LOW-CARBON BENEFIT OF INDUSTRIAL SYMBIOSIS FROM A SCOPE-3 PERSPECTIVE: A CASE STUDY IN CHINA

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Abstract. Under the pressure of climate change, reducing the Greenhouse Gases (GHGs) emissions is the key issues to keep sustainable development, especially for rapid industrialization of China. Industrial symbiosis provides a system innovation to fight climate change, and accounting for the Scope of GHGs inventory provide a new perspective for low carbon policy making, while few studies pay attention to the combination of them. Under this circumstance, this study calculates the Scope 3 CO_2 emissions and its reduction under promoting IS in China. Based on one on site survey, we conduct the case study in the industrial cluster of one typical industrial city in China. Results highlight that if all the proposed industrial symbiosis and renewable energy utilization scenarios are implemented, the Scope 3 emission would reduce by 1350295.66 tCO_2, of which, the emission in terms of up-stream material consumption and down-stream waste disposal would be reduced by 899776.04 and 452928.30 tCO_2 respectively. The emission in terms of transportation would increase by 2408.68 tCO_2. While industrial symbiosis does effectively reduce the Scope 3 emission, to enhance the transportation efficiency is necessary for its improvement. Finally, policy implications on the ever-improvement of industrial symbiosis promotion and the future research concerns are proposed and discussed.

Keywords: *renewable energy; GHGs inventory; environment; climate change; carbon dioxide emissions*

Introduction

Our earth system is becoming a highly complex network system in which economy, energy and environment restrict mutually, along with the rapid developing of the human society (Xu, 2009). Fast-growing economy after the industrial revolution brings systemic problems like resources depletion and environmental pollution (Geng and Doberstein, 2008; Van Berkel et al., 2007; Xu, 2009). Especially for rapidly developing China, its sustainable development is restricted by multiple energy and environmental problems like fossil energy depletion, atmospheric pollution and greenhouse gases emission (*Fig. 1*). Therefore, under such a complex human being's system, decision makers and scholars need innovative systematic thinking and

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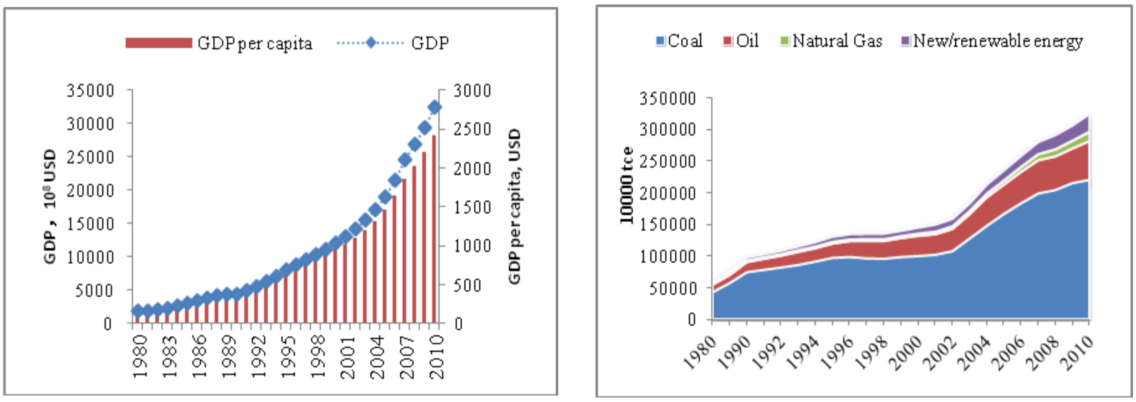
approach to solve problems hindering sustainable development (Cohen-Rosenthal, 2003; Dieter et al., 2007).

Industrial symbiosis (IS) is a system innovation that hybridizing industrial process and natural processes, human desires and the capacities of environment in an effort to reconcile the expanding conflicts among them (Chertow, 1998, 2000, 2007; Desrochers, 2004; Ehrenfeld and Gertler, 1997; Mirata and Emtairah, 2005; Pearce, 2008; Van Berkel et al., 2009; Zhu et al., 2007). It is defined as a relationship in which at least two unrelated industries exchange materials, energy and/or by-products in a mutually beneficial way, through the co-operation, a collective benefit greater than the total sum of the individual benefits without a symbiosis could be achieved It provides a specific opportunity for industries and communities to improve their eco-efficiency (Chertow, 1998, 2000; Mirata and Emtairah, 2005; Liu, 2012). In addition, in terms of urban symbiosis, which is a specific opportunity arising from the geographic proximity of urban and industrial areas (Chen et al., 2011; Geng et al., 2010; Van Berkel et al., 2009), industrial symbiosis could also innovatively utilize the societal waste into industries and reducing the related energy consumption and air pollutants.

The philosophy “IS” is particular significant for rapid industrializing China. For China, it has large industrial scale, and the industry is the pillar for the national economy. Shown as *Fig. 2*, industry contributes to about 80% of the energy consumption, and the CO_2 emissions. As a result, to promote IS in China would be an effective and efficient way to help to realize the low carbon society.

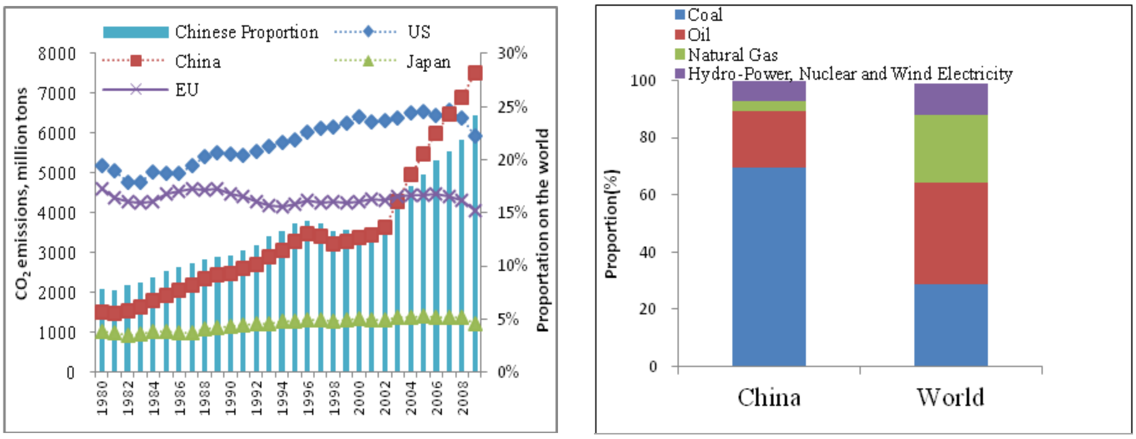
GHGs inventory accounting is important for a better understanding of the emissions source and the methods of regulation. The World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD) develop a standardized protocol for GHGs inventories. The resulting WRI/WBCSD GHG Protocol has been widely accepted by the GHG community, and identifies three potential "scopes" for GHG inventory (WRI/WBCSD, 2011). Scope 1 accounts forthe direct GHG emissionsfrom on-site energy production or other industrial activities. Scope 2 accounts for indirect emissions from energy that is purchased from off-site (primarily electricity or other energy like steam). Scope 3 includes "upstream" emissions embedded in products purchased or processed by the firm, “downstream” emissions associated with transporting and disposing of products (Downie and Stubbs, 2011; HEFCE, 2012a, b; WRI/WBCSD, 2011; Huang et al., 2016). Such method of inventory is effective to identify the emissions source and provide important information to regulate and optimize the company’s activities to reduce GHGs emissions.

Based on above, using a prevailing GHGs inventory method to identify the low carbon benefit of IS is meaningful. To our best knowledge, an application of Scope 2 and Scope 3 calculation is very few in China,due to the methodology development and the data availability. Based on this circumstance, the aim of this paper is to calculatethe Scope 3 CO_2 emissions and its reduction under promoting IS in China. Based on one on site survey, we conduct the case study in the industrial cluster of one typical industrial city in China. We mainly focus on: (1) Analyze the IS condition in and related energy consumption and CO_2 emissions in the case area; (2) Design new IS and renewable energy policy scenarios for the case area; (3) Based on the scenario design, analyze the CO_2 emission reduction from the perspective of Scope 2 and 3; (4) Finally, suggestions to resolve the bottleneck of IS promotion and low carbon society transformationin China are proposed from the perspective of hardware technology and software policy. The authors hope to contribute to the better understanding of low carbon society construction in Chinese.



(a) China GDP growth from 1980 to 2010 Note: Year 2000 unchanged price; Source: World Bank database

(b) China's energy consumption from 1980 to 2010; Source: (NBS, 2011)



(c) China's CO_2 emissions and comparison with the world; Source: (BP, 2011)

(d) Comparison of energy consumption structure between China and the world, 2010; Source: (BP, 2011; NBS, 2011)

***Figure 1.** Multi energy and environment problems in China under rapid growth*

The remainder of this paper is organized as follows. The Section 2 describes the case area. The Section 3 introduces the methodology applied in this study; Section 4 presents and discusses the analytical results. Finally, conclusions and policy implications are provided in Section 5.

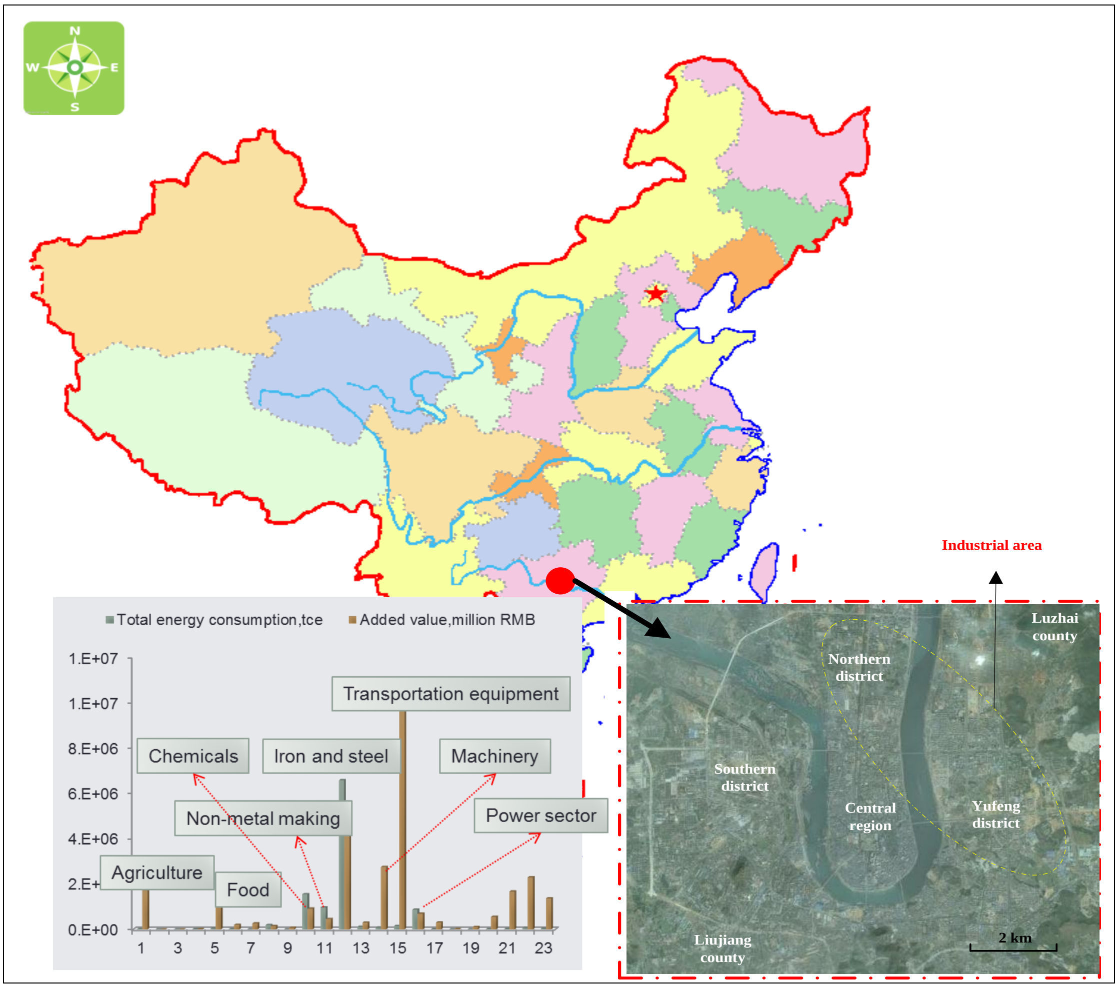


Figure 1. *The location of Liuzhou city*

Case selection and introduction

In this study, we select a typical industrial city named Liuzhou, in southern China, and focus on the industrial cluster in this city.

Liuzhou city (simplified as LIC) is the industrial center in Guangxi province, southern China, with an area of 18 thousand km^2 and a population of 3.67 million in 2009. Shown as *Fig. 3*, its total industrial production accounted one third of the total Guangxi province. The secondary industry took on more than 40% of the total GDP of the city in 2009. Iron and steel industry and automobile industry were the key industries in Liuzhou, with a fraction of 13.82% and 26.93% on the industrial added value respectively, 53.61% and 1.32% on the industrial energy consumption in 2009. The other key industries included cement industry, Chemical industry, etc.

Fig. 4 showed the current industrial cluster in Liuzhou. There are three IS activities were identified, mainly were traditional material or energy exchange, including BF slag reused to produce powder (the scale was 1.2 million tons annually), steel slag utilized by cement and construction industry (the scale was 1.2 million tons annually),

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by-product from the desulfurization process utilized to produce fertilizer(the scale was 8100 tons annually). Recently a new energy exchange chain that provided COG (Coke Oven Gas) and steam to chemical industry (producing ammonia) was under construction.

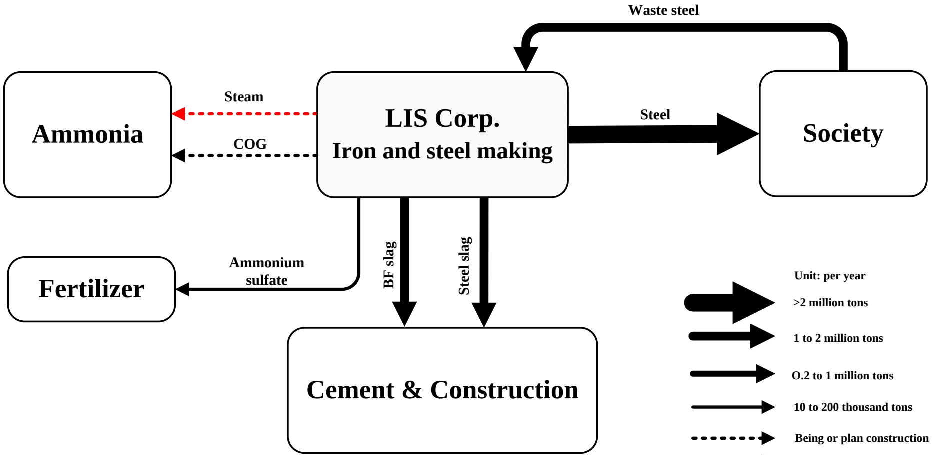

Figure 2. *Quantified material flows of symbiotic activities in LIC*

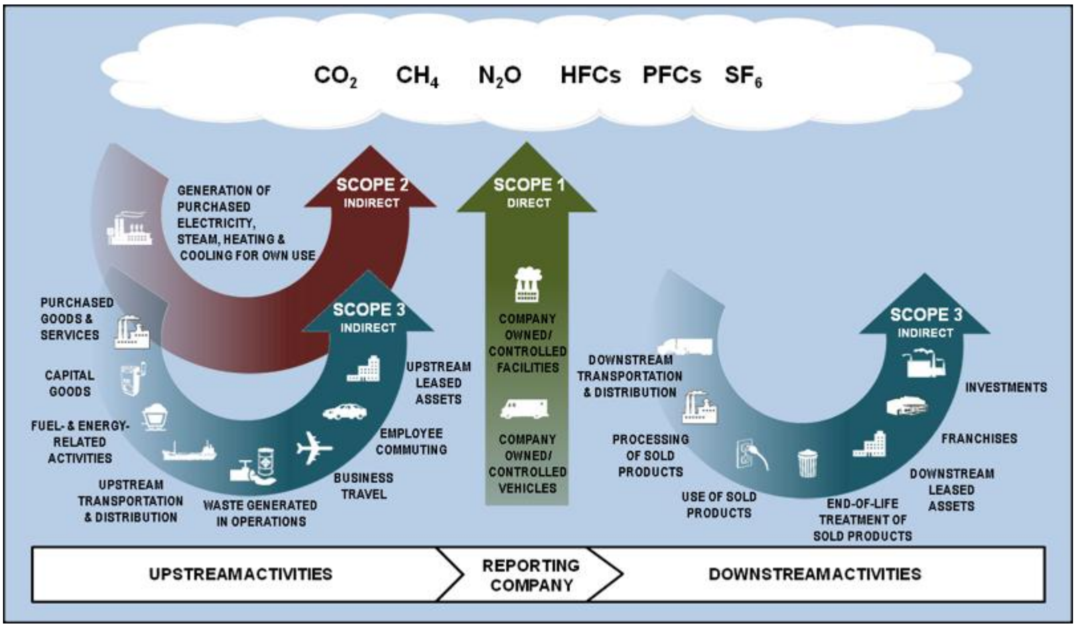

Figure 3. *The boundary of Scope 1, 2 and 3.*

On the whole, it was rather a primary stage of industrial symbiosis and circular economy. Industries co-located with the iron and steel plant included chemicals, cement, machinery manufacturing, powergeneration plant, thus there is huge potential for future symbiosis constitution and evolution.

Methodology

This section mainly describe the methodology including the definition of the scope, calculation for the inventory, scenario design and data acquisition.

Definition of the scope in GHGs inventory

Accounting for the GHGs inventory is important to investigate the emissions source and regulate the activity.

Shown as *Fig. 5*, the scope of GHGs inventory could be classified as (HEFCE, 2012a, b; WRI/WBCSD, 2011):

- Scope 1: direct GHG emissions from sources that are owned or controlled by the entity. Scope 1 can include emissions from fossil fuels burned on site, emissions from entity-owned or entity-leased vehicles, and other direct sources.
- Scope 2: indirect GHG emissions resulting from the generation of electricity, heating and cooling, or steam generated off site but purchased by the entity, and the transmission and distribution losses associated with some purchased utilities (e.g., chilled water, steam, and high temperature hot water).
- Scope 3 emissions include indirect GHG emissions from sources not owned or directly controlled by the entity but related to the entity's activities. Scope 3 GHG emission sources currently required for federal GHG reporting include T&D losses associated with purchased electricity, employee travel and commuting, contracted solid waste disposal, and contracted wastewater treatment. Additional sources that are currently optional under federal reporting requirements, but are significant, include GHG emissions from leased space, vendor supply chains, outsourced activities, and site remediation activities (WRI and WBCSD, 2011).

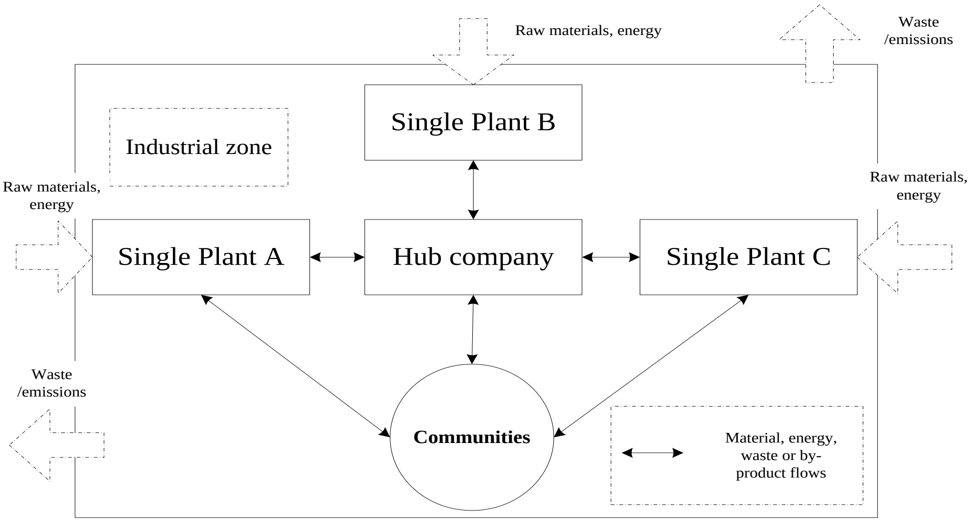

Figure 4. *The system boundary for the material flow analysis*

Calculation for the inventory

In order to identify the hypothetically win-win situation in the IS, we firstly calculate the quantity of exchanged materials and avoided consumption or emission. Then, based on this, we calculate the accordingly CO_2 emission and its reduction. Detail methodology was described below.

System boundary

Shown as *Fig. 6*, the geographical scale of the system was an iron/steel-centered industrial cluster and nearby community, with materials and energy flow exchanges. The iron/steel plant was connected with other plants in the form of waste/by-product exchange. We analyzed and quantified the material exchange between plants and the community. We mainly focused on the material/waste exchange with the iron/steel as the hub, and the according economic gains.

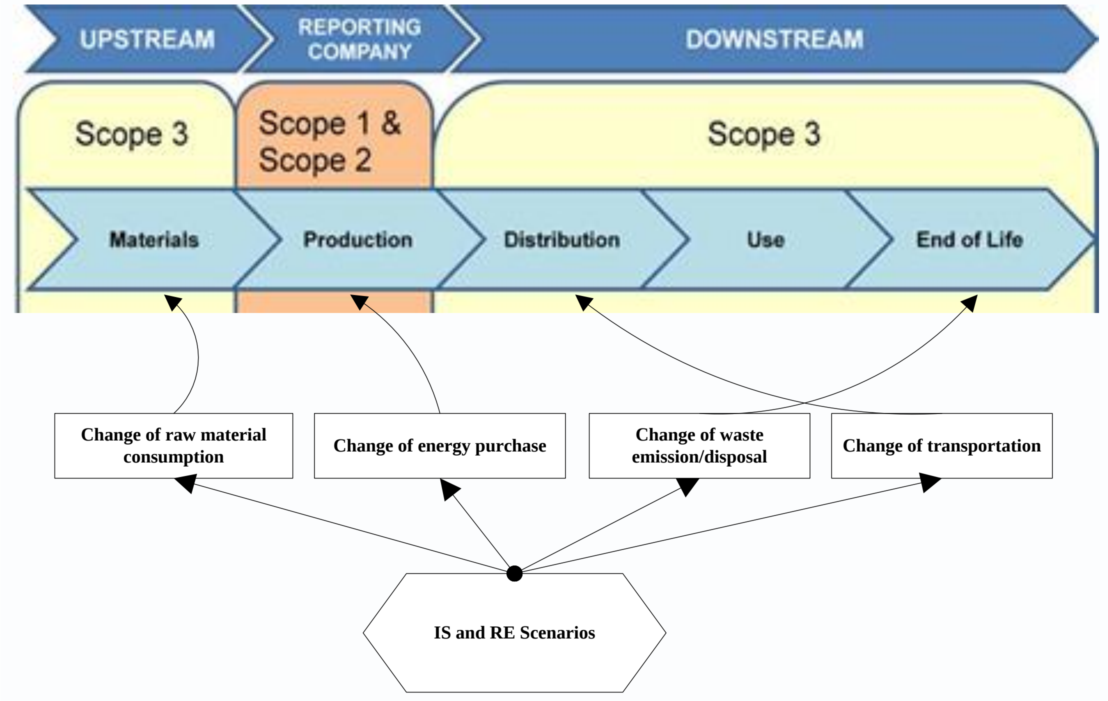

Figure 6. *Effects of IS and RE scenarios on the Scopes*

Avoided consumption or emission

Based on a material flow analysis in the above system, we calculate the difference of principal material flows such as virgin materials, energy, by-product or waste in scenarios with and without the symbiosis.

For the company or sector *i*:

$$\boldsymbol{EnvG}_{ij}=\boldsymbol{R}_{ij} \text{ or } \boldsymbol{W}_{ij} \tag{Eq.1}$$

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$$\boldsymbol{R}_{ij}=\boldsymbol{S}_j\times\boldsymbol{M}_{ij} \tag{Eq.2}$$

Where, $\boldsymbol{EnvG}_i$ is the avoided consumption or emission for the company *i*. $\boldsymbol{R}_{ij}$ is the avoided resource consumption and $\boldsymbol{W}_{ij}$ is the avoided waste emission due to the symbiotic activity. *j* is the type of resource or waste. When come to the avoided resource, $\boldsymbol{R}_{ij}$ is the multiplication of the resource substitution rate ($\boldsymbol{S}_{ij}$) and the quantity of reused/recycled materials ($\boldsymbol{M}_{ij}$). For the avoided waste emissions, the $\boldsymbol{W}_{ij}$ is the quantity of the recycled waste *j*.

CO_2 emission reduction

After gaining the avoided consumption or emission, we could calculate the CO_2 emission reduction through the CO_2 emission coefficient of the resources or waste. $\boldsymbol{CR}_{ij}$is the CO_2 emission reduction from the avoided resource orwaste *j* in company *i*, $\boldsymbol{Cof}_j$ is the CO_2 emission coefficient of the resources or waste *j*. The $\boldsymbol{Cof}_j$ could be gained from published reports and literatures.

$$\boldsymbol{CR}_{ij}=\boldsymbol{Cof}_j\times\boldsymbol{EnvG}_{ij} \tag{Eq.3}$$

CO_2 inventory

Based on the above steps, the final work is to allocate the activity effect into different scopes so as to get the reduction effect in different scope. For example, if the IS activity save the electricity, its reduction belongs to Scope 2; if reducing the waste disposal, its reduction belongs to Scope 3.

Shown as *Fig. 7*, the effects of different scenarios could be summarized as: change of raw material consumption, energy purchase, waste emissions/disposal and transportation. Through analyzing these changes under the scenarios, the CO_2 emission change in different scope is gained.

Scenario design

Based on the current IS, resource feasibility analysis, and the city government “Twelfth-five” planning, we design new scenarios for this industrial cluster. *Fig. 8* showed the scenario design, including: waste plastics recycled to iron and steel industry and cement industry, scrap tires recycled to the furnace of iron and steel industry and cement industry, coal fly ash could recycle to cement industry and construction sector as raw materials, straw could be incinerated for power generation, and renewable power as solar and wind power. The resource potential analysis is shown in *Fig. 9*. The scenario year is 2010.

The detail description of the scenario is summarized in *Table 1*.The business as usual (BAU) scenario was in 2010, the parameters were according to the Liuzhou city twelfth-five planning, energy conservation planning and environmental production planning in the twelfth-five period. The other 6 scenarios are based on BAU plus certain symbiosis or renewables options.

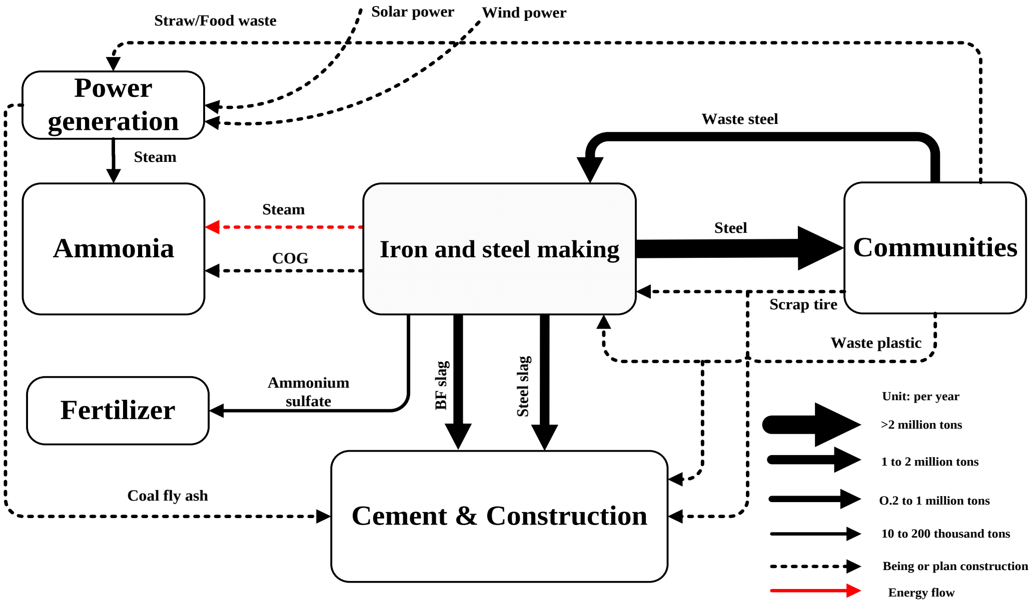


Figure 5. *Quantified material flows of industrial symbiosis in Liuzhou city*
Note: The solid line indicate the current situation. The dotted line indicate being construction or planned.

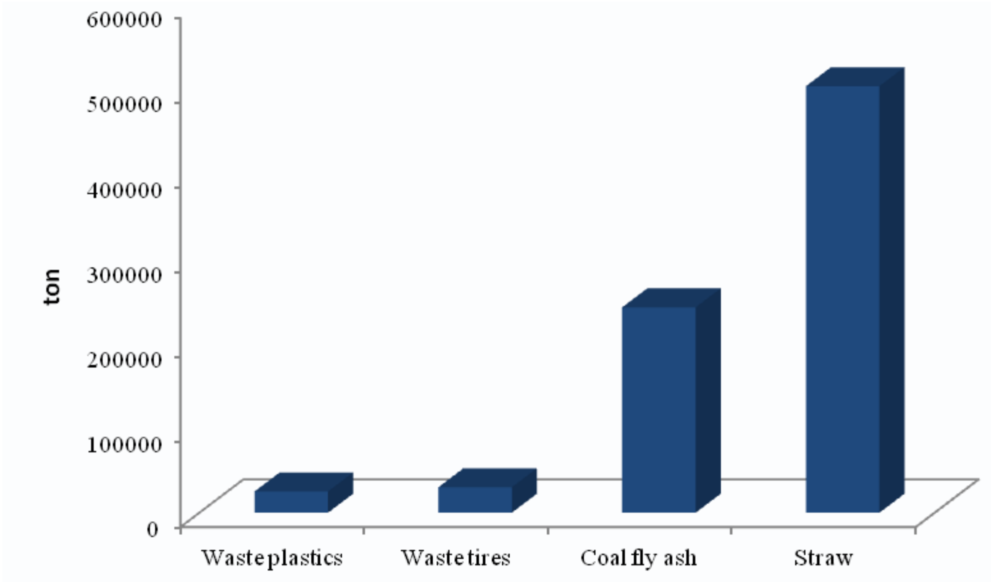


Figure 6. *Resource potential analysis*

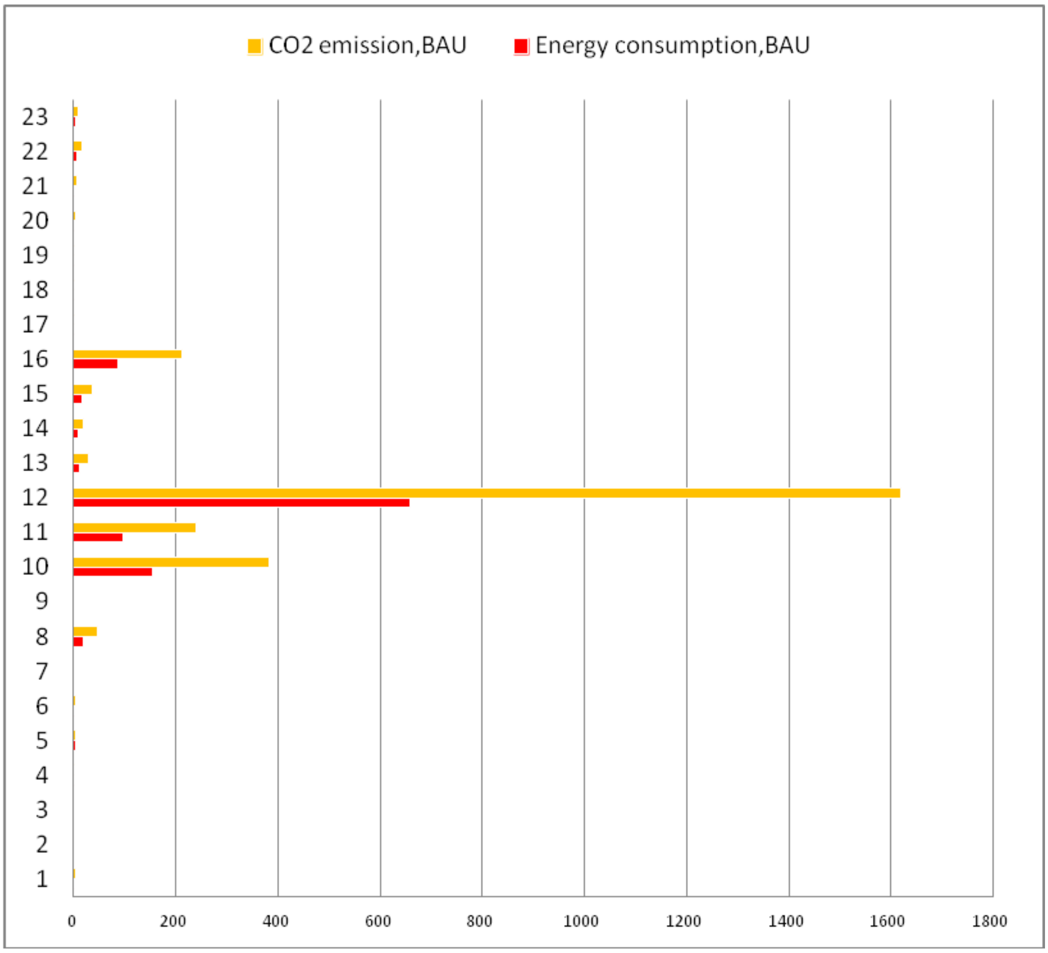


Figure 7. *Energy consumption and CO_2 emissions for each sector in BAU scenario. Unit: for energy consumption, 10000 tce; for CO_2 emission, 10000ton*

Note: 1-Agriculture; 2-Coal mining and washing; 3-Ming of petroleum and natural gas; 4-Ming and processing of non-metal ores; 5-Food products and tobacco; 6-Textile and leather; 7-Saw mills and furniture; 8-Paper and pulp; 9-Petroleum processing and coking; 10-Chemicals; 11-Non-metal making; 12-Iron and steel; 13-Non-ferrous metal; 14-Machinery; 15-Transportation equipment; 16-Electricity, steam and hot water supply; 17-Electric equipment and machinery; 18-Telecommunication products; 19-Environmental production industry; 20-Construction; 21-Transportation; 22-Commercial and service; 23-Other Public service. The "tce" means ton standard coal equivalent, 1 tce equals to 29.27 GJ.

Data acquisition

In this study, according to the research topics and data availability, we mainly focused on energy data in different sectors in the case city. The author of this study attended the energy conservation planning in the case city and thus had access to the data availability.

Energy consumption and types in various sectors came from two sources: one was Liuzhou city Statistics Yearbook, data of secondary industry's data were mainly from this way. For the first industry, transportation sector, and service sector, the data came from survey to the governmental office and unpublished governmental report. Data was further complemented by published literatures and verified through survey. In addition, cleaner production reports of the key companies were also the resource for data complement. The data of CO_2 emissions was calculated from the data of energy consumption according to the methodology of IPCC guidelines (IPCC, 2006). Data unavailable from the government agency was further gained from the Cleaner production report of key companies (Chemicals, Power generation, Iron and steel, etc).

Table 1. *Description of IS and RE scenarios*

Scenarios		Description	parameters	Source
S0	Business as usual in 2010	Current condition without IS.	See *Fig. 10*.	Survey and Liuzhou Energy Statistical Yearbook, 2011.
S1	Existing IS	See *Fig. 4*	See *Fig. 4*.	Survey.
S2	Waste plastics recycling	S0+Waste plastics recycle to iron and steel industry as primary energy.	1 ton waste plastics could substitute 1 ton coke in iron and steel industry. To produce 1 ton coke need 0.15 tce.	Survey in the Liuzhou Iron and steel company and (Web)
S3	Scrap tires recycling	S0+Scrap tires recycle to iron and steel industry and cement industry as primary energy.	1 ton scrap tire could produce 0.65 tons rubber powder, consume 0.04 tce electricity.To produce 1 kg rubber from raw material need 2 kWh electricity.	Survey in the Liuzhou Yufeng cement company and (Huang et al., 2011; Van Berkel et al., 2009)
S4	Coal fly ash recycling	S0+Coal fly ash recycle to cement industry as raw materials.	1 ton cement includes 0.3 ton coal fly ash, and consume 0.0007 tce electricity.	Survey in Liuzhou Power generation company
S5	Biomass utilization	S0+Use straw for power generation.	Recycled into power generation sector.	Liuzhou Twelfth-five Energy conservation planning (unpublished)
S6	Renewable power	S0+solar power+ wind power	Accounts for 10% of the total power generation.	Liuzhou Twelfth-five Energy conservation planning (unpublished)

Finally, we also consider the waste transportation. The parameters are summarized in *Table 2*.

Table 2. *Transportation parameters*

Waste	Energy consumption of transportation[a]	Average distance[b]	Source
Waste plastics	7.82L diesel/100 ton.km	6km	Liuzhou twelfth-five energy conservation planning (unpublished)
Scrap tires	7.82L diesel /100 ton.km	10km	Liuzhou twelfth-five energy conservation planning (unpublished)
Coal fly ash	7.82L diesel /100 ton.km	3km	Liuzhou twelfth-five energy conservation planning (unpublished)
Straw	7.82L diesel /100 ton.km	20km	Liuzhou twelfth-five energy conservation planning (unpublished)

Results and discussion

For the BAU scenario, *Fig. 10* shows the energy consumption and CO_2 emissions for key industry and sectors. The key sectors needed to make energy conservation and low carbon in priority, including Iron and steel industry, cement and construction materials industry, chemical industry, power generation industry, sugar industry, pulp and paper industry, non-ferrous metal industry, machinery manufacturing industry, and automation manufacturing industry.

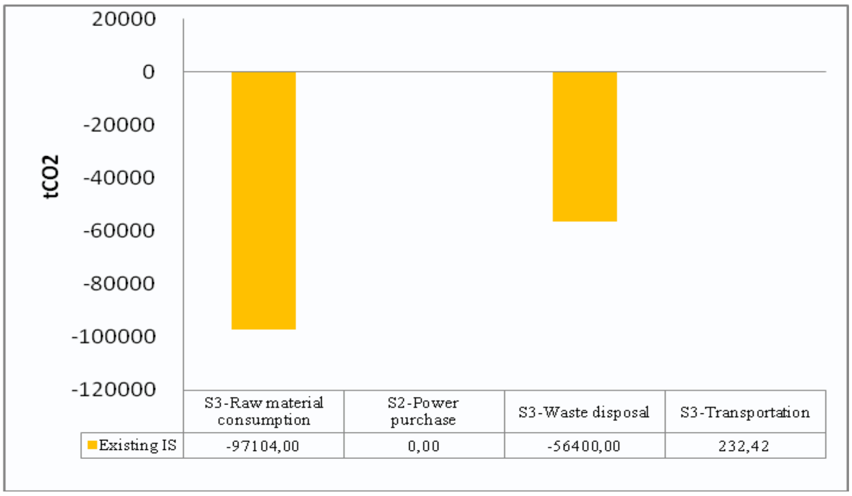


Figure 8. *CO_2 inventory for existing IS scenario*
Note: S2-Scope 2; S3-Scope 3

Then we presents the results of the benefit of IS and renewables scenario. In existing IS, shown as *Table 3*, through the IS, the iron/steel company could reduce 1.2 Mt/y slag stock-pilling and 8100t/y desulfurization byproduct stock-pilling. The cement company could save clinker 1.2 Mt/yand 136 GWh/y electricity. Based on this, the CO_2 reduction effect in Scope 3 is presented in *Fig. 11*. It could reduce the Scope 3 emission of material by 97104.00 tCO_2, while increase the Scope 3 emission of transportation by 232.42 tCO_2.

For new designed scenarios, the resource saving and waste reduction and the according scope is summarized in *Table 4*. The IS and RE scenario has great resource saving and waste reduction effects. On the whole, waste plastics recycling would save 25000t/y coke, and reduce the power purchase in the coking process by 3750 tce. Transportation for it would increase energy consumption by 11730L diesel. Scrap tires recycling would reduce the power purchase for the rubber production process by 14400 tce, while increase the transportation energy consumption by 23460L diesel. Coal fly ash recycling would reduce the solid waste by 242135t/y, but would increase the transportation energy consumption by 56805L diesel. Biomass utilization would reduce the straw stock-pilling by 5030000t/y, reduce the coal fired energy consumption by 251500 tce, and increase the transportation energy consumption by 786692L diesel. For renewable energy utilization, they would reduce the coal fired energy consumption by 105000 tce.

Table 3. *Resource saving and waste reduction in existing IS scenario*

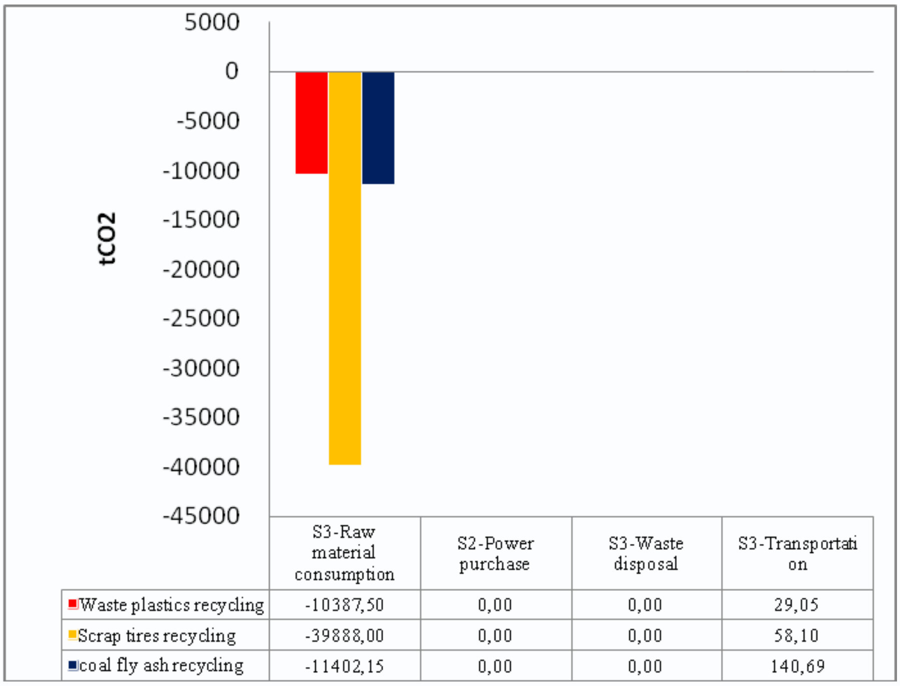
#	Symbiotic activity a, b	Resource/waste exchange	Volume	Participants	Avoided consumption/ emission	Scope
1	Production of slag powder	BF slag	1.2 Mt/y	Iron/steel-> cement;	Conserve electricity136 M KWh/y Reduce slag stock-pilling 1.2 Mt/y	3 3
2	Substitute cement material	Steel slag	1.2 Mt/y	Iron/steel->cement	Substitute clinker 1.2 Mt/y Reduce slag stock-pilling 1.2 Mt/y	3 3
3	Production of fertilizer from desulfurization byproduct c	Desulfurizationby product	8100t/y	Iron/steel->chemicals	Reduce SO2 4 kt/y Reduce solid waste stock-pilling 8100t/y	3 3

Note: the carbon embodied in the slag is 0.046t/t slag.

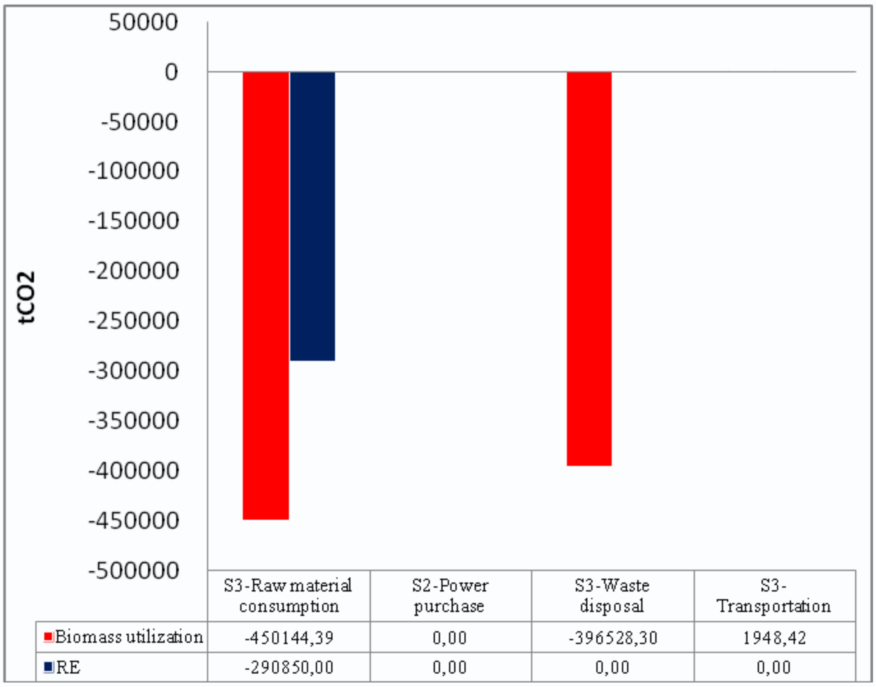
Based on this, the CO_2 reduction effect in Scope 3 is presented in *Fig. 12*. In detail, waste plastics, scrap tires and coal fly ash recycling could reduce the Scope 3 emissions in terms of material consumption by 10387.50, 39888.00 and 11402.15 tCO_2 respectively. They would also increase the Scope 3 emissions in terms of transportation by 29.05, 58.10 and 140.69 tCO_2 respectively. Biomass utilization and Renewable energy power has larger effects. They could reduce the Scope 3 emissions in terms of material consumption by 450144.39 and 290850.00 tCO_2 respectively. Biomass utilization could also reduce the Scope 3 emissions in terms of waste disposal (incinerate the straw) by 396528.30 tCO_2. The Scope 3 emission in terms of transportation is increased by 1948.42 tCO_2 in the biomass utilization scenario.

Table 4. *Resource saving and waste reduction in IS and RE in designed scenario*

#	Scenarios	Resource/waste exchange	Volume	Participants	Avoided consumption/emission	Scope
1	Waste plastics recycling	Waste plastics	25000 t/y	Community-> iron/steel	Reduce 25000t/y coke. Reduce power consumption for coking 3750 tce. Increase transportation energy consumption by 11730 L diesel.	3 3 3
2	Scrap tires recycling	Scrap tires	30000 t/y	Community-> Chemical	Reduce power consumptionfor raw rubber production 14400 tce. Increase transportation energy consumption by 23460 L diesel.	3 3
3	Coal fly ash recycling	Coal fly ash	242135 t/y	Power generation-> cement	Reduce 242135t/y coal fly ash stock-pilling. Reduce the raw material for cement, reduce the energy consumption of clinker by 5.1kgce/t, equals to 4116.3 tce saving. Increase transportation energy consumption by 56805L diesel	3 3 3
4	Biomass utilization	Straw	503000 t/y	Straw->power generation	Reduce straw combustion by503000tce/y. Reduce coal fired energy consumption by 162507tce/y. Increase transportation energy consumption by786692L diesel.	3 3 3
5	Renewable power	-	0.22 TWh	-	Reduce coal fired energy consumption by 105000 tce/y.	3



(a) CO_2 inventory for waste plastics, scrap tires and coal fly ash recycling



(b) CO_2 inventory for waste plastics, scrap tires and coal fly ash recycling

Figure 9. *CO_2 inventory for new designed IS and RE scenarios*

If all the IS and RE are implemented, the total CO_2 reduction effect is shown in *Fig. 12*. As a whole, the Scope 3 emission would reduce by 1350295.66 tCO_2.

According to the results, several issues can be highlighted:

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- The Scope of the CO_2 inventory provides an effect way to identify the emissions source so as to facilitate future carbon mitigation management. It also provides a innovative way for the supply chain management.
- Industrial symbiosis does an effective and efficient way to reduce the raw material/energy consumption in the up-stream and the production process, and reduce the waste emissions and disposal in the down-stream. This would further reduce the Scope 3 emission in terms of material saving and waste reduction.
- However, it is also noted that through implementing the IS, the emissions from the transportation would increase, highlighting that to enhance the transportation efficiency, and optimizing the transportation route would be necessary to enhance the efficiency of industrial symbiosis.

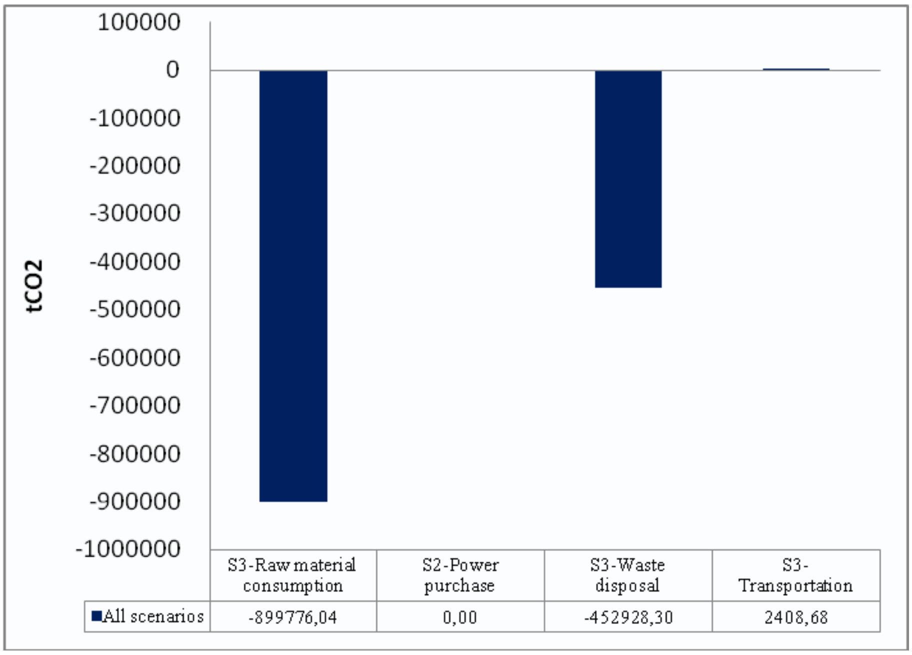

__Figure 10.__ Results for all scenarios

Conclusion and policy implication

Calculation the scope of the GHGs inventory provides a new perspective for low carbon policy making and the supply chain management. This study calculatesthe Scope 3 CO_2 emissions and its reduction under promoting industrial symbiosis and renewable energy in China. Based on one on site survey, we conduct the case study in the industrial cluster of one typical industrial city in China. Results shows that if all the proposed industrial symbiosis and renewable energy utilization scenarios are implemented, the Scope 3 emission would reduce by 1350295.66 tCO_2, of which, the emission in terms of up-stream material consumption and down-stream waste disposal would be reduced by 899776.04 and 452928.30 tCO_2 respectively. The emission in terms of transportation would increase by 2408.68 tCO_2. While industrial symbiosis does effectively reduce the Scope 3 emission, to enhance the transportation efficiency is necessary for its improvement. In addition, this study only conducts from the perspective of physical issue, the monetary issue is not the focus. In reality, the cost-benefit efficiency of the technology, the funding support would be important and generate the uncertainty.

Finally, based on the analytical results, several policy making issues to resolve the bottleneck of IS and RE promotion in China are proposed and discussed.

- To improve the immaturity of waste management system and regulation system, on the one hand, in order to establish a stable and innovative municipal solid waste management system needed to establish, public or commercial collectors needed to be encouraged to participate in the waste collection and recycling. On the other hand, the third party should be made to coordinate the stakeholders of the symbiosis. For sharing information between the industries or companies, the establishment of informationplatform was important. For the regulation system improvement, waste management legislation considering extended responsibility of the companies should be launched and implemented widely.
- For the financial supporting, we proposed to subsidies mechanism for the industrial symbiosis technology, such as iron and steel plants to reuse the alternative resource and fuel such as waste plastic, waste tires should be established; feed-in tariff policy for the electricity generated from iron and steel plants should be made; proper tax on virgin materialsand export policy for waste steel are needed to impose. To upgrade the eco-industrial technologies, government should make specific funding support to the industries, such as subsidies for the technology penetration, research and development, as well as recycling facilities construction. Providing low-priced and high-quality infrastructure services through subsidies and tax credit by the local government would be an effect way.
- Finally, Scope 3 study is emerging. For China, there is need to develop a comprehensive decision tool which based on material flow analysis and life cycle analysis, to direct waste materials between industries and external waste generators in anoptimized manner, so as to reduce the GHGs emissions in different stage and process and the whole system.

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