Improving Energy Efficiency through Industrial Symbiosis in Energy Intensive Industries: A Comparative Study of Japan and China

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Abstract
The rising cost of energy has drawn focus to global energy issues. The industrial sector alone, consumes about 50% of the world's delivered energy. This significantly impacts global consumption and production. As China's economy burgeons, the resulted severe pollution from energy intensive industrial sector has yet to be addressed. Japan is a global leader of industrial energy efficiency (IEA, 2008), however, the removal of nuclear power after the Fukushima incident in 2011 forced Japan to seek alternative clean energy to meet their increasing energy demand. Industrial symbiosis (IS) is a promising approach for improving energy utilization efficiently. The majority of literature on IS focused on the exchange of materials among industrial processes. These literatures do not study efficient energy flow within and between firms.
This research is a study based on review of literature and industry on the energy flow in China and Japan. A conceptual framework is needed to enable companies to optimize their utilization of limited energy resources through IS with non-technical improvements. This research compares energy intensive industries and eco-industry parks in both Japan and China as case studies to investigate energy flow in energy intensive industries. Specifically, establishing a systematic process of waste energy management both within and between firms, which can contribute to the reduction of natural resources/energy consumption, cost benefit, and most importantly, a solution to the present-day severe environmental pollution.

Keywords: Industrial Symbiosis, Energy Efficiency, Energy Management

Introduction

By 2040, it is estimated that the world energy industrial sector will consume approximately 51% of global delivered energy (U.S. Energy Information Agency, 2013). According to the AEO2013 report by IEA, a breakdown of this energy intensive industry shows iron & steel industry consuming 17% of the world's total energy. The increased demand and shortage of energy have led to a continuous increase in cost. This has brought pressure on many manufacturing companies. As a result, these enterprises face a huge challenge to reduce the consumption of energy and improve their corresponding energy efficiency. To survive this energy crisis and severe pollution, it is vital and urgent to improve energy efficiency (EE) within this energy intensive industry. Since industrial activities consume renewable or non-renewable materials and massive amounts of energy, they should be on the frontlines to address the resulted environmental problems (Duflou et al., 2012). To solve these problems, much attention has been on Green Manufacturing (GM) and industrial sustainability. There is a strong need for a systematic approach to manage industrial energy use (Schulze et al., 2015). The implementation of energy management in an organization is regarded as one of the most promising means of reducing energy consumption and related energy costs.

Industrial Symbiosis (IS) focuses on the material/energy exchange between different organizations or factories. Energy Efficiency (EE) is usually developed at an organization level. By combining EE with IS, the best practice of efficient energy utilisation within/between firms can be discovered. Thus, a conceptual framework is needed to enable companies (especially energy-intensive industries) to make the best use of limited energy through IS. This paper aim to explore the processes of IS with a focus on the energy flow and the energy management at both the intra-firm level and inter-firm level to understand the proper processes of achieving EE through IS.

Literature Review

1. Literature Review on Industrial Symbiosis

The concept of 'IS' dates back to 1947 when George Renner pointed out that 'here are those industries which utilize waste products of other industries', and used 'industrial symbiosis' as a phenomenon in 'Industrial Interrelationships' to described the relationship between industries. Renner further indicated that IS 'is seen to be of two kinds, disjunctive and conjunctive' (Ranner, 1947). Ayres et al. (1994) used the term 'industrial metabolism' and described it as 'the whole integrated collection of physical processes that converts raw materials, energy, and labour into finished products and wastes in a (more or less) steady-state condition'. In 2000, Chertow pointed out that IS 'engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products', and is an essential part of IS. 'Geographic proximity' provides possibilities of collaboration and the synergy (Chertow, 2000). Based on the review of three IS networks in the United Kingdom (UK), Mirata et al. (2003) analyzed determinant factors of IS developments from technical, political, economic, informational, organisational perspectives, and the role of coordination. Mirata & Emtairah (2005) outlined three factors that are important for the innovation process to help analyze the effects IS networks can have on environmental innovation. They also clarified the way activities in IS networks benefit environmental innovation (Mirata & Emtairah, 2005).

To tell IS from other types of exchanges in industries, Chertow (2007) indicated a '3-2 heuristic' criterion. This means, at a basic type of industrial symbiosis, there must be at least three different entities and at least two different resources must been involved in exchanging (Chertow, 2007). However, the boundary of the term 'entities' should be considered. In terms of reusing by-products as one of three main opportunities for resource exchange, by-product was described as 'the exchange of firm-specific materials between two or more parties for the use as substitutes for commercial products or raw materials (Chertow, 2007; Chertow et al., 2008). Most of the literatures utilized Chertow's definition to lay emphasis on the exchange between companies. However, there are emerging literatures looking at material and energy exchange between corporations and within a single corporation. For example, exchanges of by-products and energy within the firm can be seen in British sugar (Short et al., 2014) and Guitang Group (GG) in China (Zhu et al., 2007). In the case of GG, the phenomenon of by-products exchanging inside the firm are described as 'inter industrial symbiosis'. GG fits the core principle of IS because it's a mix of internal practices and new business units. This improves the utilization of materials and energy (Leigh et al., 2014; Lombardi et al., 2012; Zhu et al., 2007). From the case of British Sugar, it was observed that 'internal symbiosis' eventually evolved into IS as additional firms outside the sugar companies provided new growth opportunities and potential risk reduction' (Short et al., 2014). Walls et al. (2015) studied organizational theories in IS at four levels: institution level, network level, organizational level and individual level (Walls & Paquin, 2015). In recent years, some academia began to argue that IS engages 'both ends of the spectrum, with process and companies' (Lombardi & Laybourn, 2012). Yuan & Shi (2009) claimed that the IS concept used among different firms can also be used among different units within a company, as it improves the competitive advantages by reducing production cost and improving environmental performance. One of these approaches can be used to transform wastes/pollutants from one unit into another as inputs (Yuan & Shi, 2009). Three levels of resource optimization at the intra-firm, inter-firm, and regional levels, as Lowe (2001) puts it; are employed to improve the material and energy efficiencies of that industry. Dong et al. (2014) indicated that in present-day China, material symbiosis is much more prevalent than energy symbiosis. However, innovative energy symbiosis provides an extra opportunity to reduce greenhouse gases emissions (Dong et al., 2014).

In a traditional IS system, by-products or wastes from one manufacturer can serve as raw material for other manufacturer. Thus, helping to reduce costs, resource, energy and reducing environmental pollutants. However, it is unclear in literatures where the boundary is referred to as the 'entity'. Most researchers believe the main character of IS should be the exchange of material and energy between different firms, while more and more attention are paid on inner relationships of a firm. To date, there is little attention placed on the inner relationships of a firm. Majority of researchers in the field believe that the inner relationships are not in the scope of IS (Yuan & Shi, 2009). In this paper, each manufacturing process is seen as a unit and the boundary is drawn at unit process level. Thus, traditional IS can be regarded as an inter-firm level and the exchanges of materials and energy between different process within the firm can be seen as at intra-firm. The boundary of the term of 'entity' must be clarified.

2. Literature Review on Energy Efficiency

This section illustrates the process of manufacturing from an energy related perspective. It is vital to consider energy consumption and efficiency at different level to understand how best to minimize energy consumed during each manufacturing processes. Rahimfard et al. (2010) outlined a framework for modeling Embodied Product Energy during manufacturing. They claimed that, only by considering energy consumption at both 'plant' and 'process' levels it is not able to provide an overview of the total energy required to manufacture a unit of product. The consideration from a 'product' perspective should be combined (Rahimifard et al., 2010). From an energy management perspective in manufacturing, Bunse et al. (2011) analyzed gaps between industrial companies' needs and scientific literature. Bunse then indicated that, in order to close the gap between existing solutions in academia and the implementation in industrial firms, 'the research should focus on developing efficiency and effective energy management in production'. They advocated that it is necessary to integrate management concepts and EE as a strategic factor with technical measures (Bunse et al., 2011). Duflou et al, (2012) identified opportunities to improve EE systematically by considering the minimization of energy consumption at five levels in the manufacturing system. Their research showed opportunities for efficiency improvement at corresponding distinguished levels, some could be combined, whereas, the possible measures are not independent. For instance, energy savings at process level will result in the decrease of energy consumption at multi-machine level. "Energy efficiency is a measure of energy used for delivering a given service. Improving EE means getting more from the energy we use" (Decc, 2012). Tanaka (2011) claimed proper boundary definitions are needed for a 'meaningful assessment' of EE. Several articles of EE in manufacturing have researchers drawing boundaries at different levels in manufacturing system. Apostolos et al. (2013) divided the study of EE of manufacturing process into 4 levels: factory level, line level, machine level and process level. Even though the energy spent within the process level is minor, it still plays a vital role in the manufacturing processes. Studying this process provides a better understanding of the energy transformation that is taking place within the manufacturing process. Also, the selection of suitable process parameters has a great influence on both machine peripherals consumption and production planning at line or factory level (Apostolos et.al, 2013). In cases that have several peripherals, which may be shared with different machines in the factory, it may be difficult to estimate how much energy has been spent on a single machine. Hence, some of these considerations need to be transferred into a higher level (the line or factory level) (Duflou et al., 2012). Based on the perspective of manufacturing system organization system, manufacturing activities can be divided into five levels. They are considered as; (1) Device/Unit process level, (2) Line/cell/multi-machine system level, (3) Facility level, (4) Multi-factory system level, (5) Enterprise/global supply chain level (Duflou et al., 2012).

(1) Unit process level

The boundaries of a unit process correspond with individual machine tools that are regarded as the smallest unit to comprise production system.

(2) Multi-machine system

Duflou et al. (2012) indicated that a network of machines in a factory can be seen as a 'multi-machine ecosystem' and 'due to the structure of the network, the output of one process may be the input for another' (Duflou et al., 2012). In this system boundary, the energetic flow and material flow can be reused within the process chain and in another process chain. At the end of these exchange stages, non-used energy (waste heat) and materials leave the system. At the machine level, the demand of related peripheral equipment that preforms auxiliary processes exceeds the actual energy required for machine process.

(3) Factory level

To increase the effectiveness of manufacturing, the operation of a factory should be taken into consideration at a factory or plant level. Production planning can contribute to minimizing the total energy consumption (Duflou et al., 2012).

(4) Multi-factory level

Consequently, it is necessary to consider the reaction between several companies, such as suppliers and companies who exchange energy or materials. Duflou et al. (2012) indicated that 'the mutualism in the interaction has led to the introduction of the term 'industrial symbiosis' from the examples of mutualistic symbiotic relationships between organisms of different species in natural ecosystems'. Many researchers have pointed out, in a symbiosis system, materials and energy are exchanged for the sake of mutual benefits to companies that are in participation.

(5) Supply chain level

A supply chain is defined as 'a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flow of products, services, finances, and/or information from a source to a customer (Mentzer et al., 2001). Duflou et al. (2012) dissected the supply-chain level, the locations of specific production plays a significant role and can have a big influence on the energy embedded in a product. Sustainable supply chain management is defined as 'management of raw materials and services from suppliers to manufacturer/service provider to customer and back with improvement of the social and environmental impacts explicitly considered'.

Tanaka (2008) indicated that measures of energy efficiency performance (MEEPs) is based on three criteria (Reliability, Verifiability, Feasibility) and should be taken into consideration by policy makers. Tanaka (2011) analyzed EE policies within industries of several countries (IEA countries, Brazil, China, India, Mexico, Russia and South Africa) and assessed the key features of the main measures outlined from Tanaka's research. The research concluded that no single policy or measure could fit every country, types of industry, and situations. Thus, further in-depth research focus on selected countries is needed. Policy makers have paid much attention on measuring EE at the national level and international comparison. There are limited studies on a single firm or process even though indicators found at the general level are not suitable at a single firm (Bunse et al., 2011). Since there are different system scale levels claimed by researchers, it is important to clarify where to draw a boundary in manufacturing process. Also, it is necessary to integrate management concepts and EE as a strategic factor with technical measures to improve EE (Schulze et al., 2015).

3. Energy Efficiency in Industrial symbiosis

'Industrial symbiosis, by itself, can be seen simply as a more efficient use of energy and materials' (Chertow & Ehrenfeld, 2012). In recent years, literatures have shown that, material flow account for a large part in IS studies. Only a few articles that focused on energy saving contributed to IS. Togawa et al. (2014) developed a simulation process model to maximize the utilization of waste heat from a power plant to plants nearby in Fukushima and proposed 'an energy symbiosis' concept. Dong et al. (2014) reported that a comprehensive energy network has been designed for Liuzhou Industrial Park and calculated the energy exchanged in both Jinan and Liuzhou IP in China. Sokka et al. (2011) studied the material and energy flow in forest industry in Kymenlaakso and calculated the total fuel and energy use. Comprehensively, they identified possibilities to reduce energy consumption and greenhouse gas emissions of the corresponding industrial park(s). Li et al. (2014) analyzed the energy flow among industrial chain in the XF IP in China and proposed 'an index system for the quantitative evaluation of the energy-saving efficiency of IS' (Dong et al., 2014).

Comparison of Japanese and Chinese Energy Intensive Industries

According to the statistics of IEA, Before the Fukushima accident, Japan relied on nuclear power generation and their domestic energy resources counts for approximately 20%. Since the removal of nuclear power in 2012, that count is now less than 9%. Today, Japan's energy import bills are surging and have pushed the country to a record trade deficit in 2013. To be more specific, the manufacturing sector accounts for over 40% of energy consumption in 2012, with manufacturing industries accounting for more than 90% of industrial energy consumption. It is crucial for Japan to improve its energy utilization minimize energy consumption to lower its bills. To be more specific, the manufacturing sector accounted for over 40% of energy consumption in 2012, with manufacturing industries accounting for more than 90% of industrial energy consumption. Accordingly, it is crucial to improve energy efficiency especially in manufacturing industry to save energy and minimize energy consumption. In April 1995, the government revised the Electricity Business Act, enabling manufacturing corporations to produce and sell electricity to power companies. Since this Electricity Liberalization, major steel companies their independence from national power companies. These companies started to invest in their own power plant and devoting their corporation to the power generation business. Steel companies' power generation is derived from the gases/waste heat (the by-product during the production process); this serves as the energy source for efficient power generation. In addition to the economic benefit, this approach significantly reduced industrial CO2 emissions and saved natural energy sources. Shinko Kobe Power Station (owned by Kobe Steel Ltd.) is Japan's largest independent power producer (IPP) and self-sufficient with electricity. It is estimated that the generation capacity of the two power plants can cover 70% of the electricity used by Kobe City during peak times. This provided a new lifeline to the city devastated when the Great Hanshin Earthquake occurred in 1995. Sumitomo Metal Industries, Ltd. (Sumitomo Metals) resumed operation of its Blast Furnace in Kashima Steelworks immediately after the Great East Japan Earthquake for supplying electricity to Tokyo Electric Power Company (TEPCO) to meet the power demand in Ibaraki Prefecture. The Kashima Power Station is able to generate enough electricity to meet the power demand of all households for about 3 million people in Ibaraki Prefecture. Since the

Fukushima Disaster, there has been a trend to build local power generation system among manufacturing industries, especially among automotive corporations. In the case of Toyota Motor Corporation, the history of electricity self-generation dates back to the 1970's. As a part of the self-sufficiency at Toyota's plant, heat from the burning gases are collected and are used to dry the paint on finished vehicles. The hot water from the gas turbine runs through pipes into a nearby greenhouse that grows green peppers. Furthermore, Toyota took the lead in 'F-Grid (Factory-Grid) ' project, as a part of 'Smart Community Business', to develop an industrial area where the energy can be generated, stored, and used efficiently after the Great East Japan Earthquake. The 'F-Grid' combines the electricity from an electric power company, co-generation, and solar power generation to achieve economical and sustainable power supply over the industrial area. The factory can supply energy not only for its own manufacturing process but also for local businesses and the town. Other automakers such as Honda, Mitsubishi and Nissan have joined the power-producing field. Many have built power stations in some of their plants and introduced the self- sufficiency approach.

With 50% of the world steel production in 2014 (World Steel, 2015), China is the world's largest iron and steel producer. Although the manufacturing processes of steel making are improving, there is still a large potential for reducing CO_2 emission by achieving energy efficiency. Fig. 2-6 shows that if China can achieve the same level of energy efficiency as Japan, CO_2 emission from the Chinese Steel industry could be reduced significantly. In recent years, steel makers started to pay attention to waste heat recovery. In 2012, Taishan Steel completed the construction of a new power plant using the waste heat that was generated from the manufacturing process.

A large amount of waste heat produced by industrial processes in energy–intensive industry, such as automotive industry and steel Industry were usually emitted into atmosphere. However, this waste heat and gas can be used as a source of energy instead of being emitted as waste. Thus, the utilization of this waste energy and the energy flow within and between companies should be reconsidered. Since 1995, major steel companies have introduced electricity by developing self-generation system as IPPs (Independent Power Producer). These steel makers have become indispensable power producer that support the demand of electricity through out Japan, while Chinese steel companies are beginning to introduce this energy generation system. As for Automotive corporations, the generation of energy is for self-sufficient and supplement for the local power company, supporting the local area while gaining benefits from cost reduction. It is crucial to recover waste energy, which generated from manufacturing processes to achieve efficient energy utilization, especially in energy-intensive industries. Japanese companies can be seen as developed models while Chinese still need to gain experience from other countries, i.e. Japan. However, there is lack of established framework on the process of establishing and improving the electricity self-generation system at facility level, region level and city level.

Research Gap

A few gaps were identified while conducting the literature review:

1. From a theoretical point-of-view, the boundary of 'entity' is not clearly stated. The definition has been developed over time to conform to the practical needs. In this paper, each manufacturing processes are regarded as an entity and the exchange of

material within the firm is seen as intra-firm level, while the material and energy flow between different firms are defined as inter-firm level IS.

2. A majority of the existing literature on IS and EIPs have laid emphasis on both environmental perspective and social perspective with an aim to better understand how environmental and economic value can be created (Walls & Paquin, 2015). Only a few articles can be found from an energy efficiency perspective that can provide a potential solution to the worldwide energy scarcity problem.

3. Much attention been paid on by policy makers on the national level and international comparison when energy efficiency be measured. However, there are limited studies based on a single firm or process although indicators found on general level are not suitable at a single firm (Bunse et al., 2011). Energy management is usually improved in individual organizations. The potential for improved EE could be higher if energy management is considered (Schulze et al., 2015). Thus, there is a need to develop managerial practice within and between organizations.

4. From a practical point of view, there is lack of framework that shows the process of conducting IS from both intra-firm level and inter-firm level. This can directly help companies to achieve energy efficiency.

Preliminary Conceptual framework

Based on the research gaps have been identified, a conceptual framework is needed to enable companies to make the best use of limited energy through IS with non-technical improvements. More specifically, based on literature reviews, this paper aim to explore the processes of IS with a focus on the energy flow and the energy management at the intra-firm level and inter-firm level to understand the proper process(es) of achieving EE through IS. Research was conducted in three steps: (1) conducted a literature review of on Industrial Symbiosis (IS) and Energy Efficiency (EE)/Energy Management (EM) in manufacturing; (2) identified gaps in knowledge and practice; (3) developed a conceptual framework of efficient energy management through IS based on identified gaps.

Figure 1 shows the relationship between IS, EE, and EM literature. This research focus on the energy flow aspect of IS and the improvement of thermal efficiency of EE from a management perspective. Thus, a preliminary conceptual framework to understand the proper processes of achieving EE through IS.

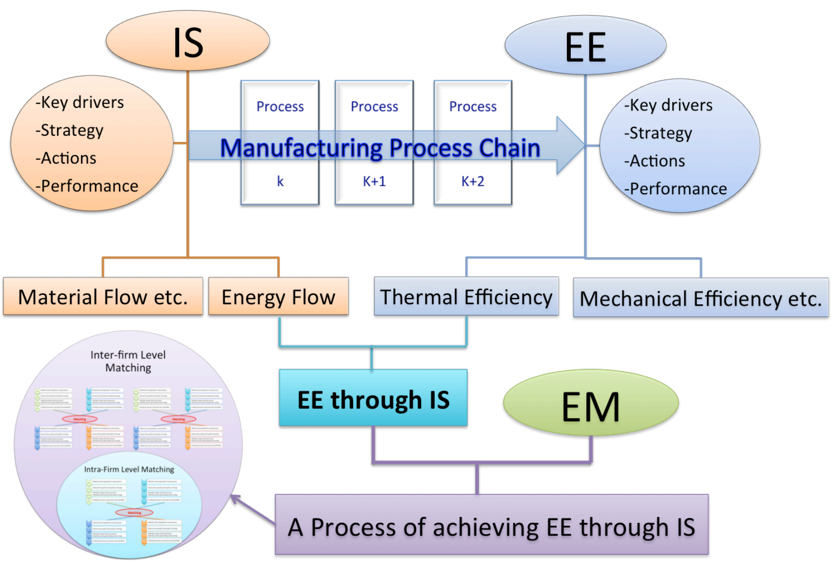

Figure 1 – Research Framework

More specifically, the process of achieving EE through IS can be divided into two main steps:

1. Identify "hot spots" of waste energy and "cold spots" of energy demanding process (Monitoring – Assessment – Identification - Report)
2. Based on theses reports, waste energy from one process to be matched to reuse in another process as resource within and between firms

In this research, each manufacturing process is seen as a unit and the boundary is drawn at unit process level. The energy exchanges between several process units within a firm are seen as intra-firm level IS and energy exchanges between different firms are seen as inter-firm level IS.

Contribution

The academic contribution of this research provides a conceptual framework of achieving EE utilization through IS. This fills the existing research gap in IS from an energy point of view. As a practical outcome, this conceptual framework provides a process of enabling local governments and companies to make the best use of limited energy through IS. The management of waste energy within/between firms can contribute to the reduction of natural resources/energy consumption, cost benefit, and most importantly, a solution to the present-day severe environmental pollution.

Further Research

Case studies will be carried out based on the proposed framework. Key drivers for IS promotion could be identified by comparing the advanced IS practices in Japan and developing IS practices in China at the intra-firm level and the inter-firm level.

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