

## Article

# The Development of Straw-Based Biomass Power Generation in Rural Area in Northeast China—An Institutional Analysis Grounded in a Risk Management Perspective

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**Abstract:** Given a lack of consideration for the role and importance of stakeholders and the importance of stakeholders in the operation of biomass power plants in China, a comprehensive analysis oriented toward stakeholder risk management is needed to further develop the country's biomass energy industry. Accordingly, we analyzed institutional factors that contribute to or constrain progress in biomass power generation in China. Data were collected from 275 straw suppliers (farmers) living around a biomass power plant, 15 middlemen, five power plant managers, and five local government officers. Interviews were held with all the participants, but questionnaires were additionally administered to the straw suppliers. Results showed that: (1) risk transfer in the biomass supply chain is one of the reasons why farmers are unwilling to supply straw; (2) middlemen are vital intermediaries between biomass power plant managers and farmers as a middleman-based biomass supply system is necessary to guarantee the quantity of straw supply, and; (3) the institutional structure that underlies the Chinese biomass energy industry is immature.

**Keywords:** institutional analysis; biomass power development; stakeholder; risk management

## 1. Introduction

Electricity production, particularly through fossil fuels, is the main contributor to greenhouse gas (GHG) emissions and their associated environmental effects [1]. Out of the total GHG emissions, 65% are accounted for by carbon dioxide (CO<sub>2</sub>) released from electricity production and combustion [2], which is a problem that highlights the need to reduce fossil fuel consumption [3] and, by extension, GHG release. Such mitigation was correspondingly accorded focus in an environmental directive established by the European Commission. GHG emission reduction is evaluated on the basis of indicators such as the increased use of renewable energy sources, energy-saving, and progressively efficient energy use. An equally favorable measure is the substitution of bioenergy for conventionally produced electricity as this decreases CO<sub>2</sub> emissions and helps mitigate climate change [4,5]. Bioenergy is therefore expected to figure importantly in energy transitions.

A bioenergy source that is extensively used around the world is biomass (e.g., agricultural and forestry residues), from which power plants can produce 280 TWh of electricity—a volume that is equivalent to 1.5% of global electricity generation per annum [6]. Biomass power generation would be especially beneficial in China, which is the largest contributor to carbon emissions from fossil fuel burning and whose carbon emissions account for 30% of the global discharge volume [7–9]. The magnitude and annual growth rate of carbon emissions in China render the country a key target

of efforts to mitigate this environmental problem. Emission reduction initiatives are feasible for the country because of the widespread availability of biomass sources in its many regions of the country enables the on-demand generation of biomass-based electricity. Biomass energy is also advantageous over other types of renewable energy because it presents more substantial benefits to local economic development and is less vulnerable to the intermittence and seasonality of supply [10]. To illustrate, a biomass power plant with 30 MW capacity can generate 1600 GWh of electricity annually (based on a case study in Wangkui County, China) from 0.2 million tons of crop straw per year. Such production is remarkable when compared against the annual straw production of approximately 728 million tons. On this basis, plants can theoretically generate 582,400 GWh of electricity.

Despite the productive potential of biomass, however, many barriers impede the large-scale development of biomass power generation. Some of the obstacles identified in previous research are technical difficulties, the cost of developing and operating a biomass supply chain, and issues in cooperation with farmers [11]. Numerous challenges confront biomass power plants in terms of acquiring raw materials for plant operation. The difficulties in obtaining raw materials are caused, among other main factors, by the unwillingness of farmers to cooperate with middlemen who collect and purchase straw from farmers and sell it to biomass power plants. This reluctance is due to insufficient market information. Overall, the development of the biomass energy industry has been hindered by the immaturity of the market's underlying institutional structure.

To systematically analyze the risks facing biomass development in China, this study investigated biomass power plants and analyzed and summarized the results through a biomass power plant in the country's northeastern region (i.e., a branch of the National Bioenergy Power Plant) through institutional analysis based on a risk management perspective. The selection of the biomass power plant, which was informed by an inquiry into the situation characterizing the Chinese biomass industry, was driven by it being identical to all other such facilities in the country. These facilities share the same problem regarding the shortage of raw materials due to the uncooperative behavior among farmers.

## 2. Review of the Literature on Institutional Analysis

Institutional analysis is the process of examining how formal and informal rules affect behavior and functioning. It is applied in the management field to derive practical policy considerations and measures for solving social problems. Several institutional studies have been carried out in different disciplines, such as forestry management [12,13], construction management [14], water management [15–17], and ecosystem service [18]. This body of research formed the initial basis of the institutional analytical framework adopted in the current work. Because a detailed understanding of the institutional analysis of energy issues and a sufficient overview of the present state of scholarship are required, we also surveyed peer-reviewed literature. Studies for evaluation were identified by conducting a search of the recently published articles indexed in Scopus. The search was based on the terms “institutional analysis” AND “energy” and “institutional analysis” AND “environment”. We then selected the articles that were most relevant to this study (Table 1).

**Table 1.** Previous studies based on institutional analysis.

Study	Topic	Institutional Theory and Factor	Results
Ref. [19]	Wind energy in France and Quebec	Finance, legislation, political style, energy context, pressure groups in society, and social movements.	Institutional factors significantly influence energy decision-making. The variety of stakeholders who play an important role
Ref. [20]	Transition to low-carbon energy	Organization, socio-technical regime, political and economic system, culture	In the systematic applying institutionalism can provide a deeper understanding of socio-technical transitions
Ref. [21]	Institutional framework for power market development in Pakistan	Governance, policy, tariff, regulation, stakeholders (consumer, generator, distributor)	With existing installed capacity and energy generation, the power market of Pakistan can operate at competitive levels, except with respect to certain conditions.
Ref. [22]	Business strategy for energy efficiency in China	Incentives, financing support, information provision, standards, and mandates	The Chinese case studies revealed a strong institutional impact on firms' choice of business strategies, particularly positioning.
Ref. [23]	Climate change adaption in Tenerife	Social actors are analyzed, including international organizations, atmospheric research centers, etc.	Public participation and an integrated approach between mitigation and adaptation plans were identified are key policy issues
Ref. [24]	Energy transition in Japan	Socio-technical transitions theory Institutional factors: policy paradigms, institutional environment, energy-related organizations, govern transactions, etc.	Policy reforms on energy sector structure and performance were proposed.
Ref. [25]	Fuel consumption reduction in Iran's transportation niches	People, car manufacturer, government, regulation	Penalty option can significantly advance the management of fuel consumption the government's decision leads to reduce fuel consumption.
Ref. [26]	Waste disposal	IAD framework Institutional factors: willingness to monitor, actual monitoring behavior, biophysical condition (environmental quality, waste pollution, illegal dumping), community, rules in use (sanitation cadres, punishment measures, peer monitoring)	Improving community infrastructure and economic conditions, reducing external intervention on community affairs, and cultivating social capital stock are important approaches to enhancing public participation in environmental governance
Ref. [27]	Energy transitions in Australia and Germany	Multi-Level-Perspective framework Institutional factors: rules, practices, and narratives in national, state, and local scales	The inclusion of modes and scales in institutional frameworks helps to nuance and refine comparative research on energy transitions
Ref. [28]	Policy instruments facilitate the adaptive governance of drought	Young's institutional environmental analysis method [29] Institutional factors: drivers, institutions, instruments, actors, etc.	The results reflected missing and weak instruments and dimensions of adaptive governance

Table 1. Cont.

Study	Topic	Institutional Theory and Factor	Results
Ref. [30]	Environmental management in Korean mobile communications industry	Regulatory mechanism, cognitive mechanism, normative mechanism	Stakeholders including users, practitioners, policymakers, and researcher should be diverse
Ref. [31]	Promoting sustainable energy	Technology change, new entrants, social movement, policy	The field requires skills that somewhat differ from those indicated in business-as-usual policy development.
Ref. [32]	Risk management in land development in the Netherlands	Transaction cost theory	The importance of institutional analysis as a means of recognizing and understanding the role played by planning institutions in allocating risk between public and private market participants in the land development process was highlighted
Ref. [33]	Comparison of energy business models	Public policy, legislation, and regulation	Public policy institutions play a critical role in energy decentralization and demonstrate how studying commercial activities through a business model-oriented lens can help reveal decentralization dynamics

Table 1 indicates that institutional analysis (a) advances policy-making [22,24,25], (b) identifies missing and weak points in governance instruments [28], (c) underscores public participation [21], and (d) emphasizes the vital role of stakeholders [19,26,30,32]. a cognitive mechanism is recognized as one of the institutional factors, which is consistent with our study [30]. The literature also reflected that looking into risk is crucial in initiatives intended for land development [32]. In the biomass industry, the risk is an interesting topic in relation to biomass supply chains [34–38]. Nevertheless, little research has been directed toward a risk management-based institutional analysis of biomass power generation and the classification of factors associated with such production. To address this gap, the present study carried out an institutional analysis from the perspective of risk management, with the examination guided first and foremost by the question of “who is to be responsible for what” in the development of biomass power generation in China. a risk management perspective uncovers actors in a multi-institutional environment, thereby clearing the way for an understanding of the risks related to responsibilities and the formulation of effective interventions.

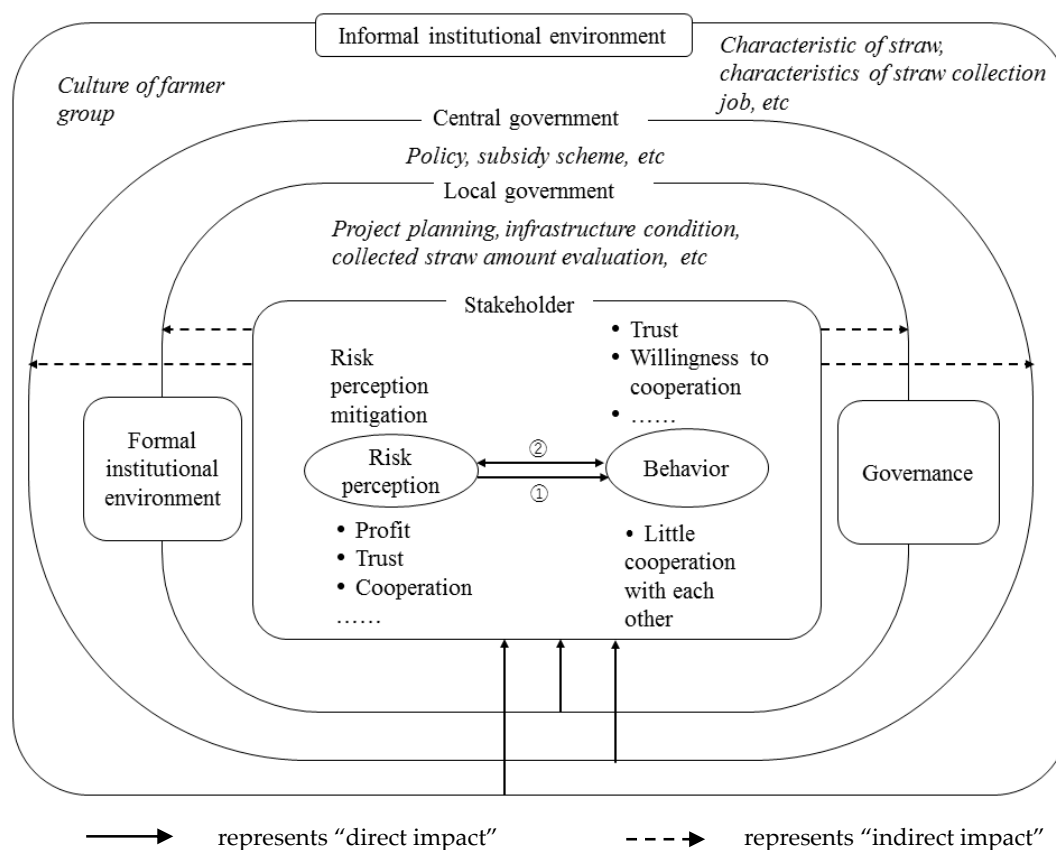
### 3. Analytical Framework

Given the highly promising potential of biomass as an alternative source of electricity and because its use discourages straw burning in fields, numerous studies have been conducted to solve the problems that confront the development of biomass power generation [36,39–41]. For instance, researchers investigated the willingness of farmers to supply straw and their perceptions regarding biomass supply to determine what incentivizes biomass provision [42,43]. Such causal relationships, which factor in the development of biomass power generation and the establishment of comprehensive strategies for risk management-based development, are effectively identified using a framework. a framework is especially favorable in the Chinese context, where the development of biomass power generation is influenced by many factors, including market conditions, policies and regulations, natural conditions, institutions, and culture [44–46]. In a country such as China, a framework enables the isolation of key variables that are specific to its circumstances and provides a clear view of fundamental real-world factors that may otherwise be overlooked.

The development of a framework can benefit from insights regarding intuitions, which play a pivotal role in the development of market activity [47]. Casting light on how institutions evolve is crucial to identifying market risks. Correspondingly, this study analyzed the development of the biomass energy industry in rural China on the basis of Oliver Williamson’s theory on institutional economics, which delineates the evolution of institutions. The transaction economics factors put

forward by Williamson are embeddedness, institutional environment, governance, and resource allocation and employment. Embeddedness pertains to the adaptation to informal institutions, customs, traditions, norms, and religion; institutional environment covers formal rules such as property regulations (policy, judiciary, bureaucracy); governance has to do with abiding by established practices, with a view to ensuring the appropriateness of governance structures by aligning such structures with transactions; and resource allocation and employment center on price quantities and incentive alignment [47].

With Williamson's institutional theory and our practical problem as bases, we created a dynamic instructional framework by incorporating the interaction between stakeholders and factors that affect the development of biomass power generation in China. Specifically, we expanded a conventional framework by including an analysis of psychological interaction on the basis of risk perception to identify dynamic changes in actors' behaviors that are influenced by informal institutional determinants, formal institutional factors, and risk perceptions. Mutual influence among actors was incorporated into the framework because decision-making by actors is underlain by a psychological process, which in turn, is influenced by the risk perceptions of actors and the behaviors of other stakeholders toward activities (Figure 1).



**Figure 1.** Institutional analysis framework for the development of the biomass power industry.

This research considered not only the above-mentioned interaction but also the changes in perceptions that occur during such encounters. These perception changes transpire in a dynamic process. First, the informal institutional environment explained in this work is important in practice, because it distinguishes the biomass power industry from other industries. Second, decision making by actors in the studied setting is constrained by policy, governance by the central government, and the project planning and infrastructural conditions of the local government. The behaviors of actors also affect the institutional arrangements of the central and local governments. Third, the interaction between the actors' risk perceptions and behaviors was examined. The dynamic interaction among

actors and the process that underlies it are illustrated in Figure 1 (middle section). Item ① in the figure indicates that the perceptions regarding a high risk of gaining little or no profit and low trust, among other negative conditions, reduce the willingness of actors to cooperate. Item ② indicates that when the risk perceptions of actors are mitigated, they are inclined to trust and cooperate and accordingly exercise these actions. a given actor's behavior influences the risk perceptions of other actors and can, therefore, stimulate such viewpoints.

Guided by the proposed framework, we analyzed the development of China's biomass energy industry from the perspective of actor-related risk management. Informal and formal institutional environments, along with the process by which actors interact, were also scrutinized to illustrate how the interplay among actors is influenced by both informal and formal institutional contexts.

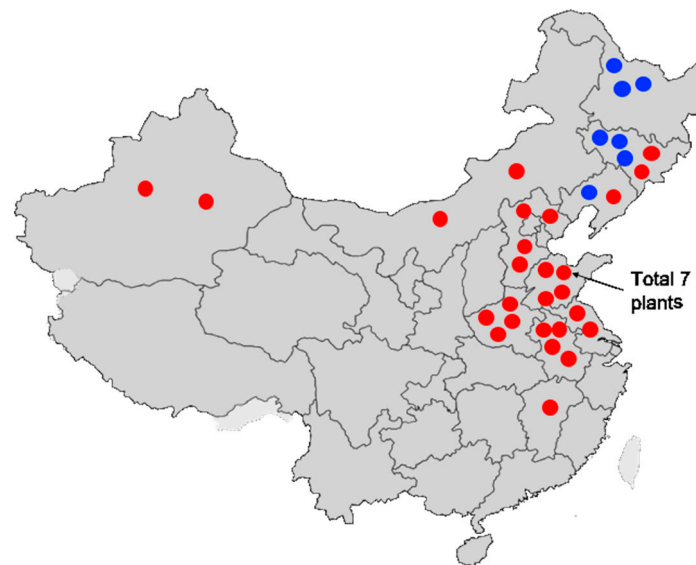
## 4. Research Design

### 4.1. Data Collection

Data collection was carried out in three phases. The power plants that we investigated are listed in Table 2. After determining that most straw-based biomass power plants in China share similar problems, we conducted a detailed survey of a branch of the National Bioenergy Power Plant, located in Wangkui County, northeast China as the case study. This biomass power plant has 36 branches in the whole of China (Figure 2), which reflected the same problem on the biomass supply chain (lack of straw). Therefore, this decision was prompted by the plant's identity in characteristics to the majority of such facilities in the country. To exhaustively understand the situation, the first phase was initiated with in-depth interviews. The second phase involved the administration of a questionnaire survey to estimate the risk perceptions of farmers regarding straw supply. The third phase entailed a follow-up survey that was conducted from 2015 to the end of 2019. The interviews with the power plant managers, local government officers, middlemen, and farmers validated the results of this study.

**Table 2.** Power plants that provided information.

Name of the Biomass Power Plant	Location
Qingan National Bioenergy Power Plant	Qingan Town in Heilongjiang Province
Bayan National Bioenergy Power Plant	Bayan Town in Heilongjiang Province
Wangkui National Bioenergy Power Plant	Wangkui County in Heilongjiang Province
Dehui National Bioenergy Power Plant	Dehui City in Jilin Province
Gongzhuling National Bioenergy Power Plant	Siping City in Jilin Province
Liaoyuan National Bioenergy Power Plant	Liaoyuan City in Jilin Province
Heishan National Bioenergy Power Plant	Heishan Town in Liaoning province



**Figure 2.** The distribution of national bioenergy power plants. Note: blue spots indicate the biomass power plant in Table 2.

#### 4.1.1. Initial Phase (Qualitative Data Collection)

A case study design [48,49] was adopted in investigating the National Bioenergy Power Plant branch in Wangkui. Specifically, qualitative data were collected through observations, the documentary method, and key stakeholder interviews to disentangle the problems that beset biomass power plants in China. These approaches unraveled the complex interaction, relationship, and conflict among the stakeholders of interest [50]. In 2013, interviews were held with the biomass power plant managers, middlemen, and farmers (straw suppliers). In 2014, the second round of interviews was carried out with the plant managers, middlemen, and local government officials, and a questionnaire survey was administered to the farmers who supply corn straw or are potential suppliers. This round involved 61 respondents, who were purposely sampled following a snowball strategy and subsequently grouped via stratified sampling (Table 3). To ensure access to a wide group of farmers, we sought assistance from the local government, middlemen, and farmer groups operating around the biomass power plant.



**Table 3.** Respondent profile.

Stakeholder	Total	Male	Female
Group 1: Farmers (suppliers) (42–68 years old)			
Educational level			
9–12 years of educational education experiences	5	4	1
5–8 years of educational experiences	15	11	4
1–4 years of educational experiences	12	8	4
Illiterate	12	7	5
Sub-total	44	30	14
Group 2: Middlemen			
Working experience as a middleman			
More than 3 years working as a middleman	3	3	0
1–3 years working as a middleman	6	6	0
Sub-total	9	9	0
Group 3: Biomass power plant manager			
Factory director	2	2	0
Sectary	3	2	1
Sub-total	5	4	1
Group 4: Local government			
Head of Local Development and Reform	1	0	0
Commission			
Deputy director of Local Development and Reform	2	0	0
Commission	3		
Sub-total	3		
Total	61		

The interviews were of a semi-structured format and covered four primary dimensions: (1) the risk perceptions of the farmers regarding straw supply and the factors that affect such viewpoints, (2) the nature of interaction between the farmers and middlemen as well as the risk perceptions of the latter in relation to cooperating with the former, (3) the “rules-in-use” that advance interaction, and (4) the impact exerted by the behaviors of the biomass power plant and middlemen on the farmers’ willingness to supply straw. The interviews and follow-up discussions were conducted in Chinese and a local dialect with the help of the local village leader. After cultivating a relationship with the biomass power plant and middlemen, we carried out succeeding informal interviews through online chatting to update the data that we collected. The analysis results and discussion were anchored in both the onsite and internet-based interviews.

#### 4.1.2. Second Phase (Quantitative Data Collection)

Considering the importance of end-suppliers (farmers) in the biomass supply chain, a field survey was administered to them in 2014 after the initial phase of the research. The questionnaire was developed on the basis of previous studies, group discussions with our team members, and the results of the semi-structured interviews. After the instrument was a pilot test, 300 questionnaires were distributed face-to-face to the respondents, among whom 275 returned valid questionnaires (See Supplementary Materials). This proportion accounted for 11.5% of the population of the entire village near the biomass power plant. The instrument consisted of questions on the farmers’ risk perceptions with respect to straw supply, and the factors that influence these impressions were regarded as core bases for data collection from the farmers.

The survey results were analyzed using four multiple regression models: (1) a model of the farmers’ willingness to supply straw to the biomass power plant as a function of economic factors, (2) a model of the farmers’ willingness to supply straw to the plant as a function of trust and demographic characteristics, (3) a representation of risk perceptions regarding biomass supply as a function of trust and demographic characteristics, and (4) a representation of a long-term, stable relationship between the farmers and the plant (which enables sustainable straw supply) as a function of trust and demographic characteristics. Table 4 defines each of the variables used in our analysis.



**Table 4.** Description of variables.

Variable	Description
Farmers' willingness to supply straw	Score from 1 to 5
Risk perceptions	Score from 1 to 5
Long-term relationship	Score from 1 to 5
Influencing factors for risk perceptions	
Policy factors	Includes government incentive, government guidance; scored from 1 to 5
Economic factors	Covers meager profit, outweighing of benefits, cost due to farmland damage; scored from 1 to 5
Trust factors	Encompassed trust in middleman's behavior, trust regarding not being cheated; scored from 1 to 5
Socioeconomic variables	
Age	Age of a respondent.
Gender	Dummy variable assigned a value of 1 if male and 0 otherwise.
Marital status	Dummy variable assigned a value of 1 if married and 0 is otherwise.
Education	Variable that presents a respondent's years of schooling
Income	Variable representing respondent's annual income.

#### 4.1.3. Third Phase (Follow-Up Study)

After building a relationship with the local government, the biomass power plant, middlemen, and some farmers, a follow-up study was conducted until 2019. To understand the situation with time changing, this study mainly interviewed two local government officers who are in the department of development and reform commission, taking in charge of local development projects, including the biomass power plant; two managers in the biomass power plants who know the whole process of power generation from straw collection to straw combustion; three middlemen; and five farmers who supply straw to the biomass power plant. Middlemen and farmers offered information on the general perception of other middlemen and the perception of other farmers. According to the local government, middlemen, and interviewed farmers, farmers' perceptions were the same as before because no events had happened to change their perception, so what they are doing currently is the same as they were doing before. Therefore, in the third phase, this study did not conduct a questionnaire survey.

## 5. Results and Discussion

The institutional factors for the development of biomass power generation in China were categorized on the basis of Figure 1. Based on the initial and second phase of the field survey (Years 2013 and 2014) and the third phase of the field survey (Years 2015 to 2019), the results of the analysis of these factors are presented in Table 5.

**Table 5.** Institutional factors for the development of biomass power generation.

Level	Institutional Factors	Institutional Characteristic (Results from the Year 2013 to 2014)	Intuition Characteristic (Results from the Year 2015 to 2019)	Effects of Factors on the Development of Biomass Power Generation
Informal institutional environment	Characteristics of biomass power generation	Immature technology for biomass power generation	There is no core technology	Low electricity generation rate
	Characteristics of straw collection activities	Seasonal activities	Seasonal activities	Unstable straw supply
	Culture and tradition			Straw burning in open farmland
Formal institutional environment (governance)	Central government level	Subsidy scheme	The same subsidy scheme	Biomass power plants' reliance on subsidy
	Local government level	Illogical project planning	Illogical project planning	Fierce competition for straw supply/acquisition increases the straw price
		Overestimation of straw supply	Overestimation of straw supply	Prolonged project and scale approval
Interaction of actors	Biomass power plant	No affiliation with middlemen	No affiliation with middlemen	<ul style="list-style-type: none"> <li>• Low loyalty to the biomass power plant</li> <li>• Unappreciated behaviors of farmers</li> <li>• Insufficient straw supply</li> <li>• Low level of trust between middlemen and power plant managers</li> <li>• Low motivation of middlemen to stay on the job.</li> </ul>
	Middleman	Difficulty in gaining farmer trust	Difficulty in building trust relationship	<ul style="list-style-type: none"> <li>• Reluctance to allow middlemen to collect straw</li> <li>• High pricing to middlemen</li> </ul>
		Increase and fluctuation in straw price	Increasing in straw price	Increasing straw price translates to less profit for middlemen, demotivates continuing with the job.
	Farmer	Low trust in middlemen	Low trust in middlemen	<ul style="list-style-type: none"> <li>• Demotivating to supply straw</li> <li>• Increasing transaction cost</li> <li>• Increasing risk perception</li> </ul>
Ecosystem		Straw burning in open fields	The situation became better due to the regulation. But still large amount of straw was burnt.	Severe deterioration of atmospheric quality
		Excessive use of coal resources	Coal consumption is still the dominant energy source.	<ul style="list-style-type: none"> <li>• Air pollution</li> <li>• Groundwater contamination</li> <li>• Health problems and mortality among workers</li> </ul>

### 5.1. Effects of Interaction among Actors, Uncertainty, and Objectives in the Biomass Supply Chain

To inquire into and delineate the interaction among the actors and the psychological changes that occur from the perspective of risk management (explanation for the middle section of Figure 3), this study used the ISO 31000 definition of risk, that is, the “effect of uncertainty on objectives.” The keywords in this definition are “effect,” “uncertainty,” and “objectives.” In this research, “effect” was identified as the risk perception harbored by an actor.

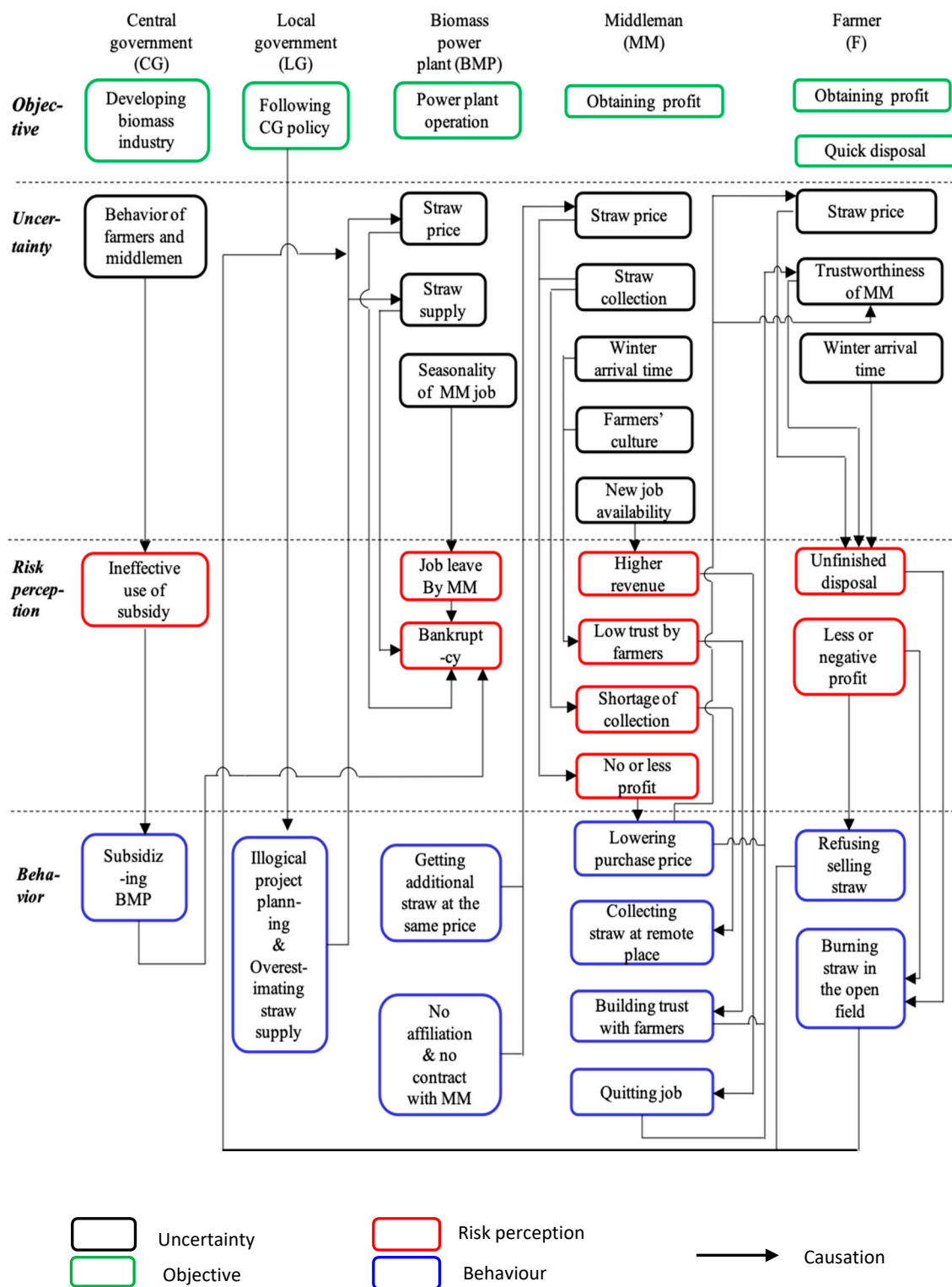


Figure 3. Interaction among uncertainty, objective, risk perception, and behavior.

Figure 3 depicts, in a summary fashion, the qualitative results derived from the interviews with the local government, power plant managers, middlemen, and farmers. In this figure, uncertainty is classified in four perspectives, (1) regarding straw: (a) price and (b) supply or collection; (2) regarding middlemen: (a) reasonability of the middlemen job and new job availability and (b) trustworthiness of middlemen; (3) regarding farmers: farmers' culture; (4) regarding the weather: winter arrival time.

Risks are also classified into four aspects, (1) for all players: financial risks; (2) for the biomass power plant: job leave by the middlemen; (3) for middlemen: low trust by farmers and shortage of collection; (4) for farmers: unfinished disposal.

The interaction among uncertainty, risk, and behavior is as follows. Illogical project planning and overestimating straw supply make straw price and straw supply uncertain, which makes the BMP (biomass power plant) suffer from anxiety of bankruptcy. The seasonality of the MM (middleman) job is another annoying factor, which makes the BMP anxious about job leave by the MM. Because of risks of bankruptcy and of job leave by the MM, the BMP becomes reluctant to invest on the MM and rather stays at “defensive measures” of “getting additional straw at the same price” and there is “no affiliation or contract with MM”. These defensive measures make straw price and straw collection uncertain for the MM. It means that the MM also suffers from the risk of no or less collection shortage. Moreover, two additional uncertainties, winter arrival time and farmers’ culture make the MM business more difficult. Straw has to be collected promptly and carefully by the arrival of winter. Straw has to be collected carefully due to farmers’ culture. The impact of only one poor job could be spread over farmers quickly. Thus, the MM is required to do her/his job “fighting against” risks of no or less profit, of collection shortage, of low trust by farmers, and of incompleteness of job. To deal with these risks, the MM tries to lower the purchase price of straw from farmers, collect straw at remote places, and build trust with farmers. It is also understandable, thus, for the MM to often quit the job if there is a better job. Lowering the purchase price of straw makes straw prices uncertain for farmers. This behavior and quitting their job makes farmers feel less trustworthy towards the MM, though some MM try to build trust with farmers. As a result, farmers who do not feel attracted to this business, refuse to sell straw to the MM and burn straw in the open field.

## 5.2. Risks and Problems at the Informal Institutional Level

The informal institutional factors identified in this work are the characteristics of straw-based biomass power generation and the characteristic features of straw collection activities, culture, and tradition in the studied context. The assessment of the qualitative survey responses from survey respondents suggests the following risks and problems as important institutional determinants.

### 5.2.1. Immature Technology for Biomass Power Generation

*“Currently, the core technology of biomass power plants is from Denmark. But we revised some parts of the technology to fit our situation.”* (plant managers)

The findings indicated that technology remains a critical problem in the development of biomass power generation in China. Most biomass power plants depend largely on imported technology and equipment as domestic technology is still in its infancy and therefore fails to satisfy the demand for linkage between production and sustainable development. Even with heavy reliance on imported equipment, however, biomass power plants still cannot resolve the difficulties stemming from transportation methods, work habits, and culture. In Denmark, for example, crops are planted over large areas, and farmers use harvesters to gather crop straw. After a harvest, straw is compressed and packaged into standard-sized bales using a packager. Nevertheless, the advantages of importation, however, do not extend to the situation of Chinese farmers. In China, however, farmlands are owned by small households, who complete harvesting by hand and with the help of small machines. Packaged bale are therefore incongruent with the sizes required for imported fuel-conveying systems. Moreover, the key components of equipment cannot be produced in China because of the lack of core technologies in the country.

### 5.2.2. Characteristics of Straw Collection Activities

Straw collection starts from autumn after the crop harvest, and middlemen are required to complete straw collection before the sowing season. Normally, middlemen finish collection before the onset of cold weather comes. The seasonality of the job increases the possibility of career changes for

middlemen. Once they are provided an alternative, they are likely to consider leaving their current profession, thereby rendering straw supply unstable.

### 5.2.3. Culture and Tradition

Although culture is difficult to measure, it is easily observable. The same holds in rural areas, where farmers have their own culture and similar ways of thinking. For example, they are mostly conservative and risk-averse, and information spreads rapidly throughout the community because of gossip. In cases wherein negative information regarding the straw collection is received, the situation would be exacerbated by a community's predilection for gossip. If, for instance, a given household says that a middleman is dishonest, few farmers in the area will provide straw to this intermediary. Our results indicated that farmers have a strong herd mentality. Without efforts to inspire concern for the environment, their behaviors are driven only by personal profit. This situation underscores the need for appropriate guidance.

### 5.3. Risks and Problems at the Formal Institutional Level

The formal institutional factors identified from the qualitative survey responses to the survey tended to focus on issues encountered at either the central or local government level.

#### 5.3.1. Central Government Level

The primary formal influencing factor for the manner by which the central government operates is the subsidization of biomass power generation. Currently, the investigated biomass power plant obtains subsidies from the government by selling electricity to the State Grid Corporation of China at US \$0.12/kWh. As reflected in the interviews, no subsidies are presently provided to farmers or middlemen. Interestingly, another study's results showed a clear difference in the effectiveness of incentives for various actors. Providing incentives to farmers can increase the profits earned by all stakeholders in biomass power generation [51].

#### 5.3.2. Local Government Level

- Illogical project planning

Facts dictate that only one biomass power plant should be constructed within at least a 30 km radius but the Local Development and Reform Commission excessively accepts an excessive number of biomass power plant proposals from investors without seriously considering the country's capacity to supply the necessary raw materials. In some provinces, four or five biomass power plants are found within 100 km from each other, which stimulates fierce competition for straw supply.

- Overestimation of straw supply

The evaluation of straw quantity in local areas influences the price of straw and the cost incurred by biomass power plants. Such evaluation is based on a theoretically estimated straw production, which is substantially greater than the actual straw collection. Certain important factors, such as the quantity of straw that farmers are willing to provide and approaches to motivating cooperation from middlemen and farmers, are neglected in project planning.

### 5.4. Issues Associated with Interaction among Actors

The qualitative responses indicate that interaction among actors can influence trust and perceived risk, related to the role of the middleman. As depicted in Figure 3, a middleman is an independent entity that works for the biomass power plant; that is, no organization for middlemen exists in the investigated context, for biomass power plants do not want to increase costs in short-term. The non-affiliation problem can be traced to the risk perceptions arising from this system. Middlemen have a low sense of connection with biomass power plants and would readily relinquish their jobs as middlemen should

an alternative be available. This study found that the non-affiliated system increases the instability of the supply chain.

The middlemen-related institutional factors identified are the difficulty in building farmers' trust in the middlemen, insufficient straw collection, increasing and fluctuating straw prices, and the absence of contracts that bind transactions between middlemen and farmers.

- Difficulty in building trust from farmers

The cultivation of trust in middlemen is regarded as a highly risky endeavor (a rating of 9, out of a full rating of 10). The middlemen realize that gaining trust from farmers is increasingly important not only for the collection of straw from individual farmers but also for the establishment of a middleman's reputation in a straw collection area.

*"In a rural area, there is no secret! Farmers have a strong bond with one another, and they like to gossip, which means information spreads very quickly. My behavior is always judged by farmers and shared with other farmers." (middleman #1)*

Gaining the trust of farmers, therefore, requires good behavior from the middlemen.

- Increase and fluctuation in straw price

The power plant managers in the biomass power plant complained about the increasing price of straw because of competition for the material among the biomass power plants in the area. The high price of collected straw, which reduces the profits earned by middlemen, can be attributed to many reasons. One is the rise in the number of operational biomass power plants, which engenders strong rivalry in the straw acquisition. Various risk perceptions from farmers and poor transportation conditions also reduce the profits earned by middlemen.

### 5.5. Farmer-Related Factors

Farmer-related factors revolve around risk perceptions, which were comprehensively investigated to shed further light on how farmers perceive participation in straw supply. The results revealed that trust is an essential influencing factor for farmer behavior.

#### 5.5.1. Farmers' Risk Perceptions

The multiple regression analyses showed that the aforementioned influencing factors predict 67.4% of the variance in the farmers' risk perceptions but that these determinants predict only 16.2% of environment-related risk perceptions [43]. This discrepancy points to the necessity of emphasizing and enhancing the environment and climate change education in rural areas. Table 6 reflects that economic factors (economic stratum, suffering from losses, farmland damage, inability to clear farmland) predict 56.1% of the farmers' willingness to supply straw.

**Table 6.** Influence of risk perception on farmers' willingness to supply straw.

Farmers' Willingness of Straw Supplying	
Risk perception factor	Model ( $\beta$ )
Economic level	0.230 * (0.298)
Suffering from losses	−0.197 * (0.109)
Farmland damage	−0.198 ** (0.106)
The farmland cannot be cleaned well	0.143 * (0.111)
R <sup>2</sup>	0.561 ***

Note: \* Significant at  $p < 0.1$ , \*\* Significant at  $p < 0.05$ , \*\*\* Significant at  $p < 0.01$ .

#### 5.5.2. Trust

In the supply chain and straw collection processes, gaining the trust of farmers is an obstacle for middlemen. The statistical results showed that among the 275 farmers, 17% distrust middlemen,

whereas 40% sometimes trust them. The degree of trust was also found to be related to risk perception and farmers' motivation to engage in straw supply activities. Specifically, high trust is correlated with low-risk perception and high motivation, whereas low trust is correlated with high-risk perception and low motivation. As presented in Table 7, for example, trust negatively predicts risk perception and significantly predicts the farmers' willingness to supply straw. Trust also effectively influences long-term relationships with the middlemen.

**Table 7.** Influence of risk perception on farmers' willingness of straw supplying.

	Farmers' Willingness to Supply Straw	Risk Perception	Long-Term Relationship
	Model 1( $\beta$ )	Model 2 ( $\beta$ )	Model 3 ( $\beta$ )
Age	n.	n.	−0.115 * (0.008)
Education	0.149 ** (0.021)	n.	0.172 ** (0.022)
Income	n.	n.	n.
Trust	0.103 *** (0.402)	−0.630 *** (0.031)	0.455 *** (0.109)
R <sup>2</sup>	0.563	0.707	0.552

Note: \* Significant at  $p < 0.1$ , \*\* Significant at  $p < 0.05$ , \*\*\* Significant at  $p < 0.01$ , n. is non-significant.

## 5.6. Impact on the Ecosystem

Ecological systems determine the climate change and air pollution associated with energy consumption. People's awareness of environmental pollution has dramatically increased, driving many city residents to be concerned about their health and that of their children. This trend accelerates renewable energy development.

### 5.6.1. Straw Burning in Open Fields

Straw burning in open fields has become a common approach to disposing of residual straw after harvest. Such practice releases pollutants that severely degrade the atmospheric quality and exacerbate climate change [52]. The main stakeholders in this matter are farmers, who are the ones practicing straw burning. The results revealed that the environmental risk perceptions (Adj.  $R^2 = 0.162$ ) of the surveyed farmers are less extensive than their personal risk perceptions (Adj.  $R^2 = 0.805$ ) [43]. The result indicates that farmers value their own benefit much more than the environmental benefit.

### 5.6.2. Excessive Use of Coal Resources

China is a coal energy-dependent country. Although coal consumption has been decreasing, it remains the dominant energy source consumed in the region, thus resulting in air pollution, groundwater damage, geological disasters, and health problems and mortality among coal miners. The external costs of coal-fired generation are as high as 90% of the current price of electricity generated through coal, whereas the external costs of biomass-based power generation amount to only 0.1% of the current price of electricity produced through biomass [53].

## 6. Project Plan Suggestion

According to the findings, the performance of biomass power plants is closely related to the formal and informal institutional environments where they operate.

### 6.1. "Flood and Boomerang" Risk Transfer Model

This policy and project are planned and implemented to achieve the value of sustainable energy and a cleaner environment. However, a principal issue that was identified in the study is risk transfer and avoidance between actors and institutional environments. The results analyzed on the basis of the definition of risk showed that top-down decision making influences actors, with risk transfer proceeding from the high-level actors or institutions (central and local governments, biomass power



plants, middlemen) to their low-level counterparts (farmers). Eventually, however, management of these risks is partly given up, which can be interpreted as risk avoidance and risk transfer. Then these risks float from the bottom to the top. Even worse, these risks may influence the ecosystem seeing as unsuccessful renewable energy development may motivate the retention of fossil fuels as the dominant energy source. Thus, the value of sustainable energy and a cleaner environment is achieved much less than expected.

In line with this process, a “flood and boomerang” risk transfer and avoidance model was developed. The model depicts risk transfer and avoidance as follows (Figure 4): The central government designs this policy scheme without fully recognizing and incorporating risk perception of stakeholders at its lower level. Behaviors by the local government, biomass power plants, and middlemen increase uncertainties of straw price and of straw collection for stakeholders at lower levels, respectively. Thus, it is possible to understand the current phenomena such that the central government, local government, biomass power plants, and middlemen transfer the risks that they bear to the lower levels of the supply chain through their decision making. This transfer brings forth the risk of flooding the lowest members of the hierarchy, i.e., the farmers. However, all farmers cannot appropriately manage all risks by themselves. It is not just a few farmers that refuse to sell straw or burn straw in the open field. These are risk avoidance behaviors: avoiding risks of less or negative profit or of unfinished disposal associated with the straw selling business. This farmers’ behavior increases the risks of a shortage of collection and of no or less profit for the middlemen, which leads to risk avoidance behavior by the middlemen i.e., job quitting. Under this situation, a biomass power plant, local government, and central government cannot implement effective countermeasures, which can be interpreted as transferring risks to stakeholders at higher levels. In summary, the stakeholders at the top four levels transfer risks to protect their own benefits. Because farmers are the straw suppliers and have decision-making power with regard to straw supply, however, the risk would then be redirected to high-level institutional stakeholders, reflecting a boomerang effect. In the end, the backfiring of risks cause project failure and present difficulty in ensuring the survival of a biomass power plant.

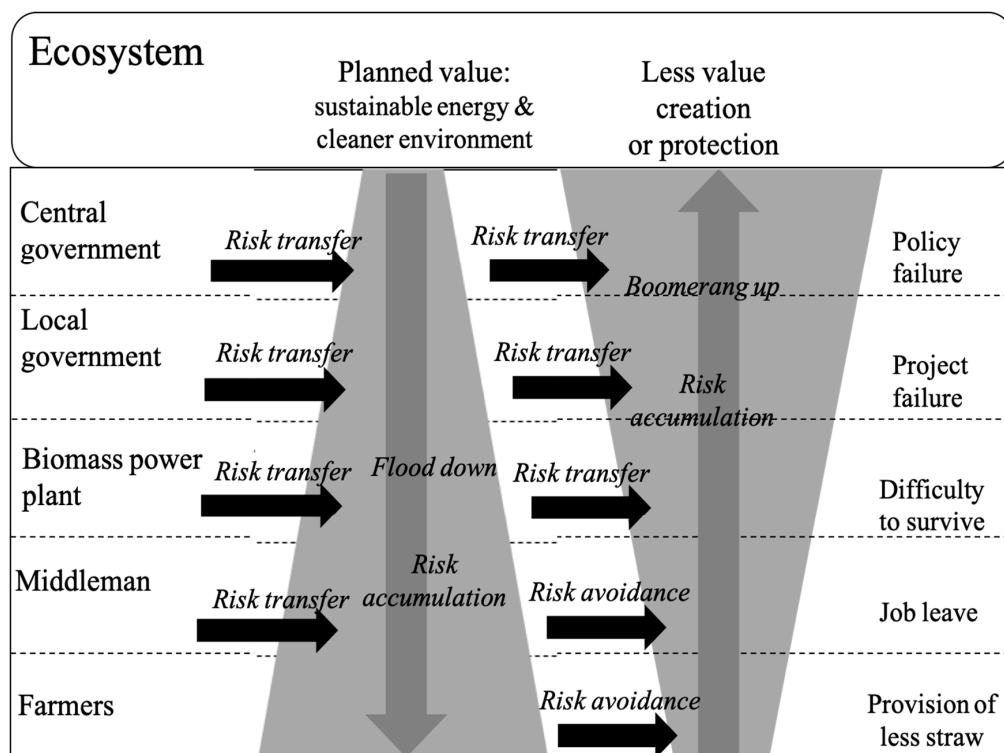


Figure 4. “Flood and boomerang” risk transfer model.

While some key results of this study are consistent with previous studies, other key results are developed based on new perspectives. Farmers, although occupying the bottom rung in the supply hierarchy, play an important role in the biomass supply chain. This result is consistent with those of previous studies that similarly involved farmers [42,54–56] and can serve as a reference for policy-makers as they formulate renewable energy policies, laws, and regulations. Previous studies on biomass supply design used institutional analysis in their investigations [35,57], but these forays disregarded the fact that the principal requirement for an effective supply chain is to increase farmers' trust in middlemen and reduce their risk perceptions regarding straw supply. This study's institutional analysis can be expanded to facilitate a more thorough grasp of the importance of lay-people involved in the biomass supply chain. Previous studies emphasized industrial requirements, such as the building of efficient mechanisms inside and outside a chain [58], and provided policy suggestions for energy development that were also provided through institutional analysis [28,59]. The current work broadens the literature through its definitive indication that the greater the risk that lay-people are compelled to undertake, the unhealthier an institution becomes. We suggest that risk be prevented from transferring to these stakeholders as follows:

- Policy-making at the central government level should be based on an investigation of different local areas. Without detailed and practical policies, it is difficult for the local government to guide the biomass industry.
- Once the regulations have made, it is important to follow the regulation strictly. For example, the regulation of building a biomass power plant ("only one biomass power plant can be built with 30 km to guarantee enough biomass") should be applied without compromising. Or the competition of biomass (straw) leads to the bankruptcy of some biomass power plants.
- Biomass power plants should provide transparent data on the operation situation to the local government. In addition, the connection between the biomass power plant and the middleman is important for the sustainable development of biomass power plants. Therefore, as it is shown in Figure 4, to include middlemen as members of the biomass power plant not only can decrease the middleman's risk of losing their job, but also make the biomass power plants have stable straw resources.
- To have contact with local residents (farmers), the relationship is the most important, rather than the price of straw. The middlemen should have honest and responsible behavior to cooperate with farmers. Biomass power plants can provide training to middlemen.

## 6.2. Strengthening the Linking Function of Middlemen

Middlemen, as the link between biomass power plants and farmers, figure critically in the biomass supply chain. Whether a biomass power plant can secure sufficient raw materials likely depends on the effect of middlemen's actions. Under the current institutional environment, the competition between middlemen progressively diminishes given that human relationships are the most important factor for guaranteeing the biomass supply; in this circumstance, contracts are ineffective. Therefore, strengthening the intermediary function of middlemen encourages sustainable biomass power development. In China, the middleman is an independent entity who is free to breach a contract at any time should he find a better alternative. Moreover, the relationship between farmers and middlemen also depend on middlemen's behaviors. Fully developing how a middleman functions may be a beneficial strategy (Figure 5).

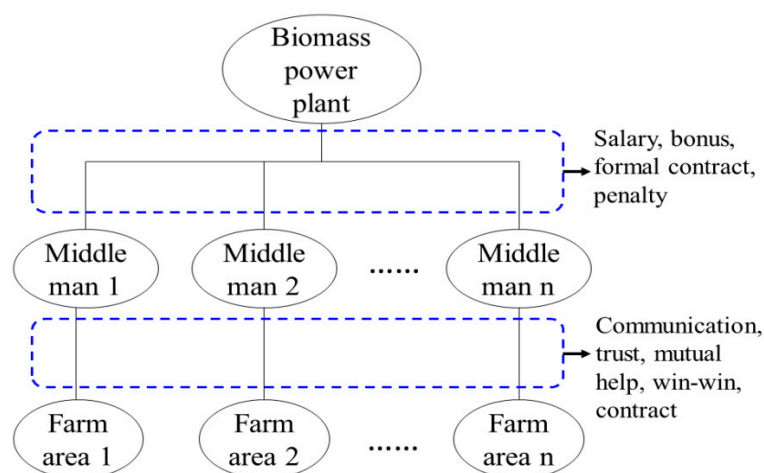


Figure 5. Middleman-based link function system.

To guarantee sufficient straw supply, an advantageous measure is to organize middlemen as members of biomass power plants through the implementation of a contract. If certain middlemen express a desire to relinquish their position within the year spanned by their contracts, then they should be required to pay a fee for nullification. As incentives for carrying on with their current positions, salaries and bonuses that are calculated on the basis of a plant's profit share can be offered. Each middleman can be conferred jurisdiction over one farmland area. A middleman's responsibility would be to build relationships with farmers and encourage farmers to sell straw. Formal contracts with farmers are also needed to build an improved straw market. All information related to farmer operations, such as the quantity of supplied straw each year by each household and the annual increase or decrease in suppliers, should be recorded in an information system for easy transfer of work duties should certain middlemen resign their positions. Under this system, power plants with sufficient straw would earn profits in a stable manner, and being a middleman would become a formal occupation.

### 6.3. Toward a Sustainable Cooperation Process in the Biomass Power Industry as an Outcome of Institutional Change

The Chinese government has dedicated substantial efforts and investments to renewable energy development, but the effectiveness of these initiatives is not clearly identifiable. A case in point is the country's continued heavy dependence on coal-fired power plants. To efficiently utilize agricultural residues and replace part of coal-fired powers, the government should maintain sustainable development in the biomass power industry because such a measure is favorable to both environmental and local economic progress. The current institutional environment in the studied context renders the biomass industry considerably reliant on subsidies and is characterized by low cooperation among stakeholders. The effectiveness of the institutional frameworks designed to address these problems has been diminished by the government. The resultant constraints on stakeholder cooperation and risk management should be eliminated to effectively refine operations in China's biomass power industry. Government preference for a risk management-based framework serves as an exogenous change agent that induces reasonable planning and investment on the grounds of a comprehensive survey coupled with an improved institutional system. An institutional change should begin to advance from infancy to growth. As shown by our results, stimulating institutional change necessitates the mitigation of stakeholders' risk perceptions in the future. In the development of biomass power generation, the central and local governments have excessively prioritized short-term performance over long-term sustainability, for example, to get more profit, the local government allows investors to build several biomass power plants in the one area, even facing a shortage of straw. This orientation has confronted the biomass power industry with difficulties in achieving further evolution. This situation, in turn, points out that institutional change should transform into a new institutional equilibrium as

a substitute for a government-oriented institution. The process of institutional change in the biomass power industry is depicted in Figure 6. After the pilot stage, the biomass industry enters the growth stage, where project planning, risk sharing, and risk mitigation should be conducted. This process does not correspond to the current circumstances of China, where problems at the growth stage have become a bottleneck that hinders elevation to the maturity stage.

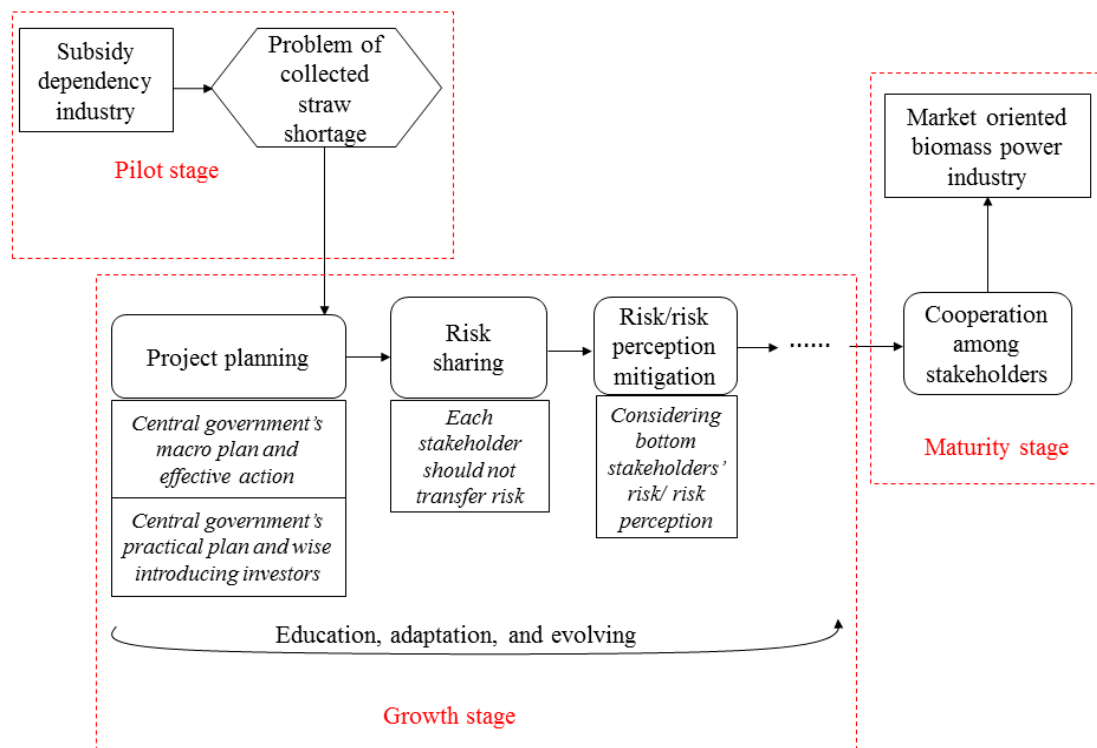


Figure 6. Institutional development in the biomass power industry.

## 7. Conclusions

This risk management-leaning institutional analysis performed in this work uncovered the institutional factors that facilitate or constrain the development of straw-based biomass power generation at four levels, namely, the informal institutional, formal institutional, actor interaction, and ecosystem levels. The mutual effects of institutional factors on one another is not restricted to the hierarchical dimension, consistent with the findings of Rowlinson and Jia's work [14]. As part of our exploration, we crafted an institutional framework, which directed the collection of data on the following: (1) informal institutional factors, such as the characteristics of straw-based biomass power plants, the characteristics of straw collection activities, and the culture typifying rural areas; and (2) formal institutional factors, including subsidy schemes, illogical projects, overestimation of straw supply, interaction of actors (biomass power plant, middleman, and farmer), and ecosystems. The results underlined the importance of the effects of interaction among actors and risk transfer and risk avoidance by institutional stakeholders. High-level institutional stakeholders should not transfer risk to their low-level counterparts because the transferred risk cannot be mitigated and will instead bring about serious problems for the former. The results also suggested that a middleman-based straw collection system is necessary to guarantee the acquisition of sufficient biomass. Finally, the findings implied that improving the institutional arrangement of China's biomass power industry requires progression from the emergent stage to the maturity stage—a process characterized by a market-oriented focus.

Similar to any other study, the current research has limitations. It was devoted to the biomass power industry in China, where straw is the main biomass resource. Many other countries use trees as biomass; therefore, these countries may not have as many suppliers as those existing in China. The applicability

of the findings to other industries and other countries requires verification. Future studies should focus on the following issues: (1) a cross-national comparison of institutional analyses to determine the institutional factors and casual relationships that are common across the energy sectors of various nations and (2) an institutional design intended to increase intrinsic motivation.

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