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Organizational Boundary Change in Industrial Symbiosis: Revisiting the Guitang Group in China

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Abstract: This study revisits the Guitang Group, one of the best known industrial symbiosis cases in the sugar industry. Our goal is to offer an evolutionary understanding of industrial symbiosis at the Guitang Group. This article focuses on the organizational boundary change of the Guitang Group over time, and acknowledges this process as one of the seven industrial symbiosis dynamics proposed by Boons et al. We offer a historical view of the critical forces behind Guitang’s industrial symbiosis evolution since the 1950s; particularly how these changes were influenced by broader economic and institutional contexts of importance in China. These insights include the role of institutionalized research and development (R&D) as well as technology-oriented leadership as driving forces for Guitang’s innovation, particularly since the 1990s, when greater efficiency and productivity were emphasized, leading to the establishment of further symbiotic relationships in the company’s evolutionary process. As a result, the Guitang Group grew from 2 internal to 11 internal and external symbiotic exchanges and is now a conglomeration with more than 3000 employees generating more than 1 billion RMB (150 million USD) in revenue annually. The driving forces of the Guitang Group’s industrial symbiosis evolution helped to create, disseminate and share information by continuously reinforcing the industrial symbiosis message as part of the Guitang Group’s business model and competitive strategy. In addition, state-level policies such as establishing the Guigang (the city where Guitang is located) Eco-Industrial Park enabled industrial symbiosis in Guitang. This study provides prospects for future research on the organizational boundary change dynamic of industrial symbiosis in the sugar manufacturing industry and beyond.

Keywords: industrial ecology; industrial symbiosis; business and environment; innovation and sustainability; environmental management

1. Introduction

Industrial symbiosis is one of the core concepts of industrial ecology, a 25-year old field that focuses on physical resource flows through systems at different scales [1]. Central to industrial symbiosis is the study of cooperative resource sharing of water, energy, and material by-products and wastes across multiple organizations for both environmental and economic gain [2]. Since the 1990s, recognition of various resource and waste sharing schemes among companies and other organizations has given shape to industrial symbiosis as a collective phenomenon that occurs in various ways all over the world. Currently, attention is focusing on looking back to understand the emergence and development of industrial symbiotic clusters, acknowledging both the difficulty and the importance of cross-national and cross-cultural comparison [3]. Boons et al. directly address the problem of comparison and characterize industrial symbiosis as a “process of connecting flows among industrial actors through (1) use of secondary material, water, and energy resources and/or (2) utility and service sharing, such as collective use of infrastructure or environmentally related services across a network” [2,4].

Applications of industrial symbiosis have helped policy makers and industry leaders to shape more resource-efficient policies and strategies. As the world's largest and one of the fastest growing economies in the world, China has been searching for strategies to mitigate the adverse environmental impact brought on by rapid industrial development over the past few decades leading to a substantive call for a viable sustainable development path [5–7]. Among the recently promoted development ideas by the government and also cited in academic research, industrial symbiosis has been an increasingly adopted pillar of China's sustainable industrial development plan. Indeed, a recent bibliometric analysis of almost 400 industrial symbiosis articles published and recorded in the two leading academic indices from 1995 to 2014 revealed that when countries were specified, by far the largest number of these articles comes from China, highlighting its prominence as an industrial symbiosis actor and therefore a motivator for probing examples from China to deepen our knowledge (Figure 1) [3].

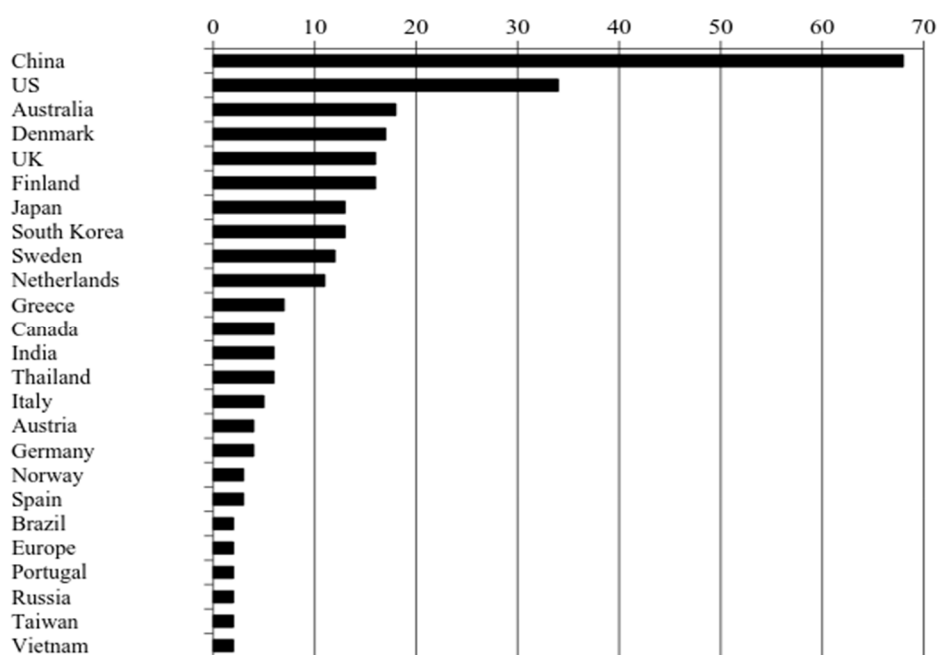


Figure 1. Countries featured in 286 academic papers on industrial symbiosis (out of total reviewed of 391 articles published from 1995–2014 and listed on Scopus and/or Web of Science). (Chertow and Park 2016 with permission).

In its modern history, China has staked much of its economic program on investment in large industrial parks. During the period of the 2006–2010 Five-Year Plan, for example, industrial parks contributed 50% of China's industrial output value in Eastern China according to the Ministry of Industry and Information Technology [8]. Eco-industrial parks have become a key vehicle for Chinese implementation of industrial symbiosis as a subset of the overall drive for industrial parks. The scale of implementation of eco-industrial parks is massive: there are already over one hundred designated Eco-Industrial Parks nationwide with on-going efforts to improve their sustainability characteristics [5,7]. Understanding China-specific context and characteristics of industrial symbiosis could help inform future environmental decision and policy making.

Studying the industrial symbiosis of the Guitang Group offers a unique opportunity to view and analyze the dynamics of industrial symbiosis of a company that has gone through multiple complex social and organizational changes over six decades.

The Guitang Group is located in Guigang City of the Guangxi Zhuang Autonomous Region, where more than 50% of China's sugar is produced (Figure A1). Originally established as a state-owned enterprise in 1956 under the first Five-Year Plan (FYP) in China, the Guitang Group only produced sugar and alcohol in the beginning. It has since introduced additional production lines for pulp and

paper, cement, alkali, fertilizer, and calcium carbonate, as well as a shared combined heat and power (CHP) facility. Over time, the Guitang Group evolved from 2 internal to 11 internal and external symbiotic exchanges. Through efficient use of its by-products and sharing of energy, infrastructure, and services, the Guitang Group has been able to create new business models and stands as an example of how Circular Economy principles apply to industrial systems [9]. The Guitang Group was among the first group of industrial complexes identified as having a well-established industrial symbiosis network in China [9,10]. Previous studies concluded that the Guitang Group illustrates an idealized industrial symbiosis model in which internal investment, cooperation with partners, and technical innovation are essential to its success [9,11]. None of the studies, however, focused analysis, as does this paper, on how the Guitang Group has evolved over time, particularly how it has changed as a business, and the social, economic, and policy drivers for these changes.

In this study, then, we dive deeply into the social and historical context of the Guitang Group. Our goal is threefold. First, we would like to provide a more comprehensive view of how industrial symbiosis of the Guitang Group has evolved, particularly focusing on the fundamentals of business operation. Second, we would like to investigate if the Guitang Group can be characterized through a specific industrial symbiosis dynamic topology proposed by Boons et al. Third, we would like to understand the potential strengths and weaknesses of the Guitang Group's industrial symbiosis activities in a global context [4]. Based on our objective, the three main questions we ask are (1) how has the operation, management, and financing of the Guitang Group evolved over time? (2) does the Guitang Group belong to one or more of the seven industrial symbiosis dynamics proposed by Boons et al.? (3) how does the Guitang Group compare to other industrial symbiosis case studies in the sugar industry internationally?

Our study links an existing industrial symbiosis success story to the recent synthesis of industrial symbiosis dynamics on a global scale. In order to tell the complete story, we used several methods including social network analysis, material flow analysis, and comparative analysis that is grounded in industrial symbiosis theories and support them with carefully-collected empirical evidence.

2. Frameworks

2.1. Theoretical Framework

The foundation of this analysis is the theoretical understanding of how industrial symbiosis (IS) emerges and develops. For many years there has been one strand of scholarship indicating that industrial symbiosis emerges spontaneously, through self-organization, and another strand supporting the idea that it is primarily a planned activity. Because the symbiosis of Kalundborg, Denmark is the best known longitudinal case of industrial symbiosis [12] and it did emerge spontaneously through the development of bilateral exchanges, some consider self-organization to be the key [9,13–16]. Other very useful examples of industrial symbiosis, particularly in East Asia, have key planning components as in China, Japan, and Korea [7,17,18]. Still, it has been difficult to limit the examples at hundreds of symbiosis sites to these two categories because the facts do not fit such a narrow framework. An indicator that the self-organized vs. planned debate was too confining was the difficulty scholars were having in successfully engaging in cross-country and cross-cultural comparison of IS projects [4].

Taking up this challenge, the current explanation offered by Boons et al offers a broader typology of industrial symbiosis “dynamics”—that is, the pathways through which IS emerges. The seven dynamics include self-organization, organizational boundary change, facilitation—brokerage, facilitation—collective learning, pilot facilitation and dissemination, government planning, and eco-cluster development [4]. The authors represent industrial symbiosis as a process of connecting flows with specific initial actors and motivations. Boons et al further describe how the dynamics can change over time, for example, the Kalundborg symbiosis begins as self-organizing in the 1970s, but by the 1990s there is a government-sanctioned coordinating body that turns the model more toward a facilitation dynamic than a self-organization dynamic [12].

This article begins with the exploration of the Guitang Group as a planned economy project typical of China in the 1950s and it is then studied over the next 60 years to the current day. Keeping the theory of industrial symbiosis dynamics in mind over this long time period reveals that the pattern best describing the evolution of the Guitang Group is the dynamic of “organizational boundary change.” The evidence is offered herein.

We also draw knowledge from economics, sociology, and innovation study to form a comprehensive understanding of the Guitang Group’s organizational changes. To understand the institutional context, we review literature from New Institutional Economics, an economic perspective that focuses on the social and institutional context of economic activities [19]. We refer to studies on technological innovation to analyze the connection between the Guitang Group’s operational changes and its capacity in research and development (R&D). We follow studies in organizational sociology, stating that any existing organization is shaped by the social forces and interactions among organizations. The social network of an organization is essential in understanding its development [20].

2.2. Methodology and Data Collection

Following the theoretical framework, we conduct the study of the Guitang Group by collecting secondary data from academia, industry, government, and the media at the Yale Center for Science and Social Science Information library as well as through internet search.

The industrial symbiosis exchanges of the Guitang Group over time are analyzed through its operational and financial data [21]. We review scholarly work about the Guitang Group to synthesize its operational development over time. In particular, we acquire detailed operational data of the Guitang Group through a number of high-quality Master’s theses with primary data on the Guitang Group’s operation collected through interviews and internal documents. We collect financial data on the Guitang Group through its publically available annual reports since 1999, as the Guitang Group went public and was listed on the Shenzhen Stock Exchange in 1998.

To outline the Guitang Group’s operation clearly, we use material flow analysis (MFA) to lay out the production details of the Guitang Group. Here, MFA includes the production process chains comprising raw material extraction, transformation, manufacturing, consumption, recycling, and disposal of materials [22]. In addition, we use social network analysis (SNA) to examine the interaction among different operations during the Guitang Group’s development. A network consists of nodes that represent the actors in the system and their ties that describe the connections between the actors [23]. Ties represent relationships, including social connection, membership, material flow, or capital flow [20]. SNA helps to present Guitang’s industrial symbiosis evolution over time, as well as recognizing trends and changes throughout Guitang’s industrial symbiosis network development.

To analyze the economic and social context of the Guitang Group’s industrial symbiosis evolution, we review scholarly work in Business and Economics as well as collect data from the local and state government, primarily in Mandarin. We acquire policy and commerce information through the official website of Guigang City Government, Guangxi Provincial Government, and the Ministry of Environmental Protection. We collect industry information from local bureaus including the Ministry of Industry and Information Technology and the Administration for Industry and Commerce. In addition, we conduct internet searches based on media reports of the Guitang Group to shed light on the organizational culture and leadership of the company.

For comparative analysis, we gather information from scholarly work on industrial symbiosis in the sugar industry around the world. We briefly review previous studies of industrial symbiosis in the sugar industry in China, the UK, and India. While there are some distinct differences, including the feedstock and processing technologies, several characteristics are universal to the sugar industry [3,24–27].

3. Analysis

We offer a step-by-step analytic approach. First, we analyze the Guitang Group as a business focusing on how its boundaries have shifted. Next, we study the Guitang Group within a local social context and review how it evolves over time. Last, we review the impact of public policies in China on Guitang's development within a broader social context.

3.1. Definition of Organizational Boundary

To be clear in our analysis, we begin by reviewing the concept of organizational boundaries. In the business literature, organizational boundaries are defined as “imagined lines drawn to separate the organization from its surrounding environment and to specify how internal roles and functions are related but also separated from one another” [28]. Central to this definition are the roles and functions of the organizations instead of the physical or geographic boundaries. Based on the definition of organizational boundaries, our analysis is focused on the changing roles and functionality of the Guitang Group.

3.2. Business Boundary Shift

The Guitang Group has come a long way from a sugar and alcohol production facility in 1956 to a multi-subsidiary corporation with more than 3000 staff and 1.5 km² operational space at present [29,30]. The organizational change of the Guitang Group is characterized as insourcing and vertical integration that generate internal and external symbiosis linkages. In this section, we closely review three main areas of organizational boundary change from the business perspective, including operation, management, and finance.

3.2.1. Operational

Broadly speaking, operations refer to activities within an organization that are necessary for production and delivery of products and services [31]. The Guitang Group has initiated various activities in order to produce desired products. At the time of establishment, the Guitang Corporation (Guangxi, China) produced sugar and molasses as main products. In addition, it produced alcohol using waste molasses. In the 1970–80s, the Guitang Group started to produce pulp and paper using the fibrous by-product of sugarcane, and created additional revenue streams to the business. During this time, there were symbiotic exchanges among the sugar, alcohol, paper operations, as well as local and regional farmers [9]. In the 1990s, the Guitang Group added products including alkali, cement, fertilizer, caustic soda, and calcium carbonate to capture more value from the by-products. The additions expanded the diversity of the symbiotic network (Figure 2).

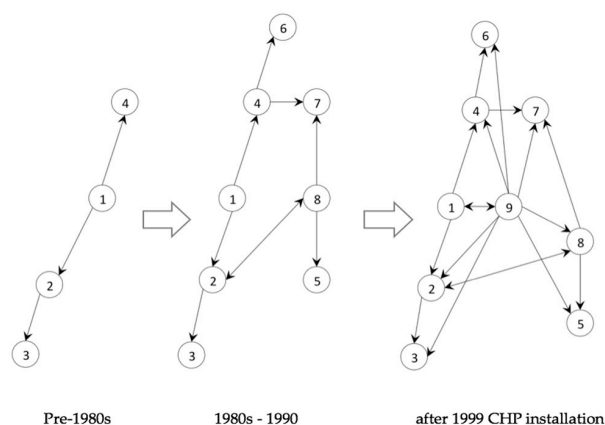


Figure 2. Major symbiotic chains of the Guitang Group (1: sugar, 2: pulp, 3: paper, 4: alcohol, 5: cement, 6: fertilizer, 7: calcium carbonate, 8: alkali, 9: combined heat and power) [9,11].

After a few expansions, the production capacity of the Guitang Group as of 2015 is much more diverse with significant quantities of products generated through by-product reuse (Figure 3).

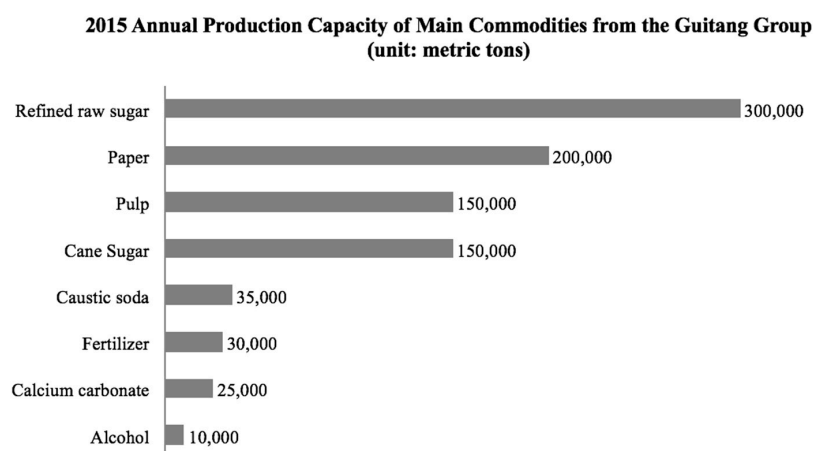


Figure 3. 2015 annual production capacity of main commodities from the Guitang Group (metric tons) [32].

It also created service-based subsidiaries that offer equipment sales and technical services, which illustrate the Guitang Group's intention to tap into areas beyond industrial and agricultural operations [30,32]. We observe that the business boundaries of the Guitang Group have continued to expand over time.

3.2.2. Management

Management generally refers to the process of conducting business and organizing people [33]. At the Guitang Group, both these aspects have changed significantly over the years. Since 1956, the Guitang Group has experienced a series of changes in management structure. It shifted from a state-owned enterprise to a shareholder system in 1993. In 1998, part of the Guitang Group became a publicly traded company. As a result, it established well-defined responsibilities related to its shareholders and disclosed management and financial details as required by law [30].

The management transitions occurring at the Guitang Group are influenced by the interplay of institutional and organizational factors within a period in China when many social and economic forces were constantly changing. As New Institutional Economics scholar Douglass North, explains, we see that "institutions are the humanly devised constraints that structure human interaction", whereas "organizations are groups of individuals bound by some common purpose to achieve objectives". North further suggests that "the continuous interaction between institutions and organizations in the economic setting of scarcity and hence competition is the key to institutional change", and that "the economies of scope, complementarities, and network externalities of an institutional matrix make institutional change overwhelmingly incremental and path dependent" [34]. In the Guitang case, the historical legacies of the enterprise systems from the Ming and Qing Dynasty, the Republican Era, and the institutional development path of the People's Republic of China together have contributed to the Group's birth and evolution.

To understand the context of Guitang Group's management shifts, we review the history of Chinese state-owned enterprises in the 20th century as described by historian Morris L. Bian. In his analysis, Bian notes that state administrative bureaucracy is an essential characteristic of China's institutional endowment largely as a result of the development of the ordnance industry demanded by the wars tracing back as far as the Taiping Rebellion (1851–1864) and the Second Opium War (1856–1860) [19]. In contrast to the U.S. where entrepreneurial initiative and capital markets play a significant role, the rise of the state-owned enterprise in China was "an organizational response to a

fundamental challenge to the survival of the Chinese nation-state”, hence heavily influenced by public policies. The desire to build a modern, industrialized socialistic country motivated a series of ambitious long-term statewide development plans led by the communist party. The first Five-Year Plan (FTY) from 1953 to 1957 was one of the first efforts. The incorporation of the Guitang factory was part of the new People’s Republic of China’s first FYP assisted by the Soviet Union. As the only project in Guangxi Province out of the 156 total projects assisted nationally by the Soviet Union during the First Five Year plan period, the Guitang project was a source of local pride. The location of Guitang’s manufacturing facilities were carefully chosen at the site of the former Luobo Bay sugar factory destroyed by the Japanese in 1944 [29]. Sugar production was also a key national priority—as of 1949, China’s sugar production was far behind the industry leader, the U.S., as well as its neighbor, India (Table A1).

Since the completion of the first group of state-owned enterprises with help from the Soviet Union, China has been trying to develop its own enterprise system through a combination of reforms and incremental changes [35–37]. Based on the history of state-owned enterprise reforms in China, we considered three aspects that could have influenced the Guitang Group’s management throughout its course of development:

- (1) *Socialist infrastructure and cultural heritage as an endowment of social capital*: the initial infrastructure of the Guitang factory was designed by Soviet Union experts. In addition to factory buildings, they designed auxiliary facilities including a school, a hospital, a movie theater, a sports stadium, small shopping malls, and residential buildings to support a working community (Figure 4). There was also a hard-working culture created through “Work Emulation Campaigns”, activities that socially acknowledged the diligent workers from the community. Although the infrastructure has gone through changes over the years, the community identity as a working community was shaped from the very beginning. As part of the shared Guitang community, the children of the workers have gone to school together. A number of them got married to each other. The community-centric cultural norm has fostered trust, social linkages, and kinship [29,35,36]. These characteristics also contribute to shaping industrial symbiosis development in Guitang, as previous industrial symbiosis research has found that trust and social ties can be key factors in the emergence of industrial symbiosis [35,38,39].
- (2) *Transition from bureaucratic to technocratic organizational structure as a premise for innovation*: political economist Max Weber states that a bureaucratic organization possesses the following features: (1) Administration is carried out continuously instead of at the pleasure of any individual leader; (2) Tasks within the organization are divided into functionally distinct areas that require authorities and sanctions [40]. Based on this understanding, initial organizational structure of China’s state-owned enterprises, including Guitang, was largely bureaucratic. Bureaucracy could allow organizations to manage intensive administrative tasks and minimize uncertainties in decision making [41]. In Guitang’s case, adopting a bureaucratic management system likely helped to build structure and authority of a brand-new organization under the new-born nation’s institutional resource constraints [19]. While the centralized bureaucratic system reduces management complexity, the Guitang management became technically inclined particularly after the 1990s because of the increasing emphasis on production and efficiency internally [11,36].
- (3) *The Communist Party system as a critical management and social linkage*: similar to any state affiliated enterprise, the Guitang Group has a Communist Party Committee group in parallel with its management team (Figure A2). The Guitang Group Party Committee leads all sub-groups in the subsidiaries depending on the distribution of party members. It advises the management on decisions in all aspects and provides political and social leadership and serves as social ties. Specifically, the Party Committee is heavily involved in human resource management and ideological development of the Guitang Group [42]. The Party Committee not only serves the enterprise but also connects to the provincial and national party system through party meetings. The Party Committee at the Guitang Group has likely reinforced Guitang’s community identity as well as made new ties to other organizations nearby.



Figure 4. Guitang's community Soviet-style architecture: Movie Theatre (top) and Residential Building (bottom). Photo Copyright: Zhi Li, 2014.

3.2.3. Financial

The financial boundary of the Guitang Group has changed along with the management change of the organization. It went through three main stages of development—public, mixed-ownership with private shareholders holding the largest share, and mixed-ownership with public shareholders holding the largest share. Figure 5 provides a chronological operational summary of the changes. We note that during the period of the restructuring of the Guitang Group from approximately 1993–2001 the number of industrial symbiosis activities also increased.

Part of the restructuring illustrated in Figure 5 involves the establishment of the Guitang Co. Ltd. It was established as a subsidiary of the Guitang Group in 1998. Since then, it has been publicly traded in the Shenzhen Stock Exchange. From the very beginning, the Guitang Group has been the single largest shareholder (40% in 1998) of the Guitang Co. Ltd. with the second largest shareholder having no more than 5% ownership. From 1998 to 2011, the share held by the Guitang Group decreased to 26%. During this period, the Guitang Group went through a complicated ownership change. In 2001, the Guitang Group was sold to Shenzhen Huaqiang Holdings Ltd. (Shenzhen, China), an employee owned corporation previously owned by the Guangdong Province as part of the state-owned Assets Supervision and Administration Committee. In 2011, the Guitang Group was sold by the Shenzhen Huaqiang Holdings Ltd. through two intermediate investment subsidiaries back to the Guangdong Hengjian Investment (Guangzhou, China), which is fully owned by the Guangdong Province State-owned Assets Supervision and Administration Committee. Although the

Guitang Group is completely owned by the state, its subsidiary Guitang Co. Ltd. remains a hybrid public-private shareholder structure with more than 50,000 shareholders comprised of mostly private entities or individuals [30]. Figure 6 illustrates the ownership structure of the Guitang Group as of early 2014.

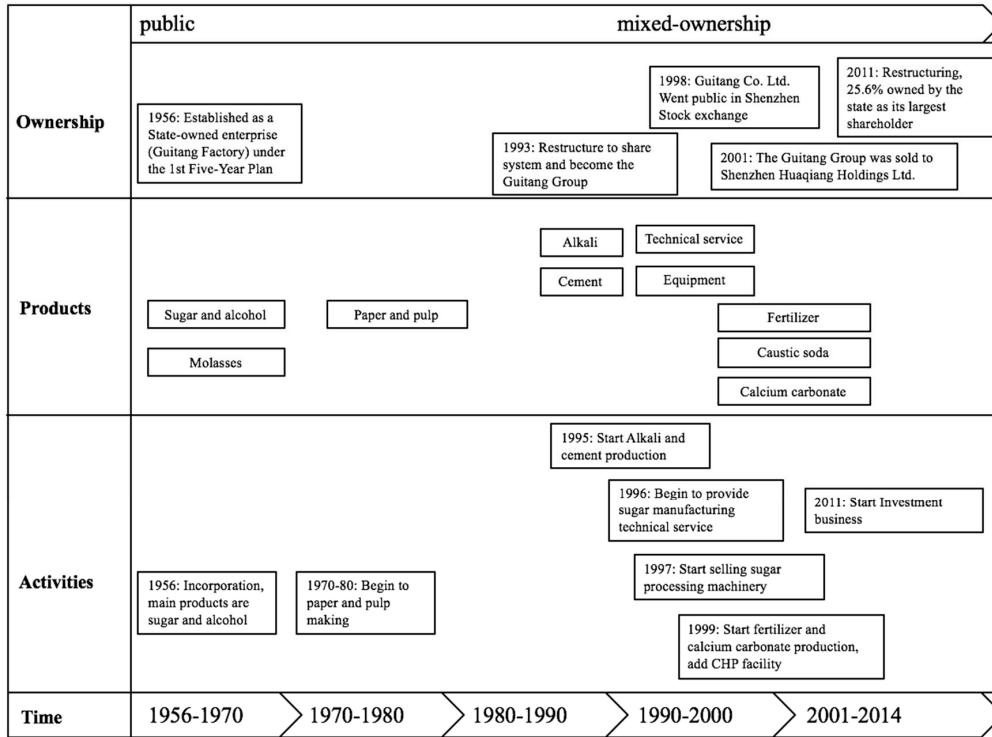


Figure 5. Summary of organizational and financial shifts of the Guitang Group [9–11,30].

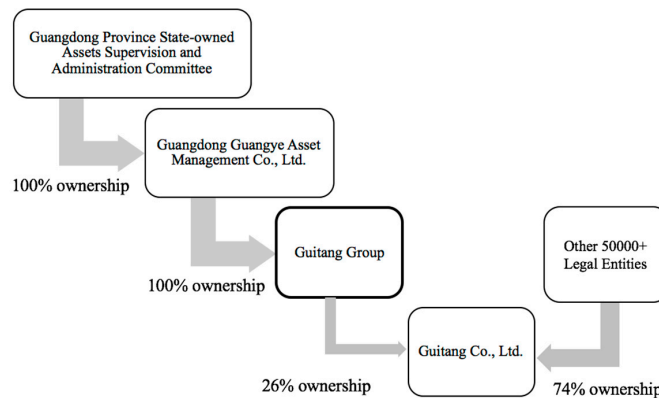


Figure 6. Current ownership structure of the Guitang Group [30].

3.3. Industrial Symbiosis Network Boundary Shift

3.3.1. Internal Symbiosis

Aside from the business boundary change, the industrial symbiosis network boundary at the Guitang Group has also shifted. We outlined the internal and external industrial symbiosis relationships within the Guitang Group in Figure 7.

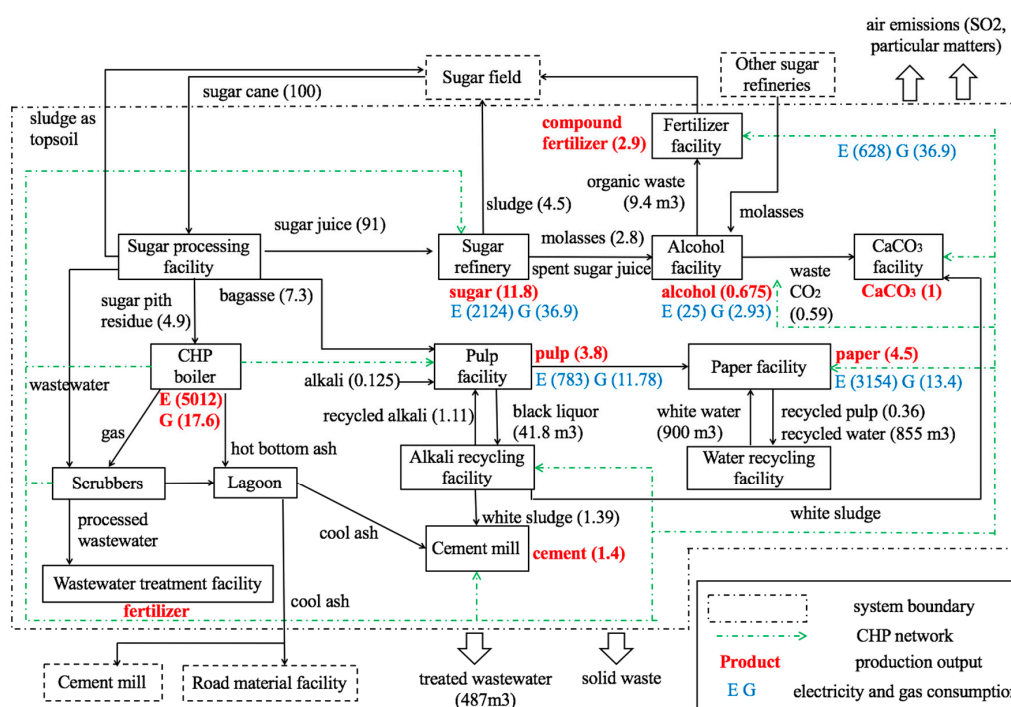


Figure 7. Material and energy flow within the Guitang Group after 1999, per 100 tons of sugarcane input; Unit: kWh for electricity, ton for materials including gas (data from Chen's work on Eco-Industrial Park Evaluation System and Case Studies) [9,43].

Currently, the Guitang Group has a well-established industrial symbiosis network that involves over 10 internal operations as well as additional ones beyond the property line. Most of sugar related by-products, including bagasse, molasses, pith, and sludge, are shared with other plants within the Guitang Group. The CHP power plant serves as the energy hub to supply the electricity and heat needed for the plants. In this section, we provide some quantitative assessments of the Guitang Group's industrial symbiosis network evolution, built upon previous analysis of its operational, management, and financial boundary shifts.

We include nine operations as network nodes. Some basic assumptions are made for simplicity: The Guitang Group's sugar processing and refinery are considered as one sugar operation; the three separate paper manufacturing facilities are considered as one paper operation; pollution-based facilities such as scrubbers, lagoons, and wastewater treatment plants are not included in the model. Based on the evolution outlined by historical facts, we summarized three time periods of the Guitang Group's industrial symbiosis evolution based on its development timeline.

Before the 1980s, the network only included sugar, alcohol, pulp, and paper operations. There were only two industrial symbiosis exchanges at the time: (1) waste molasses from sugar production was used as raw material for alcohol production, and (2) waste fibrous by-product from sugarcane was used as raw material for pulp and paper production. From the 1980s–90s, more operations including cement, fertilizer, calcium carbonate, and alkali production were added to the network. In 1999, a CHP unit partially sponsored by the United Nations Environment Program was installed to provide electricity and heat to the rest of the facilities within the network. By then, there were seven internal industrial symbiosis relationships in total. The five additional ones include: (1) the CHP facility using organic waste from sugar production as part of the fuel source for heat generation; (2) the alkali production using waste black liquor from pulp production to generate recycled alkali; (3) the fertilizer production using waste organic materials from alcohol production to produce organic fertilizer; (4) the calcium carbonate production using waste carbon dioxide from alcohol fermentation

process to produce calcium carbonate; and (5) the cement production use waste sludge and cool ash to manufacture cement.

We looked at some basic characteristics of Guitang's industrial symbiosis network including outdegree and betweenness. Outdegree measures the number of ties a node has going outward [44]. The outdegree of nodes shows that sugar and pulp operations have been active in sending out by-products since the very beginning. With the addition of other operations over time, CHP, alkali, and alcohol operations are also active in sending out by-products. Betweenness measures the number of times a node acts as a bridge along the shortest path between two other nodes [45]. Initially, pulp is the only operation that has high betweenness. As the industrial symbiosis network grows, alkali, alcohol, and CHP also become bridges of the network with high betweenness. It shows that these operations are central in the function of the industrial symbiosis network (Table A2).

Furthermore, we observe the changing roles of anchor tenants within industrial symbiosis networks. "Anchor tenant" refers to the operations that serve as the driver of the main material and energy flows of an industrial ecosystem [46]. While the sugar manufacturing chain serves as the anchor in the very beginning, other operations such as the pulp and paper units and CHP joined the network as additional anchors.

3.3.2. External Symbiosis

Aside from the seven internal symbiosis exchanges, the Guitang Group is involved in four external industrial symbiosis exchanges. Back in the 1950s, the Guitang Group refined sugar within its facility boundaries. Over time it created connections to external farmers, cement manufacturers, other sugar refineries, and road material manufacturers (Figure 7). It formed good relationships with the local farmers with long-term contracts and provided low-cost organic fertilizers to them. As the symbiotic network continues to expand, fertilizers of higher quality and greater quantity are manufactured through use of alcohol residue, sludge, or recycled cool ash and sold to the farmers [9]. The Guitang Group's alcohol plant requires more than 930,000 tons of molasses to run on full capacity for its 200,000-ton industrial alcohol production line. The waste molasses output within the Guitang Group, however, is limited to less than 70,000 tons. Since there are many other small sugar refineries within the Guangxi Province to supply over a million tons of waste molasses, the alcohol plant sources most of the waste molasses from them [11]. Similarly, the pulp and paper operations source bagasse input from sugar cane grown within a 600 km radius of Guigang [9]. The other series of external symbiosis is established through the CHP plant, which sends the coal ash to an external cement mill and road material manufacturers [11,43]. These external symbioses are significant because they show how the activities of the Guitang Group evolved from being all self-contained, to then crossing the company's organizational boundary as its use of resources expanded to numerous additional organizations in the manner of multiple-company industrial symbiosis [9,27].

3.4. Policy Context for Boundary Shift

3.4.1. R&D Investment and Innovation

Next, we analyze the Guitang Group's R&D activities under the leadership of a highly technical executive team and its Technology Center. In particular, we look into the internal-external exchanges of the Guitang Group and its relationship with upstream and downstream actors.

The Guitang Group's industrial symbiosis evolution is closely related to its R&D investment and activities around continuous innovation. During the 1930s Schumpeter was the first scholar to note that "innovation sets up a new production function" that carries out "New Combinations" [47]. Enos further defines innovation as "the combination of many different activities", which is made through obtaining capital, acquiring plant, hiring managers and workers, developing markets, and additional production and distribution" [48]. An economic perspective is provided by Mansfield that "innovation is the first commercial application of a new or improved process or product" [49].

In the 1980s, Mueser reviewed 350 papers and 100 books on the topic of innovation and came up with a consensus definition that innovation is “a new idea, a discontinuous technical event that, after a period of time, is developed to the point where it is practical and successfully used” [50]. The R&D activities of the Guitang Group illustrate the multi-faceted process of innovation with a diverse array of innovation activities (Table A3).

Shifts in management and financial boundaries contribute to an increasingly strong focus on R&D. After the 1993 restructuring, the Guitang Group added a Technology Center as a separate department. It was also the first of its kind in China’s sugar industry. The institutionalization of R&D has significantly improved the linkages from technology development to the market. Specifically, departments and their functions are designed to maximize the efficiency of the technology innovation process as the Technology Center team includes experts in science and technology, sales, production, market research, and social science (Table A4) [11].

Looking at the Guitang Group’s annual reports, the executive management team has been dominated by engineers who have strong technical backgrounds. Additionally, the total number of technical staff at the Guitang Group has increased from 244 in 1998 to 716 in 2006 with the significant addition of elementary and medium level technical staff [11,30]. The capital investment towards R&D significantly increased as well and counts towards a larger proportion of the total sales amount from 2% to 5%. There is a high correlation (0.97) between R&D investment and total sales, showing a significant positive relationship between the two metrics (Figure 8).

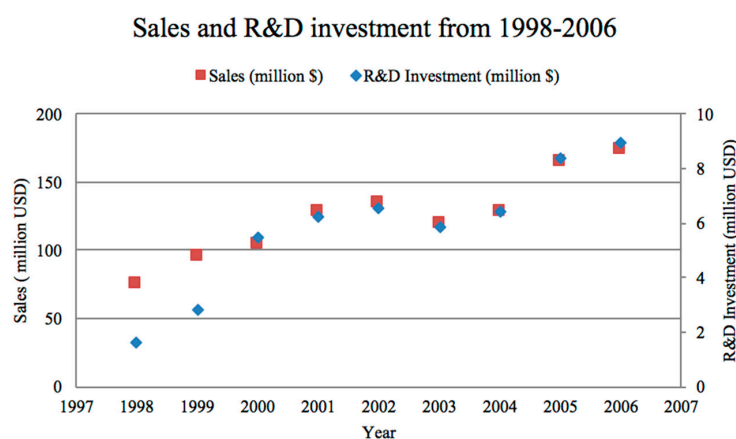


Figure 8. R&D investment and sales of the Guitang Group (1998–2006). Yuan to dollar conversion based on 2014 exchange rate [13].

Specific proportions of capital and human investment have been placed on reducing air, soil, and water pollution. As a result of the investment, the Guitang Group has made significant improvements in sharing and using by-products from various operations (Table A4). The use of by-products created significant economic value of over 90 million USD in 2004 [32]. The percentage of operating profit to sales has increased ten out of the eleven years from 2000 to 2011 (Figure A3).

3.4.2. Circular Economy and the Guigang Eco-Industrial Park (EIP)

In 2001, the State Environmental Protection Administration of China (SEPA) formally approved the Guigang Eco-Industrial Park (EIP) in the city of Guigang as the first EIP demonstration park in China. In the Guigang EIP, the Guitang Group is highlighted as a success story for other companies to follow [9]. The design plan of Guigang EIP states that the design and implementation of the Guigang EIP exemplifies principles of the Circular Economy and considers material flows across the firm, regional, and national levels [51]. The Plan tries to simulate the “Producer-Consumer-Decomposer” network in an ecological system and focuses on six main aspects related to the existing symbiosis relationships: (1) sugar fields; (2) sugar manufacturing; (3) alcohol manufacturing; (4) paper

manufacturing; (5) CHP; (6) comprehensive waste processing system. The Plan proposes investing in 11 R&D projects tackling the six symbiotic elements. It actively applies principles of industrial ecology and pays attention to 'stock' and 'flow' relationships.

Aside from operations, the Plan includes policies related to financing, tax, investment, and pollution fees as a means of providing a support system for by-product sharing. It encourages merger and acquisition activities by the Guitang Group, including the acquisition of two bankrupt state-owned sugar refining facilities. On the supply chain management side, the Plan establishes benefit sharing and pricing transparency between sugar cane farmers and the companies within the Guitang Group. It establishes a worker's cooperative as an approach to organize dispersed sugar cane farmers, bringing more bargaining power and benefits to them [51]. The outcome of the Guigang EIP development is considered positive. Chen completed a comprehensive evaluation of the Guigang EIP, which includes the Guitang Group, based on Chinese standards and ecological principles in 2007. It is noted that the evolution of the Guigang EIP is progressing towards a more comprehensive development path by improving on the structure and functionality of the EIP [43].

4. Discussions and Conclusions

Tracing the changes at the Guitang Group over many years, we have reconstructed the narrative of its industrial symbiosis evolution, considered the forces that are involved in the enabling context, and characterized the Guitang Group's industrial symbiosis evolution primarily as the dynamic labeled *organizational boundary change*. To conclude, we offer the following observations.

4.1. Enabling Context

Understanding the social and institutional context is critical in uncovering the evolution of industrial symbiosis. In the case of the Guitang Group, the unique historical legacy along with institutional facilitation helped build the social network and community at Guitang. Community connections likely contributed to the industrial symbiosis network evolution. The initial forms of symbiosis may have been facilitated through the informal social capital forged through the community-centric culture shaped by Soviet-style architecture and worker management, while the increasing emphasis on technology and productivity since the 1990s spurred the expansion of symbiosis.

The operational shifts of the Guitang Group were influenced by the state's political and economic emphasis during different time periods. The financial boundary shifts exemplify the nested impact of institutions, where there are tensions between the central and local institutions, as well as between various local institutions. The multiple ownership shifts of the Guitang Group reflected the power dynamics among institutions. Because China went through sporadic periods of rapid social changes after the establishment of the new state, we notice a cyclical interplay between the state and provincial institutions and organizations. The ownership shifts of the Guitang Group from public to semi-private, and back to mostly public serve as a good example. These changes have brought merits as well as potential challenges to the Guitang Group's development. On one hand, rapid organizational changes could bring new ideas, management practices, and information transparency, as shown by the Guitang Group's rapid industrial symbiosis development after changing its shareholder structure and information as disclosed through annual reports. On the other hand, it has the risk of disrupting existing social connections and business practices.

The establishment of the Guigang EIP was an active effort by the Chinese state to create an institution that acts as a linkage between state institutions and industrial organizations. It has contributed to the collective knowledge of Circular Economy by designing specific policies and applications that allow waste and materials to be exchanged. As the first pilot out of over 100 EIPs in China, the impact of the Guigang EIP is substantial. We need to acknowledge, however, that the creation of an institution requires time and incremental adjustments. Lowe notes that the Guigang EIP

boundary is not very clear. Instead of a defined park, it acts as a regional initiative collectively led by the local administration and the enterprise partners [52].

4.2. Comparative Analysis

The evolution of industrial symbiosis at the Guitang Group can serve as a good reference point to compare sugar-based industrial symbiosis at other locations. Here we begin the comparison of the Guitang Group with three other sugar-based operations: the Nanning Sugar Company in China, the Nanjangud Sugar Refinery in India, and British Sugar in the U.K. Guitang, Nanning Sugar, and Nanjangud Sugar use cane sugar as the feedstock whereas British Sugar uses beets. We summarize the major by-products and uses of sugar-based industrial symbiosis in Table 1. We note that: (1) the sugar manufacturing processes vary owing to differences in feedstock and manufacturing technology; (2) most sugar based industrial symbiosis reuses soil/sludge in the cleaning and purification process; (3) pulp and bagasse are also actively reused for animal feed or pulp and paper making; (4) for sugarcane-based production, molasses are recycled for alcohol production. While the Guitang Group and Nanjangud Sugar Refinery have larger industrial symbiosis networks that involve more industries, British Sugar includes more high value-added products such as betaine and raffinane, which are chemicals extracted and put to use in cosmetics and beverage production. It also explains a much higher profit percentage of British Sugar compared to the Guitang Group. In addition, British Sugar has made innovative links back to agricultural processes and uses waste heat for tomato production [27].

Table 1. Major by-products and use of sugar based industrial symbiosis.

Manufacturing Process	Guitang Group (China)	Nanning Sugar Co. (China)	Nanjangud (India)	British Sugar (the UK)
	By-Products Use			
Sampling & cleaning	Soil mix → topsoil	Sludge → fertilizer	Organic material → Compost	Soil mix → topsoil and aggregate
Slicing & diffusion & squeezing	Bagasse → pulp and paper production; CHP feed	Bagasse → pulp production		Pulp → animal feed
Purification	Sludge/mud → cement mill; Waste CaCO ₃ → CaCO ₃ production	Wet ash → sale; Coal ash → concrete hollow blocks; Stone residue → paving; Dry ash → sale	Press mud → alcohol production	Precipitate → lime
Evaporation	Heat → CHP	Steam → craft water tank for reuse		Heat → tomato horticulture
Sugar cooking & molasses separation	Molasses → sale; Molasses → alcohol production	Molasses → alcohol production	Molasses → sale; Molasses → alcohol production	
Crystallization & centrifugation				Residual resin → betaine, raffinane
Sugar storage				Feed → vinasse, bioethanol, and liquefied CO ₂ through fermentation and distillation

5. Recommendations for Further Research

This exploratory analysis is part of a greater effort to improve knowledge of industrial symbiosis evolution. During the uncovering process, we observed that there may be several industrial symbiosis dynamics co-existing within the Guitang Group. In addition to organizational boundary change, we saw the dynamic labeled “pilot facilitation” at play, as new lines were added to the overall production facility [4]. To understand this more fully, we recommend conducting interviews and aggregating details of each symbiotic activity. Additionally, it would be useful to combine the institutional context with the impact of global trade and enterprise development. While emphasis on cleaner production and industrial symbiosis plays a significant role in the Guitang Group’s development, it has also suffered from international competition and the booming black market

in sugar [9] (Figure A3). The other aspect to explore is the similar organizational behaviors among international corporations having a similar size and structure as the Guitang Group suggesting that the bureaucratization of enterprise governance transcends national boundaries [19]. Finally, we recommend a more detailed comparative study of the industrial symbiosis characteristics in sugar refining in China, India, and the UK, as well as exploring possible industrial symbiosis practices in other countries with large sugar production including Thailand, Brazil, Australia, and the Sudan.

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Appendix



Figure A1. Location of the Guitang Group (denoted by the star). Source: National Geographic Mapmaker.

Table A1. Industrial product output comparison between China, the U.S. and India in 1949.

Product	Unit	China	U.S.	India
Sugar	metric tons	200,000	1,990,000	1,180,000
Coal	metric tons	3200	43,600	3200
Electricity	GWh	4300	345,100	4900
Oil	metric tons	120,000	248,920,000	250,000
Cement	metric tons	660,000	35,940,000	2,140,000
Soda	metric tons	88,000	3,550,000	18,000
Caustic soda	metric tons	15,000	2,020,000	6000

Source: Yale University Library Digital Economic Database.

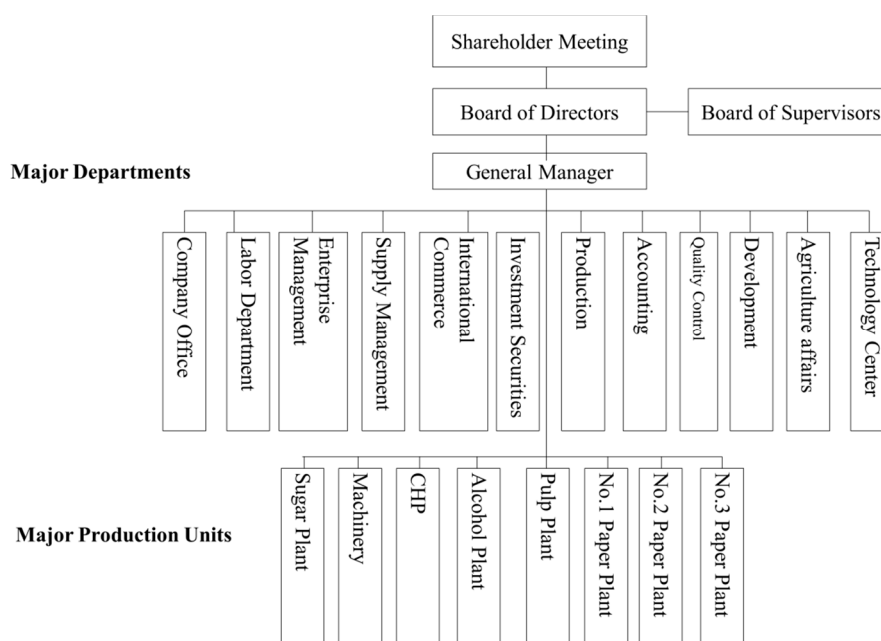


Figure A2. The Guitang Group's management structure after 1993 shareholder reform.

Table A2. Characteristics of the Guitang Group Industrial Symbiosis Network. **Outdegree** measures the number of ties a node has going outward [44]. **Betweenness** measures the number of times a node acts as a bridge along the shortest path between two other nodes [45].

Plant Name	Outdegree			Betweenness		
	Pre-1980	1980s-1990	After 1999	Pre-1980	1980s-1990	After 1999
1: Sugar	2	2	3	0	0	0
2: Pulp	1	2	2	1	4	2
3: Paper	0	0	0	0	0	0
4: Alcohol	0	2	2	0	2	1
5: Cement		0	0		0	0
6: Fertilizer		0	0		0	0
7: Calcium Carbonate		0	0		0	0
8: Alkali		3	3		3	2
9: CHP			8			3

Table A3. The Guitang Group by-product use from 2002 to 2004 (From the Guitang Group Clean Production Audit Reports) [10].

Year	By-product Use Amount (Ton/Year)					Total Economic Value ¹	
	Sludge	Sugar Residue	Molasses	Coal Ash	Pith	Yuan (1000s)	USD (1000s)
2002	42,741	127,578	39,100	139,296	119,525	405,390	48,978
2003	57,169	157,540	41,389	113,505	159,560	504,420	60,942
2004	38,122	175,024	26,686	142,887	97,174	579,300	69,991

¹ Contemporary yearly average exchange rate used. Inflation not counted for simplicity.

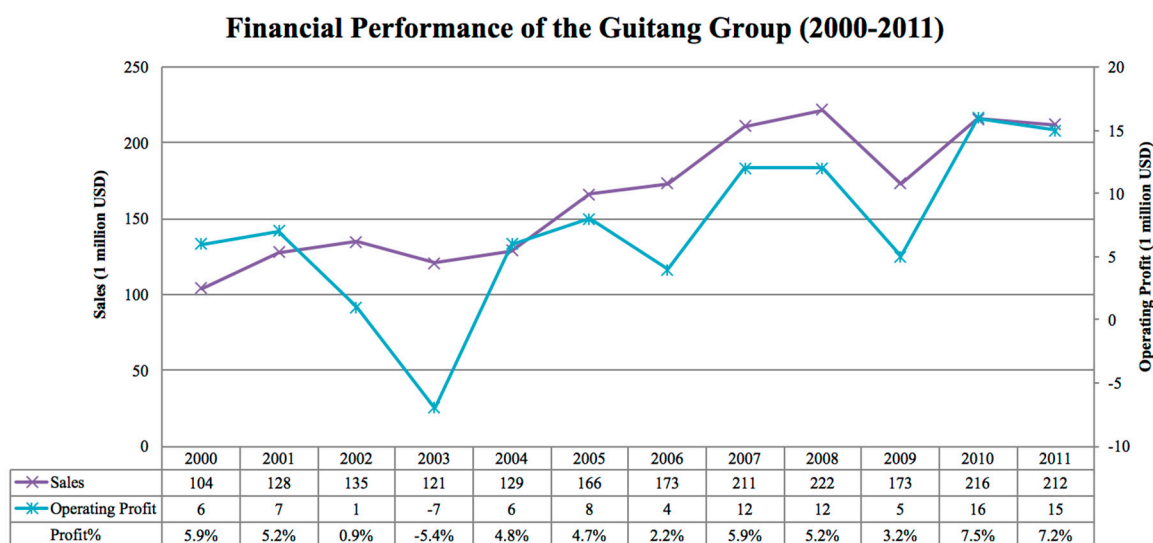


Figure A3. Financial performance of the Guitang Group from 2000 to 2011 [30].

Table A4. Motivations for innovation activities at the Guitang Group [41].

Time	Activity	Motivations
1956	Use sugar cane residue for fuel	Save fuel cost
1970–1980	Use waste sugar for alcohol	Improve cost margin, reduce waste
	Use sugar cane residue for papermaking	Improve cost margin, reduce waste
1995	Reuse alkali	Environmental law, technology improvements
1996	Water reuse	Environmental law, technology improvements (patent)
1999	Use waste alcohol for fertilizer production	Environmental law, cost margin
1999	Sludge used for free fertilizer for farmers	Environmental law
	Alkali used for Calcium Carbonate	Environmental law, cost margin
	Use sugar cane residue for CHP	UNEP fund, technology improvements
	Reuse alcohol water	Reduce water use
	Reuse alkali processing water for CHP	Environmental law, reduce water use, reduce cost
2001	Provide sugar cane residue and molasses residue to nearby plants	EIP policy

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