Ecological Supply Chain Based on By-Product Exchange

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Abstract—**In this paper, the concept and primary design principles of ecological supply chain (ESC) are discussed. And the paper shows that companies can gain economical, social and environmental efficiencies simultaneously from implementing ecological supply chain management (ESCM). The cooperation processing based on by-product exchange in ESC is discussed with the decision-making criterion of eco-efficiency maximization. Accordingly, a pricing model is given. A case study of Guangxi Guitang Group is analyzed at last, which shows the multi-win brought by ESCM.**

Key Words—Ecological Supply Chain; Ecological Design; By-product Exchange; Eco-efficiency

I. INTRODUCTION

Environmental management is more and more important for manufacturers as they face intense scrutiny from diverse stakeholder groups. Firms have to struggle for conflicting objectives: pursuing profit, complying with current regulations, and attending to various legal constraints associated with environmental protection strategies. Though researchers have created some new solutions to reconcile prosperity with environmental protection, they have not put enough attentions to by-product utilization generated during the production processing. Many manufacturers just released them after primary treatment, which causes environmental deterioration and resource waste, as dealing with by-product from a firm-level means much investment and low benefit,.

With the increasing awareness of the need to be eco-friendly at all levels, ecological supply chain (ESC) is proposed to balance efforts to reduce cost and innovate while maintaining good ecological performance (Lenny Koh, *et al.*, 2007). All the wastes discharged in the whole process of ESC are recycled to maximize economical, social and environmental efficiencies. It includes tasks referring to the product utilization phase, to by-product reusing phase and to the end-of-life phase. Ecological supply chain management optimizes forward and reverse supply chain from the view of the whole society. It can solidify the environmental impacts of economical activities within the design phase and improve operational performance objectives such as quality, reliability and volume flexibility (Gonzalez-Benito & Gonzalez-Benito, 2005). Ecological design, the core part of ESC, could transfer one-way economy represented by traditional supply chain into closed-loop economy represented by ESC.

External Diseconomy in resource utilization leads to the conflict between the thought of optimizing eco-efficiency and the behavior of maximizing economical benefit for traditionally economic man. Thus, economic man should become "ecological-economic man" whose behavior criterion is eco-efficiency maximization. According to the above premise, the author analyzes the decision-making process of by-product exchange and pricing strategies. Some companies, such as Samsung and LG, have adopted ESCM for sustainable development. Their assertive approach toward the environment has not only helped them to reap the benefits, but also make them comply with the cumbersome current legislation and anticipate necessary changes to cope with future legal environmental standards. A case study of Guangxi Guitang Group proves the above argument.

This paper is divided as follows: In section 2 we review the concept of ESC and ecological design. Primary ecological design principles are given. The benefits of implementing ESC are discussed in section 3, which are also the drivers of ESC. Next, the cooperation process of by-product exchange is studied by game theory and a pricing model is described. A case study of Guangxi Guitang Group is analyzed in section 5.

II. THE CONCEPT OF ECOLOGICAL SUPPLY CHAIN AND DESIGN PRINCIPLES

2.1 The concept of ecological supply chain

The focus on environmental management has moved from local optimization of environmental factors to consideration of the entire supply chain during the production, consumption, customer service and post-disposal disposition of products. In order to meeting the environmental challenges, traditional supply chain has to be re-designed to close material cycles and prevent the leakage of materials in the whole chain, especially in the production process. Note that the outputs of the production process not only conclude main products with a substantial value, but also consist of something produced unintentionally with a modest positive value or a negative value. Therefore, companies have to integrate issues and flows that extend beyond the core of supply chain management, such as manufacturing by-product and by-product produced during product use. Since reverse supply chain and green supply chain do not provide comprehensive solutions to dealing with all the outputs, ESC is proposed to take full advantage of products

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with a high or modest positive value, while transforming the non-desired into the desired and reducing materials with a negative value. ESC is the process of efficiently and effectively planning, implementing and controlling the flow of material and information flow in the whole supply chain, to maximize eco-efficiency by use of industry ecological thoughts. All the energy, material and information in the chain could be recycled like the natural ecosystem, so that the objects of “zero-pollution” and “zero emission” can be achieved. The supply chain can be identified as an ESC when realizing ecological logistics, which is a system in the supply chain where enterprises are collaboratively using environmentally friendly materials in production and transportation, which aims to minimize hazardous waste from the logistical operations (Koh, *et al*., 2005). Ecological supply chain management aims to create the greatest possible value along the entire supply chain from a multi-win perspective, and resolve the tradeoff between efficiency and effectiveness in environmental management. Ecological supply chain analysis is a pragmatic and credible means for analyzing, mapping, and managing environmental impacts along supply chains (Adam C., *et al*., 2001). The material flow of ESC could be described as Figure 1.

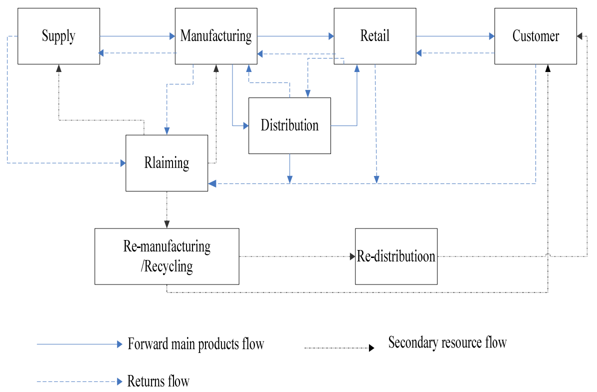

Fig.1 Ecological supply chain

It takes the entire life cycle of a product into account, from the extraction of raw materials and energy, to the consumption of products and the eventual dumping of waste, to minimize the negative environmental effects. In such a closed-loop system, not only product could be used by the down stream firm, but waste can be reused as useful material by the down stream firm or itself. The business relationships of all actors in ESC represent in product and by-product dealing. There is no difference between material and waster since both can be used fully in an ideal state or reused by other firms and then discharged harmlessly in a non-ideal state.

2.2The design principles of ESC

Ecological design is a systematic application of environmental life cycle considerations at the product development and design stage, to avoid or minimize significant environmental impacts at all stages of the life cycle of a product. As the core of ESC, the perfect degree of ecological design conception has a direct relation with the realization of multi-win goals. There are two primary design principles: (1) Economical benefit would be ensured first and foremost. Business profit is the base of existence and development of firms, as well as the original drive for developing new product and improving technology and management level. (2)Economical benefit can not be got on the sacrifice of social and environmental efficiency which are the base for firms to gain long-term economical efficiency. Sometimes, we have to scarify temporary economical efficiency for a sustainable development.

Ecological design is composed of two parts. One is the design of ESC, which optimization methods and environmental assessment instruments could be used to select a project of optimizing economic and environmental performance. The other is the design of the elements of ESC. The principles for designing the elements of ESC are as follows: 1) Product design. Designers not only consider product performance to satisfy demand and preference of customer, but also take into account the effect of design details on energy/material requirements for manufacturing and use, secondary use and by-product reuse. Company should use accounting systems that account for the full life-cycle cost of product or service and the environmental impacts it creates. Modularity and standardization also improves opportunities for repair and (cross-supply chain) reuse of components and materials. Also, suppliers may co-design the product to enable modularization and design for recycling. 2) Procurement. Purchase includes two parts: one is selection of raw material which has the least impact on the environment both in origin and use, the other is selection of environmentally friendly suppliers. Nontoxic, degradable, reused materials with a high recycling rate should be preferred. Where possible environmentally safer substitutes should be used and primary raw materials should be used only in cases where there would be no stock of secondary ones. Whether supplier is environmentally friendly is also important to manufacturer, so suppliers should be included into environmental management system (EMS). 3) Production. The identification of where great amounts energy is used could subsequently lead to redesign of the product or its use in order to make significant energy reductions. Installed water-saving techniques and the use of closed re-circulating systems can lead to reduction of water consumption. With a technical reorganization, materials formerly ended as wastes are turned into useful by-products. The wasting of materials and energy either due to inappropriate design, or due to excessive number of defects should be avoided. To replace non-renewable and polluting technologies, it is crucial to use eco-friendly energy. The elimination of the stochastic factors, which affect pollution, may lead to greener production. Sustainable production is preferred. 4) Marketing. A green marketing approach in the product area is the integration of environmental issues into all aspects of the corporation's activities, from strategy formulation, planning, construction through production and into dealings with consumers. Developing of ecological marketing effectively request firms to green 4P’s: designing green product, setting green price, developing green channel and green marketing. Enhancing product function, establishing product update policies and extending service at usage phase could improve eco-efficiency. Firms also would mark products with recycling symbols and reprocessing codes, and motivate customers to maximize return volume. Ecological marketing is also related to the selection of goods package according to the rule of"3R1D" (Reduce, Reuse, Recycle, Degradable) and limiting packaging to the necessary size. 5) Distribution and forward logistics. Ecological impacts are considered in distribution processing and loading-unloading. Environmental-friendly measurement is one of important logistics performance evaluation indexes. Effective and efficient transportation and storage mode should be adopted according to product type, with a view to energy consumption and environment pollution. Negatively environmental effects of warehouse system would be reduced, such as equipment noise, soot pollution, soil pollution. 6) Collection and reverse logistics. Firstly, companies would formulate a policy for the recovery of used products, offer waste disposal services and optimize collection network according to returns quality and collection rate. Companies could establish cooperation via local or more extended networks for the collection and recycling of similar products, or consider using existing forward supply chain facilities and transportation system as much as possible for the reverse supply chain. Secondly, collector should classify used products as early in the recovery chain as possible. In the recovery of used products, non-pollution technologies should be adopted. Note that second pollution should be avoided as by-products are difficult to store and transport. Third, the supply loop should be closed by recycling effectively and efficiently .The volume and amount of materials going to landfill should be reduce considering alternative uses of used products or wastes.

III. Benefits of ESC

Among many factors contributing to ESC practices, the primary ones are economical, social and environmental efficiencies.

3.1 Economical benefits

Even though ESC is proposed primarily based on environmental and social considerations, studies have shown that a number of economic benefits and added-value can arise from different aspects. (1) Decreases cost. Building recycling networks between companies could reduce waste treatment and disposal costs, gain access to cheaper materials and energy, and to generate income from residues (Desrochers, 2004). Firm also can escape stern punishment brought by the increasing execution degree of environment laws. (2) Creates a green image. The companies in ESC would be looked as environmental friendly, responsible, involved with community, and ecologically active. With increased awareness and means of communication, customer satisfaction and loyalty also depend on how the company has produced the goods or services, whether the company considering the social, environmental and other such aspects. A green image can improve both the sales and the value of the company (its brand goodwill). It is obvious that green product make firm get differential advantage, avoid intense price war and develop new market. (3) Improves competitive advantages. The adoption of eco-efficient manufacturing methods creates the possibility of more flexible plant configuration, enhanced productivity and credibility in business relationships, new organizational capabilities that have contributed to the appearance of advantages (Enrique Claver, 2006). It also enables the creation of international competitiveness at the global level. Companies can lower their exposure to risks, such as resource scarcity, and/or reduce their dependence on limited/non-renewable resources. And manufacturer can focus on the company core business when they empower their eco-partner in the collection process or sell their by-products to them. Certainly, a "green" firm can get the support of government by tax reduction or financial bonus.

3.2 Social efficiency

ESC makes for human society sustainable development, which add values to entire society and sets up correct expense view. (1)Ecological design may reduce harmful components of product so as to avoid consumer endangered at the process of consumption. By carrying out clean production and by-product exchange, enterprises can reduce largely the emission of wastes, consequently create a depurated working environment for employees, maintain clean environment for communities. (2) Recovery of used products lessens the social burden of treating lot of wastes, the external diseconomy of environment. ESCM make competitive ability of firm stronger, which can benefit to investors and create more job opportunities, resulting to prompt the development of local economy. Government also can benefit by increasing revenue. (3)Deficiency of water resource would be lessened since industrial waste water reuse can decrease the demand of water.

3.3 Environmental efficiency

Recovery of used products for recycling or reuse, may bring a major reduction in environmental impact along the whole supply chain. By-product exchange can recycle materials in a wider scope. Diversified energy usage has a positive relation with environment protection and energy conservation. As a result, "green effect" is lessened. For example, a power plant in Finland improved utilization efficiency from 40% to 85% by by-product exchange. According to statistic data from Bureau of Environmental Protection of U.S, waste steel used as the replacement of iron ore in steel-making can decrease almost 70% of energy consumption and 86% of waste gas emission.

IV. MODELS INTRODUCED

4.1 By-product exchange in ESC

Rapid economical development causes high resource-consumption index and big pollutant discharge amount, especially in China. Though Chinese government and enterprises make efforts to improve resource utilization, the ratio of the utilized industrial solid wastes is still 60.2%, and the output value of products made from waste gas, waste water and solid wastes is only 1026.8 (100 million RMB).

These wastes inevitably result to serious conflicts between economic development and environmental performance. Conventional end-of-pipe waste treatment is not attractive to enterprises due to high investment, long period of return, and consequent low financial benefit. Companies that seek new path for a sustainable development begin to foster network among business to improve resource utilization by by-product exchange and plan of ecological efficient energy cascades. By-product has a value less than that of the original raw material, even with a negative value, such as the process wastes, so that one has to pay for the disposal of these materials. But further processing of these residues can increase their value in some cases, such as in the case of composting or methane production. By-product reusing could reduce the use of virgin materials as resource inputs and the volume of waste products requiring disposal (with the added benefit of preventing disposal related pollution), increase energy efficiency and the amount and types of process outputs that have market value. However, traditional by-product exchange network lack of flexibility, which makes companies using other's residual products face some risks, such as uneven quality and quantity. In addition, when firms are "economic man", whether by-product exchange would be made is mostly decided by the price and cost of by-product, especially when buyers have normal resource to replace. Only both provider and demander could get some economical benefits from the exchange, could the deal be made.

However, success probability of the deal is much increased in ESC. ESC provides a more flexible and close network which could reduce these risks and offer the opportunities to small-to-mid-size companies for by-product exchange. And firms in the ESC are "ecological-economic man" whose behavioral criterion is eco-efficiency maximization, not only economical benefits maximization, which also facilitates the occurrence of by-product exchange.

4.2 Models

The cooperation process and pricing strategies of two firms aiming to maximize eco-efficiency are discussed here. Eco-efficiency proposed by the World Business Council for Sustainable Development (WBCSD) is adopted as the decision-making criteria. Environmental burden indicator I represents environmental influence here.

$$\text{Eco - } efficiency = \frac{\text{Procuct / sevice value}}{\text{Enviromental influence}} = \frac{\Sigma \Pi_i}{I}$$

There are two firms in the model: one is an upstream manufacturer M, the other is a downstream reclaiming agent D which would purchase by-product as its material or sell to others after processing. We give the following basic assumptions to set up the model: (1) Firm M with a profit Π_p from his main product, has three strategies to choose: *Strategy 1*:investing much capital to transform by-product into fully harmless material, which would have a highest process cost C_{m1} but get a reward from government Π_g and a benefit U_{m1} from recycling materials; *Strategy 2*: processing by-product to make it satisfy material standard of the downstream reclaiming agent, which would need a medium cost C_{m2} ,but gain a reward Π_g from government and a profit U_{m2} from the exchange; *Strategy3*: discharging by-product after primary process which will pollute environment, certainly can cause a penalty P_g from government but a lowest disposal cost C_{m3} . (2)the downstream reclaiming agent D has two acceptable strategies: *Tactic 1*:accepting the offer of M, which would cause a purchase cost C_{d1} and a processing cost C_{d1}' , but get a reward π_g from government and a profit U_d from his product; *Tactic 2*: rejecting the offer and purchasing normal materials, which could have a normal cost C_{d2} and a profit U_d from his product. We could get strategy portfolio showed in Table 1. We also could describe the game utility matrix of two firms in Table 2 while considering the following notations:

Tab.1 Game strategy groups of the manufacturer and the collection agent

The manufacturer M				
The reclaiming agent D		Harmless process	Offer	Primary process
	Accept	(Accept, Harmless process)	(Accept, Offer)	(Accept, Primary process)
	Reject	(Reject, Harmless process)	(Reject, Offer)	(Reject, Primary process)

Tab.2 Game benefit matrix of the manufacturer and the collection agent

The manufacturer M				
The reclaiming agent D		Harmless process	Offer	Primary process
	Accept	(E_{d1}, E_{m1})	(E_{d1}, E_{m2})	(E_{d1} , E_{m3})
	Reject	(E_{d2}, E_{m1})	(E_{d2}, E_{m2})	(E_{d2} , E_{m3})

(1) E_{m1}, E_{m2} , E_{m3} and I_{m1} , I_{m2} , I_{m3} are the eco-efficiency and environmental burden indicators of M when choosing *Strategy 1, Strategy 2, Strategy 3* separately.

(2) E_{d1} , E_{d2} and I_{d1} , I_{d2} is eco-efficiency and environmental burden indicators of D when selecting *Tactic 1, Tactic 2* separately.

(3) $I_{m1} < I_{m2} < I_{m3}$, as fully harmless processing could lead to least environmental pollution, and primary processing would cause most environmental damage comparatively.

(4) All the utilities of two firms in different strategies can be expressed as:

$$E_{m1} = \frac{\Pi_p + \Pi_g + U_{m1} - C_{m1}}{I_{m1}} \tag{4.1}$$

$$E_{m2} = \frac{\Pi_p + \Pi_g + U_{m2} - C_{m2}}{I_{m2}} \tag{4.2}$$

$$E_{m3} = \frac{\Pi_p - C_{m3} - P_g}{I_{m3}} \tag{4.3}$$

$$E_{d1} = \frac{U_d + \pi_g - C_{d1} - C_{d1}'}{I_{d1}} \tag{4.4}$$

$$E_{d2} = \frac{U_d - C_{d2}}{I_{d2}} \tag{4.5}$$

As an ecological-economical man pursuing eco-efficiency maximization, we can get conclusions as follows: 1) If $E_{m1} > E_{m2} > E_{m3}$, M prefers *Strategy 1*, which means M has advanced technologies to recycle the by-product with a low cost and the by-product has not more value to others, such as industrial waste water. However it is only suitable for few by-products. 2) If $E_{m3} > E_{m2} > E_{m1}$, *Strategy 3* is preferred, which means the processing cost is very high and government penalty is not enough high to prevent such irresponsible disposal. In this state, companies should make effort to find effective methods to reduce the processing cost, such as developing new technologies under the help of scientific and research institutes, getting the favor of non-benefit alliances or other social organizations. In addition, government should give enough support to the positive processing and penalty to irresponsible discharge. Sometimes, relative regulation should be constituted and some high resource consumption factories have to be ended. 3) If $E_{m2} > E_{m1} > E_{m3}$, when by-product has a residual value to be reused by other firms and M has no enough capital or intention to recycle it by itself, such a strategy is attractive. Many by-products belong to such a typology. However, by-products often have to process before reusing and are difficult to transport and store. Hence, only if $E_{d1} > E_{d2}$, D would consider the offer. If $E_{d1} < E_{d2}$, M should reorganize his production flow or use other materials to increase the value of by-product. Certainly, government should increase the rewards to such green users.

Now we have the conditions of cooperation which can maximize the total eco-efficiency of supplier and users: $E_{m2} > E_{m1} > E_{m3}$ and $E_{d1} > E_{d2}$. An optimal price, which can realize the cooperation, is needed now. Unfortunately, the negotiation is generally with incomplete information, so M cannot know the bottom line to D from the condition $E_{d1} > E_{d2}$. Hence, we discuss the price set by M under the condition that M only knows the decision-making typology of D . To simplify the analysis, we set: (1) $I_{d1} = I_{d2} = 1 < I_{s2} < I_{s3}$ (2) P_r is the acceptable price for D, but M only know the probability distribution of P_r which obeys the uniform distribution of $[0, p_r]$, and not know the definite value of P_r. (3) the order quantity is a constant value Q. (4) P_m is the price offered by M .(5) ρ is the probability of D accepts P_m .

According to the above, M could gain a benefit from the by-product exchange:

$$\Phi_m = E_{Em2} - E_{m1} = \frac{\Pi_p + \Pi_g + P_m * Q - C_{m2}}{I_{m2}} - \frac{\Pi_p - C_{m3} - P_g}{I_{m3}} \quad (4.6)$$

We also could get the estimated maximizing utility of M:

$$\Phi^* = \max\left[\Phi_m \times \rho + 0 \times (1-\rho)\right] \quad (4.7)$$

From (4.6) and (4.7), we can get the optimal price P_m^*:

$$P_m^* = \frac{P_r}{2} - \frac{\Pi_p + \Pi_g - C_{m2}}{2Q} + \frac{I_{m2}(\Pi_p - C_{m3} - P_g)}{2QI_{m3}} \quad (4.8)$$

From (4.8) we can conclude that: (1) P_m^* is affected by $\frac{I_{m2}}{I_{m3}}$, Π_g and P_g . It means that governmental attitudes to environmental pollution play an import role in facilitate by-product exchange. If the government has a sturdy attitude on environmental protection and increases the bonus and penalty to firms, P_m^* would decrease. A lower price can give more benefits to the downstream reclaiming agents, and strengthen their reusing motivation. (2) P_m^* is also related with C_{m2} and P_r . If the manufacturers resign their product and production processing, adopt advanced technologies to reduce the processing cost C_{m2} and increase the residual value of by-product, they can improve the price P_m^*. The profit what the gain would exceed these cost in the long run. At the same time, companies could resolve the conflict between economical efficiency and environmental, social efficiency. Besides, companies in the some industry also could work together to develop environmental protection technology.

V. CASE STUDY

Guangxi Guitang Group (Guitang) is the largest sugar-making company in China which has several other industrial enterprises, such as a pulp-making plant, an alcohol plant, a cement mill and a fertilizer plant. All these plants are based on by-products generated from the sugar refinery.

5.1 The ecological supply chain of Guitang

To reduce resource consumption and environmental pollution, a sugar ESC based on Guitang is established to recycle these industrial wastes and returns from the end of pipe. Initially, the ESC was built within Guitang and slowly extended to external firms. Now it consists of an agriculturally ecological farm, a sugar refinery, sugar distributors and retailers and other firms acting as reclaiming agents. Reclaiming agents include an alcohol-processing plant, a compound-fertilizer plant, a pulp plant, a thermoelectricity plant, a cement mill and other recyclers. The Figure 2 shows three main flows in the ESC model of Guitang: ①the forward product flow from sugarcane farmers to end users; ② the reverse supply chain from customers to suppliers, in which some returns from consumers are processed within the sugar refinery, some useless wastes are send to recyclers, such as water recovering plant; ③ the by-product flow from sugar refinery to reclaiming agents, in which the by-products from the sugar refinery are reused.

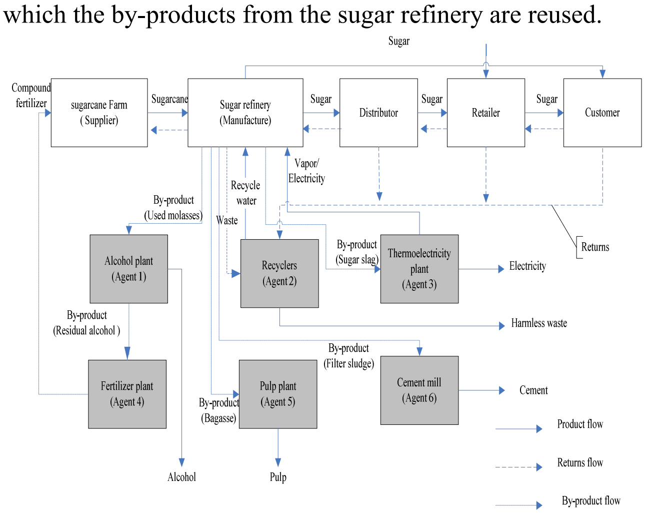

Fig.2 ESC of Guangxi Guitang Group

5.2 The ecological supply chain management of Guitang

To optimize the environmental and economic performance of the whole network, Guitang complied with the ecological design principles to develop new technologies, optimize the production processing and adopt ecological management. Within the sugar chain, three approaches can be seen to treat the residual products, namely, reuse, volume reduction and disposal. Cleaner production technologies are employed to reduce the amount of residual products. And new technologies to improve water efficiency are developed, which is expected to reduce the wastewater between 30% and 40%. Guitang also maintains close relationships with his primary suppliers. It sells the fertilizer produced from residual products back to the sugarcane farmers to prevent the use of chemical fertilizer which can decrease the quality of sugarcane. Guitang also gives technological and financial supports to farmers to improve the quality of sugarcane. The long-term contract with farmers also ensures the quantity of sugarcane and the benefit of farmers. All these efforts make sugar with a high quality and a low cost, which increase the competitive advantage of sugar in the international market. At the same time, Guitang has worked on establishing better relationships with their customers.

5.3 The benefits of the sugar ESC

By taking full advantages of by-product and managing firms in an environmentally, socially and economically responsible manner, Guitang has realized multi-win of human, nature and society. For example, Coca-Cola and Pepsi-Cola have established joint ventures in China which used to purchase sugar from other countries, now begin to buy sugar from Guitang. Many domestic soft drink companies such as the Wahaha, also buy sugar only from Guitang. The key reason is that the sulfur content in the sugar made by Guitang is lower than that made by other Chinese sugar plants. This is due to improved environmental technologies and the resulting higher quality of "green" sugar. Barriers related to information dissemination and communication, are the key obstacles to ensure the effective performance of the supply chains. Fortunately, in our case, most enterprises in the supply chains are linked tightly around Guitang, which facilitates communication among the actors. The government and employees of Guitang also can benefit, as they can get more revenue and salary. The problem of lacking water has been resolved and the quality of water from the rivers is ensured as a result of by-product reusing. Similarly air quality is improved as most CO2 and other toxic gas are treated. The rapid development of the firms in the sugar supply chain drives the development of the relate service industries and increases the job opportunities and the living level of local people.

VI. CONCLUSIONS

ESC is an emerging approach to balancing the conflict objects of optimizing economical, social and environment efficiencies simultaneously. When firms want to establish new ESC or resign existing supply chain, there are some design principles to comply with. A great deal by-product would inevitably emerged and cause environment deterioration. By-product exchange is an essential part in ESC, which plays an important role in improving waste material utilization, preventing environmental pollution and bettering firm performance. Firms also can get economical benefits from it. Government attention to environment and advanced technologies development can facilitate by-product exchange. Guitang shows the benefits of ESCM, whose successful experiences may be useful for firms intending to construct ESC.

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