Analysis on the Dynamic Evolution of Bioenergy Industry in the Yangtze River Delta Based on Multilevel Social Network Theory

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Abstract: This paper aims to explore the evolution of bioenergy from a comprehensive and dynamic perspective and study how stakeholders in the industry exert influence during the development. Taking the development of bioenergy in the Yangtze River Delta as an example, the research builds a dynamic network of bioenergy stakeholders from a social network analysis method. This paper selects six typical cities and six stakeholder groups in the Yangtze River Delta to conduct field surveys and interviews. This study integrates social network analysis with multilevel perspective theory to analyse the evolution of bioenergy from a dynamic perspective. The results show that the relationship among the stakeholders is a network based on central stakeholders involved in the material flow and is affected by multiple peripheral stakeholders. Through the analysis of the dynamic evolution relationship between stakeholders, this paper reveals the existing problems during the development of bioenergy in the Yangtze River Delta. The research results also show that the development of bioenergy has the following characteristics: (i) It is initiated by technological development during the energy transition period; (ii) It is led by policy formulation; (iii) It has evolved with the development of material flow, marketing, infrastructure, and social awareness.

Keywords: bioenergy; social network analysis; multilevel perspective; energy transition; Yangtze River Delta

1. Introduction

China is a major energy consumer, and the driver of its economic and social progress is based on the economic development model that consumes high-carbon energy such as coal and petroleum. However, from the perspective of insufficient energy resource reserves in China, serious regional environmental pollution, heavy carbon emission reduction tasks, and substantial pressure on energy security, this energy development model has substantial challenges [1]. From a world perspective, the global climate change caused by the limitation of fossil energy resources and the large amount of carbon emissions from carbon-based energy combustion also makes this economic development model and energy use method unsustainable [2]. As public concerns about energy security and climate change have deepened, bioenergy has experienced global development. Although the development of biomass results in social, economic, and environmental benefits, its development speed and scale also cause a series of challenges to society (e.g., land use conflicts and environmental pollution caused by the supply of bioenergy raw materials). From the perspective of development, the developed countries in Europe and the United States applied bioenergy earlier than China [3–6]. The development
of bioenergy in the United States relies on its strong capital base. The development of Europe and the United States is characterised by a high degree of industrialisation, such as that in Germany, Denmark, and the Netherlands. Overall, the development of China’s bioenergy industry remains in an early stage compared with the developed countries in Europe and the United States, and many difficulties must be overcome. Wei et al. analysed the obstacles to the development of China’s bioenergy from three aspects—raw materials, technology, and policy—and proposed reasonable suggestions [7]. Xie analysed the current status of China’s bioelectricity generation and proposed that backward technology and high construction and maintenance costs are the constraints of biomass power generation [8]. Wang’s research summarised the current status of bioenergy development in Shanxi Province, such as unsound policies and backward technology [9]. Yang et al. proposed, based on research, that the development of biodiesel requires policy support [10].

1.1. Explanation of Social Network Analysis and Multilevel Perspective Theory

Based on the aforementioned analysis, there are social, economic, technological, and other factors that affect the sustainable development of the bioenergy industry. However, stakeholders, as direct or indirect participants in the industry chain, affect raw material supply and policy formulation. Therefore, it is necessary to analyse the impact on the bioenergy industry from the stakeholders and their interaction network. To achieve this goal, the research adopts a multilevel perspective (MLP) and a social network analysis method and selects one of China’s largest economic belts—the Yangtze River Delta—to conduct case studies, analyse the perceptions and assessments of bioenergy stakeholders on the prospects and development of bioenergy under the influence of global issues such as climate change, energy transition, and urbanisation and use this analysis to determine the economic, environmental, and social factors that affect their decision-making.

Regarding the social network analysis method, the researchers summarise the viewpoint of social network analysis as follows [11]: social relationship research is the focus, which means that the world is not a combination of individual objects but a network based on them. An increasing number of scholars have begun to use social networks to study regional or regional resource management and adaptability [12,13]. Prell et al. [14] used stakeholder analysis and social network analysis to jointly study the management of natural resources. Abid et al. [15] used social network analysis to explore the internal links of Pakistani agricultural stakeholders and how they collaborate on agricultural production and adapt to climate change. There is also research on the theoretical basis of social network analysis, a proposed novel algorithm for Computer Detection in Social Networks based on Game Theory, and the use of multimedia data to conduct a lot of research in the field of online social networks [16–18]. MLP theoretical research is a research method proposed when discussing technological development and social transformation. Geels [19] systematically summarised and improved the research method of MLP theory when discussing technological transformation, which mainly solved the two problems of how social technological transformation occurs and whether social transformation has its specific mode and mechanism. Yu et al. [20] used the method of MLP theory to study the sustainable changes and cross-domain development of cities.

1.2. Stakeholder Concept

The concept of stakeholders has changed a lot since 1983. According to the research of Freeman and Reed [21], the concept of stakeholders can be divided into narrow and broad definitions. Mitchell et al. [22] proposed that the classification of stakeholders should be based on whether stakeholders have (1) the right to influence the organisation, (2) a legal relationship with the organisation, and (3) the extent to which the requirements of stakeholders are valued by the management of the organization. On this basis, Shu [23] and others have divided the stakeholders of the bioenergy industry into two levels. The basic level is called “central stakeholder,” and the next level is called “edge stakeholder.” Chen Fobao et al. [24] conducted a cost-benefit analysis of the farmers, enterprises, and governments of straw-shaped fuel projects, according to the theory of stakeholders, and learned
that the low calorific value and unreasonable prices of straw-shaped fuel are the main factors affecting farmers’ adoption and that market stability has affected the profitability of biomass companies.

According to Fishbein and Ajzen’s rational behaviour theory [25], understanding individuals’ perceptions is a means to understand their behavioural intentions. For the implementation of bioenergy, the public’s awareness of the advantages and disadvantages of introducing bioenergy is a key factor in whether it supports the implementation of bioenergy [26–29]. In the research on the promotion of bioenergy in society, people not only pay attention to the traditional aspects of bioenergy production technology, economy, and environment but also begin to pay attention to the social cognition and social impact of bioenergy. The society’s cognition and acceptance of bioenergy has become a hot topic for scholars [30–34].

Although the social interest network of bioenergy is relatively obvious, the public’s cognition and the knowledge, opinions, and attitudes of each stakeholder, which are directly or indirectly affected by bioenergy, should also be taken seriously [31,34]. In addition to end consumers and producers of bioenergy (mainly farmers, freight forwarders, and operators of bioenergy companies), other stakeholders such as investors, governments, academia, nonprofit organizations, and policymakers can also affect the acceptance of bioenergy in the market. Because these stakeholders participate in different stages and roles in the life cycle of bioenergy, they are likely to have different or even conflicting goals and value demands. Therefore, studying the multistakeholder relationship is an important issue that must be considered in the promotion of biomass energy.

1.3. Innovativeness of the Study

Through the analysis of the current status of research on the relationship between stakeholders and the development of the bioenergy industry using social network analysis methods at home and abroad, the innovation of this study is mainly reflected in the following aspects:

(1) From the perspective of the research object, domestic and foreign research focuses on the public as a whole and farmers, and there is a one-sided problem of research objects. This research is a systematic and comprehensive analysis of the stakeholders of bioenergy.

(2) From the perspective of research methods, the research on the relationship between bioenergy stakeholders only stays at the static level. In this research, the bioenergy industry is considered as a dynamic system for research. Using social network analysis and multilevel research perspective theory, a dynamic network of bioenergy development and its stakeholders is constructed.

(3) From the perspective of the research area, most of the research is in the United States and Europe, and the research in Asia is rare. This study selects China’s Yangtze River Delta region for research, which is to a great extent representative and practical for understanding and promoting the development of bioenergy in China.

1.4. Research Goals and Summary of Sections

The aims of this research mainly include the following three points:

(1) The current status of the social network for the development of the bioenergy industry, and the interaction between the various stakeholders in the social network;

(2) From a multidynamic perspective, the opportunities and challenges facing the biomass energy industry;

(3) To achieve the sustainable development of biomass energy, the policy measures, and methods to improve the correlation and interaction between various stakeholders.

After making a literature review of the current status of biomass energy development and an introduction about the methods and concepts involved in the research in this section, Section 2 formulates detailed research steps for the research goals proposed in the previous part and couples the two research methods into a model that is suitable for this research case. Finally, the research
case is introduced. In Section 3, first it classifies the stakeholders according to the degree of influence of the stakeholder groups on the relationship network, and then analyses the relationship between different types of stakeholders. Since different stakeholders have different division of labour due to the six links of the biomass industry from the raw material supply to consumption, the stakeholders are formed by six different social networks, which have an impact on the development of bioenergy industry. Finally, from the perspective of multilevel perspective theory, Section 3 analyses the impact of social networks on three levels. Section 4 discusses the current deficiencies of this research and gives suggestions for future research directions. Section 5 summarizes the conclusions of this research from two aspects: social network analysis and multilevel perspective theory. Finally, Section 6 gives policy recommendations based on the outcomes of research.

2. Research Methods and Case Information

2.1. Description of Research Process

To realise the research goals, the main methods adopted in this study are as follows:

(1) Social research and data collection. For the determination of social networks, field surveys should be conducted in major provinces and cities in the Yangtze River Delta, and bioenergy stakeholders should be interviewed through questionnaires and in-depth interviews to organize their relationship network of material and information flow and analyse its impact on the development of biomass on a time scale. This research mainly selects local farmers, biomass enterprises, local governments, and organisations as the research objects; in addition, the cities of Shanghai, Jiangsu, and Zhejiang are regarded as the consumption areas of biomass energy. Nongovernmental Organizations (NGOs), research institutions, local governments, and end consumers are also research subjects. The research mainly takes the form of interviews (e.g., in-depth interviews), including interviews and seminars combined with questionnaire interviews. The social survey was implemented from March to May 2018. Subsequently, the social survey data was collected and collated, and a social network analysis method was used to discuss the impact of stakeholder groups on the development of the biomass energy industry. At the same time, the opinions and suggestions of different stakeholder groups on the development of biomass energy industry are summarized.

(2) Analysis using qualitative methods. Based on the results of social surveys and collected data, a social network analysis model is used, and symbolic graphics or measurement models are used to comprehensively analyse the interrelationships and relationship networks of various stakeholders in the social network for biomass energy development. The social network analysis method used in this study first determines the network of material or information flows established by interdependent social actors through interaction and then explores the theoretical motivations that lead to environmental consequences and personal decision-making hidden in social relationships [35,36]. Through the application of MLP theory, under the three-level nesting mode, a scientific, orderly analysis of social technology transformation problems with long periods and large scales is conducted to discuss how to work based on the context of sustainable development. Under the industrial economic system, the social network transformation of biomass energy is promoted. We use the results of this study to provide a scientific basis and reference for the formulation and implementation of China’s bioenergy development policy.

In order to summarize the description above about the research steps, a research framework is given in Figure 1.

For the investigation and data collection of biomass energy stakeholders, we designed 20 questions: These questions are mainly on the definition of biomass energy stakeholders; the interaction of central stakeholders, central stakeholders, and marginal stakeholders. Regarding questionnaire design, the first part results in a list of several stakeholder groups that may be contacted by respondents in any field, to make a preliminary assessment of the relationship network mapping. Among these questions are
questions on how frequently the interviewee interacts with other stakeholders. These questions help assess the strength of the relationship between stakeholders. The second part is the survey respondents’ understanding of the policy: This part is mainly to investigate the stakeholders’ awareness of the relevant policies and provide policy recommendations. The frame design of the questionnaire for interviewing stakeholders is shown in Table 1. Through semiopen interviews, we conduct a qualitative analysis of the content of the questionnaire to provide basis and support for the next analysis of the social network of biomass energy stakeholders and the analysis of biomass energy development under the MLP theory.

![Figure 1. The research framework.](image)

| Step | Goal                  | Interview Question                                                                                                                                 |
|------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Stakeholder           | Who are the stakeholders involved/affecting the biomass energy industry?                                                                          |
| 2    | Links                 | Who will have contact with whom in the process? How often is the contact between who and whom? Who establishes contact with whom in which link? Which policy has a greater impact on different stakeholders? Different stakeholders’ understanding of biomass energy policies and suggestions. |
| 3    | Classification Analysis | The stakeholder network is classified from the aspects of material flow, technology, policy, market demand, infrastructure, and awareness dissemination. The degree of influence of different stakeholder networks on different links |

2.2. Multilevel Social Network Coupling Model

The MLP is a generalisation of social transformation (from one social technological state to another social technological state) into landscape, regime, and niche(s), three levels of analysis tools that influence each other. Regime is semirelated rules that guide and coordinate social groups to reproduce social technology; niche is the most microscopic level of multilayer perspective theory and responsible for the generation and development of radical innovation; landscape is the most macro level in MLP theory, and the perspective comprises slowly changing external factors, which provide a “slope” for the development of social technology. MLP theory can use a dynamic, systematic framework to order and simplify the analysis of complex and large-scale social transformation problems [37].

Social network analysis is mainly used to clarify the structure between interdependent social roles, using symbolic figures or econometric models to reveal hidden relationship networks [35,36,38,39].
Social network analysis is used to study the relationship structure and nature of social networks because it mainly analyses the social structure and nature formed by social units, which is also called the structural analysis method. In the research on the implementation of bioenergy in society, individuals not only pay attention to the traditional levels of bioenergy production technology, economy, and environment but also to the social cognition and social impact of bioenergy. The degree of knowledge and acceptance has become popular for scholars [30–34].

Energy transition refers to the development of existing energy utilisation and production methods in a more sustainable direction and is a long-term, multidimensional, fundamental transformation [35]. Energy transition is not about reshaping existing products or learning formed technologies but a profound change from one system to another [40]. Energy transition research is dedicated to understanding how to answer the existing highly organised and diversified interactive system, to have the opportunity to create a ground-breaking shift towards a more sustainable energy system. Therefore, understanding how environmental innovation develops and how to challenge, reconstruct, and replace the existing unsustainable system are crucial to the study of energy transition [20].

MLP theory mentions that “systems” and “technical development trajectories” are not only influenced by practitioners but also by users, policy makers, social groups, suppliers, scientists, and capital. From this point of view, the system is also generated during the interaction between social roles and simultaneously guides their interaction. Therefore, by analysing the interaction network and interaction relationship between the roles through a social network analysis method, this process can be more comprehensive and accurate to summarise MLPs by the institutional hierarchy of theory, enriching the research foundation of multilevel and viewpoints. Additionally, social network analysis methods are embedded in the research system of MLP theory, and the social network is analysed with a dynamic, systematic perspective. In this manner, the social network analysis method and MLP theory are coupled. These concepts can effectively complement each other and facilitate the study of energy transition issues in a more comprehensive, accurate, dynamic, and systematic manner. Figure 2 shows the coupling model of the social network analysis method and MLP theory. The polygon at the institutional level represents the interaction between the roles abstracted by the social network analysis method, nesting it in a dynamic MLP to analyse the evolution of the entire bioenergy industry.

**Figure 2.** Multilevel social network coupling model [19].

### 2.3. Research Case Overview

The Yangtze River Delta area covers an area of 211,700 km², accounting for about 2.2% of China’s area and has a population of 225 million [41]. The Yangtze River Delta is one of the most active regions in China’s economic development. In the first quarter of 2020, the Yangtze River Delta’s GDP reached 4.98 trillion yuan, accounting for 24% of the GDP in the first quarter [42]. The Yangtze River Delta region is the primary place for China’s energy transition, and the total energy consumption of...
the Yangtze River Delta is substantial. From 1989 to 2017, the total energy consumption increased from 110 million tons to 640 million tons, and the total energy consumption was 9.857 billion tons (data source “China Energy Statistical Yearbook”). This region gathers approximately one-third of the domestic new energy production capacity and nearly 40% of China’s installed biomass power generation capacity [43]. The Yangtze River Delta Economic Belt has a relatively well-developed bioenergy industry. The rural areas of Jiangsu Province and Zhejiang Province are regarded as areas of bioenergy raw materials. Although these provinces are all located in the Yangtze River Delta Economic Zone, the development of bioenergy has different characteristics because of differences in economic, political, and geographic factors in Shanghai, Zhejiang, and Jiangsu. For Shanghai, the proportion of bioenergy-related industries is very small, with straw returning to the field as the mainstay; for Zhejiang, the area of various types of land is 158.319 million mu, of which agricultural land accounts for 12,988.3, accounting for 81.5%, and arable land accounts for 81.5%. Notably, 18.7% of the land area is 29.62 million mu [44]. Forest wood resources are more abundant than agricultural residues. Crop straws are mainly returned to the field. Forest residues are the bulk of the biomass development in Zhejiang Province and have formed a relatively stable market. Jiangsu Province is very rich in straw production: According to statistics [45], the annual straw production is approximately 3876 tons, of which rice and wheat are the main products; rice straw production is 21.64 million tons; and wheat straw production is 12.05 million tons. The total annual output of rice straw and wheat straw is 33.69 million tons, approximately 87% of the total straw output. The treatment of wheat straw and rice straw is a key problem in Jiangsu Province and a difficult problem in Jiangsu Province.

The rural areas of Jiangsu Province and Zhejiang Province are regarded as bioenergy raw materials production areas, so farmers, biomass companies, and local governments are selected for interviews. The urban areas of Shanghai, Jiangsu Province, and Zhejiang Province are regarded as bioenergy consumption areas. Therefore, nongovernmental organizations (NGOs), research institutions, local governments, and end consumers here are selected as interview subjects. The form of interview will be through visits, interviews with questionnaires, etc. We conducted field surveys in six cities: Huzhou, Nantong, Nanjing, Hangzhou, Jiaxing, and Shanghai. The survey scale is shown in Figure 3. Six stakeholder groups are selected as the research objects. The list of stakeholder groups interviewed in the Yangtze River Delta is shown in Table 2. We have conducted the field surveys with the approvals and permissions from not only the university but also the local governments, organizations, NGOs, and farmers.

![Figure 3. The scale of field investigation.](image-url)
Table 2. Stakeholder groups in the biomass energy industry in the Yangtze River Delta for in-depth interviews [23,46–48].

| Stakeholder                                                                 | Stakeholder Type       | Stakeholder Group       | Location  |
|-----------------------------------------------------------------------------|------------------------|-------------------------|-----------|
| Farmers in Yangkou Town, Rudong County                                      | Central Stakeholder    | Farmer                  | Nantong   |
| Grain farmers in Wuxing District, Huzhou City                               | Central Stakeholder    | Farmer                  | Huzhou    |
| Rudong Jingyuan Straw Comprehensive Utilization Professional Cooperative    | Central Stakeholder    | Broker                  | Nantong   |
| Huzhou Fumin Biomass Energy                                                 | Central Stakeholder    | Biomass Company         | Huzhou    |
| Jiaxing Xinjiaaisi Thermal Power Co., Ltd.                                  | Central Stakeholder    | Biomass Company         | Jiaxing   |
| Jiangsu Lianhai Biological Technology Co., Ltd.                             | Central Stakeholder    | Biomass Company         | Nantong   |
| Guoxin Jiangsu Rudong Biomass Power Plant                                   | Central Stakeholder    | Biomass Company         | Nantong   |
| Shanghai Municipal Agriculture Committee                                   | Marginal Stakeholders  | Government              | Shanghai  |
| Energy Bureau of Jiangsu Development and Reform Commission                  | Marginal Stakeholders  | Government              | Nanjing   |
| Energy Bureau of Rudong County, Jiangsu Province                            | Marginal Stakeholders  | Government              | Nantong   |
| Shanghai Development and Reform Commission                                  | Marginal Stakeholders  | Government              | Shanghai  |
| Rural Work Bureau of Yangkou Town Zhejiang Provincial Department of Agriculture-Zhejiang Agricultural Ecology and Energy Office | Marginal Stakeholders  | Government              | Nantong   |
| Agricultural Investigation Division, Shanghai Investigation Corps, National Bureau of Statistics | Marginal Stakeholders  | Government              | Shanghai  |
| Jiangsu Provincial Agriculture Committee                                    | Marginal Stakeholders  | Government              | Nanjing   |
| Haimen Agriculture Committee                                               | Marginal Stakeholders  | Government              | Nantong   |
| Nantong Development and Reform Commission                                   | Marginal Stakeholders  | Government              | Nantong   |
| Nantong Municipal Agriculture Committee                                     | Marginal Stakeholders  | Government              | Nantong   |
| Zhejiang Price Bureau                                                       | Marginal Stakeholders  | Government              | Hangzhou  |
| Huzhou Agriculture Bureau                                                   | Marginal Stakeholders  | Government              | Huzhou    |
| Jiaxing Municipal Agriculture Bureau                                        | Marginal Stakeholders  | Government              | Jiaxing   |
| Zhejiang Provincial Development and Reform Commission                       | Marginal Stakeholders  | Government              | Hangzhou  |
| Cost Investigation Supervision and Examination Branch of Jiangsu Provincial Price Bureau | Marginal Stakeholders  | Government              | Nanjing   |
| Shanghai Resources Comprehensive Utilization Association                   | Marginal Stakeholders  | NGO                     | Shanghai  |
| Zhejiang Biomass Energy Application Association                              | Marginal Stakeholders  | NGO                     | Hangzhou  |
| Biomass Power Generation Branch of Jiangsu Electric Power Association       | Marginal Stakeholders  | NGO                     | Nanjing   |
| Tidal Flat Resources Management Division, Agricultural Resources Development Bureau of Jiangsu Province | Marginal Stakeholders  | NGO                     | Nanjing   |
| Shanghai New Energy Industry Association                                    | Marginal Stakeholders  | NGO                     | Shanghai  |
| Jiangsu Energy Research Association/Donghua University Thermal Energy Engineering Institute | Marginal Stakeholders  | Research Institutions   | Nanjing   |
3. Results and Analysis

3.1. Social Network of Bioenergy Stakeholders

In order to facilitate the analysis of the social network of the bioenergy industry, the stakeholders of the bioenergy industry are first classified. Discussion is made on the mutual influence between different stakeholder groups and what changes this influence brought to the development of the bioenergy industry.

3.1.1. Bioenergy Stakeholder Definition

In the bioenergy industry chain, the production, collection, and transport of raw materials, as well as the production, distribution, and use of bioenergy products, correspond to the producers and transporters of biomass raw materials and the producers and consumers of energy products. They are the central stakeholders of the bioenergy industry. These stakeholders constitute the organisational structure of bioenergy and are responsible for the supply of bioenergy. Their behaviour directly determines the success or failure of the bioenergy industry. Marginal stakeholders are the units that affect the bioenergy industry but are not directly involved in the production of bioenergy. The development of the biomass industry is generally affected by national and government policies, bioenergy technology, organisations and associations, and other social connections. The corresponding stakeholders are the government (i.e., central government and local governments), research institutions, NGOs, and ultimate consumers of bioenergy.

Through questionnaire surveys and in-depth interviews, the social network of bioenergy stakeholders in the Yangtze River Delta was summarised in accordance with the relationship between material and information flow in the social network analysis method (Figure 4). To explain the relationship between the stakeholders in the figure, we explain the relationship between the central stakeholders, the interaction between the central stakeholders and marginal stakeholders, and the interaction between the marginal stakeholders.

Figure 4. Social network of bioenergy stakeholders.

3.1.2. Interaction of Central Stakeholders

According to the survey results, the relationship between the central stakeholders of bioenergy in the Yangtze River Delta region can basically be summarised into two models based on their dependence on brokers.
1. Farmers are providers of biomass raw materials: in the industry chain with farmers participating, farmers are producers of biomass raw materials. The broker mainly has the functions of collecting, selling, and transporting biomass raw materials and sometimes also undertakes the functions of storage and preliminary processing. Biomass enterprises use biomass raw materials to produce bioenergy products (mainly biomass power generation and production of biomass pellets). They establish long-term agreements or short-term cooperation with brokers to ensure a stable supply of raw materials.

Rudong County, Nantong City, Jiangsu Province, has a relatively complete and typical structure and division of labour in the industrial chain of crop straw power generation, which is a typical case of this model. Farmers in Rudong County obtain agricultural residue straw by planting crops. The Jingyuan Straw Comprehensive Utilisation Professional Cooperative in Rudong County acts as a broker in the industrial chain. The cooperatives organise and employ approximately 900 idle farmers to replace other farmers for straw collection and transport. The Jiangsu Guoxin Rudong Biomass Power Plant was put into commercial operation in 2008, with an average annual purchase of approximately 300,000 tons of straw. Rudong Power Plant does not directly contact farmers but connects with brokers. Enterprises, through brokers, sign contracts to ensure that biomass power plants' regular quantitative generation.

2. Large grain-production households are providers of biomass raw materials: In the industrial chain, they generally deliver biomass raw materials to biomass enterprises, with little or no interaction with brokers. Other processes are the same as those in the bioenergy industry chain in which farmers participate.

Sun Meijin, a large grain-production household in Wuxing District, Huzhou City, Zhejiang Province, was interviewed during the survey. Their farm has a planting area of 3000 mu, with a rent of 1000 yuan per mu, and they mainly plant rice, wheat, and rape. The large grain-production households transport the collected, bundled straws to the biomass pellet production enterprises, and the biomass enterprises use the biomass pellets to exchange straw with the large grain-production households. In this form of bartering, the large grain-production household can use straw bales as the means of exchange for the fuel that can dry the rice, with no brokers involved.

3.1.3. Interaction between Central and Marginal Stakeholders

The influence of marginal stakeholders on bioenergy industry is reflected by their interaction with central stakeholders. Therefore, each marginal stakeholder is taken as the research object to assess their connection with the central stakeholders.

1. The government. In the bioenergy stakeholder network of the Yangtze River Delta Economic Belt, there are three levels of government agencies: central government agencies, provincial government agencies, and local government agencies (county, district, and township level). Figure 5 shows the hierarchical relationship between them. We classified all government units we interviewed according to their functions and levels. The classification table is shown in Table 3. During the investigation, we found that the relevant policies and financial support for the development of bioenergy have skipped the municipal level. That is, many policies on the prohibition of burning and the comprehensive utilisation of biomass are directly issued to the grassroots government through the provincial government but did not pass through the municipal level. This phenomenon will also appear in the approval of the construction of biomass utilisation projects.
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2. Research institutions. Research institutions solve problems in the production of bioenergy and promote technological innovation in the use of bioenergy through cooperation between universities and enterprises, cooperation between research institutes and enterprises, and the establishment of research departments by enterprises.

Typical cases include the establishment of cooperation between Zhejiang Jiaxing Xinjiaaisi Thermal Power Co., Ltd. and the relevant departments of Tsinghua University, Zhejiang University, Zhejiang University of Technology, and Zhejiang Agricultural University. The company has conducted experimental innovations to improve mechanical efficiency, intelligent control, denitrification, and emission reduction in the process of cooperation with research institutions. Xinjiaaisi also has a research department, undertaking major provincial science and technology projects, leading the world in denitrification and emission reduction and achieving ultra-low emissions.

3. Associations and NGOs. Associations and NGOs coordinate the government and biomass enterprises and provide expert guidance and technical advice, formulate industry standards, unify technical standards, publicise and implement policy documents, promote new bioenergy technologies, and provide a platform for learning and expressing opinions, to organise and solve an industry’s major and common problems.
A typical case is as follows: The Zhejiang Bioenergy Application Association led many biomass-processing enterprises to effectively use forest residues, formulate industry specifications and technical standards, and develop new biomass technologies independently. Shanghai Putian Energy Co., Ltd., Shanghai Yongsheng Energy Co., Ltd., and Shanghai Hongju Energy Technology Co., Ltd., and so forth, are frequently contacted by the Biomass Professional Group of Shanghai Resources Comprehensive Utilisation Association. This kind of association coordinates the actions between the government and biomass enterprises, and processing plants and provides, for example, expert advice and technical guidance.

4. End consumers and the public. End consumers and the general public are users of bioenergy and a part of the development of the social environment of bioenergy. Through a side interview in the survey, we found that the acceptance of consumers of biomass-forming fuels is relatively high, and there is a shortage of supply.

3.1.4. Mutual Influence of Marginal Stakeholders

The government supports or guides the development of research institutions, associations, and NGOs through policies and funds, and the research results of research institutions influence the decision-making of the government; the association provides decision-making suggestions for government departments and drafts relevant standards and norms. The association helps research institutions promote technology, and the research institutions provide solutions to the technical problems encountered by the technical association.

The Energy Research Society of Jiangsu Province received financial support from the state and the government to conduct relevant research and found that the excessive return of straw to the field has a negative effect on land and crops. The results of the study also affected Jiangsu Province’s policy of returning farmland. The government began to encourage farmers to use straw for energy, such as biomass power generation, after the straw is removed from the field.

Under the leadership of the government, the Shanghai Municipal Resources Comprehensive Utilisation Association conducts biomass industry research and planning and formulates product standards in accordance with the work requirements of the relevant departments in Shanghai. The association can also reflect the wishes and demands of enterprise members to the government and propose reasonable suggestions to provide references for government decision-making.

3.2. Social Network Analysis of Bioenergy Stakeholders

To facilitate the analysis of the social network of bioenergy stakeholders, we analysed the social network of biomass stakeholders into six aspects based on the survey results: material flow, policy, technology, infrastructure, market demand, awareness, and information dissemination network (Figure 6).

Figure 6. Social network analysis of bioenergy stakeholders [19].
3.2.1. Material Flow Analysis

Material flow analysis includes:

1. Material source. In the bioenergy industrial chain of the Yangtze River Delta Economic Belt, the biomass raw materials are mainly agricultural and forestry biomass such as straw and wood waste. At present, there is no commercial planting and collection of energy crops. Due to the strong dependence on biomass raw materials for companies that produce biomass shaped fuels, raw materials are often in short supply. The Huzhou Fumin Biomass Enterprise in Zhejiang Province adapts to the shortage of raw materials by controlling the daily production time, and each batch of moulded fuel sells out quickly.

2. Material production. The raw materials are mainly straw and forest wood. The suppliers of straw and farmers are scattered, making it difficult to collect and transport raw materials, and they are greatly affected by the weather. The large grain growers are more concentrated and have a certain scale for the production of biomass raw materials, advanced agricultural machinery, and a high level of modernisation.

3. Material transport. For agricultural residues, the density of straw is low, the volume of a single transport is large, and the mass is small; thus, individual farmers have a greater dependence than large grain growers on transporters; for large grain growers, because they have transport and intensive cultivation of crops, it is more convenient to collect and transport raw materials than it is for individuals. For the forest residues, transport is generally independent and convenient. Based on the aforementioned analysis, the main service targets of the transporters of bioenergy raw materials are individual farmers.

4. Material processing. At present, the bioenergy production in the Yangtze River Delta mainly includes biomass power generation and biomass pellet manufacturers. For biomass power plants, the production scale is large, the equipment modernisation is in good condition, the pollution emission management is strict, and they enjoy state subsidies; for small biomass fuel production enterprises, the production scale is small, and the equipment modernisation level is insufficient; there is no uniform standard for pollution emission management, making it difficult to survive.

3.2.2. Technical Analysis

On the whole, the bioenergy industry is not technologically innovative, technical specifications are not perfect, and there are problems in operational safety, environmental protection, and specifications. In the production process of biomass fuel, the utilization technology of straw is relatively backward. Due to the low calorific value of the straw briquette fuel, it does not meet the calorific value requirements of the boiler; furthermore, the fuel is easy to coke after combustion, which affects the subsequent use of the boiler. The above problems directly lead to poor sales of biomass briquettes and low marketization. After technical improvement, a compressed biomass briquette of wood and straw was formed, and the calorific value was improved.

There is no unified standard for pollution emissions from biomass fuel production enterprises, and the standard system for bionatural gas and bioforming fuel has not been established. The biomass energy certification system has not been improved, which has become an obstacle to the standardized development of biomass. For biomass power generation, the power generation technology is relatively complete, but the environmental protection inspections in terms of desulfurization and denitrification are strict, and large investments in technology and capital are required.

3.2.3. Policy Analysis

According to the purpose of the government’s policy formulation, it can be roughly divided into two types: promote the development of bioenergy and solve the environmental problems caused by the burning and disposal of biomass (e.g., straw), with the main task of protecting the environment and the development of energy as a supplementary policy. From the survey, we observe that among the policies
that affect the recycling of biomass raw materials, the government’s burning ban policy is the main influencing factor for farmers to collect and use straw, followed by the government’s economic reward and punishment policy. The policy affecting brokers is to encourage brokers to actively participate in the supply of biomass raw materials by providing brokers with economic benefits. Policies that affect biomass enterprises can be basically divided into two types of national and local policies: national policies that mainly affect biomass power generation enterprises and local policies that mainly affect small local biomass fuel production enterprises.

3.2.4. Market Demand Analysis

Overall, the bioenergy market in the Yangtze River Delta Economic Belt is insufficiently mature. According to different regions, different levels of supply and demand imbalances have occurred. The market supply and demand of bioenergy for different purposes is shown in Table 4. The market is basically sustained by government subsidies. For biomass power, the state implements biomass power generation to the national grid and promises to provide subsidies. However, biomass power generation is smaller than that of wind power, hydropower, and other power output and has not formed a scale, mainly because the state grid plays the role of power supplement. For biomass-forming fuels, they generally have low heating value and easy coking; thus, market demand is low. After improving the heating value, the market demand improved but remains insufficient. Because straw purchases are seasonal, they also affect the production of moulded fuel, mainly because of unstable output and large seasonal changes.

Table 4. Condition of market demand of bioenergy.

| Types of Bioenergy | Electricity | Forming Fuel |
|--------------------|-------------|--------------|
| Market Demand      | State Grid unconditionally complete acquisition | Market demand is not optimistic |
| Market Supply      | Small output, mainly supplement | The output varies according to the season and is unstable |

3.2.5. Infrastructure Analysis

The overall infrastructure construction level of the bioenergy industry is low, the number is insufficient, and the regional development is uneven. Regarding the collection of biomass raw materials, the amount of collection, storage, and transport sites present a regional imbalance, and the overall number is insufficient. The collection, storage, and transport sites have insufficient construction land, backward construction of sites, and backward modernisation of machinery and equipment. Regarding bioenergy production companies, biomass companies were shut down a lot in 2019, and the infrastructure is inadequate; biomass power generation companies have high grid maintenance costs, and biomass fuel companies have insufficient mechanisation and modernisation.

3.2.6. Awareness and Information Dissemination Analysis

The environmental awareness of various stakeholders in the bioenergy industry and the use of new energy have improved, but overall, the level remains low, especially the insufficiently strong environmental awareness of farmers. Farmers mainly participate in the development of bioenergy based on punishment and economic benefits. Farmers are seriously ageing and have little to no awareness of environmental protection. Under the propaganda of the government’s ban on burning straw and the subsidies for biomass, farmers gradually began to accept the use of straw for resource and energy utilisation. However, the motive behind these uses was mainly driven by economic interests, rather than a focus on environmental protection.
3.3. Analysis of Bioenergy Development under MLP Theory

According to the diagram of the dynamic evolution of bioenergy under the multilevel social network theory in Figure 7, we conduct a specific analysis and discussion from the perspective of three aspects: landscape, niche, and regime.

![Figure 7. Multilevel perspective (MLP) of bioenergy development [19].](image)

### 3.3.1. Landscape Analysis

At present, China’s bioeconomy is in the stage of development. It is in the development span of the information economy era to the bioeconomy era, and China’s energy utilisation status and energy transformation needs have created a “slope.” This slope constitutes the most macro level of bioenergy development, the landscape level. This slope affects the regime and niche levels: from the perspective of the niche level, the continuous development of the bioeconomy has formed a demand for the development of new biological technologies, which can promote the production and utilisation of bioenergy. Technological breakthroughs have pushed human society towards a new era of bioeconomy; from the regime level, the development of bioeconomy will affect China’s energy development planning policies, thereby promoting the development of bioenergy, and China’s development strategies and other policies have also accelerated the pace of progress towards the biological age.

Among the effects of the landscape on the regime level, the policy aspect is the most typical. Based on the assessment of the domestic energy situation and energy transition, China issued the “13th Five-Year Plan for Bioenergy Development,” which shows that accelerating the development and utilisation of bioenergy is important to promote the revolution in energy production and consumption and an important task to improve environmental quality and develop a circular economy [49]. This phenomenon also reflects the transition to the era of bioeconomics.

### 3.3.2. Niche Analysis

The emergence and development of niches’ hierarchical innovation is influenced by the landscape and regime, which provides a slope for the development of the niches’ hierarchy. The core of the energy transformation is to improve energy efficiency and develop renewable energy. Bioenergy is an important renewable energy. The clean, renewable characteristics of bioenergy fulfil the development needs of the bioeconomy.

The impact of the regime on the niches is more direct and obvious than the landscape hierarchy, for example, the development history of third-generation biofuels [50]. The rise of first-generation biofuels
to produce bioethanol from grain raw materials in China has created competition for food resources. Technically, the bioethanol produced from grain can only be mixed with fossil fuel. These factors led to great limitations in the development and application of first-generation biofuels. The raw materials of second-generation biofuels are mainly nongrain crops. However, second-generation biomass fuel technology remains unable to convert lignin and cellulose, which account for approximately 40% of the total raw materials, causing waste similar to that of the first-generation technology. Third-generation biofuels use algae to transform inorganic substances into bioethanol, from terrestrial to aquatic, and from organic matter to microbial production.

Based on the aforementioned analysis, we observe that the impact of landscape and regime on bioenergy innovation can be positive or negative, and this effect is also mutual. However, when the innovation of bioenergy is not mature, bioenergy industry is easy to be negatively affected and “die.” Therefore, a suitable system-level environment is a necessary condition to ensure the successful birth and development of bioenergy innovation and is also a necessary means to achieve landscape-level goals.

3.3.3. Regime Analysis

As China’s bioeconomy has just emerged, the regime level of the bioenergy industry has the following characteristics: In terms of material flow, a raw material flow of biomass has been formed in Jiangsu, Zhejiang, and Shanghai. However, the lack of technology and infrastructure makes it difficult to achieve large-scale collection of agricultural and forestry biomass raw materials. In terms of policies, such as burning bans and energy utilisation, they have promoted the development of bioenergy, but the relevant policies for straw treatment remain based on burning bans. Although measures such as returning straw to the field and removed from the field for energy are provided, because of technical difficulties in manual collection, bundling of straw, and high mechanical failure rates, straw remains difficult to collect. From a technical perspective, advanced technologies such as coal-fired coupling have not been promoted. A power grid with the distributed characteristics of bioenergy has not been established, and the maintenance cost is high. In terms of awareness and information dissemination, the public has improved environmental awareness. However, in the countryside, farmers have little to no consciousness of using straw for energy. Although under the influence of the burning ban policy the environmental pollution caused by straw burning has been reduced, farmers’ environmental awareness has not significantly improved. Farmers treat crop straws mainly by returning them to the fields, with not awareness of resource utilisation. Biomass moulding fuel technology has improved, and the market has expanded. However, in general, its insufficient commercial development has caused regional supply imbalances, and the biomass moulding fuel market is chaotic.

There is also interaction between the niche and regime levels: the emergence of bioenergy provided a new means of using straw after the burning ban: The government began to encourage farmers to collect straw for energy utilisation and changed policy at the institutional level. That is the impact of the niches on the regime level, and the regime level provides feedback. As policies promote and encourage the energy utilisation of straw, policies and financial incentives have begun to be given to farmers, brokers, and biomass enterprises. Material flow, technology, infrastructure, and so forth have begun to improve, and the conditions for the development of biomass moulded fuels have improved. In short, when the regime level changes, the niche level will also be affected by this change and react to this change. Such mutual influences promoted energy transformation.

4. Discussion

(1) Quantitative analysis of the strength of influence among stakeholders
(2) This study uses the social network analysis method to conduct a qualitative analysis of the interaction between bioenergy stakeholders, indicating the priority and direction of the interaction between stakeholders (for example, for the ban on straw burning, the government issued a ban on burning straw policy has the greatest impact, economic support is the second, and environmental awareness has the least impact, etc.). There is no quantitative research and analysis on the magnitude
of the mutual influence of various stakeholders in the actual situation [51]. Future research can consider establishing an indicator system for the mutual influence between stakeholders, conducting quantitative analysis, more accurately expressing the strength of each stakeholder’s mutual influence and establishing a more scientific and systematic social network of bioenergy stakeholders [14,52].

(3) More comprehensive research on the bioenergy industry chain
(4) The survey site of this study is mainly the Yangtze River Delta, where there are two main ways of using bioenergy: biomass power generation and biomass briquette. The main reason for selecting this research object is that the Jiangsu, Zhejiang and Shanghai regions have relatively mature industrial chains for biomass power generation and biomass briquette and have high research value. In addition to the above two utilization methods, biomass utilization methods also include the production of biomass liquid fuel, biomass gas, and so on [41–43]. However, biomass liquid fuels are still in the early stages of development in China. Biomass gas (such as biogas and other products) is generally consumed locally and has no established industrial chain, so it is not included in the scope of investigation. With the continuous development of bioenergy and the deepening of research, other bioenergy industries can be included in the scope of investigation, and the dynamic evolution of the bioenergy industry can be analysed more comprehensively and systematically.

(5) Quantitative investigation of comprehensive social, economic, and environmental factors
(6) This study aims to reveal the dynamic evolution of bioenergy in the context of China’s energy transition, analyse the various factors affecting the development of biomass, explain and distinguish the development of bioenergy, and provide policy recommendations for promoting the development of bioenergy and energy transition. However, the current analysis in this paper is mainly based on qualitative analysis of social factors, such as qualitative analysis of the influence of various stakeholders, analysis and prospects of the development status, and prospects of bioenergy based on multilevel perspective theory. It has not established a quantitative investigation and research system based on economic and environmental factors, such as economic benefit analysis and environmental benefit analysis of the bioenergy industry [53–55]. If the social, economic, and environmental benefits are comprehensively and quantitatively analysed, the development of bioenergy will be presented more clearly, scientifically, and comprehensively, identifying the development trend of bioenergy and formulate strategies for bioenergy development and energy transition.

5. Conclusions

Through the comprehensive use of a social network analysis method and MLP theory, to study and discuss the development status of bioenergy in the Yangtze River Delta, the main conclusions drawn in this research are as follows:

Through social network analysis, it is concluded that the relationship between bioenergy stakeholders is a relationship network with central stakeholders participating in the bioenergy material flow as the core and affected by multiple marginal stakeholders. Among them, the central stakeholders are the central network composed of biomass raw material producers (farmers), biomass raw material consumers, biomass energy producers (biomass enterprises), and biomass raw material transporters (brokers). In addition, marginal stakeholders influence the development of the bioenergy industry by influencing this central network.

Through social network analysis, this method summarises the characteristics of bioenergy stakeholder interaction: in terms of material flow, a basic industrial chain system has been established, but there is insufficient experience in the commercial development and utilisation of various parts, such as the collection of raw materials and market disorder. In terms of technology, biomass-forming fuels have made breakthroughs in the improvement of heating value. However, the production standards and pollutant emission standards for biomass fuels have not yet been
established, which hinders the formation of a standardized biomass energy market. Therefore, the use of biomass-forming fuels as a basic energy source requires a key technological leap. In terms of policy, a policy and financial system with the ban on straw burning as the mainstay and resource utilisation as a supplementary approach has been formed, effectively solving the problem of environmental pollution. However, in the long run, these policies tend to target individual links in the bioenergy industry chain. There is no systematic and centralised industrial policy, and no subsidy for the use of bioenergy terminals, but there is a subsidy for biomass power generation. In terms of infrastructure, a collection, storage, and transport infrastructure unit represented by brokers has been formed. However, brokers rely on government subsidies for profits and need to further expand service areas and improve site environment. Due to the high maintenance cost of a biomass power grid, the industrial standard system of biomass fuel has not been established. No consensus has been reached in terms of awareness and information dissemination. At present, the understanding of bioenergy from all sectors of society is not sufficient, and the development of bioenergy is restricted.

From the perspective of landscape hierarchy, China has been in the process of entering the bioeconomic era from the information economy era in the long run and is in the period of social transformation of energy transformation, from the development mode relying on fossil energy to the development mode relying on bioenergy. This profound social transformation is the slope of the landscape level. From the analysis of niches hierarchy, the emergence and development of biotechnology and biofuels are the technical foundation of the bioeconomic conception. These innovations have promoted social transformation. From the analysis of the regime level, the characteristics of current bioenergy development environment are summarised from six aspects: material flow, technology, policy, market, infrastructure, awareness, and information dissemination. According to the development trend of the landscape level and development needs of the niche, the hierarchy of the regime does not match the development concept and development model of the bioeconomy. Therefore, under the guidance of landscape slope, technology and policy development, material flow, market, infrastructure, consciousness, and information communication began to influence and evolve with each other. The three hierarchies of landscape, regimes, and niches influence each other and evolve together.

6. Policy Recommendation

According to the social network analysis and MLP theoretical analysis of the current bioenergy industry, this research found that the current deficiencies of biomass at present, and the future development trend of bioeconomic society is prospected, to effectively promote the development of bioenergy, and the following suggestions are proposed:

1. Policy development level: systematically establish a bioenergy industry policy system, coordinate the development of bioenergy, and implement various subsidies for the bioenergy industry.

2. Technology development level: promote cogeneration technology in the biomass power generation industry to explore the solution to the problems of raw material collection and low heating value of biomass moulding fuel, broadening and stabilising the biomass pellet fuel market.

3. Market development level: to implement the state’s requirements on the priority utilisation of renewable energy and full guaranteed purchases, establish a priority utilisation mechanism for bioenergy and expand the sales channels for biomass fuels.

4. Infrastructure development level: support the construction of biomass raw materials collection, storage, and transport system and vigorously promote the current successful broker collection, storage, and transport model; establish a matching infrastructure with the characteristics of biomass raw material dispersion. Raise and implement subsidies for agricultural machinery to promote the removal of straw from the field.

5. Development of awareness and information dissemination: To improve citizens’ environmental awareness, incorporate the use of bioenergy in national energy, environmental protection,
and agricultural strategies; and strengthen publicity and education on environmental protection, energy conservation, and emission reduction.

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