別紙 4

報 告 番 号	※ 第 号

主 論 文 の 要 旨

論 文 題 目 Research on analytical methodology to plan and evaluate industrial symbiosis in steel plant industrial complex (産業共生を計画・評価する分析手法に関する研究：鉄鋼産業を含む産業集積地区を対象に)

氏 名 董 亮（DONG Liang）

論 文 内 容 の 要 旨

Industrial symbiosis (IS) is a core concept of “industrial ecology”. It encourages the material and energy flows circulate in the industrial and urban systems, so as to reduce the consumption of virgin material, fossil fuels, and mitigate the generation of waste and pollutants. Industrial symbiosis provides a system innovation to fight for a series of environmental challenges like the climate change, sustainable urban development and so on, especially for industrializing countries. It provides solution from network optimization perspective. To make a quantitative analysis on the industrial symbiosis is important to generalize the IS project, verify its effects and support the policy making, while to date, quantitative analysis is rather few.

Under this circumstance, this doctoral dissertation aimed to conduct a planning and quantitative evaluation on industrial symbiosis with case study on steel plant industrial complex in China, which had been under rapid economic growth and industrialization. Two typical industrial cities in China were selected as case studies.

This paper was organized as follows:

Chapter 1 presented the background of this research. Industrialization had brought both prosperity and environmental challenges to human beings. The concept of industrial symbiosis and its application as urban symbiosis provided new solution to address the challenges. Especially, to generalize and transform the industrial symbiosis concept to developing countries, which were under rapid industrialization and urbanization, was proved to be good idea. However, research on planning local industrial symbiosis for them and quantitative evaluation to verify the effects of industrial symbiosis implementation was relative few. Therefore, it was important to conduct the planning of local industrial symbiosis and develop integrated evaluation model to assess the effects of planned industrial symbiosis in typical developing country. With this consideration, this research chose China as case study. The research objectives and dissertation structure was introduced.

Chapter 2 reviewed the development of the theory, practice and analytical methodologies in the research field of industrial symbiosis. It was found that, on the whole, industrial symbiosis was still an emerging research field. In the aspect of project practice, developed countries had promoted a series of successful projects, and the application of industrial symbiosis had brought both environmental and economic benefits to them. However, in developing countries, there was still a lot of room to enhance the promotion of industrial symbiosis. In the field of analytical methodologies, material flow analysis (MFA), life cycle assessment (LCA) and input-output analysis (IOA) had become mature tools, however, to extend their application in micro level and developing countries which lacked data, modification and integration was needed. Conducting case studies in developing countries was necessary to verify the effects of IS, so as to provide useful information for the decision making process. However, to date, there had been a lack of both case studies in developing countries and integrated modeling studies in the literatures.

Chapter 3 compared industrial symbiosis promotion in China and Japan. It was found that even though both the two countries had promoted "sound material-cycle society" related strategy, the development stage was different. In Japan, industrial and urban symbiosis was promoted like Kawasaki eco-town, and regional symbiosis was implemented. While to China, development stage was still focus on cleaner production and the eco-industrial park, to promote industrial and urban symbiosis, as well as regional symbiosis would be focus in the next promotion stage. Based on the review on Japanese case, experiences related to industrial symbiosis were learned and transformed to this case study.

Chapter 4 focused on the data acquisition. Innovative survey procedure was designed to collect local industrial symbiosis data in Jinan and Liuzhou city, local industrial symbiosis database was constructed including technical data, company input-output data, economic data, emission factors and general regional socio-economic data. Main findings in this chapter were the industrial symbiosis development condition in Jinan and Liuzhou could present two levels: national advanced level with more synergies and primary urban symbiosis, and local level with focusing on cleaner production and bulky waste recycling. Even though Liuzhou had the similar industrial system as Jinan, a lot of industrial symbiosis opportunities were not uncovered.

Chapter 5 conducted the integrated model development. Material and energy flow analysis, process based LCA and hybrid input-output model was integrated to assess the planning of industrial symbiosis.

The main findings and contributions were that: through the model integration, it resolved the bottleneck of process based LCA and IO-LCA application in the industrial symbiosis evaluation and lack of scenario analysis in China.

Based on the data acquisition and model development, **chapter 6** and **7** presented two case studies. In **chapter 6**, network analysis and assessment on the symbiosis in the national pilot project in Jinan city was made. Results highlighted extinguish environmental benefit. In total, more than 4 million ton raw material and 1.5 million ton coal equivalent (tce) energy was saved, and more than 4 million ton waste was reduced. Considerable CO_2 reduction was achieved through the implementation of industrial symbiosis. 3944.05 ktCO_2/y was reduced in total. Material and energy symbiosis reduced CO_2 emissions by 3792.42 and 151.62 ktCO_2/year respectively. In addition, as an advanced national pilot project, Jinan's experience could be transformed into local cases.

In **chapter 7**, based on the study in Jinan city, planning and quantitative assessment for industrial symbiosis in Liuzhou city was presented. Two main findings were highlighted:

(1) Considerable environmental benefits were achieved. There were dramatic carbon mitigation effects. Compared with BAU, planned industrial and urban symbiosis could contribute to the CO_2 reduction by 1104.96 ktCO_2/y. Waste plastics recycling, waste tire recycling and biomass utilization presented great CO_2 mitigation in the lifecycles. They reduced 39.59, 39.92 and 845.89 ktCO_2/y respectively. Scenario analysis by 2015 highlighted that industrial symbiosis was able to help the local city realize co-benefit, reduced CO_2 emissions and air pollutants together. IS provided an extra mitigation measure beyond traditional technological development and structure adjustment.

(2) On the other hand, results emphasized a need of trade-off thinking. Coal flying ash recycling reduced 11.40ktCO_2/y, but meanwhile, it also increased 827.55 tCO_2/y from second energy consumption. As a cost of constructing the industrial symbiosis, emissions from transportation increased by 2246.61 tCO_2/y. In detail, with implementation of waste plastic recycling, waste tire recycling, coal flying ash recycling and biomass utilization, CO_2 emissions from transportation increased by 29.05, 58.10, 140.69, and 1948.42 tCO_2/y, respectively. This finding highlighted a future research need on optimizing the symbiosis and transportation network, and made technology shift to reduce second emissions.

Finally, in **chapter 8**, policy implications related to the generalization and extension of industrial symbiosis in China, as well as supporting policies to enhance the promotion of industrial symbiosis were proposed and discussed. Based on the planning in the case studies, the future concerns on the developing energy symbiosis in the case cities were discussed. With smart design, waste heat from the factories could be utilized more efficiently. Utilize the concept of IS to support the transit thinking on China's industrial policy was important, like the improvement on the factories location, freight network, and technical shift. Conclusion of the main findings in this work and future concerns were drawn in the final part of this chapter.

The main findings of this research would be critical for China and other developing countries' future industrial and regional planning policy, and shed a light on the future low-carbon development in developing countries in Asia.