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Carbon reduction from sustainable consumption of waste resources: An optimal model for collaboration in an industrial symbiotic network

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ABSTRACT

Inter-firm collaboration is an effective way to achieve carbon emission reduction by sustainable consumption of waste resources. To find out how to bring collaborative effects to bear upon emission reduction for multiple-firm networks, industrial symbiosis is taken as a tool for inter-firm cooperation on carbon emission reduction (CER). The input-output matrix is built to identify the carbon footprint within the flows among the industrial firms in a symbiotic network. Fuzzy goals programming is employed to convert the parameter of amount of carbon emissions to the degree of satisfaction, which avoids the problem whereby the carbon emissions of different industrial firms are not comparable across different demographics. An optimisation model is then constructed with the constraint of both product demand and CER cost. Finally, there is a scenario simulation of CER cooperation from perspective of industrial symbiosis for the iron and steel industry. It provides empirical experience from which industrial firms can implement CER cooperation through industrial symbiosis.

1. Introduction

With the strengthening of energy-saving regulations and enhancement of environmental protection awareness, carbon emissions reduction has become an unavoidable problem in the production and operation of industrial enterprises, and attracted more and more attention from enterprises and scholars. It is noteworthy that most of our current carbon emissions awareness is still relatively weak. The relevant systems, and supporting facilities, are not yet sound enough. Carbon emission reduction technology is insufficiently advanced. It is difficult, and will be so in the near future, to meet the growing demand for carbon reduction. Enterprises with significant carbon emissions face widespread difficulties. It can be seen that broadening the channels of emission reduction and strengthening the emission reduction capacity of enterprises are of great significance as we all seek to cope with increasingly severe resource and environmental pressures (see Fig. 1).

Improving energy efficiency and structure are often taken for energy-saving and emission reduction, which mainly depends on technological innovation in energy usage, however, technological innovation cannot solve all the problems in the process of reducing emissions, Liu et al. (2010) pointed out that relying solely on industrial technology can only reduce emissions of carbon by 40–45% of the target contribution of 15.2%–16.2% overall by 2020. For a single enterprise, technological innovation is a high cost, and the short-term effect of emission reduction is often not obvious, which limits energy-saving emission reduction activities. Moreover, in the practice of carbon emission reduction activities, the traditional method simply relies on individual enterprises to carry out energy-saving emission reduction alone, gradually making it difficult to meet the new requirements of Chinese energy-saving and emissions reduction. Enterprises rely solely on their own resources to carry out energy-saving emissions reductions. These are often of low-efficiency, incur a high cost, and are accompanied by a lack of enthusiasm for carbon emission reductions by single firms. Corporate emissions reductions is often subject to industry-related enterprises, such as upstream suppliers of low-carbon raw materials and downstream customers with emissions reduction claims that can have important impacts on corporate emissions (Zhu and Geng, 2013). Moreover, some scholars have shown that low-carbon cooperation between industry-related enterprises (such as

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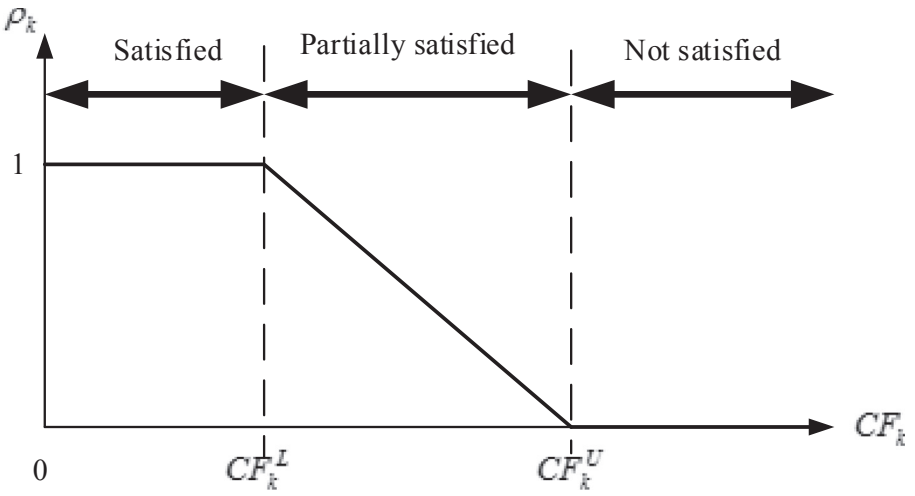

Fig. 1. Enterprise carbon footprint level of satisfaction measurement diagram (Source, Aviso et al., 2011).

upstream and downstream enterprises) can reduce the cost of R & D and the cost of procurement of environmentally friendly components, thus reducing the cost of environmental responsibility to enterprises (Gunasekaran et al., 2015; Soysal et al., 2018). Similarly, emission reductions can be achieved through the optimal allocation of resources between multiple enterprises (Zhang et al., 2012).

Industrial symbiosis refers to the network system with combination of traditional independent industrial enterprises, taking competitive advantage through the exchange of material resources such as raw materials, energy, water, and by-products among enterprises (Chertow, 2007). The establishment of a symbiotic relationship between enterprises to achieve the recycling of waste resources, effectively reduces the waste of resources, as well as the production and procurement of raw materials in the process of energy use and carbon emissions: however, although some scholars are aware of industrial symbiosis and its potential role in energy-saving emission reduction (Hashimoto et al., 2010), there are few studies related thereto. Especially in the context of low-carbon emission reduction, how to design the symbiotic structure of inter-firm synergistic emission reduction, and then to achieve the optimal allocation of resources among enterprises is a basic scientific problem, but also one that lacks systematic scientific analysis.

This paper contributes to the provision of an optimal way towards inter-firm collaboration over carbon emission reduction in an industrial symbiotic network. With the employment of carbon footprint theory and environmental input-output model, we design an industrial symbiosis network for synergistic carbon emission reduction on the basis of the inter-firm demand-supply relationship. It is expected to provide a scientific theoretical basis and practical decision-making reference for enterprises to rely on symbiotic relationships to carry out collaborative emissions reductions.

2. Literature review

The concept of industrial symbiosis was first proposed by Frosch and Gallopoulos in 1989. They believe that enterprises with industry associations can achieve the recycling of waste resources among enterprises by simulating the interaction of natural biological populations, thus forming a win-win situation for the economy and our environment, meeting the goal of the industrial ecological network (Herczeg et al., 2018). The characteristics of industrial symbiosis determine that the enterprises and their stakeholders in the symbiotic network can reduce the environmental problems in industrial operations and promote the coordinated development of economic and environmental benefits through various forms of ecological cooperation and their own ecological construction. The research has shown that relying on the symbiotic network to transform the economic activities into a "resources - products - renewable resources - renewable products" cycle is of benefit to the maximum reduction of emissions from production to consumption (Tseng et al., 2018).

Particularly, energy as an essential resource for enterprise production and business activities, can also achieve multi-level recycling of energy resources through the symbiotic cooperation among enterprises, thereby reducing energy consumption and waste to achieve energy conservation and carbon reduction effects. Many scholars in the past industrial symbiosis-related research, have been aware of the symbiotic inter-firm collaboration on the role of energy conservation. Korhonen (2001) analysed the symbiotic relationship among enterprises in the Jyvaskyla industrial ecosystem in Finland, noting that 40% of all fuel consumption was reduced by the cascaded use of energy and the reuse of industrial waste, with the achievement of 30% CO_2 reduction. Also, Du and Zhao (2008) showed that the establishment of the symbiotic relationship saves the Mengxi Group, in its annual digestion coke oven gas consumption, some 21.6 million cubic meters, or more than 15,000 tons of carbon dioxide: however, further analysis shows that is not difficult to find that most previous studies only treat energy-saving emissions reduction as one of the ancillary effects of symbiotic cooperation between enterprises. Particularly for the issue of carbon reduction, research into symbiotic inter-firm cooperation remains rare. This provides a wealth of space for our next study.

Inter-firm collaboration in sustainable consumption of waste resources through industrial symbiosis has its unique advantages in emission reduction. Industrial symbiosis helps firms in the symbiosis network to reallocate wasted resources and share important information about carbon emissions reduction. The coordinated development of the economy and the environment can be realised by the application of industrial symbiosis. The collective benefits of the symbiotic system are greater than that the sum of the benefits of all individual enterprises, resulting in a "$1+1>2$" effect (Martin, 2015). For inter-firm collaboration in the reduction of carbon emissions, the establishment of the relationship between enterprises is the focus of coordination and reduction of the difficulties. For this point, industrial symbiosis has the advantages in internal businesses which are strongly correlated and densely distributed: