The Construction of Competitive Bioenergy Industry in China: Status Quo and Prospects

Kesheng Shu

Abstract

While facing various global problems, including energy crisis and climate change, the Chinese government began to advocate vigorously for the development of renewable energy industries in recent years—especially the bioenergy industry. Although the industry has existed in China for about a decade, systematic and professional research towards this industry is scarce. This paper, therefore, concentrates on the question of how to construct a competitive bioenergy industry in China. To achieve this goal, I firstly propose a conceptual model of cascade use and recycling of biomass in the context of the circular economy, from which the bioenergy industry is derived. Then, I clarify the structure of the bioenergy industry by using the stakeholder theory, which defines two groups of stakeholders (central stakeholders and periphery stakeholders). After that I analyze the communication between the both. Finally, adopting the analysis framework of Porter's Diamond Model, I study the pathway of forging competitiveness of the Chinese bioenergy industry. Through discussing six factors constituting the industry's competitiveness (factor conditions, demand conditions, related and supporting industries and firm strategy, structure and rivalry, government, and chance in specific), I conclude that three key issues of the industry require special attention: the provision of biomass feedstock, the integration of energy market, and the innovation of bioenergy infrastructure.

Introduction

Biomass is all the earth's living matter growing through photosynthesis, which includes animals, plants, microbes, and organic materials generally that are excreted and metabolized by them (Demirba 2001). The use of biomass to produce bioenergy for a wide range of energy services (heat, light, comfort, entertainment, information, mobility, etc.), and biomaterials as substitutes for petrochemical-based goods is an integrative response to several global problems. In 2010, the global supply of bioenergy reached 1,277 million of tonnes of oil equivalent (Mtoe), ranking fourth after the mainstream traditional fossil fuels, including crude oil (4,069 Mtoe), coal (3,596 Mtoe) and natural gas (2,719 Mtoe), but led other renewable energies (IEA 2012, 37).

China, as the most populous country in the world, supplied the largest amount of total primary energy in 2010 (2,417 Mtoe), of which 13.90 percent (336 Mtoe) is imported. Correspondingly, CO_2 emissions from fuel combustion in China reached 7,269.85 megatonnes (Mt), rendering China the biggest CO_2 emitter in the world (IEA 2012, 50). China currently need not assume any emissions obligations, but it is expected that in the post-Kyoto Protocol era, the country will face rising pressure both domestically and internationally to reduce its greenhouse gas (GHG) emissions. Developing bioenergy will be a preferable choice for China to realize its goal of sustainable development, since bioenergy can play a positive role in adjusting its energy consumption structure, maintaining national energy security, and reducing environmental pollution and GHG emissions.

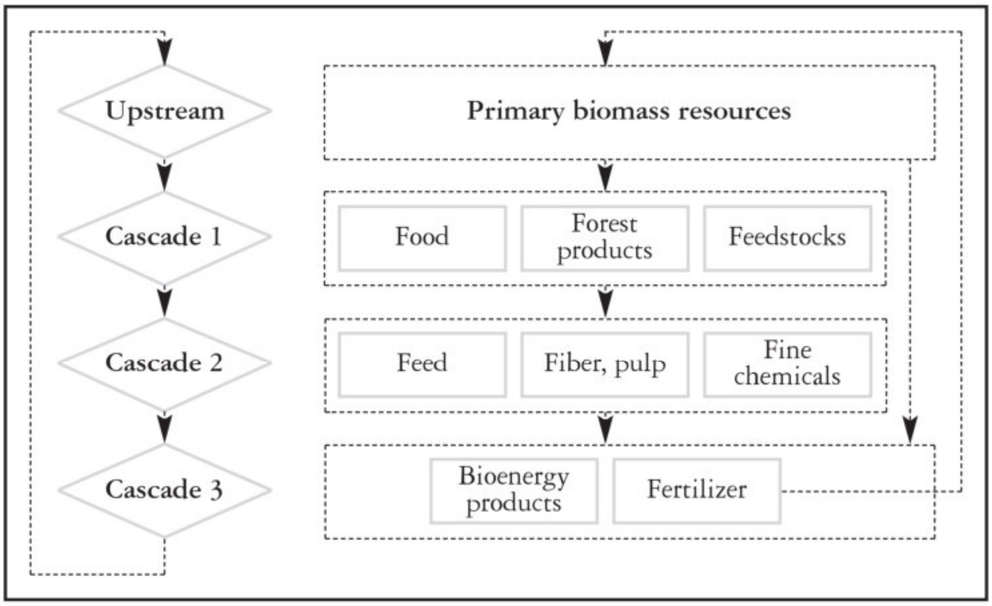
In the last decade, the bioenergy industry has been founded and developed in China (Peidong et al. 2009; Zhu et al. 2011), but systematic and professional research on this industry is scarce. This paper, therefore, concentrates on the question of how to construct a competitive bioenergy industry in China, and tries to answer this question in three steps. First, I introduce the philosophy of the circular economy to design a cascade use and recycling of biomass, from which the bioenergy industry is derived. After that, I apply stakeholder theory to explore the structure of the bioenergy industry—especially the role of each actor corresponding to each phase of bioenergy production. In the end, I propose a development strategy of constructing a competitive bioenergy industry in China by adopting the analysis framework of Porter's Diamond Model, which has been widely used in management science and industrial economics.

The cascade use and recycling of biomass

The concept of the circular economy was first introduced to China in 1998, and formally accepted by the Chinese central government as a new development strategy in 2002, aiming to alleviate the contradiction between booming economic development and the shortage of raw materials and energy (Yuan, Bi & Moriguichi 2006). This concept is built on the notion of loop-closing. In other words, a circular economy should replace a linear type of industrial chain ('resources-products-rubbishes') by a circular type ('resources-products-renewable resources'). In the loop-closing chain, the '3R' principles (reduce, reuse and recycle) have to be upheld.

Following this '3R' principle, some researchers have suggested the cascade utilization of biomass, which is defined as the sequential use of original raw material (primary crop, rapeseed, etc.) as well as a co- or by-product to produce materials and bioenergy (Raschka & Carus 2012). Prior to the introduction of cascade utilization, biomass is treated as an energy carrier and as a raw material separately, shaping two parallel flows of utilization. Biomass use, under such circumstance, is 'optimized' only over parts of its utilization, rather than over the whole chain. Conversely, cascading biomass use reflects the different characteristics of various biomass sources, and the diverse sectors of the economy's requirements for biomass with particular physical characteristics (Haberl & Geissler 2000). In accordance with these principles, I offer a conceptual model of cascade use and recycling of biomass in Figure 1, and argue that the construction of the bioenergy industry in China should be based on this model.

Figure 1. The conceptual model of cascade use and recycling of biomass



The structure of the bioenergy industry

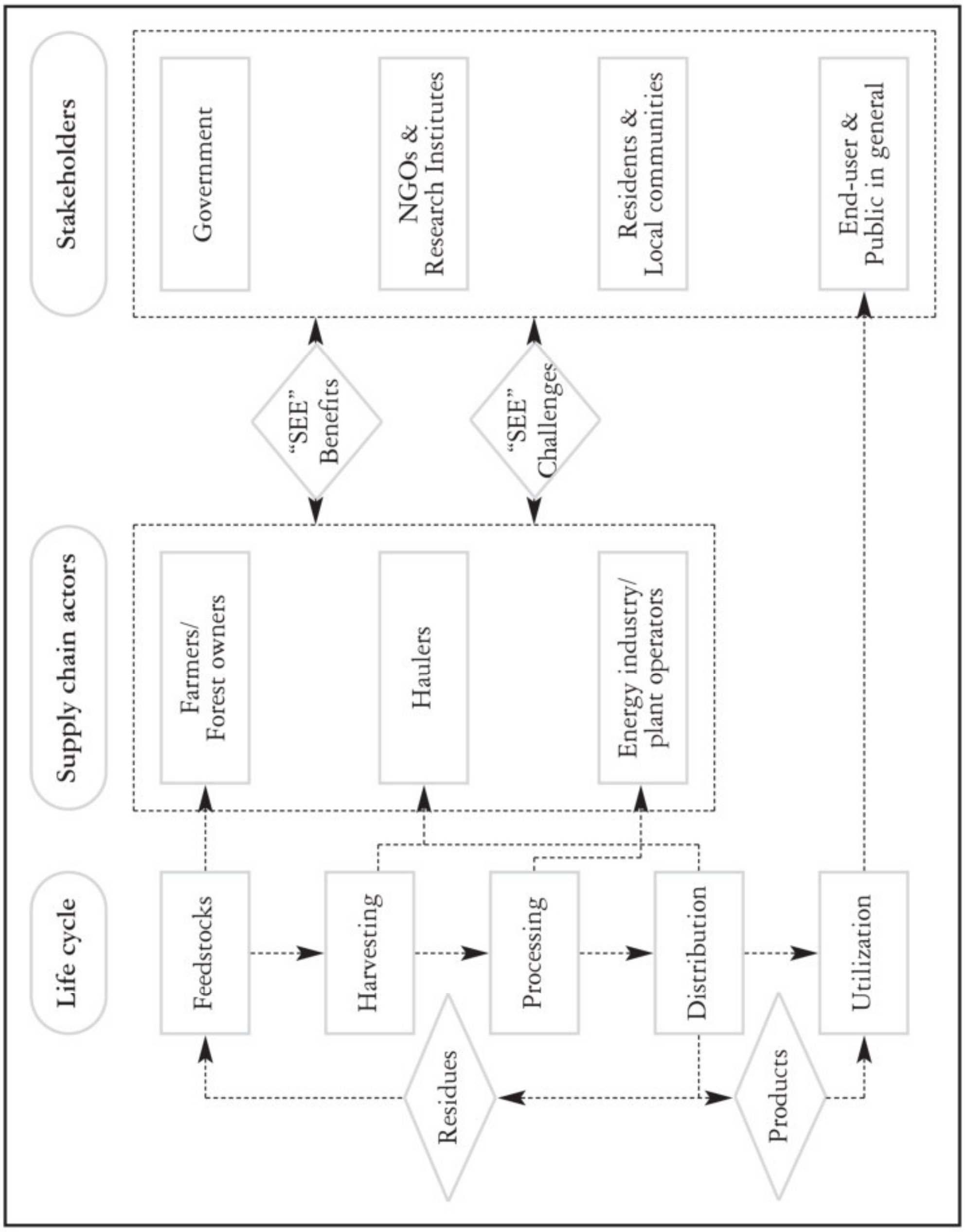
Stakeholder analysis of the bioenergy industry

The range of stakeholders has changed a lot during the evolution of stakeholder theory. According to Freeman and Reed's research, there is a twofold definition of stakeholders. The narrow one defines stakeholders as 'any identifiable group or individual on which the organization is dependent for its continued survival,' and a wider definition considering stakeholders as 'any identifiable group or individual who can affect the achievement of an organization's objects or who is affected by the achievement of an organization's objectives' (Freeman & Reed 1983, 91). Mitchell, Agle and Wood (1997) propose that the typology of stakeholders can be based on their possession or non-possession of (1) power to influence the organization, (2) legitimacy of the relationship towards the organization, and (3) urgency of the claim.

Consistent with the above definitions, we can categorize two layers of stakeholders within the bioenergy industry. The basic layer of actors, or 'central stakeholders', are the bioenergy 'organization', i.e. the supply chain of bioenergy. Their behaviors are the decisive factor of the success of this industry. The upper layer of actors, or 'peripheral stakeholders', is a group of actors impacted by bioenergy production, who in turn also affect this industry by exerting influence on the central stakeholders in both positive or negative ways.

To specifically list every actor in this center-periphery framework of the bioenergy industry, I examine the lifecycle of biomass resources. From its production—the so-called 'cradle'—to its consumption, named as the 'grave', the whole life cycle of biomass resources comprises five phases: producing, collecting, processing, distributing, and utilizing (Scheffran 2009). The first four phases constitute the supply chain of the bioenergy industry, and the actors corresponding to each step are defined as central stakeholders in this research. They are farmers, forest owners, haulers, and bioenergy plant operators. Peripheral stakeholders include governments, non-governmental organizations (NGOs) and research institutes, residents and local communities, energy end users, and the general public, who together compose the outer environment of central stakeholders. In terms of their contributions to the central stakeholders, they can either obstruct or promote execution of bioenergy projects (See Figure 2).

Figure 2. Central and peripheral stakeholders in the bioenergy industry



According to Mentzer et al. (2001), a supply chain is generally defined as 'a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.' For the bioenergy industry, farmers are located in the upstream of the biomass utilization flow. They are responsible for a steady and adequate feedstock supply for biomass energy conversion, in the forms of either crop straws or the by-products and sludge of other non-energy biomass processing industries. As independent agents, they decide which type of crops (food or energy) they will plant, how large an area to plant, and which cultivation methods to use. In general, their decision-making process is influenced not only by the differentiated cost-benefit-ratios of various crops and regional geographical conditions, but also by the risk assessment of energy crop introduction. The risk, to be specific, comes from the uncertainties of capital input, financial reward, and related physical and psychological impacts derived from the switch from traditional agriculture to energy-oriented agriculture.

As to the bioenergy plant operators, they lie in the downstream of the flow and are critical actors within the bioenergy industry. To some extent, these operators are the dominant power of the bioenergy supply chain. Backwards, they collect biomass feedstock from farmers directly or indirectly, and provide the latter income as a reward. Forwards, they connect agriculture and other non-energy biomass processing industries to the energy industry by offering commercial bioenergy products to end users. The types of biomass these operators collect depend on the facilities and technologies they adopt, the form of bioenergy they produce, as well as the corresponding cost-benefit ratio.

Finally, haulers are the carriers of the material flow. They focus on the transportation of biomass feedstock from farmers and non-energy biomass processing industries to the bioenergy plants, the distribution of bioenergy products from processing plants to end users, and the delivery of processing waste, like bioslurry, back to arable lands. Due to some intrinsic characteristics of primary biomass resources, such as low bulk density and seasonal availability, reliable and cost-effective transportation is vital for the sustainable development of the bioenergy industry. In this sense, haulers are also essential in the supply chain.

Bioenergy supply chain management

Once the actors of the bioenergy supply chain have been confirmed, how to execute an effective supply chain management (SCM) is the next issue to be solved. Mentzer et al. offer us a useful perspective on this. They view SCM as 'the system, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across business within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole' (Mentzer et al. 2001, 18). Furthermore, Gold (2011) underlines five parts pivotal for evaluating supply chain design and management. They are (1) supply chain cooperation, (2) supply chain coordination, (3) supply chain governance, (4) long-term relationships, and (5) communication for conflict settlement and joint development. Such a point of view guides us to integrate energy crops into conventional crop management.

For China, development of its agriculture relies on a large number of small-scale peasant farmers. They are decentralized and have insufficient ability to exert their influence on the food market, or to cope with unexpected natural hazards, never mind expecting them to steer the development of agriculture. As most promising energy crops are perennial plants, the uncertainty of crop yields across several years (which poses a risk to the farmers' income) will become one of the barriers obstructing the long-term development of the bioenergy industry in China.

In this case, a model led by bioenergy plant operators can be employed to reform the traditional agriculture structure, so as to construct an energy-oriented agriculture. With sufficient funding and advanced biomass energy conversion technologies, operators are poised to offer a valuable opportunity for agriculture upgrading. And, because of their standing in the central stage of the supply chain, every choice operators make has a profound effect on both upstream and downstream actors. Their consumption of biomass feedstock shapes a derived demand for agriculture and the transportation industry, which in turn boosts the development of industries and improves infrastructure in rural areas. Particularly for obtaining plentiful, steady feedstock in a long period, operators are pleased to sign long-term contracts with farmers and haulers. These contracts can, on one hand, guarantee the short-term profitability of energy crop plantation, and on the other hand, credibly affirm the plant's long-term purchase commitment, which stimulates the alliance of individual farmers, haulers, and operators. This alliance can greatly improve their resilience to the uncertainties through information- and benefit-sharing mechanisms. Therefore, a reliable learning-by-doing partnership can follow.

Communication between central and periphery stakeholders

Now that the supply chain of bioenergy has been analyzed, communication between central and periphery stakeholders can be explored. As previously mentioned, periphery stakeholders can be either obstructers or promoters for the bioenergy supply chain. In other words, central and periphery stakeholders of the bioenergy industry can communicate with each other through the channel of bioenergy projects, which brings both social-economic-ecological ("SEE") benefits and challenges.

"SEE" benefits

As mentioned above, China is the biggest energy consumer in the world. Meanwhile, up to 336 Mtoe of primary energy are dependent on foreign supply. In this situation, bioenergy projects promise to alleviate the severe energy shortage, and optimize the energy provision structure greatly. The utilization of bioenergy can thereby diversify and secure the energy supply, as well as save a lot of foreign exchange reserves. Besides that, the role bioenergy plays in China's rural development cannot be neglected. Because of the long-term existence of a dual economy in China, the gap between urban cities and rural areas is enormous. Different from traditional energy facilities, decentralized bioenergy plants can provide valuable development opportunity for the vast rural areas. Li and Wang (2008) estimate that for Jiangsu Province alone, if each village founded a small bioenergy plant of annual 3,000 tonnes (t) solid fuel output, about 10,000 supportive companies could be set up for biomass gathering, processing, transporting and selling. These companies could yield an annual value of CNY 9–14 billion and offer about 300,000 jobs. The farmers providing feedstock could gain CNY 6 billion for straw selling too.

The founded bioenergy plants could further attract investments on rural infrastructure facilities and other related industries, which would have profound significance in the context of the Chinese 'new village construction' campaign, aiming for balancing its development between urban cities and remote areas. Additionally, the introduction of bioenergy to rural areas could release women from straw or fuel wood gathering, improve the quality of life for rural residents, increase community participation, and decrease the costs of commercial energy— a significant expenditure for rural households. All of these would benefit rural area regeneration.

Apart from social and economic benefits, the environmental benefit of bioenergy also draws attention, especially the function of reducing GHG emissions (Schneider & McCarl 2003). Many LCA analyses of bioenergy focus on the calculation of CO2 emissions in the whole lifetime of biomass, and view it as a potential substitute for traditional fossil fuels like gasoline—even for aviation fuel—to cope with climate change (BBC 2011). The Chinese 'Mid-Long term Development Plan for Renewable Energy' also points out this role (NDRC 2007).

Not only would it be beneficial to GHG emissions mitigation on the global level, the utilization of bioenergy could also reduce indoor air pollution, decrease the occurrence of respiratory diseases, and contribute to natural resource conservation and ecosystem rehabilitation. In urban areas, both combustion of municipal waste and digestion of landfill waste are applicable methods for waste disposal. All of these benefits can be shown in Figure 3 (see annex page 236).

"SEE" challenges

Although it brings us various benefits from social, economic, and environmental aspects, the bioenergy projects also incurs some challenges in the process of implementation. These are illustrated in Figure 4 (see annex page 237).

In China, the most urgent challenge for bioenergy long-term development is how to acquire sufficient and steady biomass feedstock supply. The intense human-land relationship highlights food security issues, forcing delicate management of land use in a bid to balance the output of both food and biomass. Along with the rapid economic growth in China through the last several decades, arable land resources are shrinking year by year. In this context, the most practical method for increasing biomass supply is to assess the possibility of integrating energy crops into the traditional agriculture system. Based on existing cultivation methods, we need to envisage the appropriate distribution of energy crops in order to maintain biodiversity and landscape conservation. With a long coastal line, China can take advantage of its mudflat resources for energy crop plantation, like for example planting cotton and sorghum in the reclaimed mudflat in the Jiangsu province (Wang et al. 2010).

Meanwhile, the sustainable use of water resources and chemicals for tillage needs to be taken into consideration; and the resilience of crops to climate change is also an important factor. The more frequent climate hazards such as typhoons, droughts, rainstorms and heat waves, will potentially have negative effects on crop growth (Fang et al. 1992).

In terms of the social-economic component, isolated and complex legislative issues are a huge challenge for the development of the bioenergy industry. In China, the National Development and Reform Commission (NDRC), along with seven other ministries, announced the 'State Scheme of Extensive Pilot Projects on Bioethanol Gasoline for Automobiles' in 2004. Aiming at curbing the negative impacts of bioethanol production on food security to a small extent, this scheme allows only four ethanol plants to produce fuel ethanol from grains and enjoy the financial subsidy. In biofuel distribution, the scheme entitles the China Petroleum and Chemical Corporation (Sinopec) and the China National Petroleum Corporation (CNPC) to sell E10 gasoline (NDRC 2006). Such administrative means do play a positive role in maintaining food security, but they also prevent potential participants from joining the bioenergy market, and delay the development of the bioenergy market to some degree.

In addition to that, the absence of sustainability criteria for bioenergy, which is a prerequisite for large-scale bioenergy international trade, and insufficient incentives, like the lack of convincing feed-in tariffs (Shen et al. 2010) hinder the industry development (Markevicius et al. 2010; Solomon 2010). Because of a lack of sufficient research and development (R&D) investment, the biological conversion technology for cellulose-based liquid fuel in China, for example, is far behind the need of large-scale commercial production (NDRC 2006).

Last but not the least, the odors, noise and other pollutant emissions, as well as traffic congestion by biomass transportation could result in the resistance of local communities. If there were no effective public participation mechanisms, the local residents would adopt lobby, voting, or even demonstration under extreme conditions to prevent the projects from being executed. To avoid traffic congestion, Richard (2010) suggests building an innovative supply system. Specifically, he suggests that the application of decentralized conversion processes, dispersed preprocessing, densification of primary biomass feedstock for long-distance transport, and a suitable business model that can balance the biomass growth in both short- and long-term is necessary. In this case, optimizing the distribution of biofuel plants and designing the appropriate transportation system are of high importance.

Development strategies for the bioenergy industry

In 1990, Michael E. Porter built a new analytic paradigm to analyze national competitiveness: the so-called the Diamond Model (Porter 1990). This model can answer questions like, why are some countries successful while others fail in international competition? Why can some industries gain international competitiveness for a long time? Porter conducted historical research on several hundred types of industries in eight advanced countries (U.S., U.K., Sweden, Japan, Italy, Germany, and Denmark) and two new industrialized countries (South Korea and Singapore). He concluded that a country or an industry eager to gain a competitive advantage has to focus on four key elements—factor conditions, demand conditions, related and supporting industries and firm strategy, structure and rivalry—and two auxiliary factors—government and chance. The name of the Diamond Model is derived from the outline of the network formed by the interactions between these variables (see Figure 5, annex page 238).

Factor conditions

Porter divided factor conditions into primary factors and advanced factors of production. In terms of bioenergy industry, primary factors refer to the basic proved reserve of Chinese biomass resources. Although China has a long history of using biomass resources, currently we are still unclear on the state potential of biomass resources. In this sense, conducting a national biomass resources survey to clarify the possible sources of biomass—as well as the potential for each source and its distribution—is not only necessary, but urgent.

Advanced factors of production include human resources, such as experts on the operation and management of bioenergy, and research institutes which engage in bioenergy research. Compared to primary factors, advanced factors cannot be achieved in a short time. Rather, they require continuous investments for a relatively long period. Thus, supportive policies on promoting the vocational training in the area of bioenergy are required.

Demand conditions

Demand markets include domestic markets and global markets. In terms of natural attributes of biomass resources, long-distance transportation of unpacked biomass is not profitable. Thus, the main biomass market is a domestic market, especially a local market. Domestic demand includes market structure, scale, and growth. To the bioenergy industry, the bioenergy market structure can be mainly divided into biochemical conversion (biogas and fuel alcohol), biomass gasification (power generation or thermal power coproduction), biomass liquefaction (biodiesel), and direct burning (boiler burning, dense burning, and garbage burning). In terms of market scale, the market of biomass power generation ranked first and installed capacity was 5.5 gigawatts (GW) by the end of 2010, generating electricity of 33 billion kilowatt-hours (kWh). Following power generation, the annual capacity of biogas for energy generation was about 10 million tonnes of coal equivalent (tce). Ranking third and fourth places were biomass liquid fuel (1.8 million tonnes of bioethanol and 0.5 million tonnes of biodiesel), and biomass solid fuel (3 million tonnes) (NDRC 2012). In favor of their values on large-scale commercialized utilization, biomass-based power and bioethanol have been emphasized by the Chinese government. Different from biogas and biomass briquettes, the production of power and biofuel is technology- and capital-intensive. Therefore, the government has issued preferential fiscal and tax policies and supportive regulations to accelerate their applications.

In addition, the overseas market for either biomass feedstock or modern bioenergy products is also worth considering. However, a major breakthrough in critical technologies and biomass conversion devices is the precondition for China's bioenergy industry to gain global competitiveness in the long term.

Related and supporting industries

Porter claims that for single firms or single industries it is hard to keep their competitive advantage, and that only by means of forming effective industrial clusters and active interactions between upstream and downstream industries can industrial competitive advantage be kept. This rule can also be applied to the bioenergy industry. Due to the various sources of biomass feedstock, the bioenergy industry has a close connection with many other industries and thus can lead the formation of an industrial cluster (See Figure 6, annex page 239).

To be specific, the industries having backward linkages to the bioenergy industry are mainly agriculture, forestry, and machine manufacturing. As there is a big difference between the cultivation of energy crops and conventional crops, an adjustment of field management as well as agricultural machineries is needed. The industries which have forward linkages to the bioenergy industry are automobile manufacturing and transportation. The development of the bioenergy industry can guide the development directions and broaden the application ranges and levels of these downstream industries, and conversely the development of these downstream industries propose certain requirements to the bioenergy industry. This mutual feedback helps the biomass industry to maintain its own advantage and realize its sustainable development.

From the perspective of the bioenergy industry supply chain, the industries having lateral linkages to the biomass industry include the following. (1) The pulp and paper production industries and the chemical industry share the same primary biomass resources with the bioenergy industry. At first glance, a competition of biomass feedstock may exist among them. However, thanks to the cascade use of biomass, by-products and sludge from the pulp, paper, and chemical industries can be used as feedstock for the bioenergy industry. Thus, these industries can cooperate with each other. (2) Other renewable energies, for instance wind energy, solar energy, geothermal energy, and tidal energy may challenge biomass renewable energy within the renewable energy market, and in terms of government support measures. However, the competition among these renewable energies is not a zero-sum competition. Due to their differentiated levels of utilization technology development, and the gaps between their potential, the target market of these energies are not completely overlapping, and naturally, the development priority of each renewable energy may vary from time to time. In addition, compared to traditional fossil fuels, all these energies, as the components of the renewable energy industry, face the same policy environment. Therefore, the 'promotion effect' would be observed among them. This effect is even more common in the initial development stage of an industry which has a high proportion of interoperability technology. The bioenergy industry is just such a case. (3) The traditional fossil fuel industries share transportation resource with bioenergy industry. A distinctive characteristic of bioenergy, which wind energy and solar energy do not have, is the spatial and temporal mobility of the bioenergy carrier. In other words, biomass feedstock can be stored and transferred. In this sense, biomass energy has a similar feature to traditional fossil fuels, being capable of load shifting and stable energy supply. On the other hand, because of this similar feature, bioenergy has to compete with traditional energies for limited transportation resources, including competition for haulers, vehicles, and road resource. But in terms of energy provision, the bioenergy industry in the short-term is complementary to the traditional energy industry, and in the long-term, together with other renewable energies, it will replace the traditional ones. For this reason, it is possible to launch cooperation between bioenergy industry and traditional energy industry.

All in all, the development of bioenergy industry is not isolated. We should consider the development of bioenergy industry in a broader scope and engage in promoting its development through building industrial clusters.

Firm strategy, structure, and rivalry

Firms, as the micro organizations in the industrial system, play an important role in the formation and development of industries. According to the development orientation of the bioenergy industry, professional bioenergy firms which have definite property rights, perfect governance mechanisms, a matured technological background, and scientific management methods should be responsible for the development and utilization of biomass resources. An effective management mode of the development and utilization of biomass resources is expected to form on the basis of the philosophy of developing under protection and protecting under development. These professional firms are encouraged to operate in compliance with market principles and the related governmental regulations, in the aim of gaining both social benefits and economic benefits, as well as promoting local development. In such a case, free competition is the overarching factor, which can efficiently allocate resources, launch the innovation consciousness of bioenergy companies, and provide continuous forces for the upgrading of biomass utilization technology. After the selection of the domestic bioenergy market, the prominent firms will earn confidence and capability to explore the overseas markets.

Chance and government

On the one hand, in the twenty-first century, countries around the world have to face the challenges of the energy crisis. The shortage of fossil fuels has greatly undermined the foundation of a traditional development path on a global scale. Searching for alternative energies has become an urgent task for all the countries. On the other hand, to curb the global warming tendency, the United Nations Framework Convention on Climate

Change has set concrete and ambitious GHG mitigation targets. Under these circumstances, biomass energy, as an option to reach both targets, has a bright prospect. Meanwhile, it is worth noting that these chances do not exist independently. Only linked with other factors of the Diamond Model can they play a positive role.

Government is the final variable in the Diamond Model. Porter claims that the government cannot create competitive industries by itself, but must work together with other variables of the Diamond Model, and guide them. The only role which government is designed to play in the procedure of new industry nurturing is to provide a positive outer environment for the development of industries and firms. To be specific, the Chinese government should carry out three major functions.

The first one is an administrative function. Governments should 'supervise' rather than 'participate in' the bioenergy industry. Further, the management method of government has to respect the intrinsic features of the bioenergy industry. In other words, parallel with the bioenergy utilization process, starting from biomass feedstock supply to biomass conversion process, then to bioenergy product distribution and consumption, a series of governmental departments have been involved. In order to smooth the communication between the different sections of bioenergy industry, organizing a cross-department council, composed of agriculture, land, industry, business, technology, and environmental protection divisions, is feasible.

The second function is legislation assurance. Compared to conventional energies, the bioenergy industry is relatively nascent, and the corresponding market mechanisms have not fully formed yet. In order to offer bioenergy a favorable environment for its development, and prevent the traditional energy industry from strangling the new one by taking advantage of their predominant share in the state primary energy mix (for example, setting up entrance barriers for renewable energies), the status and the role of bioenergy in the future energy supply system need to be clarified and guarded through the issuing of related regulations. Besides that, I suggest conducting a nationwide, bottom-up investigation on biomass resources so as to obtain first-hand and high resolution data of China's biomass potential. On the basis of that, compiling a special development plan of the bioenergy industry, and integrating it into the National Development Plan is necessary. In addition, the combination of this special development plan with other industrial plans, regional development plans, and the plan of crop residue comprehensive utilization is also suggested. Following this thought, the economic, social and environmental benefits of bioenergy can be completely exploited.

The last one is mechanism construction. In light of the participation of multiple governmental departments, the design of the supportive mechanism should start from the top level, with a set of related and cooperating incentives covering all sections of the bioenergy industry and targeting each actor of the bioenergy supply chain. From the perspective of industrial economics, governmental interference in a reasonable scale can facilitate correcting market failure led by the industry with positive externality and cultivating new industries. Nevertheless, we have to be very cautious about the extent of these policies' implications, because in the long-term, bioenergy firms are to face fair market competition, and allocating biomass resources through the market mechanism is the most efficient way. Besides offering economic impetus, the government has the responsibility to improve the financing channels for biomass resources development and the risk warning system, and to construct the demonstrative area of biomass resource utilization. All in all, for government, providing a positive market environment and appropriate policy tools for each phase of the bioenergy market development is of prime importance.

Based on the above discussion, I suggest that to ensure the Chinese bioenergy industry competitiveness, three key issues must be carefully dealt with: the provision of biomass feedstock, the integration of the energy market, and the innovation of bioenergy infrastructure.

Conclusion

While facing global problems such as 'energy crisis' and 'climate change', more and more countries have pinned their hopes on renewable energy. Bioenergy, as one of the most promising renewable energies, has gained great attention around the world. China, as the largest energy consumer and GHG emitter in the world, has also promoted the development of the bioenergy industry on its soil.

In this context, this paper focuses on the development of the bioenergy industry in China. Starting from the introduction of the notion of circular economy, I proposed a conceptual model of cascade use and recycling of biomass, stressing the coordinated utilization of biomass as an energy carrier and as a raw material. On the basis of that model, I used the analysis framework of stakeholder theory to delineate the structure of the bioenergy industry. In details, the bioenergy industry is composed of central stakeholders and periphery stakeholders. The former constitute the supply chain of bioenergy, while the latter make up the outer environment. They communicate with each other through the channel of bioenergy projects implications, which bring both SEE benefits and challenges.

After analyzing the structure of bioenergy industry, I explored the pathway of forging competitiveness of this industry with the analysis framework of Porter's Diamond Model, which was originally applied to analyze national competitiveness. Through discussing six factors constituting the industry's competitiveness (factor conditions, demand conditions, related and supporting industries and firm strategy, a structure and rivalry, and government and chance), I conclude that three key issues of the industry need to be paid special attention: the provision of biomass feedstock, the integration of energy market, and the innovation of bioenergy infrastructure.

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Annex

Figure 3. The social, economic and environmental benefits of bioenergy industry implication

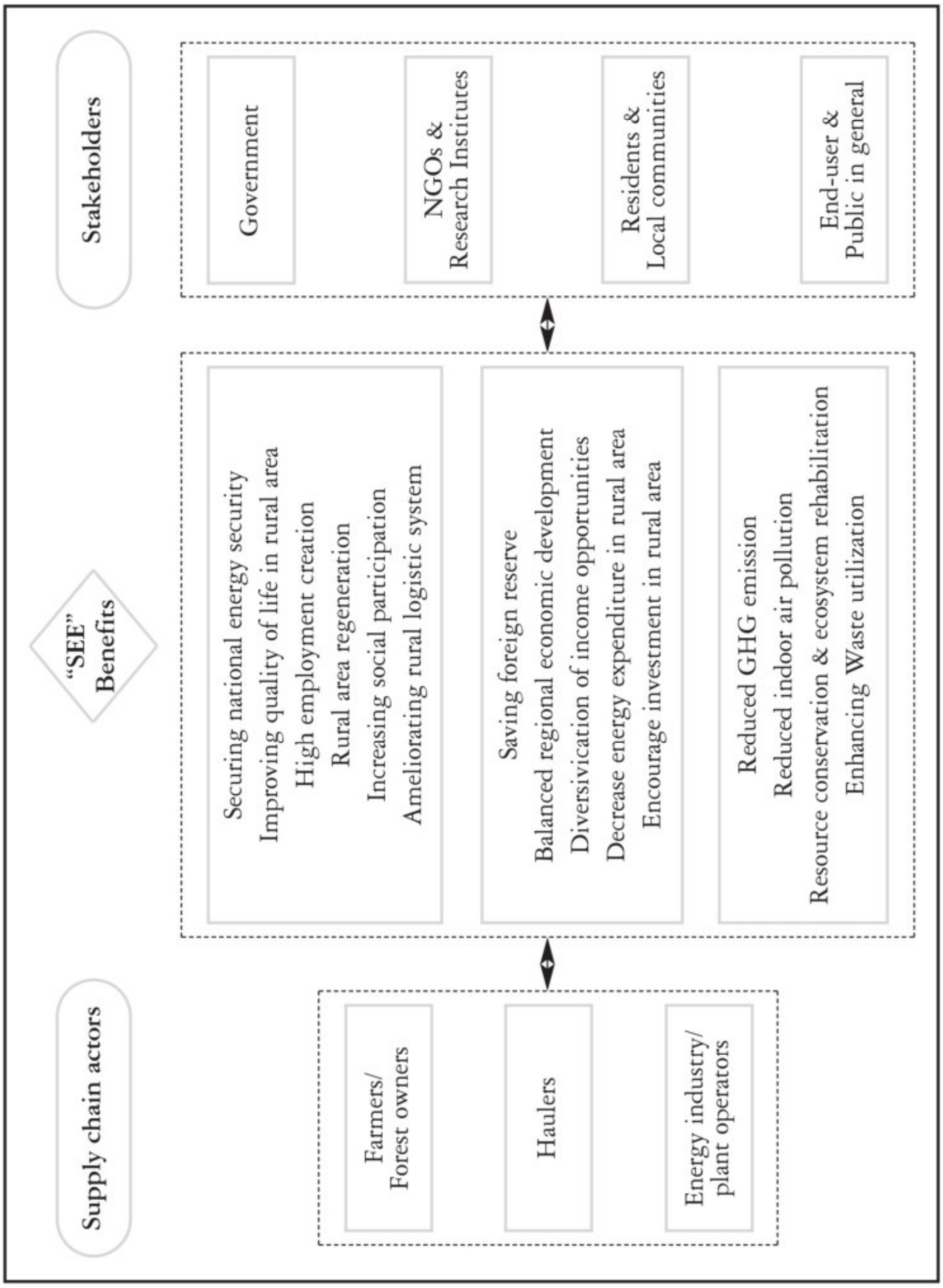

Figure 4. The social, economic and environmental challenges of the bioenergy industry

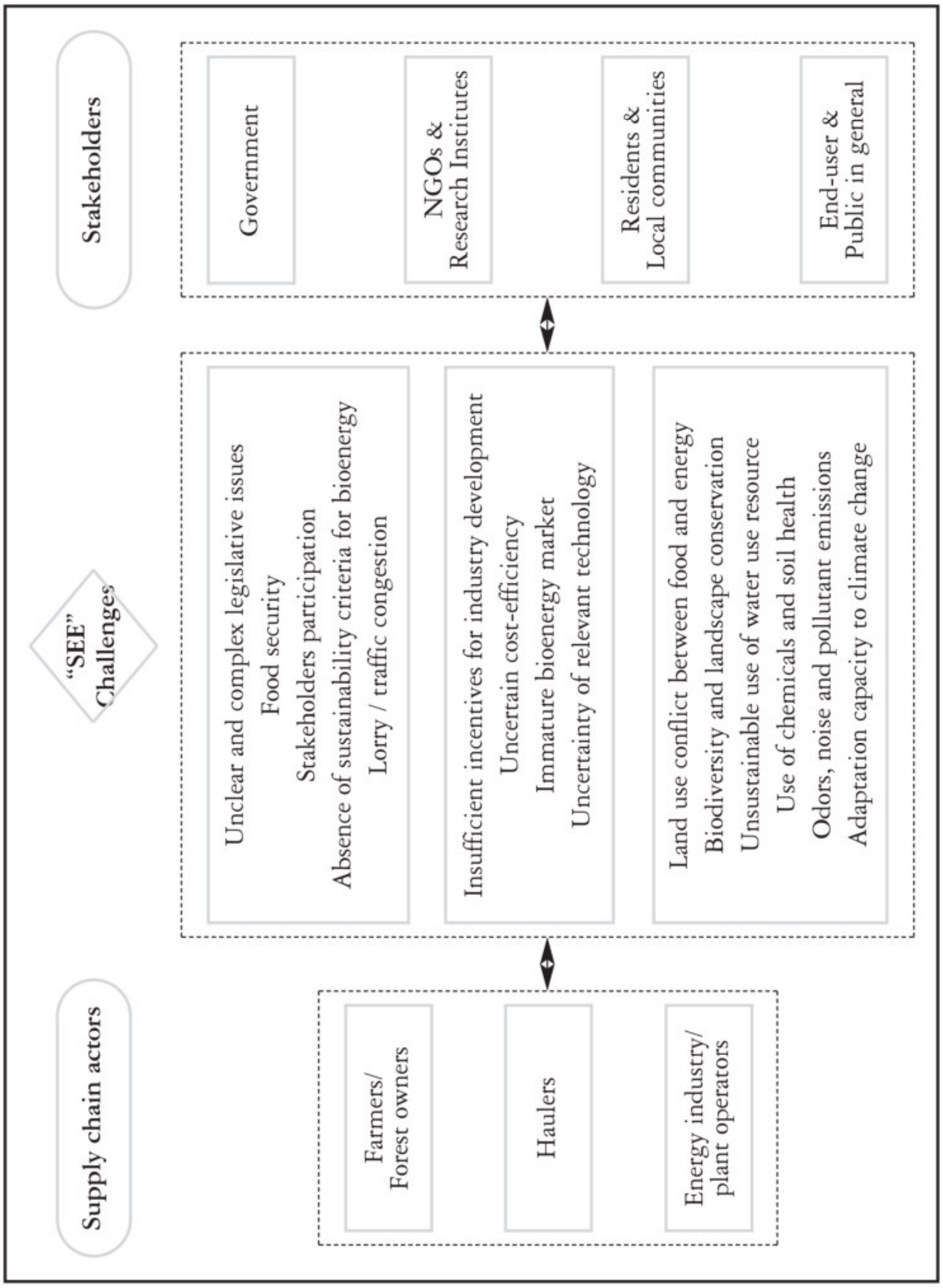

Figure 5. Porter's diamond—the determinants of national advantage (Adapted from Porter, 1990)

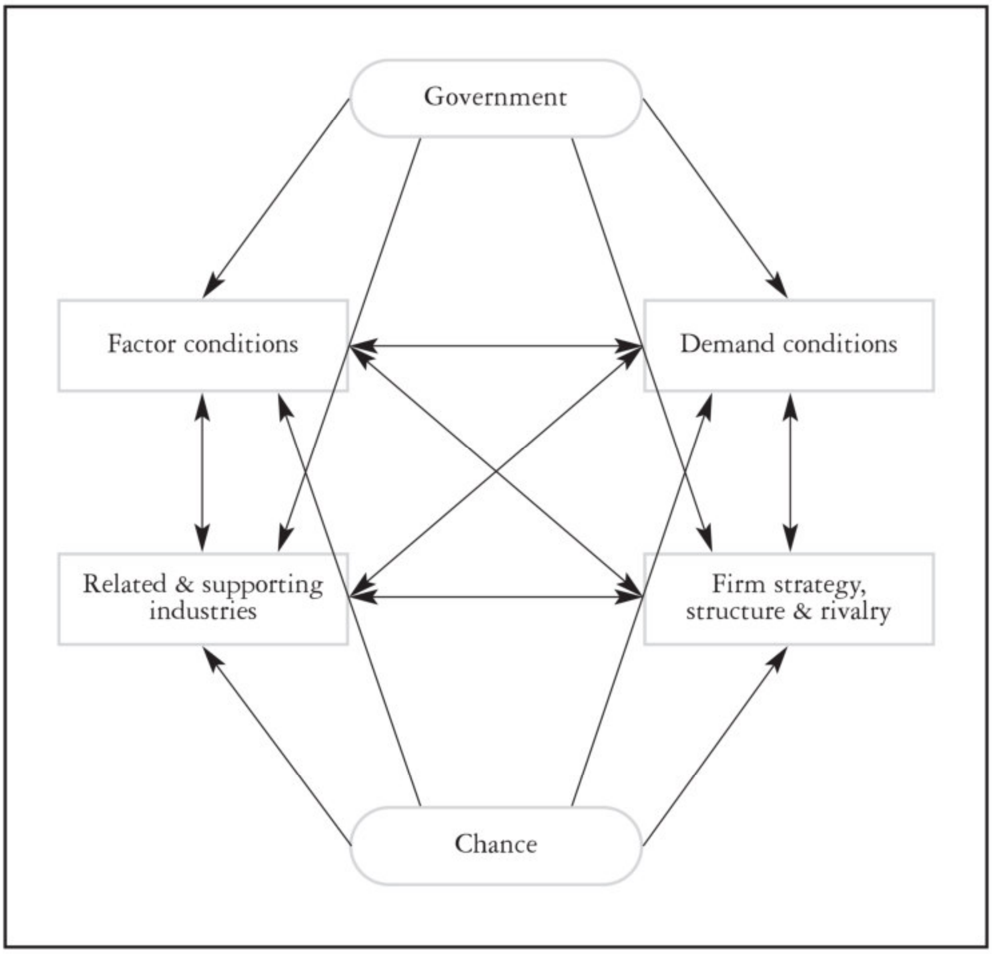

Figure 6. The industrial cluster in which the bioenergy industry takes the center stage