Industrial ecology, industrial symbiosis and supply chain environmental sustainability: a case study of a large UK distributor

LEIGH, Michael and LI, Xiaohong <http://orcid.org/0000-0001-8148-7348>

Published version

LEIGH, Michael and LI, Xiaohong (2015). Industrial ecology, industrial symbiosis and supply chain environmental sustainability: a case study of a large UK distributor. Journal of Cleaner Production, 106, 632-643.

Industrial ecology, industrial symbiosis and supply chain environmental sustainability: A case study of a large UK distributor

Michael Leigh* and Xiaohong Li

Sheffield Business School, Sheffield Hallam University, Sheffield, UK

*Corresponding author, m.leigh@shu.ac.uk

Abstract
The supply chain management literature indicates that limited research has explored the roles of Industrial Ecology and Industrial Symbiosis in relation to supply chain environmental sustainability development. Studies have explored supply chain environmental sustainability development and provided different approaches for developing environmentally sustainable supply chains. These include environmental management, design for environment, product stewardship, green purchasing, reverse logistics, recycling, reuse, and remanufacturing. These approaches have often been considered independently. Industrial Ecology and Industrial Symbiosis offer systematic thinking for companies to integrate key elements of these approaches into their supply chain environmental sustainability development. This study aims to develop a conceptual framework to embrace the integration and identify opportunities for companies to work collaboratively. The initial framework was proposed based on the review of the literature associated with environmentally sustainability supply chain management, Industrial Ecology, and Industrial Symbiosis. It is improved by corroborating the case study company's experience, a large UK distributor. Different hierarchies in waste management have also been considered when developing the framework. The paper emphasises the importance of prevention and reduction methods. The developed framework illustrates the areas and opportunities for supply chain parties to work collaboratively towards environmentally friendly activities. The developed framework contributes to the environmentally sustainable supply chain management literature and encourages companies to apply Industrial Ecology and Industrial Symbiosis to develop their environmentally sustainable supply chains.

Keywords

Environmentally sustainable supply chain, Industrial Ecology, Industrial Symbiosis, Conceptual framework

Highlights

1. This paper focuses on supply chain environmental sustainability development.
2. Industrial ecology (IE) and Industrial Symbiosis (IS) provide new ways of thinking.
3. A framework is developed to highlight possible applications of IE and IS.
4. Companies need to work collaboratively towards a closed-loop material exchange.
5. The developed framework emphasises the importance of prevention and reduction.

1. Introduction

Supply chain management (SCM) has evolved into design, management and optimisation of activities of external and internal parties and their relationships along a supply chain (Spekman et al., 1998). It aims to facilitate better information and material flows through developing integration and collaboration among supply chain parties to form better relationships (Ashby et al., 2012; Handfield and Nichols, 1999). SCM proposes a development opportunity for different parties along a supply chain to work towards a higher level of collaboration through breaking organisational boundaries (Frankel et al., 2008). Sustainable supply chain management (SSCM) considers social, environmental and economic aspects of sustainability along the supply chain (Carter and Rogers, 2008). All three dimensions of sustainability are important to supply chain sustainability development. However, it is not possible to cover all three dimensions whilst undertaking an in-depth exploration in a single research paper. This paper focuses on environmental sustainability. Environmental sustainability is concerned with reduced negative impact of companies' activities on the environment with a long term consideration (Goodland, 1995; Li and Leigh, 2010). Environmental sustainability proposes a challenging area for SSCM and for applying concepts such as Industrial Ecology (IE) and Industrial Symbiosis (IS).

IE considers principles of biological ecosystems when designing and redesigning industrial systems to create more efficient interactions both within industrial systems and between industrial natural systems (Ayres and Ayres, 2002; Lombardi and Laybourn, 2012). IS applies the ecological metaphor of IE to create a collective approach to firms and industries traditionally viewed as separate entities and considers the entire system with regard to the physical exchange of materials, energy, water and by-products (Chertow, 2000; Costa and Ferrão, 2010). IE aims to improve the efficiency of exchanges within and between systems; whilst IS emphasises the collaboration amongst firms in industries to promote actions which are consistent with ecological principles (Chertow, 2000). IS, considering the core of IE, focuses on innovation and networks for knowledge sharing to improve the efficiency of the use of materials and energy, which is beyond waste and by-product exchanges (Lombardi and Laybourn, 2012). Hence, IS and IE are directly related and are increasingly relevant to environmental sustainability of a supply chain (Mattila et al., 2010; Yuan and Shi, 2009). IE and IS offer valuable thinking to environmental sustainability development of a supply chain by identifying opportunities for businesses along a supply chain through working collaboratively towards reduction of the overall negative impact on the environment. IE has been considered at the firm level (Despeisse et al., 2012; Wells and Orsato, 2005), at the regional level (Boons, 2008; Deutz and Gibbs, 2008; Röser et al., 2011), and the global level (Duchin and Levine, 2013). IS has been applied to a supply chain concept (Bansal and McKnight, 2009; Yuan and Shi, 2009). Only a few studies have considered both IE and IS in the context of supply chain environmental sustainability development with limited consideration of integration (Ashton, 2008; Mattila et al., 2010; Seuring, 2004; Yuan and Shi, 2009). A framework which embraces IE and IS integration within the context of supply chain environmental sustainability development is desirable.

This study aims to develop a conceptual framework for supply chain environmental sustainability development through exploring possible integrations of IE and IS with environmentally SSCM. This is achieved through literature learning and a case study of a large UK distributor. Following the introduction, the literature reviews environmentally SSCM approaches, IE and IS. The research method is presented, followed by an overview of the case study organisation. The company interview results and further implications for the development of the framework are discussed leading to the presentation of the developed framework. Conclusions are drawn at the end and future research areas proposed.

2. Literature review

This literature review contains two parts. The first part presents approaches for achieving environmental sustainability of a supply chain. The second part reviews IE and IS and explores their possible integrations within a supply chain network. The literature review generates the initial framework.

2.1 Environmentally sustainability supply chain approaches

Environmentally SSCM aims to reduce the negative impact on the environment of all activities along a supply chain (Andiç et al., 2012; Sarkis et al., 2011; Wu and Pagell, 2011; Yeh and Chuang, 2011). The development of environmentally sustainable supply chains begins when a focal firm collaborates with its suppliers and/or customers to improve the environmental performance of its products, services, processes, and supply chains (Simpson and Power, 2005). Environmental performance refers to the level of the impact on the environment. Reducing the impact on the environment indicates a better environmental performance. By applying different approaches, the environmental performance of a company and its supply chain could be improved. The environmentally SSCM literature offers different approaches for companies to implement and achieve improvement of their supply chain environmental performance. These approaches along with some representative key references are provided in Table 1 below.

Approaches	**Key References**
Environmental management/Environment management system	van Hoek (1999), Lee and Rhee (2005), Vachon and Klassen (2006), Darnall et al. (2008), Nawrocka et al. (2009), Agarwal and Thiel (2012), Wiengarten et al. (2013), Grekova et al. (2014)
Design for environment	Gupta (2005), Tsoulfas and Pappis (2006), Kurk and Eagan (2008), Soylu and Dumville (2011), Bevilacqua et al. (2012)
Product stewardship	Sarkis (1995), Lewis (2005), Ruskino (2007), Snir (2009), Rogers et al. (2010)
Green purchasing	Tsoulfas and Pappis (2006), Gold et al. (2009), Zhu et al. (2007), Eltayeb and Zailani (2010), Green et al. (2012), Yen and Yen (2012)
Reverse logistics	Lippman (2001), Blumberg (2005), Kleindorfer et al. (2005), Varma et al. (2005), Gupta (2005), Anderson and Skjoett-Larsen (2009), Jayant et al. (2012), Huscroft et al. (2013), Mutingi (2014)
Recycle, reuse and remanufacturing	Sarkis (1995), Kleindorfer et al. (2005), Gupta (2005), Kuik et al. (2011), Loomba and Nakashima (2012)

Table 1 – Environmentally SSCM approaches and key references in the literature

'Environmental management' contains three different methods within a business strategy at different impact levels: reactive 'end of pipe' pollution control, proactive reusing, remanufacturing, and recycling of products and materials within the supply chain, and an integrated approach into value-seeking supply chain re-design integrated into business strategy (van Hoek, 1999). A value-seeking pollution preventive approach results in a better environmental performance than an end of pipe approach (Lee and Rhee, 2005). However, environmental management investments tend to be reactive, thus most production processes and products remain unchanged (Vachon and Klassen, 2006).

The use of environmental management system (EMS) such as ISO 14001, are adopted as part of a wider effort by supply chain parties to reduce their negative impacts on the environment along their supply chains (Wiengarten et al., 2013). Organisations implementing an EMS require the corporation with their suppliers and customers along their supply chains to achieve better results (Agarwal and Thiel, 2012). Organisations that have achieved a high level of in-company environmental management are more likely to have developed an externally-orientated EMS (Darnall et al., 2008; Grekova et al., 2014). However, the implementation of an EMS in a company may not necessarily lead to cooperation amongst the purchasing and environmental functions, and its supply chain parties (Nawrocka et al., 2009).

'Design for the environment' includes both product design and supply chain process design. Design for a more environmentally friendly product considers the creation of recoverable parts of a product that are durable, repeatedly usable, and environmentally recoverable in disposal at its design and development stage (Kurk and Eagan, 2008; Tsoulfas and Pappis, 2006). This approach also takes additional environmental concerns into consideration of a design to enable possible recycling and disassembly at the end of product life cycle (Gupta, 1995). Desirable environmental attributes for designing a product may include free from toxic substances, biodegradable, recyclable, upgradeable, and with low energy consumption (Soylu and Dumville, 2011). This approach focuses on the design stage and emphasises the importance of product, process and supply chain design to their life cycle impact on the environment (Bevilacqua et al., 2012).

'Product stewardship' is an important concept in 'design for product'. It emphasises the importance of the 'cradle to cradle' responsibility of a product by aiming to keep all materials within a closed-loop cycle to avoid the material flow to the external environment (Lewis, 2005; Sarkis, 1995; Varma et al., 2006). This approach ensures the reduction of liability along supply chains (Snir, 2009). Developing a better product stewardship needs the consideration of lifecycle management and requires the understanding of secondary markets which deal with unwanted items and attempt to create values from them (Rogers et al., 2010). 'Product stewardship' can extend the environmental sustainability perspective to services and an entire supply value chain. This requires designers, suppliers, producers, and customers to work collaboratively and have transparent and clearly defined responsibilities towards developed products and services. This concept can also be applied to process design, which could be called 'process stewardship'. A designed process within this concept uses a high level of renewable resources and hence reduces the negative impact on the environment (Rusinko, 2007). The process with the consideration of 'process stewardship' indicates supply chain parties' responsibilities towards ensuring its environmentally friendly aspects.

'Green purchasing' requires both logistical and technological integration with suppliers to strengthen the collaboration of their environmentally friendly activities. The collaboration includes the development of new products and the introduction of new production lines which are more environmentally friendly (Yen and Yen, 2012). 'Green purchasing' of new product development considers achieving the maximum utilisation of potential reuse of products, parts or materials, where every output is either returned to its natural system or becomes an input to produce another product (Tsoulfas and Pappis, 2006). It emphasises the importance of building relationships with suppliers for a greener supply process (Gold et al., 2010). In addition, green information systems are necessary precursors to the implementation of green purchasing practices (Green et al., 2012). In order to achieve ‘green purchasing’, a company intends to source from suppliers that are environmentally certified (Zhu et al., 2007). The implementation of green purchasing is influenced by regulations, customer pressures, and expected business benefits (Eltayeb and Zailani, 2010).

‘Reverse logistics’ relates to the handling process of returned products by customers to the focal company. Traditionally, a firm is only responsible for the disposal of its unshipped products which no longer carry any value (Andersen and Skjoett-Larsen, 2009). The purpose of ‘reverse logistics’ is for the focal company to either recover or dispose of the returned products properly, whilst generating value whenever possible (Blumberg, 2005; Lippman, 2001). ‘Reverse logistics’ begin when a customer returns a unwanted product, in which case it can be re-sold or used to replace faulty products returned under warranty (Kleindorfer et al., 2005). Alternatively, it may be remanufactured and re-marketed through different channels, or its parts can be used as spares for another product (Kleindorfer et al., 2005). Reverse logistics extends this responsibility when the company accepts its previously shipped products for recycling, remanufacturing, reuse or disposal. Thus firms become responsible for products from the ‘cradle to cradle’ (Varma et al., 2006). Waste products and materials can be recycled as an input into the same or a different production process wherever possible or further processing may be required (Gupta, 1995). Reverse logistics extends the concept of the existing supply chains, which can lead to improved economic performance (Jayant et al., 2012). Key factors for implementing reverse logistics are customer support, top-management support, communications, costs, formalisation, timing of operations, and environmental awareness (Huscroft et al., 2013).

‘Recycling’, ‘reuse’, and ‘remanufacturing’ appear in many of the above approaches reviewed, such as reuse in ‘environmental management’, ‘green purchasing’ and ‘reverse logistics’ and remanufacturing in ‘environmental management’. Many of these approaches overlap; however each emphasises a different focus in terms of achieving a reduced negative impact on the environment. A possible integration of these approaches with the consideration of IE and IS principles offers a new way of thinking and potential opportunities among supply chain parties to develop their environmentally sustainable supply chain network more effectively. Therefore, the next sub-section reviews IE and IS and their roles in developing environmentally sustainable supply chains.

2.2 Industrial Ecology, Industrial Symbiosis and environmentally sustainable supply chains

IE considers the ecological aspect when dealing with the interaction and inter-relationship both within industrial systems and between industrial and natural systems (Despeisse et al., 2012; Lombardi and Laybourn, 2012). Interactions within industrial systems are termed ‘technosphere’ exchanges; whilst interactions between industrial and natural systems are termed ‘ecosphere’ exchanges (Despeisse et al., 2012). It is clear that fewer ecosphere exchanges or a reduced amount of exchange produces a lesser impact on the environment. There are three common IE models in the literature: linear IE models, quasi-cyclic IE models, and cyclic resource flow IE models (Graedel, 1994). These three IE models represent three different levels of environmental impact of resource exchanges, from high to low. The linear IE model considers that an industrial system has a strong dependency on natural systems for resources and assumes that natural systems, which are part of the environment, have unlimited capacity to produce resource inputs and assimilate waste outputs. Resource exchanges under this model have the greatest negative impact on the environment. The quasi-cyclic IE model deals with a certain degree of cycled resources in an industrial system; hence this reduces external resource inputs and waste outputs. Hence, negative impact on the environment due to resource exchange by business activities has been reduced. The cyclic IE model consists of the closed circulation of resource usage and exchange within an industrial system, where the sole input to sustain a system is energy. The cyclic IE model represents the ultimate goal of IE where a closed circulation of resources of an industrial system takes place within the technosphere (Chertow, 2000). It represents a total independent industrial system and has zero negative impact on the environment (Chertow, 2000). Working towards a higher level of IE resource exchange supports environmentally sustainable supply chain development. A closed-loop approach can be considered at every phase of a product life cycle, from its design, production, usage, and disposal in order to achieve the overall technosphere exchange within a supply chain network. Developing a total closed-loop of resource flow in a supply chain network requires collaboration among supply chain parties, which is the key principle of IS (Bansal and McKnight, 2009).

IS encourages a collective approach through applying IE principles amongst firms within an extended system (Chertow, 2000; Costa and Ferrão, 2010; Lombardi and Laybourn, 2012). IS was not originally designed for a supply chain environment. However, the principle of IS encourages inter-organisational relationships amongst organisations along a supply chain. IS may assist a supply chain to develop a tighter network through improved relationships amongst supply chain parties to work towards more environmentally friendly activities (Bansal and McKnight, 2009). To distinguish an IS relationship from other types of relationships, the IS relationship must consist of at least three different entities exchanging at least two different resources (Chertow, 2007). Chertow and Ehrenfeld (2012) developed a three-stage model to describe the stages that organisations may experience as they embark on IS. These three stages are 'sprouting', 'uncovering', and 'embeddedness and institutionalisation'. Moving from stage 1 to stage 3 creates a business environment which allows more environmental sustainability activities amongst companies and along their supply chain. Chertow and Ehrenfeld (2012) further developed five IS models characterised by resource exchanges and the level of environment impact. The five IS models are: 'the build and recruit model', 'the planned eco-industrial park model', 'the self-organising symbiosis model', 'the retrofit industrial park model', and 'the circular economy eco-industrial park model', moving from a low to high level in terms of collaboration and environmental-friendliness (Chertow and Ehrenfeld, 2012). The IS principle encourages supply chain parties working towards a high level of collabaration to facilicate environmentally friendly initiatives to be developed and implemented. IS partners discover innovative and mutually beneficial solutions to remove external threats based on the rich exchange of information that result from close relationships (Bansal and McKnight, 2009). The development of IS interactions among supply chain parties also depends on the enabling context of social, informational, technological, economic and political factors. The power of influence is largely determined by agents such as governments, businesses, and coordinating entities (Costa et al., 2010).

Opportunities for organisations to apply IS are no longer limited in geographical proximity (Lombardi and Laybourn, 2012). Location may be useful to create possibilities for firms to work collaboratively towards more environmentally friendly designs, more effective waste management, and beyond (Chertow and Ehrenfeld, 2012). However, the most important factor for developing IS relationships is collaboration amongst organisations, because individual firms cannot implement IS alone (Bansal and McKnight, 2009). IS emphasises the need for community, cooperation and connectedness to work towards a more eco-friendly extended system (Ehrenfeld, 2000). Symbiotic relationships are driven by community initiatives that provide multiple mechanisms to connect partners and develop idiosyncratic and mutually beneficial relationships. With regards to IS in the supply chain perspective, IS requires supply chain parties to improve their coordination mechanism, which results in net environmental benefits, such as major reductions in the total environmental impact (Mattila et al., 2010). IS could effectively improve the competitive advantage of an enterprise and its supply chain in terms of decreased cost and improved environmental performance (Yuan and Shi, 2009). It is achieved through promoting, creating and sharing knowledge amongst supply chain parties in the supply chain network, through improved supply chain configurations by embarking on IS (Ashton, 2008). Thus, implementing IS along a supply chain yields mutual benefits for novel sourcing of required inputs, adds value in destinations for non-product outputs, and improves the performance of a business and its supply chain (Lombardi and Laybourn, 2012).

2.3 Proposition for the initial framework

Despeisse et al. (2012) developed a conceptual model with IE applications at factory level; however, their recource life cycle value analysis model presented resembles a similar structure of a supply chain material flow among different organisations. Therefore, we borrow this structure and incorporate the literature contents regarding IE and IS and environmentally SSCM approaches to propose the initial framework for this research (see Figure 1).

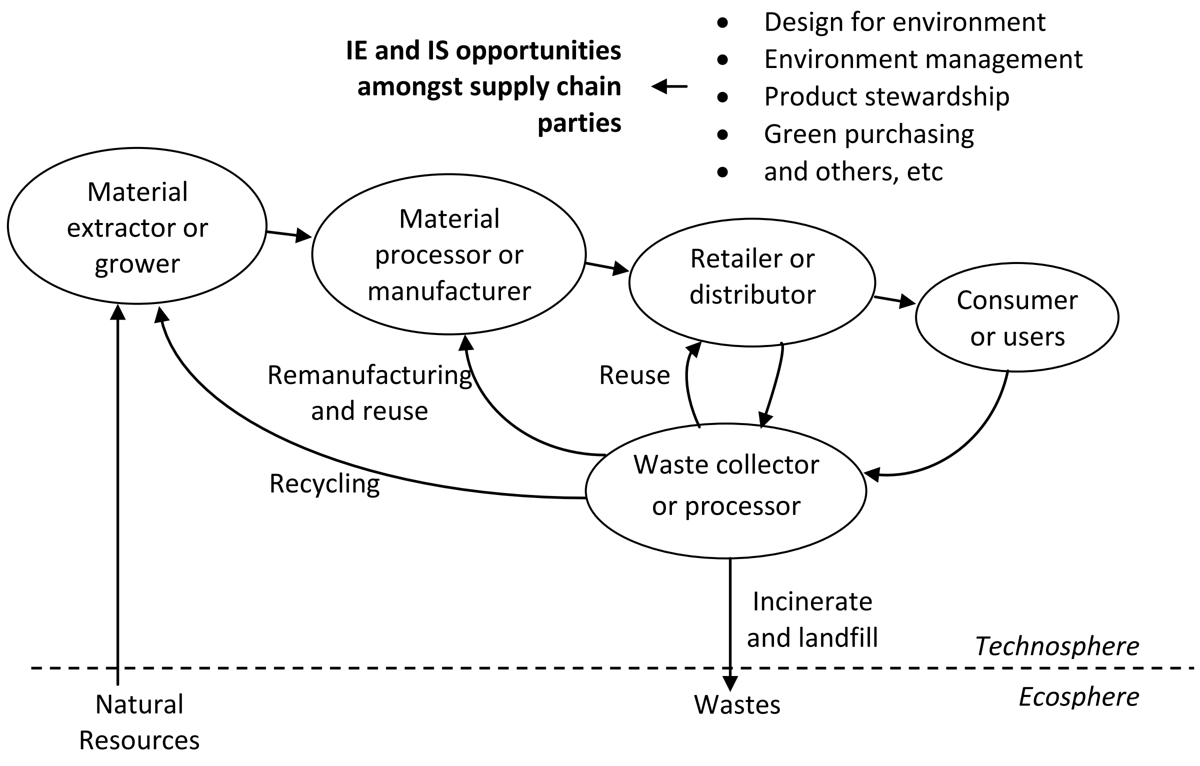

Figure 1 - Supply chain environmentally sustainability development – the initial framework (adopted and developed from Despeisse et al, 2012)

The initial framework illustrates potential opportunities for integrating environmentally SSCM approaches such as design for environment, environmental management, product stewardship, green purchasing, reuse, recycling, and remanufacturing with IE and IS in a supply chain network. The environmentally SSCM approaches may be integrated at different stages of the supply chain network, depending on the operating context of the focal organisation. The detailed integration is illustrated in the final developed framework after the empirical investigation has taken place. The case study method is presented below, followed by an overview of the case study organisation.

3. Methods

A case study was used as it offers an insightful understanding and exploration towards how improvements can be made in a topic area. A single case study was selected as this provides a representative and revelatory opportunity to observe a phenomenon previously inaccessible to a social science inquiry (Yin, 2009). A single case study allows the field to be researched whilst providing illustrative evidence of new developments (Seuring and Müller, 2008). In order to ensure the rigor of the case study method, a five-stage generic research process model identified by Stuart et al. (2002, p. 420) is employed for this study. These five stages are given in Figure 2.

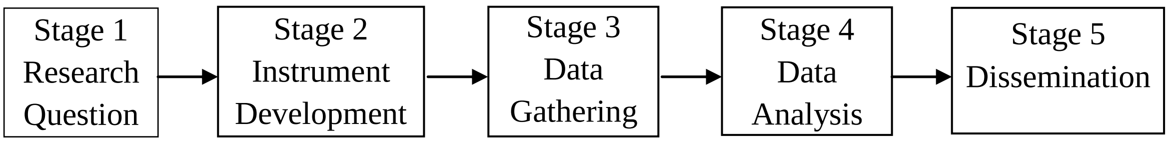

Figure 2 - The five-stage research process model (Stuart et al., 2002, p. 420)

As emphasised by Seuring (2008), this approach may appear to be linear in appearance. However, several stages are often repeated whilst conducting case study research. For example, for this study in particular, stages 3, 4 and 5 were repeated a number of times until a satisfactory result of the developed framework had been achieved. The repetition of stages along this five-stage process ensures the rigor of the case study method in application and allows the theoretical constructs to form to achieve the research aim more profoundly (Seuring, 2008).

Following the five-stage research model (Stuart et al. 2002, p. 420), the objectives of conducting a case study method were defined at stage 1 and the following dimensions were planned in investigation (the case study company is referred as the Company):

- Current environmental initiatives used in the Company.
- Factors impacting on environmental sustainability within the Company's supply chain.
- Environmental aspects of products, materials, service process and packaging offered by the Company.
- Collaborations of the Company with its supply chain partners and the knowledge exchanges and possible improvement by applying the IE and IS principles.
- Opportunities for IS and IE to be integrated into the current environmental sustainability development along its supply chain.

Open-ended interview questions were developed (see Appendix A) and used to collect the information regarding the dimensions listed above, which is in line with stage 2 of the research process model (Stuart et al., 2002, p. 420). The simplicity of interview questions normally generates better results in terms of the data collected, because it allows a better understanding of the phenomena being investigated, where additional questions can be asked later if required, as the process is repeated.

In order for data collection to take place at stage 3, initially face-to-face interviews were carried out with the sustainability director and a distribution centre manager to explore and understand the environmental sustainability policies and initiatives. The interviews were audio recorded and transcribed using word processing software. At stage 4, the initial framework proposed by learning from the literature (see figure 1) was further developed using the interview information and publicly available company documentation. A grounded theory approach (Glaser and Strauss, 1967) was used to analyse the transcriptions to identify concepts, categories, themes, and common factors. A constant comparison technique with the literature was also applied at this stage.

At stage 4, questions were identified requiring further clarification. Additional interviews took place, and the case study process returned to stage 3. Additional interviews collect data to facilitate the continuous development of concepts and categories (Seuring, 2008). The repeated process of data collection, coding, and analysis allows patterns to emerge, as the theory building process starts at early conceptual development stages and continues throughout a study (Partington, 2002). The categories and themes identified were used to develop the conceptual framework to explore further opportunities offered by IE and IS. The completed framework is presented in the discussion section which fits into stage 5 of the case study process model, after the results section.

A single case study has its limitations. The method is particularly limited for generalisation. However, generalisation is not the purpose of this study. A single case study method is useful as it provides feedback for the improvement of a theoretical framework developed from the literature. In the case of qualitative research, reliability and validity are conceptualised as trustworthiness, rigor and quality in the qualitative paradigm (Golafshani, 2003; Lincoln and Guba, 1985; Stenbacka, 2001). In order to ensure the trustworthiness, rigor and quality, a repeated process was applied. In addition, the researchers' interpretations of the data were shared with the participants, who were then given the opportunity to discuss and clarify the interpretation. These provide new and additional perspectives and offer the increased rigor of a study (Baxter and Jack, 2008). Through the evaluation of the organisational inter- and intra-resource flows among the supply chain parties using IE and IS principles, possible improvement opportunities towards its supply chain environmental sustainability improvement have been identified.

4. The Case study Organisation

The Company is a UK leading distributor supplying timber and building materials to trade. It had more than 1,000 distribution centres nationwide and a total of 23 per cent market share in the UK in 2012. The Company offers its customers more than 700,000 products and has tailored logistics. The Company also has a European parent company which was ranked in the Global 100 list of the most sustainable companies in the world in 2009.

Sustainability management is led by the sustainability director, who was appointed because of his understanding of the Company's culture and competence in technological matters. The sustainability director has the full support of the managing director in improving the Company's environmental profile. The environmental initiatives are implemented within the various functional departments in the Company. One of the key roles of the sustainability director is to ensure decision makers involved in functional activities of the business, such as transportation and procurement, include 'environmental consideration' in their decision-making processes and final decisions. Table 2 summarises the Company's environmental development history since 2003, when environmental sustainability development was first considered to be on the agenda.

Date	Environmental sustainability development history
2003-2005	• Environmental sustainable development strategies were included in the Company's agenda. • The Company was reactive towards meeting the governmental legislations.
2006-2008	• Environmental sustainability was included in the Company's policy and presented in a single sheet format. Within this policy, environmental sustainability was mentioned specifically regarding the reduction of the business impact on the environment. • The introduction of ISO14000 and ISO14001 environmental management system (EMS). • An environmentally sustainable-oriented culture was developing.
2009-2013	• ISO 14000 and ISO14001 EMS were accredited through all distribution centres within the Company. • Continuously developing the environmental sustainable-oriented culture. • A set of initiatives regarding reuse and recycling through working with the waste management provider were implemented. • Energy and water saving initiatives were implemented in distribution centres. • Some performance indicators were used in monitoring the environmentally sustainable actions of distribution centres.
2013-	• Implementing proactive approaches to meet government legislation. • Developing close relationships with suppliers to identify possible environmentally friendly designs for products. • Working closely with the waste management provider to reduce waste • Transport logistics route planning is in practice. • Energy and carbon reduction initiatives implementation in distribution centre was continuing to reduce energy and water usage.

Table 2: The timeline of the environmental sustainability development of the Company

The Company has adopted proactive approaches compared to a decade ago, such as searching for new ways to save energy and increase recycling and reuse activities. However the Company realises that there are many areas which still need to be addressed, particularly working more closely with its suppliers and customers to identify new areas to develop more environmentally friendly products, services and processes. The Company is used as the case study organisation for this study to verify and further develop the initial framework proposed based on the literature (see Figure 1).

5. Results

This section presents the Company's initiatives and explores the role of these initiatives in the Company's environmental supply chain development. This leads to a discussion as to how IE and IS can contribute to the further development of the Company's environmental supply chain in the next section. The Company's current key environmental sustainability development initiatives are explained below.

The organisation currently operates a certified ISO14001 EMS. This system is used to manage the environmental performance of each of the Company's distribution centres (see Figure 3). This ensures the ownership of environmental sustainability and encourages cultural change at the distribution centre level. The Company intends to integrate key performance indicators from ISO50001 into its EMS. To certify the ISO14001 EMS, consideration towards legislation, benchmarking, innovation and the Company's public brand image was taken into account. This was used to develop the environmental sustainability policies and strategies which include the key objectives and success factors for the EMS (Li and Leigh, 2010).

The utilities, which include gas, electricity, and water, are currently being monitored using systems supplied by control system companies. A monthly report is produced to analyse the performance of the distribution centres of the Company on a case-by-case basis. This is to ensure that all locations are achieving the optimum usage of utilities. The control systems are managed using a real-time web-based monitoring system (see Figure 3). In the case of the heating system, it is possible to measure both the internal and external temperatures to allow the measurement of the thermal insulation capacity of the building. When a distribution centre is considered to have used more utilities than necessary, a baseline analysis is employed to determine if a distribution centre is operating as efficiently as possible. This has produced savings of 5,961,433 Kwh from the first 120 distribution centres, which equates to 1,101 tonnes of CO_2.

The Company compiles with the European Waste Directive and currently uses the European Waste Hierarchy (EWH) in order to adhere to the directive (Department for Environment, 2014). The EWH consists of five distinct hierarchies to guide companies to manage their wastes. An additional hierarchy 'reduction' has been included in this study to emphasise reduction in consumption through improved efficient processes. The six distinct hierarchies used for this study therefore include, '1-prevention', '2-reduction', '3-preparation for reuse', '4-recycling', '5-other recovery', and '6-disposal'. Prevention represents the top level because it has the greatest outcomes on the reducing negative impact on the environment. Disposal is the lowest in the hierarchy and should be considered only as a last resort.

All wastes are handled by the Company's waste management provider, which is a third party company specialising in waste management. In the past, the Company's distribution centres had some control over their own waste streams which resulted in different approaches being operated across the country and performance between distribution centres was incomparable. Now the Company deals with a single waste management provider exclusively, which gives more effective and comparable results. Waste to landfill has been reduced by 65 per cent (11,256 tonnes). This has produced financial savings of circa £3.5m per year, CO_2 savings of 240 tonnes from diesel (176,581 miles), 1,288 tonnes from timber (3.68kg per pallet) and a total reduction 1,528 tonnes of CO_2 emissions. Thus, these recyclable wastes remain in the technosphere. Some non-recyclable wastes are being used as a fuel source for generating electricity, which the Company purchases from the waste management provider company at a reduced price rate. In the future, the Company aims to achieve zero waste to landfill in order to completely avoid disposal.

The Company makes great efforts to ensure the quality of products. This reduces the possibility of the Company and its suppliers wasting natural resources. Efforts are made to reduce excessive packaging as packaging is considered to be a 'necessary evil'. In most cases, the Company has achieved an optimised packaging level as further reduction may result in damaged products and hence unhappy customers. All packaging is now 100% recyclable. An analyst is employed to record the material content in all packaging. At present the Company is engaging with its major suppliers along the supply chain to minimise the environmental impact of packaging. They use the Pareto analysis technique to determine the priority for modifying packaging that has the highest impact on the environment. With the anticipation that upstream suppliers would save packaging costs and downstream customers would have less waste to manage, the implementation of these initiatives achieves both the reduced environmental impact and cost saving.

In some cases, clean damaged stock was returned to the manufacturers for remanufacturing (see Figure 3). Special cases existed where obsolete products were returned to the original manufacturers to become reused as an input into producing other products. The main motive for this was that the obsolete products no longer carried any market value and the reuse of the obsolete product avoided the cost of landfill. As part of this process, transportation planning was utilised for the returning process, which under normal circumstances transportation vehicles would have been empty on their return journeys. Thus, the need to facilitate additional transport was not required. The EMS was instrumental in highlighting these waste products that would have previously been dealt with at the distribution centre level, but are now managed at the company level. An example of this is when surplus block paving was converted into type 1 hard-core, which resulted in more than four thousand tonnes of material avoiding being sent to landfill in this instance. The Company takes into account the cost in disposing wastes before negotiating with its supplying manufacturers in order for these products to be reused as raw materials in future production where possible.

The Company uses a logistics software package that calculates the closest dispatch point regardless of the distribution centre where the orders are made. This has reduced the average distance of a delivery to eight miles per customer, resulting in reduced delivery mileage by 16 per cent which equates to 820,000 miles and 806 tonnes of CO2 over a year. This application has reduced CO2 emissions significantly (see Figure 3).

The Company operates an innovative pallet-return scheme where the Company collects pallets from their customers' sites and distribution centres using the Company's logistics systems. So far, three hundred and fifty thousand pallets have been recovered and put back into the supply chain, saving seven thousand tonnes of timber per year. These collected pallets are transported to a reverse logistics packaging company that reconditions and redistributes them (see Figure 3). There are other opportunities for taking back of other clean wastes for recycling from customer sites. However, it is impossible under the current regulation that restricts any activities of this nature, for example, collecting unused masonry and concrete blocks.

The Company currently has a disposal arrangement in place with its customers, which is managed by a partner organisation. This allows customers to take their Waste Electrical and Electronic Equipment (WEEE) to specified sites across the UK, so that this type of waste can be disposed of in accordance with the WEEE directive. The Company also use a partner company to dispose of its internal WEEE (see Figure 3).

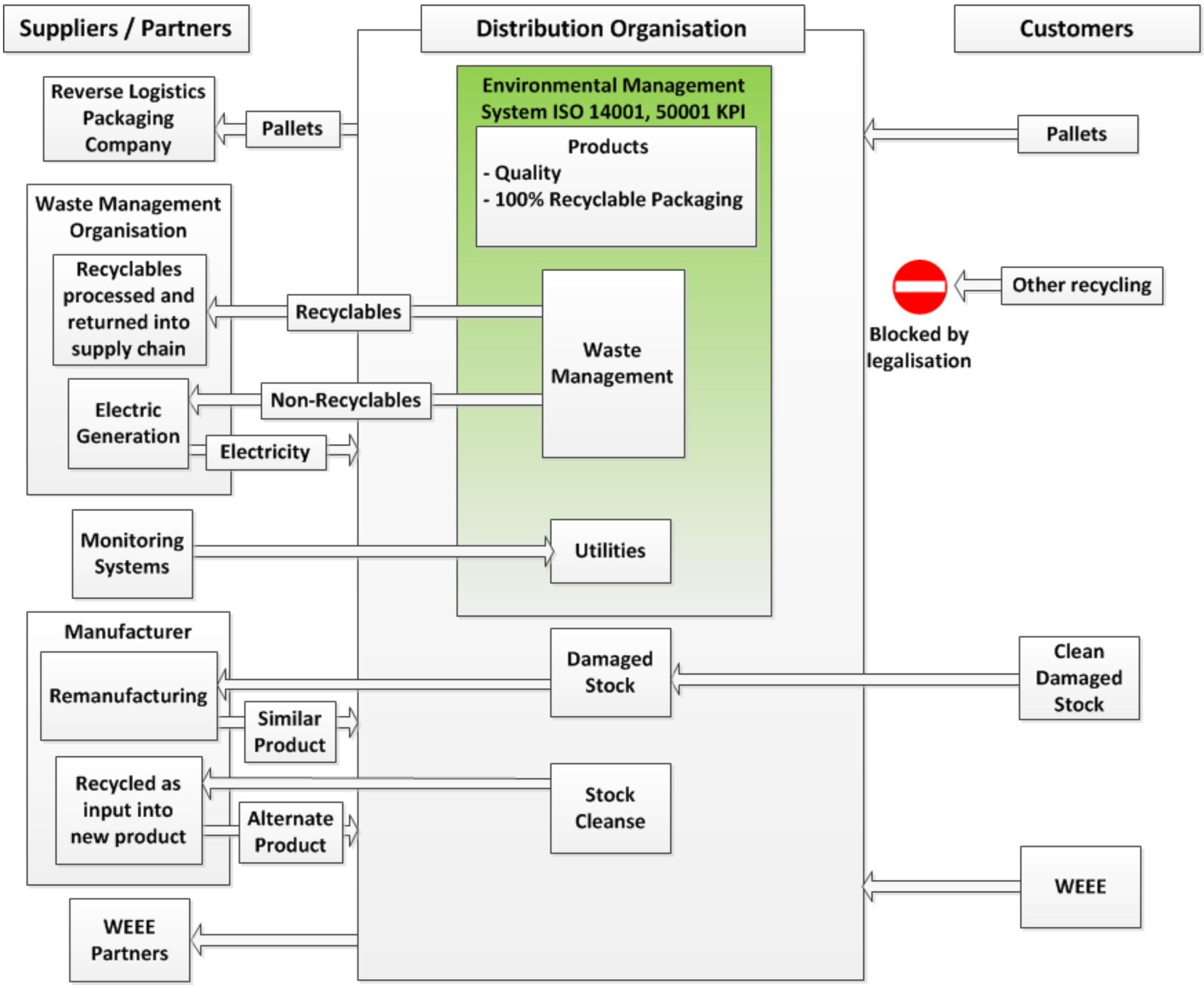

Figure 3 – The case study company supply chain exchanges

The Company is committed to environmental sustainability. However, it was emphasised during the interviews that it must remain focused on its core business objectives. In order to meet these objectives, the Company welcomes any partner relationships that add value to the business while at the same time improve its environmental sustainability development. Partner companies provide control equipment, expertise, and real time data for waste reduction, control and prevention which have a considerable impact on the reduction of the use of the Company's valuable resources (see Figure 3). The changes in environmental legislation, for example landfill and CO2 emission tax, are still significant driving forces for the Company to focus on environmentally sustainable issues. Due to these legislative changes, wastes are seen as much more costly to the Company as most types of company waste have no residual value and thus must be reduced where possible.

The Company has also changed its strategy from a reactive approach to a proactive one by reusing and recycling products and materials wherever possible. In some cases, this has added value to the business by integrating environmental behaviour into its supply network; but this only occurs serendipitously at present (van Hoek, 1999). Environmental sustainability has become an important part of the Company strategy because of the cost savings achieved by implementing these initiatives and working with waste management partner companies. Cost savings have increased profit without the need of increasing sales.

The Company aims to employ a holistic view in dealing with wastes produced, from products and materials sourced and sold to processes and facilities used to store and distribute them. To some extent, the Company is working towards a closed-loop approach within the Company by using the shortest path whenever possible through reuse, remanufacturing, and recycling activities. This approach can be further applied to its sustainability development along the Company's supply chain, which requires a full integration amongst its suppliers, customers, and other partner organisations working on environmental related issues.

Closer collaboration between the Company, its suppliers, customers, and end users may provide further opportunities to prevent waste generation and recycle and remanufacture clean wastes. This can be further enhanced by the assistance of the waste management provider and environmental partners. These activities actually contribute to the Company's core business objectives.

6. Discussion

Presently the resource exchange for anything other than waste disposal takes place randomly when an opportunity arises in the Company and along its supply chain. The majority of the environmental management initiatives evidenced in the case study consist of reactive end of pipeline technology approaches (Vachon and Klassen, 2006), such as reuse and recycling. The production processes and product designs associated with 'integrated production process innovation' remain little changed. 'Environmental R&D' has not been taken into sufficient consideration along the supply chain. A value seeking approach to environmental development of products, services, process and supply chain network needs to be integrated into business strategy (van Hoek, 1999), in order to achieve more desirable results.

The Company fits in a quasi-cyclic model in terms of IE application. The model represents the middle level of the three-level IE models by Graedel (1994). This is because some activities relating to reuse, recycle and remanufacturing of returned products and wastes are taking place to avoid their disposal into the ecosphere. In terms of IS application, the Company is at the 'sprouting stage', the earliest stage of the three stages defined by Chertow and Ehrenfeld (2012). The organisations involved are economically motivated to exchange resources to meet targets specified in governmental regulations, cost reduction and revenue enhancement. This is a 'self-organising symbiosis model', where resource exchanges need to be financially viable before considering the environmental contribution (Chertow and Ehrenfeld, 2012). The environmentally sustainable supply chain of the Company can be further developed by moving towards a further application of IE and IS models. In order for companies to achieve a higher level of environmental sustainability development, we have applied IE and IS into the adapted EWH (Department for Environment, 2014). EWH is closely associated with IS and IE principles and these key points are summarised in Table 3.

EWH	Explanations	Possible alignments of IE and IS within the Company
1- Prevention	Product designs that use less raw and hazardous materials, and consider possible reuse and remanufacturing at the end of product life cycles. Improve supply chain network design to utilise a reduction in resource exchanges	Yes, great opportunity for IE application. This requires collaboration along the supply chain parties (IS). The emphasis is placed on the design stage. Designers and manufacturers must work closely (IS) in order to create innovative ideas for the design of a product, services, processes and supply chain network design. The Company currently has not integrated this into its supply chain.
2- Reduction	Reduce consumption via the use of business initiatives for improved process efficiency; use intelligent monitoring systems.	Yes, IE principle is applicable in terms of reduced consumption of natural resources and energy. Benchmarking can be applied within a company and across its supply chain partners (IS) to identify areas for improvement. The Company uses (1) an intelligent monitoring system to monitor its distribution centres' utilities usage; (2) better route planning is used to avoid empty journeys where possible and reduce the total overall mileage covered by delivery vehicles.
3- Preparing for reuse	Check, clean, repair, refurbish either a whole item or its parts	Yes, reduces ecosphere exchange (IE) and a great opportunity for up-cycling and down-cycling to take place (IS). The Company's pallet return scheme allows reuse by integrating the used pallets back into the supply chain.
4- Recycling	Turn waste into a new substance or product, including composting if it meets quality requirement	Yes, a great opportunity for IS and also under the principle of IE because recycled materials rather than new materials from ecosphere are re-integrated into the supply chain. The Company works with its suppliers, manufacturers and waste management provider to ensure wastes are recycled when possible.
5- Other recovery	Include anaerobic digestion, incineration, gasification and pyrolysis which produce energy and materials from wastes.	Yes, great opportunity for IS and also under the principle of IE by recovering energy and materials related to natural resources. The Company is working with its waste management provider to generate electricity from all types of waste that cannot currently be managed by the methods in the first four levels of the hierarchy.
6- Disposal	Landfill and incineration without energy recovery	To be avoided. This is possible with greater effort applied to implementing the first five levels of the hierarchy. The Company has reduced its waste to landfill by 65 per cent and aims to achieve zero waste to landfill.

Table 3 - Applications of IE and IS using different methods for achieving an environmentally sustainable supply chain (developed based on the adapted version by the Department for Environment, 2014)

The hierarchy emphasises the importance of the prevention and reduction of the use of resources. Methods used for prevention and reduction are preferred because they have a more profound impact on the total reduction of the negative impact on the environment than the lower level methods. This also reduces the total amount of wastes which are needed to be handled at the later stages. IS creates additional opportunities for material exchanges to take place using new approaches to recycling, reuse, remanufacturing, and other recovery. The Company has implemented many initiatives from hierarchies 2 to 5. But the prevention through design or re-design by working with customers and suppliers has not currently been considered.

Environmentally SSCM approaches reviewed in the literature and identified within the case study also have direct links with EWH. Table 4 summarises how these environmentally SSCM approaches can be related to the EWH. Eight approaches have been included in Table 4. The first six all consider prevention and reduction. The last two focus on recycle and reuse approaches. The best course of action should focus on prevention and reduction approaches which have fundamental and long-term impact, thus reducing the requirements for reuse, recycle, and remanufacturing of products and wastes. Implementing effective environmental initiatives in prevention and reduction is more desirable. This leads to a reduction in the amount of materials needed for producing products in the first place, and also the amount of energy and water required as well. Most significantly, this produces less waste at the end of the supply chain. If wastes are generated, they need to be integrated as an input into other processes or remanufactured or recycled as the second option. In turn this reduces expenses and requirement for extracting additional raw materials from the ecosphere (Ishii et al., 1994). Without cooperation leading to information and benefit sharing along the supply chain partners, this would not be possible. Supply chain parties need to adopt a holistic view to their supply chain environmental sustainability development in order to effectively reduce the total waste of a supply chain returned to the ecosphere.

Environmentally SSCM approaches	Waste management hierarchy for the application (refer to table 2)	Key application attributes associated with the approach
Design for Environment	Prevention (1), reduction (2), preparing for re-use (3), recycling (4), other recovery (5)	Product, process and supply chain design, with consideration of reduced environment impacts, including products and packaging designed to be durable, reusable, recoverable, recyclable and disassemble; and process and supply chains designed to facilities these and consuming less natural resources.
Product Stewardship	Prevention (1), reduction (2), preparing for re-use (3), recycling (4)	Traceable liability of a product in its life cycle, creating the 'cradle to cradle' responsibility of a product to encourage supply chain parties to work towards keeping all part of a product within a closed-loop cycle.
Green Purchasing	Prevention (1), reduction (2), preparing for re-use (3), recycling (4), other recovery (5)	Logical and technological integration with suppliers through collaboration to strengthen environmentally friendly activities. Consideration towards achieving the maximum utilisation of reusable products, parts or materials. Emphasis on building relationships with suppliers for a greener supply process.
EMS: ISO 14001, 50001	Prevention (1), reduction (2)	Systematically managing environmental related activities to ensures environmental sustainability performance, encouraging cultural change within the business.
Environmental Management: Value seeking integration	Prevention (1), reduction (2), preparing for re-use (3), recycling (4), other recovery (5)	Adopting a holistic value seeking supply chain management strategy. Working with manufacturers to improve the use of existing logistical processes. Recovering clean wastes from customers. Improving logistical and distribution route plans through the use of software packages.
Environmental Management: proactive reuse and recycle	Prevention (1), reduction (2), preparing for re-use (3)	Product packaging optimised to the 100% recyclable. Return of obsolete and clean damaged goods to manufacturers for remanufacturing and reuse.
Environmental Management: end-of-pipe pollution control / Waste Management System	Recycling (4), other recovery (5), disposal (6)	The employment of a waste management provider to reduce wastes to landfill to increase recycling, and. non-recyclable wastes as a fuel source to generate electricity.
Reverse Logistics	Preparing for re-use (3), recycling (4), other recovery (5)	Handling of returned products and the use of WEEE. Re-marketing products returned, with replaced faulty parts through different existing channels. is Employing a partner company for WEEE operation.

Table 4 – Approaches of integrating IE and IS into environmentally SSCM

With the consideration of the case study analysis and discussions along with the relevant literature, the conceptual framework which integrates IS and IE in a supply chain network is proposed (see Figure 4). The framework illustrates the possible relationships between customers or end users, retailers or distributors, material processors or manufacturers and material extractors or growers. In this framework, retailers or distributors have an important role to play because they are considered at the centre of the network. Opportunities for the consideration of both IE and IS are identified in the conceptual framework. The prevention and reduction methods have been highlighted in the framework with bold lines. Supply chain partners need to focus on methods for achieving improved product and process design and a reduced need for new materials by working collaboratively. In these prevention and reduction-related approaches, IE creates a core element of these approaches; however IS must be present in order to successfully generate effective approaches among supply chain parties to their implementation.

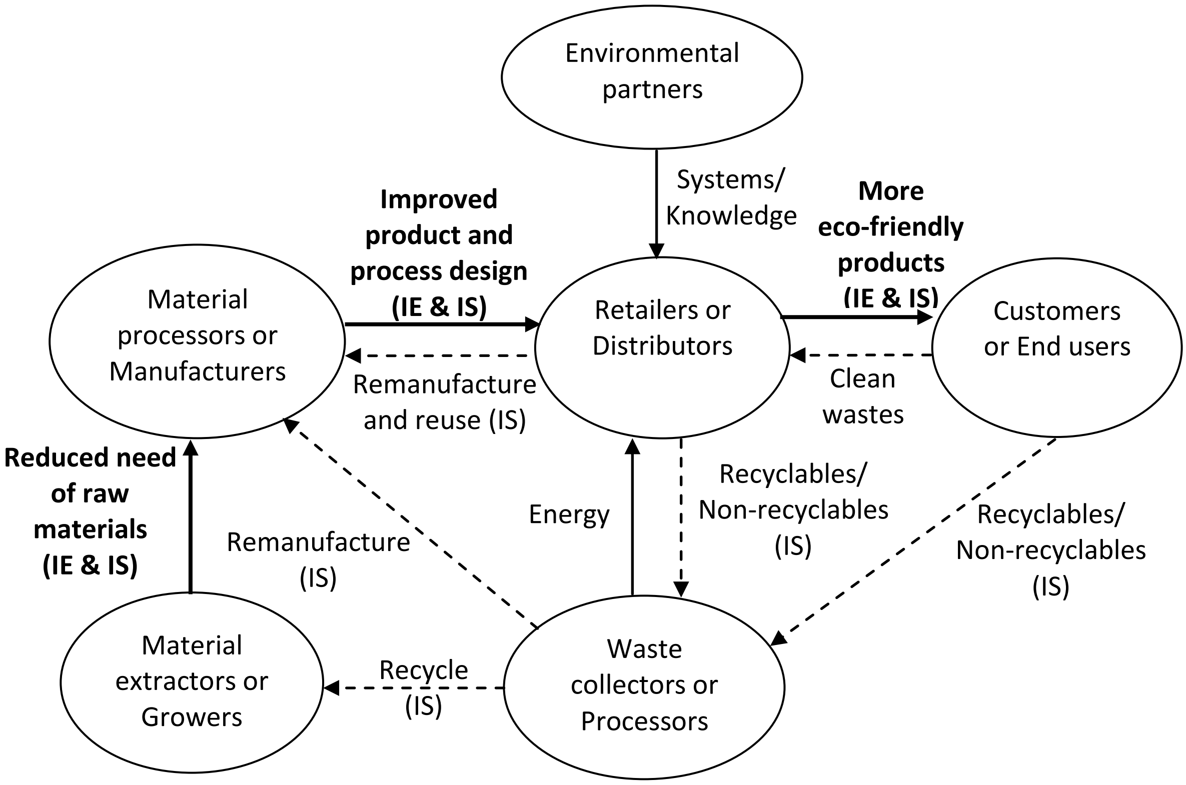

Figure 4 – A conceptual framework for IE and IS implementation into environmentally SSCM

The framework considers the critical role of waste collectors or processors which are not normally presented in a supply chain network as one of supply chain parties. Waste collectors and processors provide more opportunities for recycling, reuse, and remanufacturing. These opportunities are illustrated by the dotted lines, where IS is present. As reviewed in the literature, IS considers the core element of IE, the ecological metaphor, into its concept. Hence all the IS activities presented in the conceptual framework actually contain the IE elements as well. The relationship between customers and waste collectors/processors is the only relationship which is outside of the control of the supply chain.

A collective system or a lifecycle approach needs to be adopted between supply chain activities in order to promote IE and IS applications along a supply chain, and encourage the implementation of these approaches at the earlier stages of the hierarchy. Equally coordinated ownership amongst all parties involved needs to be established. The critical question is how to achieve such desirable supply chain collaboration. Further research needs to be undertaken to understand how this can be co-ordinated and what is required to avoid the premature return of products or materials to the ecosphere.

7. Conclusions

This paper has explored IE, IS and environmentally SSCM approaches in relation to supply chain environmental sustainability development. An initial framework was proposed which considered the possible integration of IE and IS within environmental SSCM approaches. A case study of a large UK distributor has been conducted to facilitate the final development of the conceptual framework. The case study company have implemented a set of environmental sustainability initiatives. The analyses of these initiatives and their relationships with the waste management hierarchy ranged from ‘prevention’, ‘reduction’, to ‘disposal’, this indicates the importance of the approaches associated with ‘prevention’ and ‘reduction’. All waste management approaches are useful in avoiding disposal at the end of a supply chain. This is particularly consistent with IE and IS principles in terms of achieving a closed-loop of material exchanges through collaboration amongst supply chain parties. These results are incorporated into the developed conceptual framework which is the aim of this study.

The conceptual framework highlights the critical role of retailers and distributors in a supply network in achieving its environmental sustainability. The framework emphasises the importance of initiatives associated with ‘reduced need of raw materials’, ‘improved product and process design’ and ‘more eco-friendly products’. These initiatives reflect the integration of IE and IS into a supply chain network. Developing and implementing these initiatives can profoundly reduce the negative impact on the environment. IS and IE supports the development of these actions and their implementation. The framework illustrates the integration of both of IE and IS in order to avoid the final disposal stage in the waste management hierarchy. This research contributes to the environmentally SSCM literature through the developed framework which integrates IS and IE into a supply chain context. The framework can also be used by researchers and practitioners who are interested in environmentally sustainable supply chain development across different industries. It may also be used by companies that wish to consider applying IS and IE into their environmentally sustainable supply chain development. The framework can help companies become more confident in achieving their environmental targets and developing a more environmentally friendly supply chain. In addition, further research can also be conducted based on this framework to understand how different wastes dealt by waste management providers and processors can be managed in a more environmentally friendly way.

Companies that pay attention to environmental sustainability development along their supply chains can gain competitive advantages over rival companies. The experience of the case study company confirmed that cost savings made by implementing environmental sustainability development initiatives improved its environmental performance as well its profitability. Further research is required to investigate how closer collaboration amongst supply chain parties can be established to support the development of detailed action plans for the application of IE and IS at the highest level of the waste management hierarchy.

References

Agarwal, R., Thiel, M., 2012. IBM's environmental management system supplier requirements: corporate responsibility performance or deviation? Int. J. Bus. Glob. 9, 225–235.

Andersen, M., Skjoett-Larsen, T., 2009. Corporate social responsibility in global supply chains. Supply Chain Manag. An Int. J. 14, 75–86. doi:10.1108/13598540910941948

Andiç, E., Yurt, Ö., Baltacıoğlu, T., 2012. Green supply chains: Efforts and potential applications for the Turkish market. Resour. Conserv. Recycl. 58, 50–68. doi:10.1016/j.resconrec.2011.10.008

Ashby, A., Leat, M., Hudson-Smith, M., 2012. Making connections: a review of supply chain management and sustainability literature. Supply Chain Manag. An Int. J. 17, 497–516. doi:10.1108/13598541211258573

Ashton, W., 2008. Understanding the organization of industrial ecosystems. J. Ind. Ecol. 12, 34–51. doi:10.1111/j.1530-9290.2008.00002.x

Ayres, R., Ayres, L., 2002. A handbook of industrial ecology. Edward Elgar Publishing Ltd, Cheltenham UK.

Bansal, P., McKnight, B., 2009. Looking forward, pushing back and peering sideways: analyzing the sustainability of industrial symbiosis. J. Supply Chain Manag. 45.

Baxter, P., Jack, S., 2008. Qualitative case study methodology: Study design and implementation for novice researchers. Qual. Rep. 13, 544–559.

Bevilacqua, M., Ciarapica, F.E., Giacchetta, G., 2012. Design for Environment as a Tool for the Development of a Sustainable Supply Chain. Springer, London.

Blumberg, D.F., 2005. Introduction to management of reverse logistics and closed loop supply chain processes. CRC Press, London.

Boons, F., 2008. Self-organization and sustainability: The emergence of a regional industrial ecology. Emerg. Complex. Organ. 10, 41–48.

Carter, C.R., Rogers, D.S., 2008. A framework of sustainable supply chain management: moving toward new theory. Int. J. Phys. Distrib. Logist. Manag. 38, 360–387. doi:10.1108/09600030810882816

Chertow, M., Ehrenfeld, J., 2012. Organizing self-organizing systems. J. Ind. Ecol. 16, 13–27. doi:10.1111/j.1530-9290.2011.00450.x

Chertow, M.R., 2000. Industrial symbiosis: Literature and taxonomy. Annu. Rev. energy Environ. 25, 313–337.

Chertow, M.R., 2007. "Uncovering" industrial symbiosis. J. Ind. Ecol. 11, 11–30. doi:10.1162/jiec.2007.1110

Costa, I., Ferrão, P., 2010. A case study of industrial symbiosis development using a middle-out approach. J. Clean. Prod. 18, 984–992. doi:10.1016/j.jclepro.2010.03.007

Costa, I., Massard, G., Agarwal, A., 2010. Waste management policies for industrial symbiosis development: case studies in European countries. J. Clean. Prod. 18, 815–822. doi:10.1016/j.jclepro.2009.12.019

Darnall, N., Jolley, G., Handfield, R., 2008. Environmental management systems and green supply chain management: complements for sustainability? Bus. Strateg. Environ. 18, 30–45.

Department for Environment, 2014. Waste legislation and regulations - Detailed guidance - GOV.UK [WWW Document]. URL https://www.gov.uk/waste-legislation-and-regulations (accessed 5.21.14).

Despeisse, M., Ball, P.D., Evans, S., Levers, a., 2012. Industrial ecology at factory level – a conceptual model. J. Clean. Prod. 31, 30–39. doi:10.1016/j.jclepro.2012.02.027

Deutz, P., Gibbs, D., 2008. Industrial ecology and regional development: Eco-industrial development as cluster policy. Reg. Stud. 42, 1313–1328. doi:10.1080/00343400802195121

Duchin, F., Levine, S.H., 2013. Embodied resource flows in a global economy. J. Ind. Ecol. 17, 65–78. doi:10.1111/j.1530-9290.2012.00498.x

Ehrenfeld, J.R., 2000. Industrial ecology: paradigm shift or normal science? Am. Behav. Sci. 44, 229–244. doi:10.1177/0002764200044002006

Frankel, R., Bolumole, Y.A., Eltantawy, R.A., Paulraj, A., Gundlach, G.T., 2008. The domain and scope of SCM's foundational disciplines, insights and issues to advance research. J. Bus. Logist. 29, 1–30.

Glaser, B.G., Strauss, A.L., 1967. The Discovery of Grounded Theory: Strategies for Qualitative Research. Aldine de Gruyter, New York.

Golafshani, N., 2003. Understanding reliability and validity in qualitative research. Qual. Rep. 8, 597–607.

Gold, S., Seuring, S., Beske, P., 2010. Sustainable supply chain management and inter-organizational resources: a literature review. Corp. Soc. Responsib. Environ. Manag. 17, 230–245.

Goodland, R., 1995. The concept of environmental sustainability. Annu. Rev. Ecol. Syst. 26, 1–24.

Graedel, T., 1994. Industrial Ecology: definition and implementation, in: Socolow, R., Andrews, C., Berkhout, F., Thomas, V. (Eds.), Industrial Ecology and Global Change. Cambridge University Press, Cambridge, pp. 23–41.

Green, K.W.J., Zelbst, P.J., Meacham, J., Bhadauria, V.S., 2012. Green supply chain management practices: impact on performance. Supply Chain Manag. An Int. J. 17, 290–305. doi:10.1108/13598541211227126

Grekova, K., Bremmers, H.J., Trienekens, J.H., Kemp, R.G.M., Omta, S.W.F., 2014. Extending environmental management beyond the firm boundaries: An empirical study of Dutch food and beverage firms. Int. J. Prod. Econ. 152, 174–187. doi:10.1016/j.ijpe.2013.12.019

Gupta, M.C., 1995. Environmental management and its impact on the operations function. Int. J. Oper. Prod. Manag. 15, 34–51.

Handfield, R., Nichols, E., 1999. Introduction to supply chain management. Prentice Hall, New Jersey.

Huscroft, J., Hazen, B., Hall, D., Skipper, J., Hanna, J., 2013. Reverse logistics: past research, current management issues, and future directions. Int. J. Logist. Manag. 24, 304–327. doi:10.1108/IJLM-04-2012-0024

Ishii, K., Eubanks, C., Marco, P. Di, 1994. Design for product retirement and material life-cycle. Mater. Des. 15, 225–233.

Jayant, A., Gupta, P., Garg, S.K., 2012. Reverse logistics: Perspectives, empirical studies and research directions. Int. J. Ind. Eng. 19, 369 – 388.

Kleindorfer, P., Singhal, K., Van Wassenhove, L., 2005. Sustainable operations management. Prod. Oper. Manag. 14, 482–492.

Kuik, S.S., Nagalingam, S.V., Amer, Y., 2011. Sustainable supply chain for collaborative manufacturing. J. Manuf. Technol. Manag. 22, 984–1001. doi:10.1108/17410381111177449

Kurk, F., Eagan, P., 2008. The value of adding design-for-the-environment to pollution prevention assistance options. J. Clean. Prod. 16, 722–726. doi:10.1016/j.jclepro.2007.02.022

Lee, S.-Y., Rhee, S.-K., 2005. From end-of-pipe technology towards pollution preventive approach: the evolution of corporate environmentalism in Korea. J. Clean. Prod. 13, 387–395. doi:10.1016/j.jclepro.2003.10.010

Lewis, H., 2005. Defining product stewardship and sustainability in the Australian packaging industry. Environ. Sci. Policy 8, 45–55. doi:10.1016/j.envsci.2004.09.002

Li, X., Leigh, S., 2010. Integrating environmental management system with environmental performance evaluation across the supply chain: a systematic and balanced scorecard approach. Knowl. Collab. Learn. Sustain. Innov. ERSCP-EMSU Conf. Delft, Netherlands 1–28.

Lincoln, Y.S., Guba, E.G., 1985. Naturalistic inquiry. Sage, Beverly Hills, CA.

Lippman, S., 2001. Supply chain environmental management. Environ. Qual. Manag. 11, 11–14. doi:10.1002/tqem.1301

Lombardi, D.R., Laybourn, P., 2012. Redefining industrial symbiosis. J. Ind. Ecol. 16, 28–37. doi:10.1111/j.1530-9290.2011.00444.x

Loomba, A.P.S., Nakashima, K., 2012. Enhancing value in reverse supply chains by sorting before product recovery. Prod. Plan. Control 23, 205–215. doi:10.1080/09537287.2011.591652

Mattila, T.J., Pakarinen, S., Sokka, L., 2010. Quantifying the total environmental impacts of an industrial symbiosis - a comparison of process-, hybrid and input-output life cycle assessment. Environ. Sci. Technol. 44, 4309–4314. doi:10.1021/es902673m

Mutingi, M., 2014. The impact of reverse logistics in green supply chain management: a system dynamics analysis. Int. J. Ind. Syst. Eng. 17, 186–201.

Nawrocka, D., Brorson, T., Lindhqvist, T., 2009. ISO 14001 in environmental supply chain practices. J. Clean. Prod. 17, 1435–1443. doi:10.1016/j.jclepro.2009.05.004

Partington, D., 2002. Grounded Theory, in: Partington, D. (Ed.), Essential Skills for Management Research. SAGE, Thousand Oaks, CA, pp. 136–157.

Rogers, D.S., Rogers, Z.S., Lembke, R., 2010. Creating value through product stewardship and take back. Sustain. Accounting, Manag. Policy J. 1.

Röser, D., Sikanen, L., Asikainen, A., Parikka, H., Väätäinen, K., 2011. Productivity and cost of mechanized energy wood harvesting in Northern Scotland. Biomass and Bioenergy 35, 4570–4580. doi:10.1016/j.biombioe.2011.06.028

Rusinko, C., 2007. Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. IEEE Trans. Eng. Manag. 54, 445–454.

Sarkis, J., 1995. Supply chain management and environmentally conscious design and manufacturing. Int. J. Environ. Conscious Des. Manuf. 4, 43–52.

Sarkis, J., Zhu, Q., Lai, K., 2011. An organizational theoretic review of green supply chain management literature. Int. J. Prod. Econ. 130, 1–15. doi:10.1016/j.ijpe.2010.11.010

Seuring, S., 2004. Industrial ecology, life cycles, supply chains: Differences and interrelations. Bus. Strateg. Environ. 13, 306–319. doi:10.1002/bse.418

Seuring, S. a., 2008. Assessing the rigor of case study research in supply chain management. Supply Chain Manag. An Int. J. 13, 128–137. doi:10.1108/13598540810860967

Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 16, 1699–1710. doi:10.1016/j.jclepro.2008.04.020

Simpson, D.F., Power, D.J., 2005. Use the supply relationship to develop lean and green suppliers. Supply Chain Manag. An Int. J. 10, 60–68. doi:10.1108/13598540510578388

Snir, E.M., 2009. Liability As a Catalyst for Product Stewardship. Prod. Oper. Manag. 10, 190–206. doi:10.1111/j.1937-5956.2001.tb00078.x

Soylu, K., Dumville, J.C., 2011. Design for environment: The greening of product and supply chain. Marit. Econ. Logist. 13, 29–43. doi:10.1057/mel.2010.19

Spekman, R.E., Kamauff Jr, J.W., Myhr, N., 1998. An empirical investigation into supply chain management: a perspective on partnerships. Supply Chain Manag. An Int. J. 3, 53–67. doi:10.1108/13598549810215379

Stenbacka, C., 2001. Qualitative research requires quality concepts of its own. Manag. Decis. 39, 551–556. doi:10.1108/EUM0000000005801

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R., Samson, D., 2002. Effective case research in operations management: a process perspective. J. Oper. Manag. 20, 419–433. doi:10.1016/S0272-6963(02)00022-0

Tsoulfas, G.T., Pappis, C.P., 2006. Environmental principles applicable to supply chains design and operation. J. Clean. Prod. 14, 1593–1602. doi:10.1016/j.jclepro.2005.05.021

Vachon, S., Klassen, R.D., 2006. Green project partnership in the supply chain: the case of the package printing industry. J. Clean. Prod. 14, 661–671. doi:10.1016/j.jclepro.2005.07.014

Van Hoek, R.I., 1999. From reversed logistics to green supply chains. Supply Chain Manag. An Int. J. 4, 129–134. doi:10.1108/13598549910279576

Varma, S., Wadhwa, S., Deshmukh, S.G., 2006. Implementing supply chain management in a firm: issues and remedies. Asia Pacific J. Mark. Logist. 18, 223–243. doi:10.1108/13555850610675670

Wells, P., Orsato, R.J., 2005. Redesigning the industrial ecology of the automobile. J. Ind. Ecol. 9, 15–30. doi:10.1162/1088198054821645

Wiengarten, F., Pagell, M., Fynes, B., 2013. ISO 14000 certification and investments in environmental supply chain management practices: identifying differences in motivation and adoption levels between Western European and North American companies. J. Clean. Prod. 56, 18–28. doi:10.1016/j.jclepro.2012.01.021

Wu, Z., Pagell, M., 2011. Balancing priorities: Decision-making in sustainable supply chain management. J. Oper. Manag. 29, 577–590. doi:10.1016/j.jom.2010.10.001

Yeh, W.C., Chuang, M.C., 2011. Using multi-objective genetic algorithm for partner selection in green supply chain problems. Expert Syst. Appl. 38, 4244–4253. doi:10.1016/j.eswa.2010.09.091

Yen, Y.X., Yen, S.Y., 2012. Top-management's role in adopting green purchasing standards in high-tech industrial firms. J. Bus. Res. 65, 951–959. doi:10.1016/j.jbusres.2011.05.002

Yin, R.K., 2009. Case Study Research, Design and Methods, 4th ed. SAGE, London.

Yuan, Z., Shi, L., 2009. Improving enterprise competitive advantage with industrial symbiosis: case study of a smeltery in China. J. Clean. Prod. 17, 1295–1302. doi:10.1016/j.jclepro.2009.03.016

Zhu, Q., Sarkis, J., Lai, K., 2007. Green supply chain management: pressures, practices and performance within the Chinese automobile industry. J. Clean. Prod. 15, 1041–1052. doi:10.1016/j.jclepro.2006.05.021

Appendix A - Interview Questions

1. What efforts to reduce CO2 emissions are the company making?
2. What measures are being taken to reduce water usage?
3. What relationships with other companies involving sustainability measures does the company have?
4. What measures are taken to reduce waste?
5. Do your products have recycling information to encourage the end users to recycle the goods?
6. Do you provide end of life collection services for the products you sell?
7. Does your company endeavour to reduce the quantity of non-renewable raw materials in the products it sells?
8. Do you work with suppliers and customers to provide sustainable products?
9. Is the durability of products sold considered?
10. What drives the sustainable initiatives?
11. How valuable is ISO 14001 to the business?
12. Does the company have a change management system in place to encourage sustainability?
13. What factors influence the successful implementation of sustainable projects?
14. What are the impacts of legislation on recycling of wastes and reuse or the take back of products?
15. Are any of these exchanges used in the inputs to other production processes?
16. Are there any exchanges of information or knowledge exchange that take place as part of these exchanges? Who is involved in these exchanges?
17. Are these exchanges driven by environmental or economical drivers?
18. Are any of the products returned to the original suppliers for remanufacturing or reuse?
19. If the exchanges are successful do more opportunities arise for additional exchanges?
20. Is geographic proximity important when considering partners?
21. What is the value to the waste produced to the company?
22. Are these exchanges considered to be special or is it business as usual?
23. How many of these exchanges are reliant on an external entity to facilitate this?
24. Are any measures used to evaluate the environmental impact across the supply chain?