessed on 10 April 2022)) and JDK 11 software (<https://www.oracle.com/java/technologies/downloads/#java11> (accessed on 10 April 2022)).

2.2.1. Concept Layer Construction Based on Domain Ontology

The construction of the domain knowledge graph consisted of two parts: the structure of the schema layer and the structure of the data layer. The structure of the schema layer mainly relied on the multi-source heterogeneous data integrated in the early stages and

the intervention of domain experts to extract and define the terms, concepts and relationships involved in the policy text knowledge graph, providing a set of explicit knowledge representation normative frameworks to facilitate the clear conceptual boundaries of the knowledge graph. According to the top-down concept, first we needed to define the data schema. The schema of the knowledge graph was constructed as the data model in the domain, which included the meaningful concept types in this domain and the attributes of these types. The types and properties mainly expressed the schema of any field.

Based on this, three entities were designed: sustainable energy policy, the authority that enacted the policy (i.e., central government, or local government), and the level of effectiveness of the policy. There were four relationships: the implement/according to relationship, issuing relationship, jointly-issuing relationship, and the belonging to the effectiveness level. Combining the knowledge characteristics of sustainable energy policy texts, this paper interpreted semantic relations in a fine-grained environment, and the sustainable energy policy entities included seven attributes. Table 2 shows a set of predefined schemas for sustainable energy policies. The RDF graph of the sustainable energy policy domain ontology was obtained through the semantic association of concepts, attributes and relationships. Figure 3 shows the RDF graph of the sustainable energy policy domain ontology.

Table 2. Predefined schema set.

No.	Subject Type	Predicate	Object Type	No.	Subject Type	Predicate	Object Type
1	Central government	Issuing	Policy	8	Policy	Have	Area of Law
2	Central government	Jointly issuing	Policy	9	Policy	Have	Level of Authority
3	Local government	Issuing	Policy	10	Policy	Have	Date Issued
4	Local government	Jointly issuing	Policy	11	Policy	Have	Effective Date
5	Policy	Implement/ According to	Policy	12	Policy	Belong to	Issuing Authority
6	Policy	Have	Name	13	Policy	Have	Status
7	Policy	Have	Document Number	14	Policy	Have	Text link

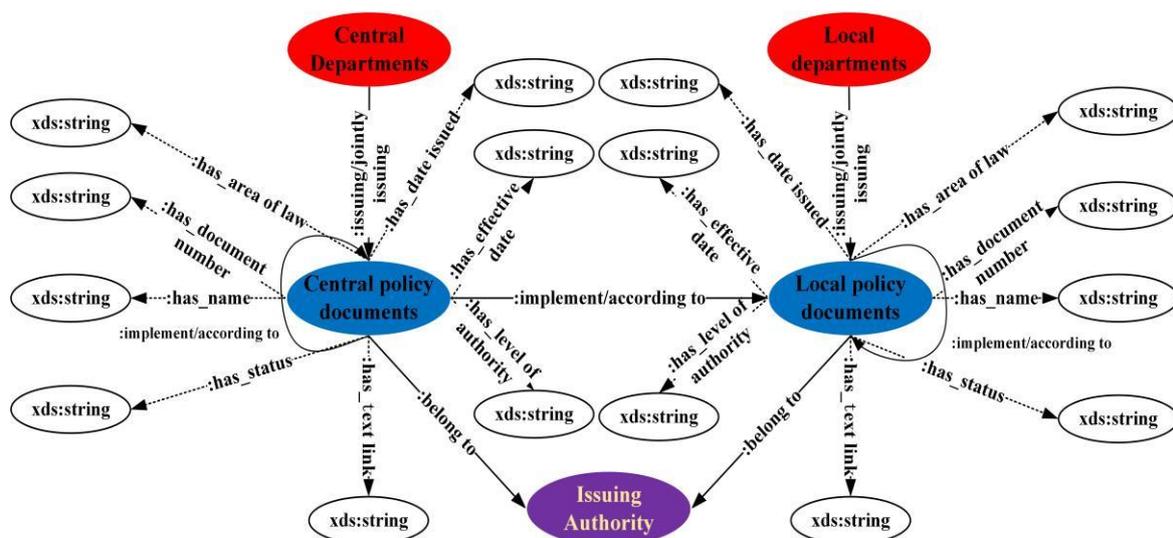


Figure 3. RDF diagram of sustainable energy policy domain ontology.

2.2.2. Policy Entity Extraction and Relationship Construction

A policy knowledge graph is a structured way to describe policy data with a graph model, and it is a technical method to build policy relationship modeling. Policy entities are

nodes in the policy knowledge graph, such as policy documents, policy release agencies, policy themes, etc., which can be abstract policy concepts or policy-related things. Policy entity extraction is extracted from text data through an entity extraction algorithm [39]. Policy entities can also attach various attribute information, such as policy title, policy release period, policy effectiveness level, etc. The relationship between or within policies is the edge in a policy knowledge graph. The edge can also be attached with various attribute information. In a word, the nodes and edges are comprehensively extracted to organize and associate policy resources as much as possible.

2.2.3. Knowledge Fusion

Knowledge fusion [40] is the process of processing and integrating the data extracted from knowledge. It needs to mine hidden knowledge, find the potential knowledge association, and then realize a deep understanding of that knowledge to interpret the data better. Among them, entity alignment [41,42] is the main challenge in the process of knowledge integration. For example, the *Renewable Energy Law* and the *Renewable Energy Law of the People's Republic of China* all point to the same entity and need to be merged. Based on the work of knowledge extraction, this paper used the distance metric method to align the policy entities, and further removed incorrectly aligned entities through a manual verification. At the same time, by enhancing the continuous iteration of the seed graph, the processing and integration of large-scale knowledge were finally completed, and the types and quantities of the entities and relationships are shown in Tables 3 and 4.

Table 3. Summary of knowledge graph entity types.

Entity Type	Chinese Meaning	Entity Quantity	Example
Policy	Name of regulations issued by the central government	10,815	Environmental protection law of the people's Republic of China (revised in 2014)
Issuing authority	Name of the institution issuing the policy	1789	National Energy Administration
Level of authority	Policy level	22	Departmental working documents, and normative documents

Table 4. Summary of knowledge graph relationship types.

Entity Relationship Type	Chinese Meaning	Relationship Quantity	Example
Implement/ According to	Sources of law, legislative authority	10,808	<Notice of the National Energy Administration on Matters Related to Reducing the Burden of Enterprises in the Field of Renewable Energy, According to, Renewable Energy Law of the People's Republic of China>
Issuing	Promulgate policies	10,578	<Standing Committee of the National People's Congress, Issuing, Environmental protection law of the people's Republic of China (revised in 2014)>
Jointly issuing	Jointly issuing policies	683	<Ministry of Finance, Ministry of Housing and Urban Rural Development, Jointly issuing, Notice of the Ministry of Finance and the Ministry of Housing and Urban Rural Development on Further Promoting the Application of Renewable Energy in Buildings>
Belong to	Effectiveness level	10,815	<Renewable Energy Law of the People's Republic of China, Belong to, Law>

After the above key steps of data preprocessing and knowledge modeling, extraction, and fusion, the entity relationship pairs were finally imported into the graph database neo4j for knowledge storage, and a knowledge graph with China’s sustainable energy policy as the core was obtained. Through the visual display, we can intuitively find the relevant knowledge of sustainable energy policies, and more conveniently query the direct and indirect relations between the different policy entities. Figure 4 represents an example graph of China’s sustainable energy policy knowledge graph.

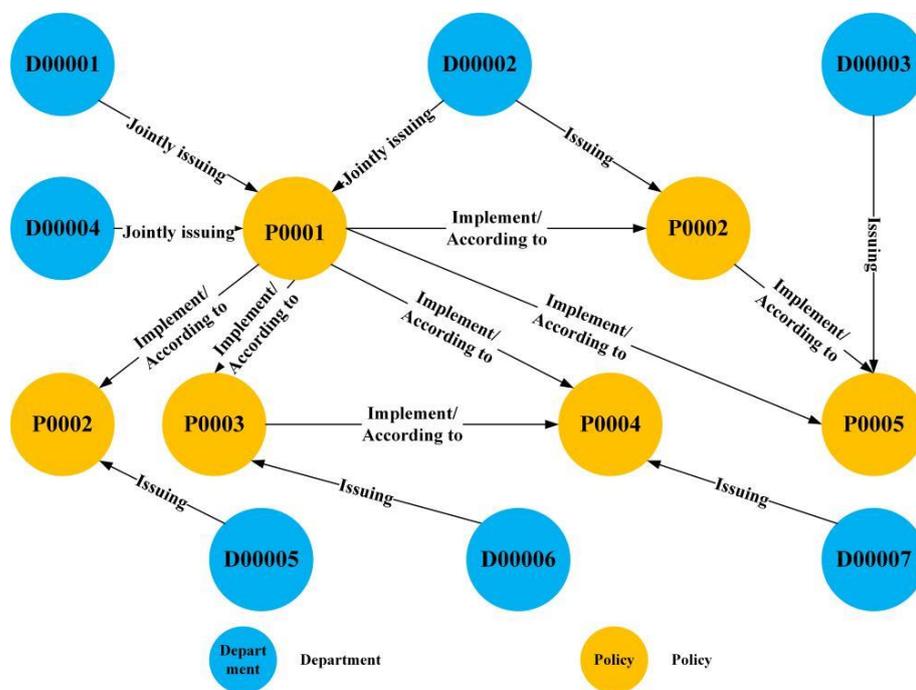


Figure 4. Example graph of China’s sustainable energy policy knowledge graph based on Neo4j (partial).

2.3. Graph Calculation Method

This paper maps the relationships between the sustainable energy policy entities (implement/according to), and the relationships between the government departments and policies (issuing, jointly issuing) into a graph model. The graph G is defined as:

$$G = (V, E, W, T) \tag{1}$$

In the formula, V represents the set of sustainable energy policies and the set of government department entities, for example, $V_i = [V_i](i = 1, 2, \dots, n)$ is the policy entity, and $V_j = [V_j](i = 1, 2, \dots, n)$ is the policy department entity; E represents the relationship between the sustainable energy policy entities (e.g., implement/according to) and the collection of the relationship between government departments and policies (i.e., issuing, and jointly issuing), for example: $E_i = [E_i](i = 1, 2, \dots, n)$ is the relationship between policy entities, and $E_j = [E_j](i = 1, 2, \dots, n)$ is the relationship between the promulgating policy departments; W represents the attribute information set of all policy nodes; T represents the set of policy enactment years. This paper used graph structure metrics to analyze the characteristics of the sustainable energy policy nodes, government department nodes, and government department nodes and policy nodes, and used graph/network clustering to identify the group structure characteristics within the graph structure.

2.3.1. Degree Centrality

Degree centrality is one indicator to effectively measure a node’s importance. The larger the value, the greater the influence and importance of the node.

The in-degree or out-degree can be used as the degree centrality, called the in-degree centrality and the out-degree centrality, respectively. The degree centrality $C_d(V_i)$ is defined as follows:

$$C_d(V_i) = \sum_{i=1, i \neq j}^n d_i^{in} \quad (2)$$

$$C_d(V_i) = \sum_{i=1, i \neq j}^n d_i^{out} \quad (3)$$

where d_i^{in} is the in-degree of node V_i and other nodes, and d_i^{out} is the out-degree of node V_i and other nodes.

2.3.2. Betweenness Centrality

The meaning of betweenness centrality is the total number of policy nodes passing through the shortest path of the policy node V_i . The greater the betweenness centrality, the stronger the control ability of the policy node in the network, and the more important it is that it occupies a pivotal position. The betweenness centrality $C_B(V_i)$ of the policy node V_i is defined as follows:

$$C_B(V_i) = 2B_i / [(N - 2)(N - 1)] \quad (4)$$

where B_i represents the node betweenness, and N represents the number of nodes in the graph.

2.3.3. Closeness Centrality

Closeness centrality removes the interference of special values by computing the average of the distances of a policy node from all other policy nodes in the graph. The smaller the average distance between the policy node and other policy nodes in the graph, the greater the value of the closeness centrality of the policy node. For a connected graph with N policy nodes, the average shortest distance from any policy node V_i to other policy nodes in the graph can be obtained by calculation:

$$d_i = \sum_{j=1, j \neq i}^N d_{ij} / (N - 1) \quad (5)$$

A smaller d_i means that the policy node V_i is closer to other policy nodes in the network; therefore, the reciprocal of d_i is defined as the closeness centrality C of the policy node V_i and is defined as follows:

$$C_c(V_i) = 1/d_i \quad (6)$$

2.3.4. PageRank Algorithm

The PageRank algorithm [43] is designed for Web systems. The basic idea is that a link to a page will increase the PageRank value of the page. Inspired by this algorithm, the nodes in the social network can be simulated as pages in the web, and the edges in the social network can be simulated as hyperlinks in the web; therefore, a similar PageRank algorithm can be used to calculate the influence of nodes.

In this paper, we regarded the relationship (i.e., implement/according to) between policies and the relationship (i.e., issuing, or jointly issuing) between government departments and policies as the link relationship between web pages, and the importance of nodes in the graph can be calculated using the PageRank algorithm. First, this involves defining a directed graph $G = (V, E)$, where V is the set of nodes of the graph and E is the set of directed edges of the graph. Assuming that the total number of nodes in the directed graph G is n , the expression is:

$$P(i) = \sum_{(j,i) \in E} \frac{P(j)}{O_j} \quad (7)$$

where P represents the PageRank value of node V_i , and O_j represents the number of edges that exist from node V_j to node V_i . Define the column vector P to represent the PageRank value of n nodes, and the expression of P is:

$$P = (P(1), P(2), \dots, P(n),)^T \quad (8)$$

The adjacency matrix A of the directed graph G , assigns a value to each directed edge according to the following rules:

$$A_{ij} = \begin{cases} \frac{1}{O_i}, & \text{if } (i, j) \in E \\ 0, & \text{else} \end{cases} \quad (9)$$

This can be obtained using the following equation:

$$P = A^T P \quad (10)$$

Given the adjacency matrix A , it is then possible to solve the vector P .

2.3.5. Louvain Algorithm

Community detection [44], also known as graph/network clustering, aims to automatically discover subgraphs with the same label or dense connections in the network. Modularity [45] is used to evaluate the quality of a network partition, and its value ranges from -1 to 1 . Generally speaking, the larger the value of modularity, the better the stability of the community. On the contrary, the smaller the value of modularity, the worse the stability of the community [46]. The formula for calculating modularity is:

$$Q = \frac{1}{2m} \sum_{ij} [A_{ij} - \frac{k_i k_j}{2m}] \delta(c_i, c_j) \quad (11)$$

$$\delta(u, v) = \begin{cases} 1, & \text{where } u == v \\ 0, & \text{else} \end{cases} \quad (12)$$

where A_{ij} is recorded as the weight of the edge between the node V_i in the graph and the node V_j in the graph; k_i and k_j represent the sum of the weights of all edges connected to the node V_i and node V_j in the graph; c_i represents the community to which the node in the graph belongs; $m = \frac{1}{2} \sum_{ij} A_{ij}$ represents the sum of the weights of all edges. The $\delta(c_i, c_j)$ function indicates that several points of V_i and node V_j are in the same community, and the return value is 1 , otherwise it returns a 0 . After one round of iterations, if Q does not change at all, then it is necessary to stop the iteration, otherwise iterate again.

Modularity is a measurement method to evaluate the division of a community network. It is measured by the modularity gain; therefore, the calculation formula of the modularity gain ΔQ is as follows:

$$\Delta Q = \left[\frac{\sum_{in} + k_{i,in}}{2m} - \left(\frac{\sum_{tot} + k_i}{2m} \right)^2 \right] - \left[\frac{\sum_{in}}{2m} - \left(\frac{\sum_{tot}}{2m} \right)^2 - \left(\frac{k_i}{2m} \right)^2 \right] \quad (13)$$

Formula (13) can be simplified into Formula (14), which can greatly reduce the complexity of the algorithm. The calculation result is the relative gain, and not the absolute gain:

$$\Delta Q' = k_{i,in} - \frac{\sum_{tot} \times k_i}{m} \quad (14)$$

where $k_{i,in}$ is recorded as the sum of the weights of the incoming cluster C from the node V_i in the graph, \sum_{tot} is recorded as the total weight of the incoming cluster C , and k_i is recorded as the total weight of the incoming nodes. In the first round of iteration, to determine which community a node joins, a maximum value of ΔQ needs to be calculated.

3. Results and Discussion

3.1. Analysis of Policy Evolution

Policies with the time nodes of 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022 were taken as the research objects, and each time node was up to December 31 of that year. The policy knowledge graph was constructed based on the reference relationship (i.e., implement/according to) between the policies in each period.

The source of law refers to the ultimate source, effectiveness source and form of law. It emphasizes the norms on which judicial practice is based and the written provisions on which the national government is based. It includes formal legal sources such as the constitution, laws, administrative regulations, local regulations, rules, treaties and agreements, and informal legal sources such as the precedents, customs, moral norms, justice concepts and legal theories. It is a key perspective to see through the judicial situation and a concentrated embodiment of the rule of law. The introduction and formulation of the policy contain a strong legal source. Based on the knowledge graph of sustainable energy policy, this paper visualized the complex cascade relationship between the policies through the penetrating intelligent query of the knowledge graph, it traced the legal source of the sustainable energy policy, and explored the evolution process of the sustainable energy policy issued by the Chinese government and the dynamic operational relationship between the policies. The policy knowledge graph constructed by neo4j was visualized. As shown in Figure 5, the legal source of China's sustainable energy policy was visualized (i.e., the part).

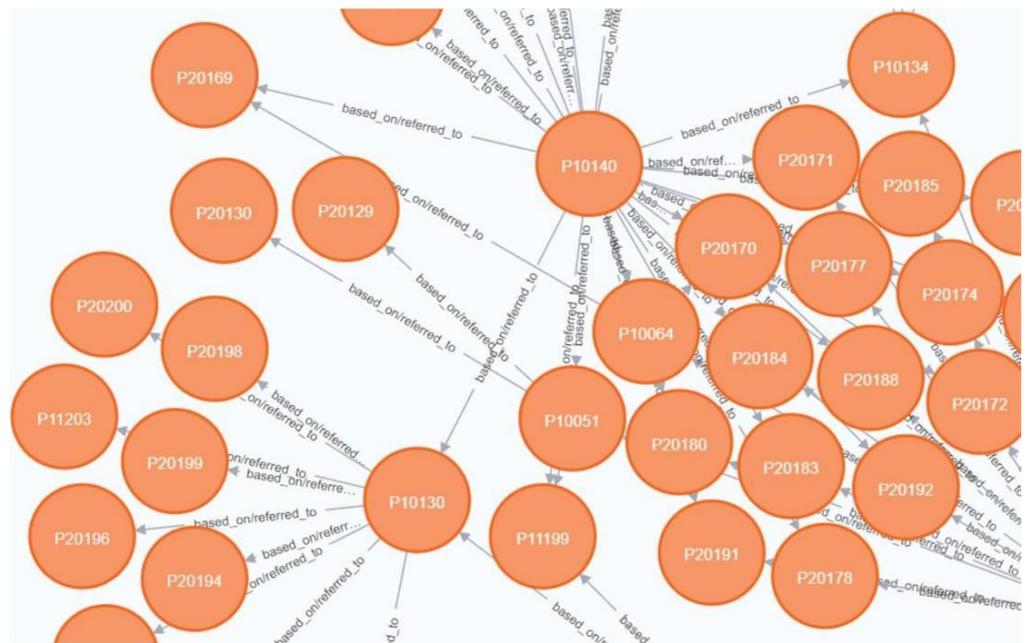


Figure 5. Legal origin of China's sustainable energy policy (part). (1) The node represents the policy, and the border represents the implementation, basis and other reference relationship between the policies, presenting the legal source between the policies; (2) the more connected edges of nodes indicate the closer relationship between nodes and other nodes; (3) the graph contains 1752 policies issued by the central government and 9063 policies issued by local governments, with 10,808 legal sources. The data was obtained on 30 June 2022, and this figure is partial.

The measurement index values of each policy node was calculated through the reference relationship (i.e., implement/according to) network between the policy nodes. Figure 6 shows the measurement index values of major policy nodes at different stages. Tracing the legal origin of the sustainable energy policy can reflect the evolution process of the sustainable energy policy promulgated by the Chinese government. The research

proves that there are laws to follow in the transformation of sustainable energy, such as: *Regulations on the Collection and Use of Sewage Charges* (Policy No.: P11048), *Regulations on Land Acquisition Compensation and Resettlement for Large and Medium-sized Water Conservancy and Hydropower Projects (2006)* (Policy No.: P10164), and *Renewable Energy Law of the People's Republic of China* (Policy No.: P10704), etc. These legal provisions have become the main legal source of the sustainable energy policy, ensuring that there are laws and regulations for the sustainable energy transformation. From the perspective of policy evolution, with the implementation of the sustainable development strategy, the sustainable energy policy is constantly advancing with the times. From the cascade of legal sources, it can be seen that policies such as *Regulations on the Collection and Use of Sewage Charges* (Policy No.: P11048), *Regulations on Land Acquisition Compensation and Resettlement for Large and Medium-sized Water Conservancy and Hydropower Projects (2006)* (Policy No.: P10164), and *Renewable Energy Law of the People's Republic of China* (Policy No.: P10704) have been cited by other policies many times, and it shows that these policies have an important position and influence in the sustainable energy policy system. The reference and other relations between policy documents can not only reflect the basis and starting point of policy formulation, but also reflect the succession of a policy intent, which is the transmission and diffusion of political values and ideas among the policy documents. Therefore, the changes in the legal sources of local policies can reflect the response speed and work intensity of local government departments' policies with the introduction and refinement of the central policy. From the calculation results, we can see that the *Interim Measures for the Collection of Sewage Charges* (Policy No.: P11047) and *Regulations on the Collection and Use of Sewage Charges* (Policy No.: P11048) have played an important role as policy nodes from the seventh "Five Year Plan" to the fourteenth "Five Year Plan"; starting from the Ninth "Five Year Plan", the *Renewable Energy Law of the People's Republic of China* (Policy No.: P10704) has gradually become an important policy. The *Standing Committee of the National People's Congress* promulgated the first version of the *Environmental Protection Law of the People's Republic of China (for Trial Implementation)* on 13 September 1979, and then promulgated the second version of the *Environmental Protection Law of the People's Republic of China* on 26 December 1989, while the third edition of the *Environmental Protection Law of the People's Republic of China (2014 Revision)* was promulgated on 24 April 2014. The three versions of the *Environmental Protection Law of the People's Republic of China* have successively become the main legal source of other sustainable energy policies.

To sum up, it can be seen that massive public documents can construct a knowledge graph of the sustainable energy policy. The knowledge graph of the sustainable energy policy can not only trace the legal source of sustainable energy transformation, but also reflect and evaluate the legitimacy of the sustainable energy policy and the evolution of the sustainable energy policy.

3.2. Analysis on the Coevolution of Jointly Issuing Departments and Powers

Policies with the time points of 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022 were also taken as the research objects, and each time point ended on December 31 of the current year. For the different periods, the knowledge graph was built through the relationship between the government departments and sustainable energy policies (i.e., issuing, jointly issuing).

The process of policy formulation is also the process of state organs exercising their decision-making powers. In different development periods, some sustainable energy policies were issued by the same institutions and departments; however, some sustainable energy policies were needed to be jointly issued by different institutions and departments. In this way, departments are urged to jointly exercise their decision-making powers to ensure the smooth formulation and implementation of policies. The joint issuing between different agencies and departments contained the complex interactive relationship formed by governments at all levels to implement the policies. The jointly issuing network is the division of power network formed by different power centers within the government in the

policy formulation process. Therefore, based on the knowledge graph of sustainable energy policy, the power coordination between different agencies can be mapped from the jointly issuing relationship through the time-based intelligent query of the jointly issuing network.

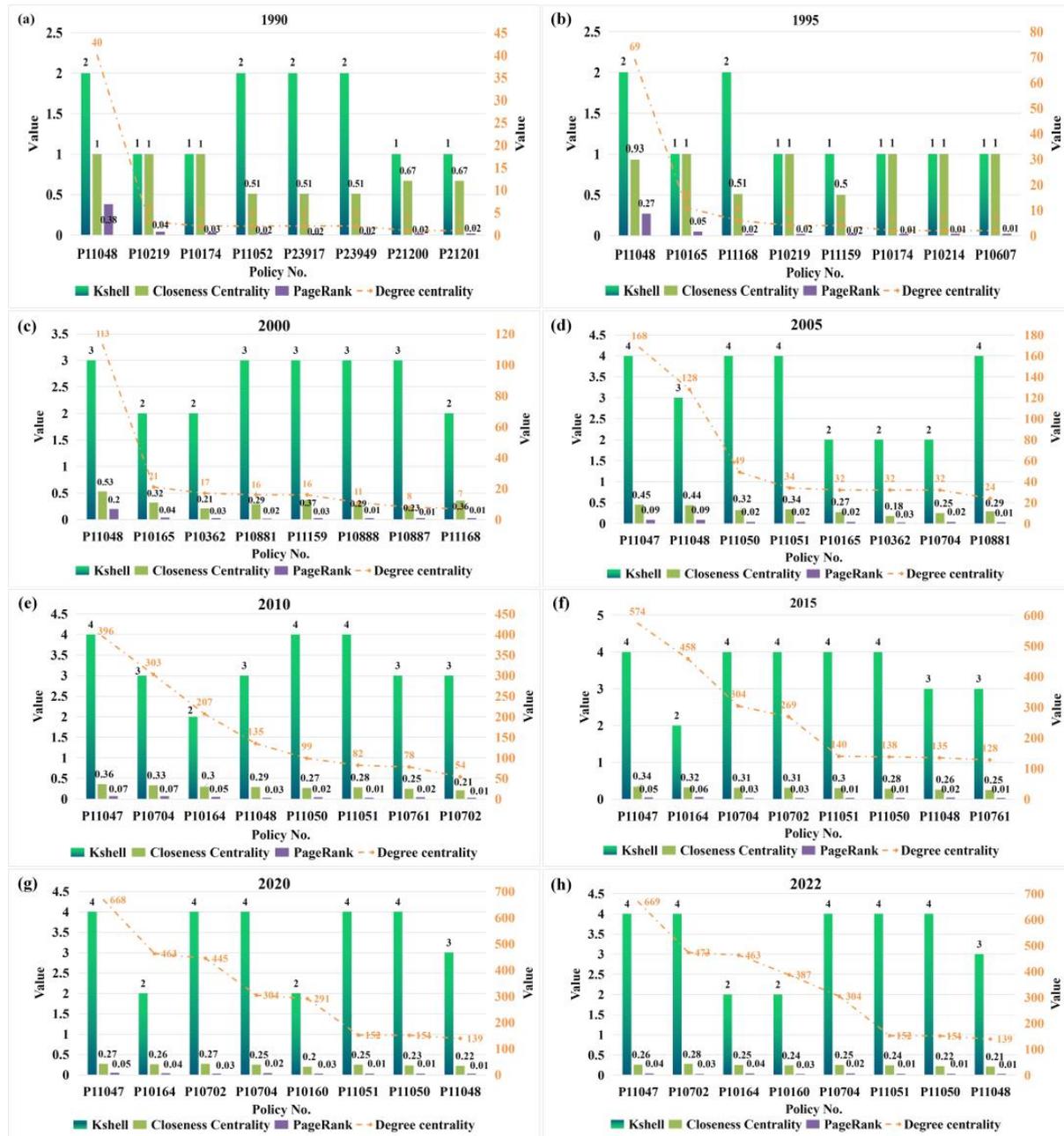


Figure 6. Kshell, Closeness centrality, PageRank and Degree centrality values of main policies at different stages. (1)The primary coordinate axis (right) is the coordinate axis of the Kshell, Closeness centrality, and PageRank values, and the secondary coordinate axis (left) is the coordinate axis of the Degree centrality values. (2) The subgraphs (a–h) in Figure 6 correspond to 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, respectively.

3.2.1. Analysis of Departmental Evolution

Through the research on the relationship network of the policies issued by the government departments that issue the sustainable energy policies, the measurement index values of each department was calculated. Figure 7 shows the measurement index values of the main government departments that promulgated policies at different stages. From the

calculation results, we can see that the departments with the *State Environmental Protection Administration (revoked)* (Department No.: D0007), the *Ministry of Water Resources* (Department No.: D0003), the *Ministry of Finance* (Department No.: D0004) and other departments have always played the most important role in promulgating relevant policies. Starting from the tenth “Five Year Plan”, the *National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission)* (Department No.: D0002) was gradually called the key node. Starting from the 13th “Five Year Plan”, the *National Energy Administration* (Department No.: D0001) was gradually called the key node.

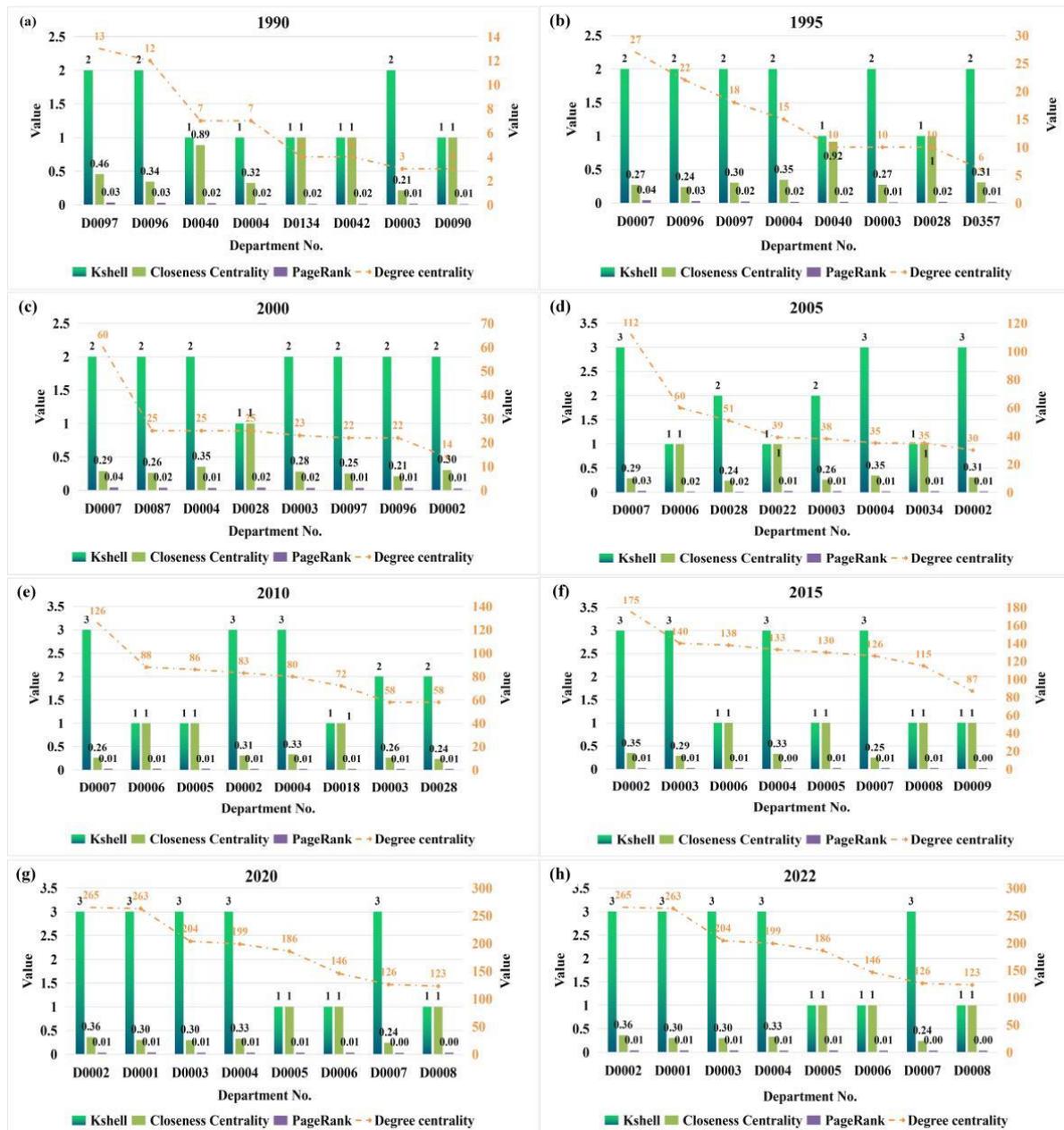


Figure 7. Kshell, Closeness centrality, PageRank and Degree centrality values of the main policy issuing departments in different stages. (1)The primary coordinate axis (right) is the coordinate axis of the Kshell, Closeness centrality, PageRank values, and the secondary coordinate axis (left) is the coordinate axis of the Degree centrality values. (2) The subgraphs (a–h) in Figure 7 correspond to 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, respectively.

3.2.2. Analysis on the Coevolution of Departmental Power

The power coordination network of the government departments jointly issuing policies was visualized through neo4j, as shown in Figure 8, which is the power coordination network among the government departments.

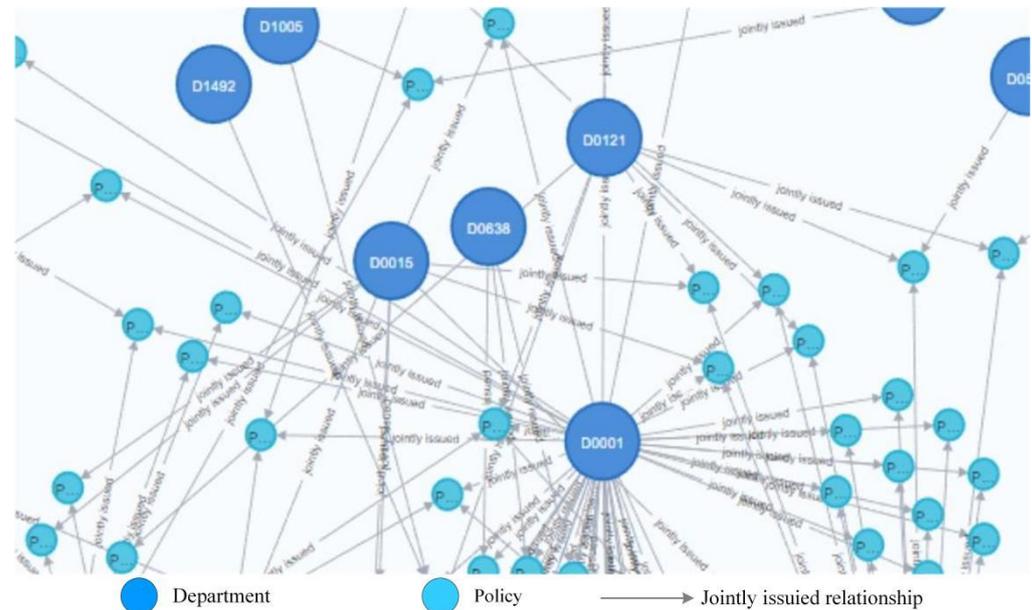


Figure 8. Power coordination network between government departments (part). (1) The blue node represents the department, the light green node represents the policy, and the connecting edge represents the issuing relationship between the part and the policy; (2) the more edges of the blue node, the more policies issued by the node; (3) the graph includes 683 policies jointly issued by government departments and 10,132 policies issued by government departments separately. The issuance of policies by various government departments shows the power synergy network of various departments. The data was obtained on 30 June 2022. This figure is partial.

Through the calculation of the measurement index values of each department in the power coordination network of the government departments jointly issuing policies. As shown in Figure 9, the measurement index values of the departments mainly jointly issuing policies in the different stages. From the calculation results, we can see that *the National Energy Administration* (Department No.: D0001), the *National Development and Reform Commission* (Department No.: D0002), the *Ministry of Water Resources* (Department No.: D0003), and the *Ministry of Finance* (Department No.: D0004) have always played the most important role in jointly issuing relevant policies. Starting from the eleventh “Five Year Plan”, the *National Development and Reform Commission* (Department No.: D0002), and the *Ministry of Finance* (Department No.: D0004) have always been the most important key departments in the department power coordination. During the process from the 12th “Five Year Plan” to the 14th “Five Year Plan”, the *National Development and Reform Commission* (Department No.: D0002), the *Ministry of Finance* (Department No.: D0004), the *National Energy Administration* (Department No.: D0001), the *Ministry of Water Resources* (Department No.: D0003), the *Ministry of Housing and Urban Rural Development* (Department No.: D0012), the *Ministry of Science and Technology* (Department No.: D0072), the *Ministry of Industry and Information Technology* (Department No.: D0079), the *Ministry of Environmental Protection (abolished)* (Department No.: D0015), and other departments have participated in the joint issuing of relevant policies more frequently, indicating that these departments have played an irreplaceable and important role in the power coordination process in the promulgation of sustainable energy policies in the last decade.

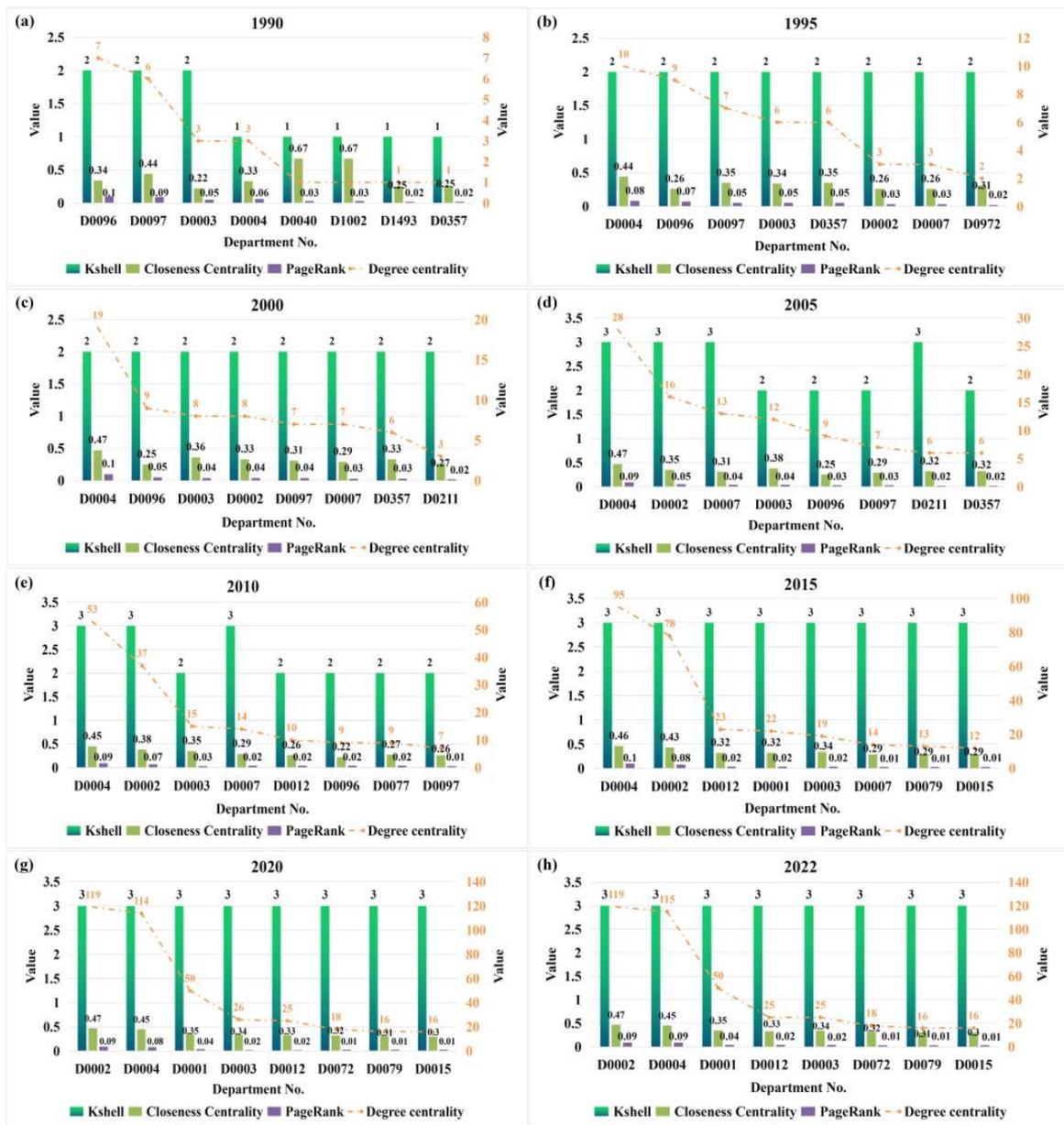


Figure 9. Kshell, Closeness centrality, PageRank and Degree centrality values of the main departments that jointly issue policies at different stages. (1)The primary coordinate axis (right) is the coordinate axis of the Kshell, Closeness centrality, PageRank values, and the secondary coordinate axis (left) is the coordinate axis of Degree centrality values. (2) The subgraphs (a–h) in Figure 9 correspond to 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, respectively.

Through the Louvain algorithm, the departments that jointly issue policies were clustered, and the department groups that were formed in different stages and their power coordination were analyzed. With the continuous introduction of policies, the number of associations clustered by jointly issuing departments has also shown rapid growth. Figure 10 shows the number of clustering communities and the number of departments involved as jointly issuing departments at different stages. From the changes in the number of communities clustered by joint administrative agencies, it can be concluded that with the intensive promulgation of sustainable energy policies, the number of government departments has gradually increased. The government’s powers and joint powers promote the implementation and play of sustainable energy policies. Figure 11 shows the clustering visualization of the jointly issuing departments at different stages.

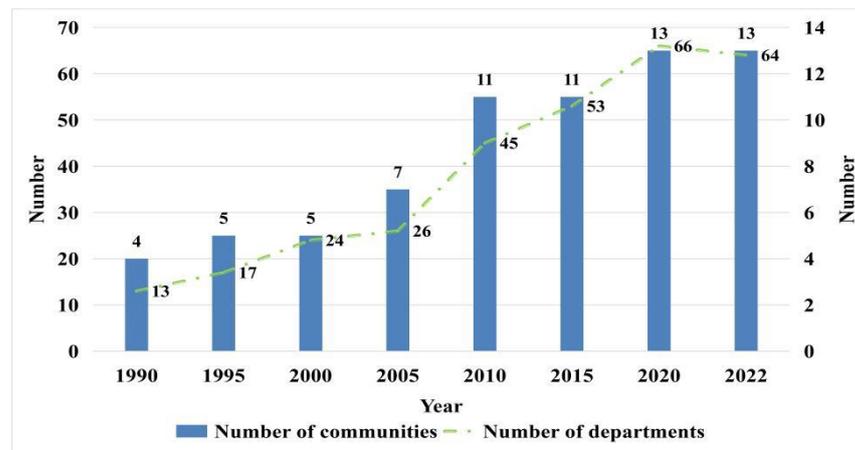


Figure 10. The number of clustered communities and the number of departments involved as jointly issuing departments at different stages.

To sum up, it can be seen that the coordination of various agencies and departments around policy documents reflects the role and positioning of Chinese agencies and departments in the sustainable energy, and has an irreplaceable influence on the realization of the sustainable development strategy and the early deployment of the dual-carbon goal.

3.3. Discussion

The official document of sustainable energy policy open to the public is a concentrated reflection of the government's firm commitment to sustainable development and high-quality development. At the same time, sustainable energy policy documents are of great value for long-term preservation and development. Most of the research on sustainable energy policy is conducted through conventional qualitative and quantitative methods. The qualitative research methods of renewable energy policy mainly focus on the policies of multiple policy issuing departments and fields as well as policies with a long time span. Among them, bibliometrics and meta-analysis methods have been paid attention to, but the mining and analysis of the semantics of the relationships between policies has been ignored. The above methods have certain limitations, and it is difficult to mine and extract the characteristic information of the policy network. In addition, the network construction method based on traditional bibliometrics can fully build the relationship between policy-related elements, but it ignores the mining and analysis of text semantics. The content analysis method can mine the semantic information of the policy text, but it cannot study the relationships between policies. This paper builds a knowledge graph of sustainable energy policy based on open official documents. Through the construction of related organizations and knowledge graphs, it is an effective way to realize the intelligent analysis of a policy knowledge graph and to analyze China's sustainable energy policy. This paper uses the graph algorithms to mine the information of points, edges and subgraphs in the constructed structured data (i.e., the graph data), and to interpret China's effective work in the issue of sustainable energy policies from different perspectives. This paper explores the evolution of China's sustainable energy policy, the evolution of policy issuing departments and the process of the power synergy between the policy issuing departments. Mining the evolution process of China's sustainable energy policy has been undertaken through the combination of a knowledge graph and graph algorithms. This paper explores the process of a coordinated evolution of multi-sectoral power and policies, and provides a reference basis for future government departments to formulate policies, optimize policies and evaluate the implementation effect of policy objectives. This paper introduces graph machine learning, a knowledge graph and big data technology to provide new ideas and methods for policy research.

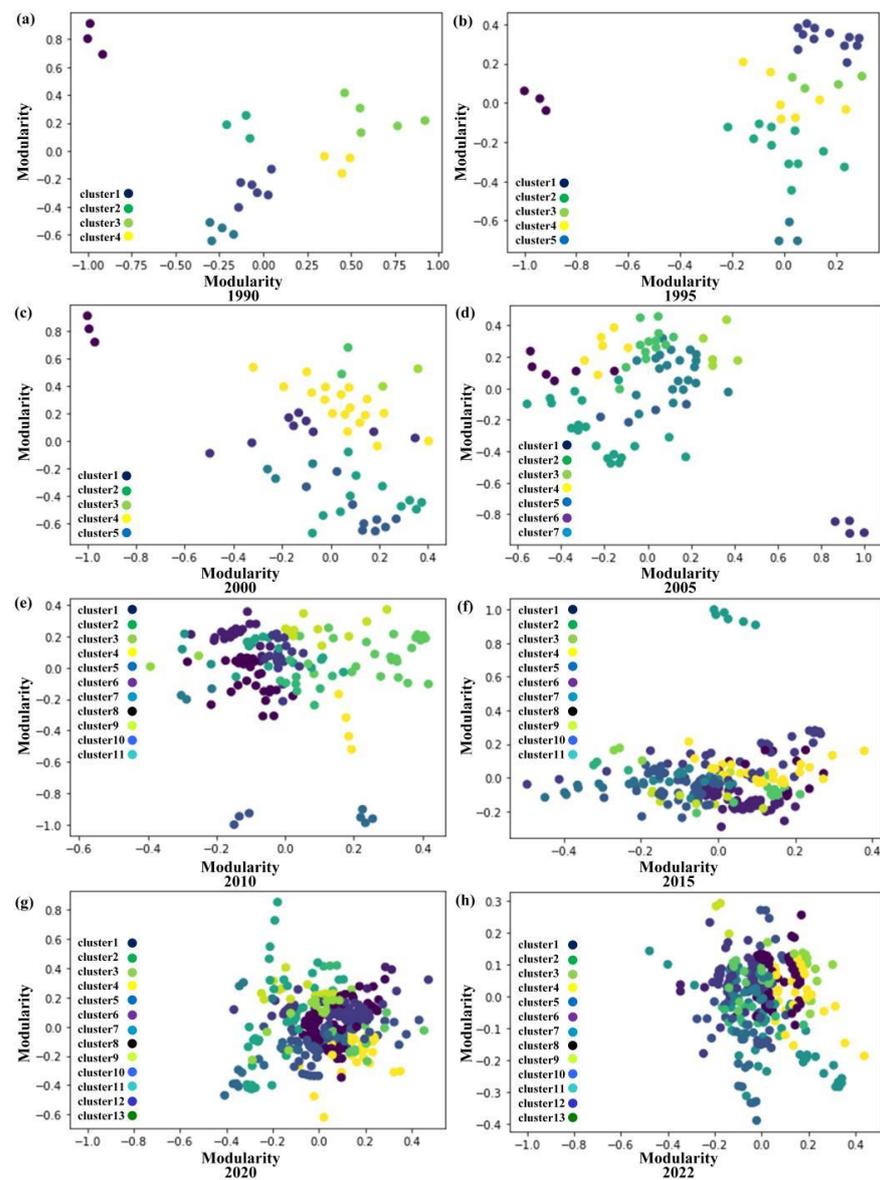


Figure 11. Cluster visualization of jointly issuing departments at different stages. (1) In this paper, the Louvain algorithm was used to cluster according to the relationship between departments jointly issuing policies; (2) through the clustering algorithm, the clustering results between the jointly issuing policy departments at different time nodes were obtained: 4, 5, 5, 7, 11, 11, 13 and 13 communities in 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, respectively. In addition, the department groups formed at different stages and the power coordination between the departments are visualized; (3) the subgraphs (a–h) in Figure 11 correspond to 1990, 1995, 2000, 2005, 2010, 2015, 2020 and 2022, respectively. Appendix A (Table A1) shows the clustering results among the departments that jointly issue policies.

There are also limitations in this study: (1) The subject of this study is the sustainable energy policy at the national level, and the research on the policy evolution of provincial administrative units is relatively weak; (2) there are also differences in the promulgation of sustainable energy policies in the eastern, central and western regions of China, and the focus of policies in different regions is also different.

The main research work in the future: (1) Research the impact mechanism of policy synergy and multi-sector power synergy on the realization of policy objectives; (2) policy focus topic is the research work that will continue to be carried out in the future. It uses natural language processing to mine the theme of policy text, and displays the policy focus and policy differences in different regions through geographic visualization technology;

(3) in terms of the research on the influencing factors of government policy formulation, it is necessary to explore the influencing factors of government policy formulation, and explore the key factors affecting government policy formulation.

4. Conclusions and Policy Implications

4.1. Conclusions

This study took China's sustainable energy policy open documents issued from 1981 to 2022 as an example to construct a knowledge graph of China's sustainable energy policy. In order to investigate policy evolution, policy promulgation department evolution, and power coevolution among the policy promulgation departments on sustainable energy policy promulgation in China, we involved graph algorithms in identifying the key policy nodes at different stages, the key government departments for policy promulgation, and the clustering of policy promulgation departments. Using knowledge graphs and graph algorithms, we explored the evolution process of China's sustainable energy policy.

Through the analysis of the relationship networks between the policy nodes, the measurement index values of each policy node at different stages were calculated. From the analysis of the experimental results, it can be concluded that tracing the legal origin of the sustainable energy policy can reflect the evolution process of the Chinese government's promulgation of the sustainable energy policy. From the perspective of policy evolution, with the implementation of sustainable development strategies, the sustainable energy policies are constantly advancing with the times. This can be seen from the cascading context of legal sources, while the changes in the legal sources of local policies can reflect the response speed and work intensity of the local authorities and departments through the introduction and refinement of central decision-making processes.

Through the research on the relationship networks of the policies promulgated by the government departments then promulgating sustainable energy policies, the measurement index values of each department was calculated in different stages. At different stages, the measurement index values of the government departments mainly promulgated the policies, and analyzing the experimental results, it can be concluded that with the continuous evolution of policies, the government departments that issue policies are also evolving. Furthermore, through the analysis of the power coordination network of the joint government departments, a calculation of the power coordination measurement index values between the various departments at different stages was carried out.

Through the Louvain algorithm, the joint document agencies were clustered, and the departmental groups and power coordination formed in different stages were analyzed. With the continuous introduction of policies, the number of associations clustered by joint document agencies has also shown rapid growth. With the intensive promulgation of sustainable energy policies, the number of government departments involved has gradually increased, and at the same time, the number of competent departments with different functions has gradually increased. It is necessary for multiple departments to jointly exercise government functions and powers to jointly promote the implementation and play of sustainable energy policies.

4.2. Policy Implications

Based on the above research, the enlightenment of China's new energy transformation policy formulation process in the future is as follows:

First, when the Chinese government formulates sustainable energy policies in the future, the relevant government departments should focus on the strategic and systematic nature of the policies. By designing the overall effectiveness of sustainable energy transformation from the top level, the sustainable energy policy can meet both the short-term development goals and long-term development goals.

Secondly, in implementing sustainable energy policies, we should give full play to the synergy of various policies and measures, and pay attention to the effect of the policy mix. In addition, we should seek timely feedback on the implementation effect of sustainable energy policies in order to adjust the different policy mix methods of sustainable energy policies.

Finally, the world is currently undergoing a transformation and upgrading of its industrial structures and related high-tech development, and it is necessary to further strengthen the power coordination between the departments issuing sustainable energy policies. At the same time, we should give full play to the joint exercise of government functions and powers by multiple departments to jointly promote the implementation and role of sustainable energy policies.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Clustering results between departments jointly issuing policies at different stages.

Year	Department Number	Department Name	Cluster
1990	<p>Cluster 1: {'D0097', 'D0003', 'D0096'}</p> <p>Cluster 2: {'D0972', 'D0004', 'D0337', 'D0077', 'D0007'}</p> <p>Cluster 3: {'D0040', 'D1002'}</p> <p>Cluster 4: {'D1493', 'D0357'}</p>	<p>Cluster 1: {Ministry of Water Resources and Electricity (changed), Ministry of Water Resources, and Ministry of Energy (changed)}</p> <p>Cluster 2: {The Agricultural Bank of China, Treasury Department, People's Bank of China, Ministry of Construction (cancelled), and State Environmental Protection Administration (revoked)}</p> <p>Cluster 3: {The State Council, and Central Military Commission}</p> <p>Cluster 4: {National Economic Commission (changed), and State Price Bureau (changed)}</p>	4
1995	<p>Cluster 1: {'D0007', 'D0004', 'D0077', 'D1494', 'D0357', 'D0002', 'D1499', 'D1493'}</p> <p>Cluster 2: {'D0097', 'D0003', 'D0096'}</p> <p>Cluster 3: {'D0337', 'D0972'}</p> <p>Cluster 4: {'D0040', 'D1002'}</p> <p>Cluster 5: {'D0211', 'D1497'}</p>	<p>Cluster 1: {State Environmental Protection Administration (revoked), Treasury Department, Ministry of Construction (cancelled), National Family Planning Commission (renamed), State Price Bureau (changed), National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), Economic and Trade Office of the State Council (changed), and National Economic Commission (changed)}</p> <p>Cluster 2: {Ministry of Water Resources and Electricity (changed), Ministry of Water Resources, Ministry of Energy (changed)}</p> <p>Cluster 3: {People's Bank of China, The Agricultural Bank of China}</p> <p>Cluster 4: {The State Council, Central Military Commission}</p> <p>Cluster 5: {National Economic and Trade Commission (changed), National Science and Technology Commission (changed)}</p>	5

Table A1. Cont.

Year	Department Number	Department Name	Cluster
2000	<p>Cluster 1: {'D0077', 'D0061', 'D0004', 'D0979', 'D1497', 'D0211', 'D0002', 'D0007', 'D0072'}</p> <p>Cluster 2: {'D0003', 'D0096', 'D0087', 'D0542', 'D0097', 'D0557'}</p> <p>Cluster 3: {'D1494', 'D1499', 'D1493', 'D0357'}</p> <p>Cluster 4: {'D0040', 'D1002'}</p> <p>Cluster 5: {'D0972', 'D0337'}</p>	<p>Cluster 1: {Ministry of Construction (cancelled), State Administration of Taxation, Treasury Department, Ministry of Labor and Social Security (including the Ministry of Labor) (revoked), National Science and Technology Commission (changed), National Economic and Trade Commission (changed), National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), State Environmental Protection Administration (revoked), and Department of Science and Technology}</p> <p>Cluster 2: {Ministry of Water Resources, Ministry of Energy (changed), Ministry of Electric Power Industry (changed), State Power Corporation, Ministry of Water Resources and Electricity (changed), and State Administration for Industry and Commerce (revoked)}</p> <p>Cluster 3: {National Family Planning Commission (renamed), Economic and Trade Office of the State Council (changed), National Economic Commission (changed), State Price Bureau (changed)}</p> <p>Cluster 4: {The State Council, and Central Military Commission}</p> <p>Cluster 5: {The Agricultural Bank of China, and People's Bank of China}</p>	5
2005	<p>Cluster 1: {'D0097', 'D0003', 'D0456', 'D0557', 'D0096', 'D0077', 'D0087', 'D0542'}</p> <p>Cluster 2: {'D0061', 'D0004', 'D1494', 'D0357', 'D0979', 'D1499', 'D1493'}</p> <p>Cluster 3: {'D0072', 'D0002', 'D1497'}</p> <p>Cluster 4: {'D0211', 'D0007'}</p> <p>Cluster 5: {'D0028', 'D0121'}</p> <p>Cluster 6: {'D0337', 'D0972'}</p> <p>Cluster 7: {'D1002', 'D0040'}</p>	<p>Cluster 1: {Ministry of Water Resources and Electricity (changed), Ministry of Water Resources, Personnel Department (cancelled), State Administration for Industry and Commerce (revoked), Ministry of Energy (changed), Ministry of Construction (cancelled), Ministry of Electric Power Industry (changed), and State Power Corporation}</p> <p>Cluster 2: {State Administration of Taxation, Treasury Department, National Family Planning Commission (renamed), State Price Bureau (changed), Ministry of Labor and Social Security (including the Ministry of Labor) (revoked), Economic and Trade Office of the State Council (changed), and National Economic Commission (changed)}</p> <p>Cluster 3: {Department of Science and Technology, National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), and National Science and Technology Commission (changed)}</p> <p>Cluster 4: {National Economic and Trade Commission (changed), and State Environmental Protection Administration (revoked)}</p> <p>Cluster 5: {State Environmental Protection Administration (including the State Environmental Protection Administration) (revoked), and Ministry of Land and Resources (revoked)}</p> <p>Cluster 6: {People's Bank of China, and The Agricultural Bank of China}</p> <p>Cluster 7: {Central Military Commission, and The State Council}</p>	7

Table A1. Cont.

Year	Department Number	Department Name	Cluster
		<p>Cluster 1: {Ministry of Health (revoked), Customs Head Office, National Women’s Federation, Ministry of Education of the People’s Republic of China, National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), Office of the Central Steering Committee for the Construction of Spiritual Civilization, State Administration of Traditional Chinese Medicine, State Electricity Regulatory Commission (revoked), and Ministry of Environmental Protection (withdrawn)}</p> <p>Cluster 2: {Ministry of Water Resources and Electricity (changed), State Administration of Work Safety (former State Administration of Work Safety) (revoked), Ministry of Water Resources, State Administration for Industry and Commerce (revoked), Ministry of Energy (changed), The Agricultural Bank of China, Ministry of Electric Power Industry (changed), State Power Corporation, and State Administration of Coal Mine Safety}</p> <p>Cluster 3: {Treasury Department, State Oceanic Administration (revoked), Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, and Ministry of Labor and Social Security (including the Ministry of Labor) (revoked)}</p> <p>Cluster 4: {National Economic and Trade Commission (changed), People’s Bank of China, State Environmental Protection Administration (revoked), and National Science and Technology Commission (changed)}</p> <p>Cluster 5: {Ministry of Construction (cancelled), Personnel Department (cancelled), and Ministry of Supervision (revoked)}</p> <p>Cluster 6: {National Family Planning Commission (renamed), State Price Bureau (changed), Economic and Trade Office of the State Council (changed), and National Economic Commission (changed)}</p> <p>Cluster 7: {State Environmental Protection Administration (including the State Environmental Protection Administration) (revoked), Ministry of Railways (revoked), and Ministry of Land and Resources (revoked)}</p> <p>Cluster 8: {Department of Science and Technology, and National Energy Administration}</p> <p>Cluster 9: {Central Military Commission, and The State Council}</p> <p>Cluster 10: {Ministry of Commerce, and State Administration of Taxation}</p> <p>Cluster 11: {National Certification and Accreditation Administration, General Administration of Quality Supervision, and Inspection and Quarantine of the People’s Republic of China (revoked)}</p>	
2010	<p>Cluster 1: {'D0298', 'D0243', 'D0621', 'D0133', 'D0002', 'D1512', 'D1355', 'D0049', 'D0015'}</p> <p>Cluster 2: {'D0097', 'D0976', 'D0003', 'D0557', 'D0096', 'D0972', 'D0087', 'D0542', 'D1503'}</p> <p>Cluster 3: {'D0004', 'D0102', 'D0079', 'D0012', 'D0979'}</p> <p>Cluster 4: {'D0211', 'D0337', 'D0007', 'D1497'}</p> <p>Cluster 5: {'D0077', 'D0456', 'D0879'}</p> <p>Cluster 6: {'D1494', 'D0357', 'D1499', 'D1493'}</p> <p>Cluster 7: {'D0028', 'D0587', 'D0121'}</p> <p>Cluster 8: {'D0072', 'D0001'}</p> <p>Cluster 9: {'D1002', 'D0040'}</p> <p>Cluster 10: {'D0025', 'D0061'}</p> <p>Cluster 11: {'D0091', 'D0115'}</p>		11

Table A1. Cont.

Year	Department Number	Department Name	Cluster
		<p>Cluster 1: {Ministry of Health (revoked), National Women’s Federation, National Standardization Administration, National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), General Administration of Quality Supervision, Inspection and Quarantine of the People’s Republic of China (revoked), Office of the Central Steering Committee for the Construction of Spiritual Civilization, National Certification and Accreditation Administration, State Organ Affairs Administration (formerly the State Council Organ Affairs Administration), Ministry of Industry and Information Technology, State Administration of Traditional Chinese Medicine, State Electricity Regulatory Commission (revoked), and China Banking Regulatory Commission (revoked)}</p> <p>Cluster 2: {State Administration of Taxation, Treasury Department, State Oceanic Administration (revoked), Ministry of Housing and Urban-Rural Development, and Ministry of Labor and Social Security (including the Ministry of Labor) (revoked)}</p> <p>Cluster 3: {National Economic and Trade Commission (changed), and People’s Bank of China State Environmental Protection Administration (revoked), National Science and Technology Commission (changed), National Family Planning Commission (renamed), State Price Bureau (changed), Economic and Trade Office of the State Council (changed), and National Economic Commission (changed)}</p>	
2015	<p>Cluster 1: {'D0298', 'D0621', 'D0346', 'D0002', 'D0115', 'D1512', 'D0091', 'D0181', 'D0079', 'D1355', 'D0049', 'D1735'}</p> <p>Cluster 2: {'D0061', 'D0004', 'D0102', 'D0012', 'D0979'}</p> <p>Cluster 3: {'D0211', 'D0337', 'D0007', 'D1497', 'D1494', 'D0357', 'D1499', 'D1493'}</p> <p>Cluster 4: {'D0097', 'D0976', 'D0003', 'D0096', 'D0972', 'D0087', 'D1503'}</p> <p>Cluster 5: {'D0280', 'D0546', 'D0557', 'D0001', 'D0542'}</p> <p>Cluster 6: {'D0072', 'D0133'}</p> <p>Cluster 7: {'D0077', 'D0456', 'D0879'}</p> <p>Cluster 8: {'D0015', 'D0634'}</p> <p>Cluster 9: {'D0028', 'D0587', 'D0121'}</p> <p>Cluster 10: {'D0991', 'D0025', 'D0243'}</p> <p>Cluster 11: {'D0040', 'D1002', 'D0947'}</p>	<p>Cluster 4: {Ministry of Water Resources and Electricity (changed), State Administration of Work Safety (former State Administration of Work Safety) (revoked), Ministry of Water Resources, Ministry of Energy (changed), The Agricultural Bank of China, and Ministry of Electric Power Industry (changed), State Administration of Coal Mine Safety}</p> <p>Cluster 5: {Ministry of Agriculture (revoked), State Archives Administration, State Administration for Industry and Commerce (revoked), and National Energy Administration State Power Corporation}</p> <p>Cluster 6: {Department of Science and Technology, and Ministry of Education of the People’s Republic of China}</p> <p>Cluster 7: {Ministry of Construction (cancelled), Personnel Department (cancelled), and Ministry of Supervision (revoked)}</p> <p>Cluster 8: {Ministry of Environmental Protection (withdrawn), and National Bureau of Statistics}</p> <p>Cluster 9: {State Environmental Protection Administration (including the State Environmental Protection Administration) (revoked), Ministry of Railways (revoked), and Ministry of Land and Resources (revoked)}</p> <p>Cluster 10: {Publicity Department of the CPC Central Committee, and Ministry of Commerce, Customs Head Office}</p> <p>Cluster 11: {The State Council, Central Military Commission, and Central Committee of the CPC}</p>	11

Table A1. Cont.

Year	Department Number	Department Name	Cluster
		<p>Cluster 1: {Ministry of Agriculture (revoked), National Flood Control and Drought Relief Headquarters, Poverty Alleviation Office of the State Council, China Banking Regulatory Commission (revoked), State Environmental Protection Administration (including the State Environmental Protection Administration) (revoked), Ministry of Land and Resources (revoked), National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), Ministry of Railways (revoked), and National Energy Administration}</p> <p>Cluster 2: {Customs Head Office, State Administration of Radio and Television, Ministry of Education of the People's Republic of China, All-China Federation of Trade Unions, Central Committee of the Communist Youth League, Ministry of agriculture and rural affairs, Department of Science and Technology, Ministry of Commerce, Publicity Department of the CPC Central Committee, State Organ Affairs Administration (formerly the State Council Organ Affairs Administration), Ministry of Transport, Ministry of Ecological Environment, and State-owned Assets Supervision and Administration Commission of the State Council}</p>	
2020	<p>Cluster 1: {'D0280', 'D0971', 'D0638', 'D1735', 'D0028', 'D0121', 'D0002', 'D0587', 'D0001'}</p> <p>Cluster 2: {'D0243', 'D0538', 'D0133', 'D0570', 'D0572', 'D0347', 'D0072', 'D0025', 'D0991', 'D0181', 'D0154', 'D0038', 'D0358'}</p> <p>Cluster 3: {'D0061', 'D0004', 'D0102', 'D0012', 'D0979'}</p> <p>Cluster 4: {'D0003', 'D0546', 'D0557', 'D0096', 'D0972', 'D0542', 'D0097', 'D0087'}</p> <p>Cluster 5: {'D0211', 'D0337', 'D0007', 'D1497', 'D1494', 'D0357', 'D1499', 'D1493'}</p> <p>Cluster 6: {'D0115', 'D0091', 'D0346', 'D0079'}</p> <p>Cluster 7: {'D0032', 'D0015', 'D0634'}</p> <p>Cluster 8: {'D0077', 'D0456', 'D0879'}</p> <p>Cluster 9: {'D0049', 'D0976', 'D1503'}</p> <p>Cluster 10: {'D0040', 'D1002', 'D0947'}</p> <p>Cluster 11: {'D0335', 'D1005', 'D1492'}</p> <p>Cluster 12: {'D0621', 'D1512'}</p> <p>Cluster 13: {'D1355', 'D0298'}</p>	<p>Cluster 3: {State Administration of Taxation, Treasury Department, State Oceanic Administration (revoked), Ministry of Housing and Urban-Rural Development, and Ministry of Labor and Social Security (including the Ministry of Labor) (revoked)}</p> <p>Cluster 4: {Ministry of Water Resources, State Archives Administration, State Administration for Industry and Commerce (revoked), Ministry of Energy (changed), The Agricultural Bank of China, State Power Corporation, Ministry of Water Resources and Electricity (changed), and Ministry of Electric Power Industry (changed)}</p> <p>Cluster 5: {National Economic and Trade Commission (changed), People's Bank of China, State Environmental Protection Administration (revoked), National Science and Technology Commission (changed), National Family Planning Commission (renamed), State Price Bureau (changed), Economic and Trade Office of the State Council (changed), and National Economic Commission (changed)}</p> <p>Cluster 6: {General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (revoked), National Certification and Accreditation Administration, National Standardization Administration, and Ministry of Industry and Information Technology}</p> <p>Cluster 7: {China Securities Regulatory Commission, Ministry of Environmental Protection (withdrawn), and National Bureau of Statistics}</p>	13

Table A1. Cont.

Year	Department Number	Department Name	Cluster
2020	Cluster 1: {'D0280', 'D0971', 'D0638', 'D1735', 'D0028', 'D0121', 'D0002', 'D0587', 'D0001'}	Cluster 8: {Ministry of Construction (cancelled), Personnel Department (cancelled), and Ministry of Supervision (revoked)} Cluster 9: {State Electricity Regulatory Commission (revoked), State Administration of Work Safety (former State Administration of Work Safety) (revoked), and State Administration of Coal Mine Safety} Cluster 10: {The State Council, Central Military Commission, and Central Committee of the CPC} Cluster 11: {Ministry of Natural Resources, Ministry of Human Resources and Social Security, and State Bureau of Religious Affairs (former State Council Bureau of Religious Affairs)} Cluster 12: {National Women's Federation, and Office of the Central Steering Committee for the Construction of Spiritual Civilization} Cluster 13: {State Administration of Traditional Chinese Medicine, and Ministry of Health (revoked)} Cluster 1: {Ministry of Agriculture (revoked), National Flood Control and Drought Relief Headquarters, Poverty Alleviation Office of the State Council, China Banking Regulatory Commission (revoked), State Environmental Protection Administration (including the State Environmental Protection Administration) (revoked), Ministry of Land and Resources (revoked), National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), Ministry of Railways (revoked), and National Energy Administration} Cluster 2: {Treasury Department, State Administration of Taxation, State Oceanic Administration (revoked), Ministry of Housing and Urban-Rural Development, and Ministry of Labor and Social Security (including the Ministry of Labor) (revoked)} Cluster 3: {Customs Head Office, State Administration of Radio and Television, Ministry of Education of the People's Republic of China, All-China Federation of Trade Unions, Central Committee of the Communist Youth League, Ministry of agriculture and rural affairs, Department of Science and Technology, Ministry of Commerce, Publicity Department of the CPC Central Committee, State Organ Affairs Administration (formerly the State Council Organ Affairs Administration), Ministry of Transport, and State-owned Assets Supervision and Administration Commission of the State Council} Cluster 4: {Ministry of Water Resources, State Archives Administration, State Administration for Industry and Commerce (revoked), Ministry of Energy (changed), The Agricultural Bank of China, State Power Corporation, Ministry of Water Resources and Electricity (changed), and Ministry of Electric Power Industry (changed)}	13
	Cluster 2: {'D0243', 'D0538', 'D0133', 'D0570', 'D0572', 'D0347', 'D0072', 'D0025', 'D0991', 'D0181', 'D0154', 'D0038', 'D0358'}		
	Cluster 3: {'D0061', 'D0004', 'D0102', 'D0012', 'D0979'}		
	Cluster 4: {'D0003', 'D0546', 'D0557', 'D0096', 'D0972', 'D0542', 'D0097', 'D0087'}		
	Cluster 5: {'D0211', 'D0337', 'D0007', 'D1497', 'D1494', 'D0357', 'D1499', 'D1493'}		
	Cluster 6: {'D0115', 'D0091', 'D0346', 'D0079'}		
	Cluster 7: {'D0032', 'D0015', 'D0634'}		
	Cluster 8: {'D0077', 'D0456', 'D0879'}		
	Cluster 9: {'D0049', 'D0976', 'D1503'}		
	Cluster 10: {'D0040', 'D1002', 'D0947'}		
	Cluster 11: {'D0335', 'D1005', 'D1492'}		
	Cluster 12: {'D0621', 'D1512'}		
	Cluster 13: {'D1355', 'D0298'}		
2022	Cluster 1: {'D0280', 'D0971', 'D0638', 'D1735', 'D0028', 'D0121', 'D0002', 'D0587', 'D0001'}	Cluster 8: {Ministry of Construction (cancelled), Personnel Department (cancelled), and Ministry of Supervision (revoked)} Cluster 9: {State Electricity Regulatory Commission (revoked), State Administration of Work Safety (former State Administration of Work Safety) (revoked), and State Administration of Coal Mine Safety} Cluster 10: {The State Council, Central Military Commission, and Central Committee of the CPC} Cluster 11: {Ministry of Natural Resources, Ministry of Human Resources and Social Security, and State Bureau of Religious Affairs (former State Council Bureau of Religious Affairs)} Cluster 12: {National Women's Federation, and Office of the Central Steering Committee for the Construction of Spiritual Civilization} Cluster 13: {State Administration of Traditional Chinese Medicine, and Ministry of Health (revoked)} Cluster 1: {Ministry of Agriculture (revoked), National Flood Control and Drought Relief Headquarters, Poverty Alleviation Office of the State Council, China Banking Regulatory Commission (revoked), State Environmental Protection Administration (including the State Environmental Protection Administration) (revoked), Ministry of Land and Resources (revoked), National Development and Reform Commission (including the former National Development Planning Commission and the former National Planning Commission), Ministry of Railways (revoked), and National Energy Administration} Cluster 2: {Treasury Department, State Administration of Taxation, State Oceanic Administration (revoked), Ministry of Housing and Urban-Rural Development, and Ministry of Labor and Social Security (including the Ministry of Labor) (revoked)} Cluster 3: {Customs Head Office, State Administration of Radio and Television, Ministry of Education of the People's Republic of China, All-China Federation of Trade Unions, Central Committee of the Communist Youth League, Ministry of agriculture and rural affairs, Department of Science and Technology, Ministry of Commerce, Publicity Department of the CPC Central Committee, State Organ Affairs Administration (formerly the State Council Organ Affairs Administration), Ministry of Transport, and State-owned Assets Supervision and Administration Commission of the State Council} Cluster 4: {Ministry of Water Resources, State Archives Administration, State Administration for Industry and Commerce (revoked), Ministry of Energy (changed), The Agricultural Bank of China, State Power Corporation, Ministry of Water Resources and Electricity (changed), and Ministry of Electric Power Industry (changed)}	13
	Cluster 2: {'D0004', 'D0061', 'D0102', 'D0012', 'D0979'}		
	Cluster 3: {'D0243', 'D0538', 'D0133', 'D0570', 'D0572', 'D0347', 'D0072', 'D0025', 'D0991', 'D0181', 'D0154', 'D0038', 'D0358'}		
	Cluster 4: {'D0003', 'D0546', 'D0557', 'D0096', 'D0972', 'D0542', 'D0097', 'D0087'}		
	Cluster 5: {'D0211', 'D0337', 'D0007', 'D1497', 'D0357', 'D1499', 'D1493'}		
	Cluster 6: {'D0115', 'D0091', 'D0346', 'D0079'}		
	Cluster 7: {'D0032', 'D0015', 'D0634'}		
	Cluster 8: {'D0077', 'D0456', 'D0879'}		
	Cluster 9: {'D0049', 'D0976', 'D1503'}		
	Cluster 10: {'D1492', 'D0335', 'D1005', 'D0038'}		
	Cluster 11: {'D0621', 'D1512'}		
	Cluster 12: {'D0040', 'D0947'}		
	Cluster 13: {'D1355', 'D0298'}		

Table A1. Cont.

Year	Department Number	Department Name	Cluster
2022	Cluster 1: {'D0280', 'D0971', 'D0638', 'D1735', 'D0028', 'D0121', 'D0002', 'D0587', 'D0001'}	Cluster 5: {National Economic and Trade Commission (changed), People's Bank of China, State Environmental Protection Administration (revoked), National Science and Technology Commission (changed), State Price Bureau (changed), Economic and Trade Office of the State Council (changed), and National Economic Commission (changed)} Cluster 6: {General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (revoked), National Certification and Accreditation Administration, National Standardization Administration, and Ministry of Industry and Information Technology} Cluster 7: {China Securities Regulatory Commission, Ministry of Environmental Protection (withdrawn), and National Bureau of Statistics} Cluster 8: {Ministry of Construction (cancelled), Personnel Department (cancelled), and Ministry of Supervision (revoked)} Cluster 9: {State Electricity Regulatory Commission (revoked), State Administration of Work Safety (former State Administration of Work Safety) (revoked), and State Administration of Coal Mine Safety} Cluster 10: {State Bureau of Religious Affairs (former State Council Bureau of Religious Affairs), Ministry of Natural Resources, Ministry of Human Resources and Social Security, and Ministry of Ecological Environment} Cluster 11: {National Women's Federation, and Office of the Central Steering Committee for the Construction of Spiritual Civilization} Cluster 12: {The State Council, and Central Committee of the CPC} Cluster 13: {State Administration of Traditional Chinese Medicine, and Ministry of Health (revoked)}	13
	Cluster 2: {'D0004', 'D0061', 'D0102', 'D0012', 'D0979'}		
	Cluster 3: {'D0243', 'D0538', 'D0133', 'D0570', 'D0572', 'D0347', 'D0072', 'D0025', 'D0991', 'D0181', 'D0154', 'D0358'}		
	Cluster 4: {'D0003', 'D0546', 'D0557', 'D0096', 'D0972', 'D0542', 'D0097', 'D0087'}		
	Cluster 5: {'D0211', 'D0337', 'D0007', 'D1497', 'D0357', 'D1499', 'D1493'}		
	Cluster 6: {'D0115', 'D0091', 'D0346', 'D0079'}		
	Cluster 7: {'D0032', 'D0015', 'D0634'}		
	Cluster 8: {'D0077', 'D0456', 'D0879'}		
	Cluster 9: {'D0049', 'D0976', 'D1503'}		
	Cluster 10: {'D1492', 'D0335', 'D1005', 'D0038'}		
	Cluster 11: {'D0621', 'D1512'}		
	Cluster 12: {'D0040', 'D0947'}		
	Cluster 13: {'D1355', 'D0298'}		

Data source: PKULAW.COM laws and regulations library (<http://www.pkulaw.cn>). Accessed on 30 June 2022.

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