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A Closed-loop Supply Chain Model for Managing Overall Optimization of Eco-efficiency

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Abstract

The focus and scope of environmental care has been extended over the past four decades. More and more attention has been attached to pollution prevention and minimization rather than end-of-pipe pollution control. It is believed that there is an optimized break-even point where more goods and services are created with fewer resources, less waste and pollution. This point is termed eco-efficiency. This paper discusses, firstly, the major challenges of managing eco-efficiency in the context of a supply chain. The challenges in optimization of eco-efficiency are also addressed. The disadvantages of applying traditional supply chain models in managing overall optimization of eco-efficiency are analyzed. A closed-loop supply chain model is proposed. Suggestions on future works are given at the end of this paper.

Key words: Eco-efficiency, sustainable supply chain management, closed-loop model

1. Introduction

Lately, business organizations are facing the increasing pressure of balancing marketing and environmental performances (Hui et al., 2006). A growing number of environmental conscious end-consumers are placing increasing green-requirements on the finished products, the fabrication and the service processes, the reverse logistics procedures as well as on waste treatment programs for products after their lifecycle. To catch up with this global trend, supply chains must orientate themselves in this environment-intensified competition arena. A

supply chain's ability of delivering environmentally-sound products at a competitive performance level will gain it sustainable profitability in a longer run.

It is evident that green supply chain practice leads to significant values for competitiveness and economic performance. An early study on five major UK companies conducted by (Lamming and Hampson, 1996) indicated that supply chains did benefit from better environmentally-sound approaches. (Rao and Holt, 2005) have carried out a survey on organizations in the South East Asia region. Based on this investigation, they confirmed that there was “a significant correlation between greening certain phases of the supply chain and the competitiveness and economic performance of the organizations involved”.

In parallel with environmental issues, the increasingly severe global energy shortage has drawn much attention to the topics like energy conservation (Markis and Paravantis, 2007, Lin, 2007, He et al., 2006) and development of renewable energy (de Vries et al., 2007, Dincer, 2000, Jefferson, 2006). Comparing with the development of renewable energy which has its objective in developing and utilizing regenerated and self-recoverable energy sources, energy conservation aims to reduce or eliminate energy use and waste by increasing energy efficiency during the production and consumption processes. Increasing energy efficiency can ease energy shortage crisis with immediate effect while developing renewable energy has rather longer term influence. Further, comparing with traditional energy sources (i.e., fossil fuel, coal and natural gas), renewable energy represents those energy sources with zero or minimal negative environmental impact. However, because over 75% of current energy comes from traditional energy sources and traditional energy industry is the biggest environment polluter in the world, it is of paramount importance to increase energy efficiency and therefore reduce energy consumption so negative environmental influences can be diminished.

Eco-efficiency is a break-even point on which the use of natural resources is most efficient, the environmental pollution is minimal and the balance between economical and ecological aspects of the system is achieved. As level of eco-efficiency is influenced by factors i.e., available technology, management philosophy, and etc., its continuous improvement is feasible over time.

A sustainable supply chain aims to deliver customer-satisfied products and services in an eco-efficient manner. Many state that a focus on supply chain is already a step towards the broader adoption and development of sustainability since the supply chain considers the product from initial processing of raw materials to delivery to the customer (Linton et al., 2007a). As true as it is, however, current material-to-customer supply chain perspective is rather anthropocentric than bio-centric. The economic measures in these chains are usually preponderate comparing with their environmental objectives. Further, a major part of value generation as well as energy consumption and their environmental influences usually happen during the processes before the formation of raw material as well as after the products are finished with their first utility lifecycles. Applying current supply chain formulation as the base to discuss sustainability is, at best, achieving only local eco-efficiency optimization and, at worst, providing excuses for moving environmental problems over to others in the chain. Neither is optimal for overall eco-efficiency optimization of entire supply chain system. The arising of sustainable supply chain demands therefore a closed-loop supply chain model to be defined.

Currently, despite the fact that an increasing attention is being paid to green supply chain management and sustainable supply chain management, very little research has been undertaken in the area of connecting sustainability with eco-efficiency and closed-loop supply chain. In this paper, the authors first discuss the evolution of supply chain management regarding the role of environment plays in each phase. Further, the concept 'eco-efficiency' is

discussed based on its relevance to explain the interdisciplinary nature and continuously optimization needs within sustainable supply chains. A review of current supply chain models is provided. A discussion is followed and concluded with a need for closed-loop supply chain model. The authors continuous with suggesting a closed-loop supply chain. In the final part of the paper, the implication of this research to further work is discussed.

2. Evolution of Sustainability and Supply Chain Management

It is widely accepted that supply chain and its management are the logical progression of developments in logistics and logistics management respectively (Cooper and Ellram, 1993; Bowersox and Closs, 1997; Kent and Flint, 1997; Ganeshan et al., 1998). Many literatures agrees that the evolution of logistics and later supply chain management experienced three phases (Masters and Pohlen, 1994; Langley Jr., 1992): (1) functional management (1960-1970) – functions such as purchasing, shipping, and distribution are each managed separately, (2) internal integration (1980s) – the management of supply chain functions of a single facility are unified and become the responsibility of a single individual, and (3) external integration (1990s) – the management of supply chain functions throughout the chain are unified requiring cooperation and coordination between links in the chain. These phases are rather being viewed based on an increasingly extended concept of management scope. Prior to 1990s, the environmental or green issues are barely mentioned. Major focuses were on productivity, cost-efficiency and time-related performances. None of these phases had their focus on environmental issues. The prevailing of reverse logistics was not until the beginning of 1990s.

At the same time, green issues can be traced back as far as the 50's with the introduction of the Clean Air Acts (1956 & 1968) and the 60's when environmentalism became “fashionable” with “hippies” and the mass publication of the environmental cause¹.

¹ <http://scom.hud.ac.uk/scomjm4/mmport/susmod/Page2.htm>

Yet it was not until 1980s the global warming has become the major trigger for sustainable development (as shown in Figure 1). The famous Brundtland (1987) report was the first that gave “sustainable development” a comprehensive definition as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Since then, the sustainability is gaining exponential relevance and increasing popularity in almost all research fields. In 1990s, several studies showed evidences that the damaging effect of ozone depletion on human health (Longstreth et al., 1998, Lim and Cooper, 1999). These further prompted the establishment of environment-energy-ecology trilogy in managing sustainability. With this trilogy, sustainability can be managed by balancing environmental, energy and ecology issues of any system.

In Figure 1, we summarized the evolution of sustainability and supply chain management together. As one can see, the evolution courses of sustainability and supply chain management were not merged until the earlier 1990s. It was then when policy makers, environmentalists, researchers, industrial practitioners, and general public realized the needs and importance of reclaiming the value of the products after their first useful lifecycles. Further, the idea of conducting upstream pollution prevention rather than end-of-pipe pollution treatment was also arising.

Nevertheless, it takes another decade to include reverse logistics part into the scope of a green supply chain. A green supply chain, aiming at pollution prevention and value reclamation from both forward and reverse material flows, includes all stages of lifecycle of a product from a manufacturing perspective (e.g., (Karinuma and Tawara, 2006, Sheu et al., 2005a). Furthermore, a new concept termed “sustainable supply chain” is appearing in recent supply chain research arena. (Linton et al., 2007b) in their short introduction on sustainable supply chain argued that “the interaction between sustainability and supply chains is the critical step from recent examinations of operations and environment and operations and

sustainability”. They went further to state that though the “important contributions have been made in relation to environmental operations and policy, strategy, finance, product design, supplier relations and post-consumer product management it is critical to move forward to the systemic issues that exist at the intersection of sustainability, environmental management and supply chains”. Comparing with green supply chain management, one of the most significant differences is that, with sustainable supply chains, the energy consumption and efficiency issues are integrated with system operational functions and environmental measures. In other words, a sustainable supply chain is based on environment-energy-ecology trilogy in which considering energy and material are reused (Sarkis, 2003) and environment and energy are

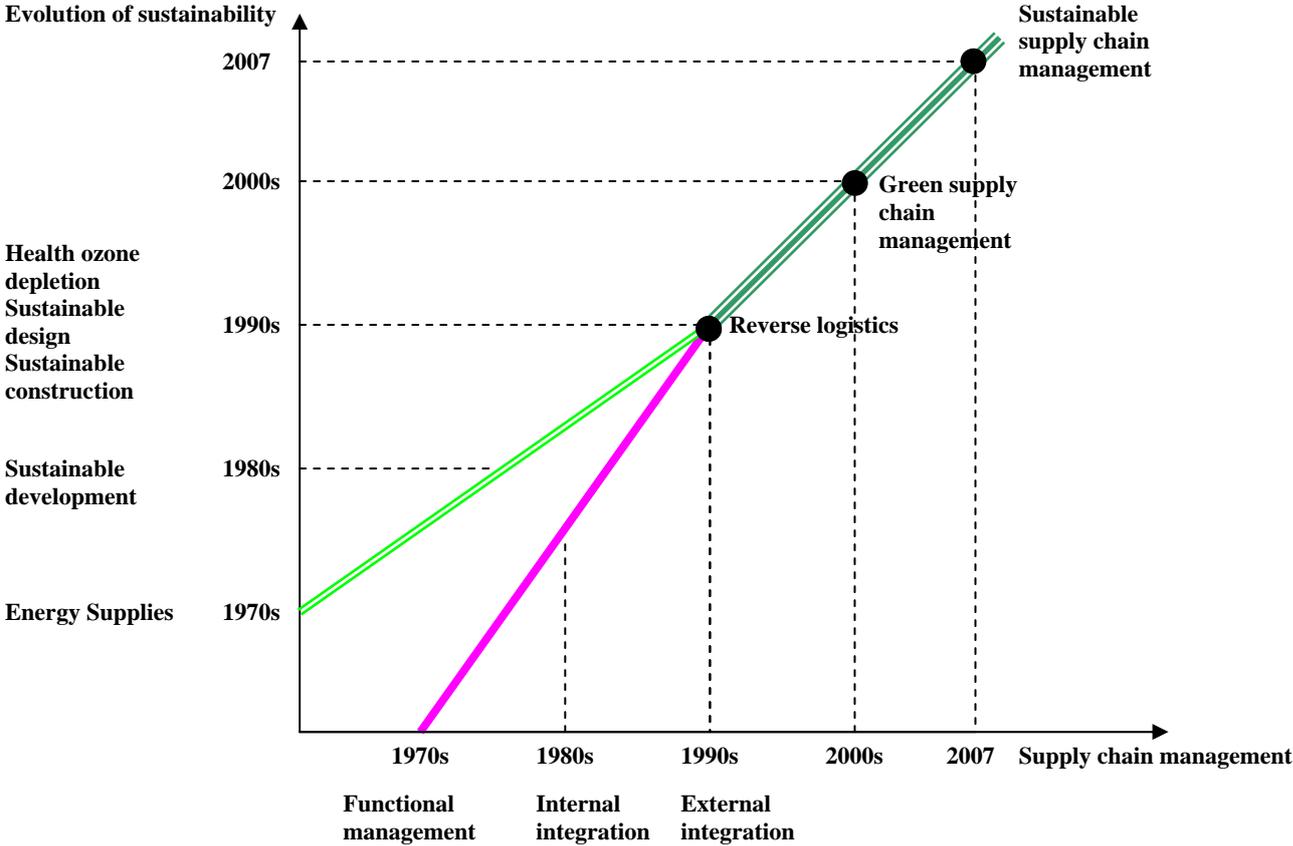


Figure 1 Sustainability merges with supply chain management

reversible to each other within the system.

3. Eco-efficiency

It is argued that sustainable development has been widely adopted as a goal and it does not in itself provide the means by which an unsustainable development could be transformed into a sustainable one (Mickwitz et al., 2006). It is therefore eco-efficiency was proposed as a route to promote such a transformation.

There is a growing interest and wide acceptance of eco-efficiency among industrial practitioners. According to (Burritt and Saka, 2006), eco-efficiency improvement is being adopted by a growing number of businesses as a logical driver for management and a way of enhancing strategies that promote, maintain or repair social legitimacy.

However, being widely accepted as critical measure of sustainability, eco-efficiency is not consistently defined. (Reith and Guidry, 2003) viewed eco-efficiency as “the efficiency with which resources are converted into product”. (Vogtländer et al., 2002) viewed eco-efficiency as a measure for the sustainability and described it simply as eco-costs/value ratio of a product. Most of the researches cite the definition given by the World Business Council for Sustainable Development² as: “the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, throughout the life cycle, to a level at least in line with the earth’s estimated carrying capacity”.

Crystallizing the definitions of both sustainability and eco-efficiency, it is clear that, for approaching system sustainability and eco-efficiency, both short-term consequence and long-term influence of current system should be considered.

Many researches have pointed out that eco-efficiency is a central strategy in the cradle-to-cradle development method and seeks to create industrial systems that emulate healthy natural systems. Regarding supply chain systems which originally focused on cradle-

² www.wbcsd.org

to-grave, pursuing sustainability and eco-efficiency demands supply chains to close the loop. Sustainable supply chain management demands a closed-loop supply chain model as its base.

4. Closed-loop Supply Chains

A closed-loop supply chain can be defined as a system with no waste. Comparing with traditional supply chain which has open ends (Figure 2), a closed-loop supply chain put all outputs back to the system. In other words, a closed-loop supply chain is a conjunction of forward and reverse material flows. It completely reuses and recycles of all materials and transforms waste to energy.

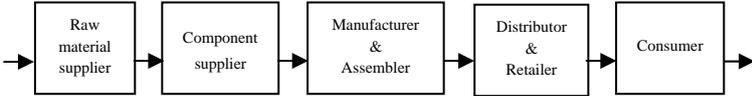


Figure 2 Traditional supply chain model

There is limited research being conducted in the field of closed-loop supply chain modeling. (Beamon, 1999) defined a closed-loop supply chain model with major focus of handling wastes (Figure 3). Energy measures were left out in this model.

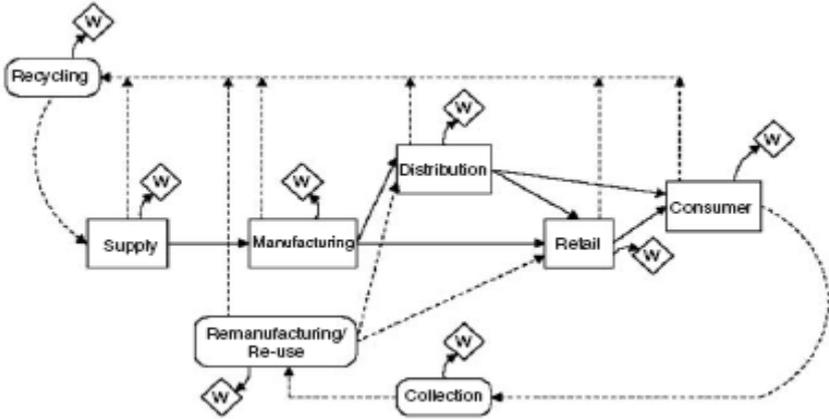


Figure 3 Closed-loop supply chain W: waste (Adapted from (Beamon, 1999a))

Sheu et al. (2005) also proposed a comprehensive conceptual framework as shown in Figure 4. In this model, the forward and reverse material flows and their interrelationships were defined. However, this model includes neither waste treatment nor energy supply.

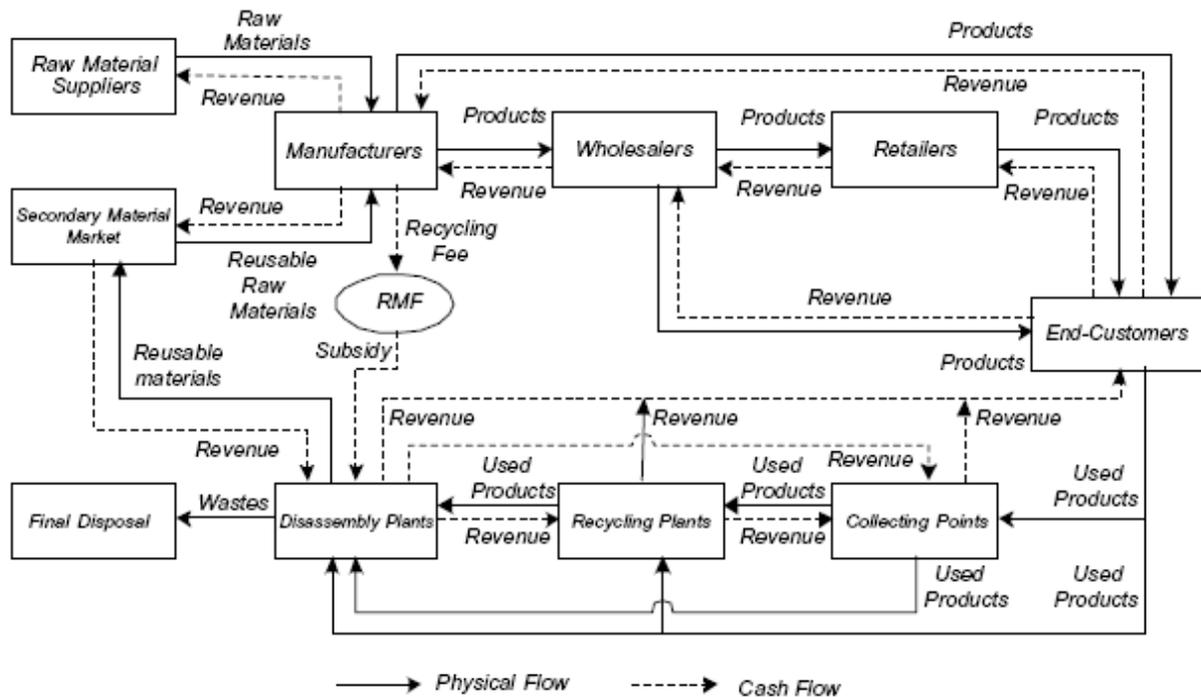


Figure 4 Conceptual Framework for Integrated logistics control across a green-supply chain (Adapted from Sheu et al., 2005)

Kumar and Malegeant (2006) treated reverse supply chain and closed-loop supply chain as equivalent and suggested that collection, inspection/separation, reprocessing, disposal, re-distribution are five main groups of activities conducted.

All these models are made from a manufacturing perspective. None of them have managed to combine forward-reverse material flow together with waste and energy flows.

In Figure 5, we propose a closed-loop supply chain model. The primary material flow which starts from raw material supplier and ends at consumer has been extended. For the products which have no utility value, they will be decomposed or disassembled in the *direct treatment* process and the utilizable material/parts go back to the chain. The rests go further to *indirect treatment* where methods as chemical (i.e., incineration) and biological transformation are applied (Shah, 2000). Examples of outputs of this stage are renewed material and/or energy. The residuals after this stage are transported to landfill. Over the last decade wastes that end up at landfills are the most hazardous ones (Lagerkvist, 2001). Waste being put into landfills can be categorized as:

- Organic waste from households produces gasses as methane, hydrogen and ammonia;
- Plastic material are broken down very slowly;
- Heavy metals and environmental poisons such as dioxine, polyaromatic hydrocarbons (PAH) are dissolved in the leachate. Small concentration can make much harm when coming into contact with ecosystems since they are persistent.

Handling all these wastes consume energy. Further *purification* processes are also needed in order to absorb last portion of detrimental composition from the leachate and render harmless gasses (green house gasses) from the landfill.

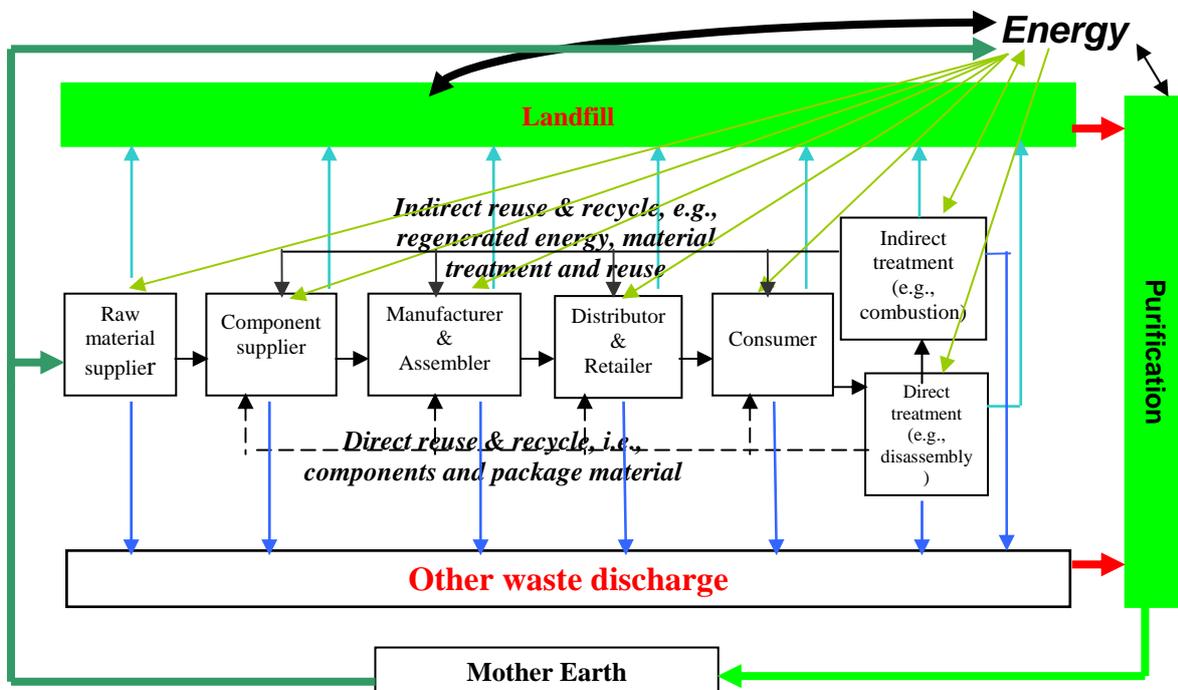


Figure 5 A closed-loop supply chain model

The treatment of other liquid and gassy wastes that generated in processes, i.e., production, transportation and consumption, is conducted usually in a *purification* process on the spot. This process often needs huge amount of energy and has great potential to reclaim value through a waste-to-resource conversion.

5. Conclusion, Discussion and Suggestion for Future Works

Sustainability is the backbone of current and future economical development. For achieving increasing level of sustainability in a supply chain system, the introduction of eco-efficiency is necessary. In this paper, eco-efficiency represents the balance of economical and ecological measures of a system. The ecological issue which are associated with a supply chain system is further broken down to environmental and energy issues. Including economical, environmental, and energy measures in a supply chain system prompted a closed-loop supply chain model to be defined.

This paper, in contrast with others in the same research field, justifies the needs for including waste treatment and purification processes into the traditional supply chain model and current closed-loop/green supply chain model. Further, energy supply and waste-energy interrelationship are becoming visible in the closed-loop supply chain model that proposed. Though both energy supply and waste-energy conversion issues are belong to other fields of study, the implication of this research suggests that the cooperation among all relevant fields are absolutely necessary in managing eco-efficiency in a closed-loop supply chain. The proposed closed-loop supply chain model may serve as a starting point for such a multidisciplinary collaboration.

As we have mentioned in an earlier section, sustainable development itself is adopted as a goal and it is eco-efficiency provides the means that directing the transformation of an unsustainable development into a sustainable one. However, this transformation is not promised to be obviously easy. Now as the closed-loop supply chain model provides the answers for questions like “who should be involved in an eco-efficiency transformation?” and “what their interrelationships are?” the following question will naturally be “how should we measure eco-efficiency in a closed-loop supply chain?” Until this question is answered, we do not have any condition to discuss the optimization problem of eco-efficiency.

6. References

- BEAMON, B. M. (1999) Designing the Green Supply Chain. *Logistics Information Management*, 12, 332-342.
- BOWERSOX, D. J. & CLOSS, D. J. (1997) *Logistics Management - the integrated supply chain process*, McGraw-Hill.
- BURRITT, R. L. & SAKA, C. (2006) Environmental management accounting applications and eco-efficiency: case studies from Japan. *Journal of Cleaner Production*, 1262-1275.
- COOPER, M. C. & ELLRAM, L. M. (1993) Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy. *The International Journal of Logistics Management*, 4.
- DE VRIES, B. J. M., VAN VUUREN, D. P. & HOOGWIJK, M. M. (2007) Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy Policy*, 2590-2610.
- DINCER, I. (2000) Renewable energy and sustainable development: a crucial review. *Renewable & Sustainable Energy Reviews*, 157-175.
- GANESHAN, R., JACK, E., MAGAZINE, M. J. & STEPHENS, P. (1998) A Taxonomic Review of Supply Chain Management Research. *Quantitative Models for Supply Chain Management*. Kluwer Academic Publishers.
- HE, J., LIU, B. & ZHANG, A. (2006) Analysis of the effect and potential of energy conservation in China. *Energy Policy*, 3702-3708.
- HUI, K. H., SPEDDING, T. A., BAINBRIDGE, I. & TAPLIN, D. M. R. (Eds.) (2006) *Creating a Green Supply Chain: A Simulation and Modeling Approach*, Springer.
- JEFFERSON, M. (2006) Sustainable energy development: performance and prospects. *Renewable Energy*, 571-582.
- KARINUMA, Y. & TAWARA, N. (2006) A multiple attribute utility theory approach to lean and green supply chain management. *International Journal of Production Economics*, 99-108.
- KENT, J. L. & FLINT, D. J. (1997) Perspectives on the evolution of logistics thought. *Journal of Business Logistics*, 18.
- KUMAR, S. & MALEGEANT, P. (2006) Strategic alliance in a closed-loop supply chain, a case of manufacturer and eco-non-profit organization. *Technovation*, 1127-1135.
- LAGERKVIST, A. (2001) Landfill Technology. Luleå university of technology, Department of environmental engineering, Division of waste science & technology.
- LAMMING, R. & HAMPSON, J. (1996) The environment as a supply chain management issue. *British Journal of Management*, 7, S45.
- LANGLEY JR., C. J. (1992) The evolution of the logistics concept. IN CHRISTOPHER, M. (Ed.) *Logistics: the strategic issues*.
- LIM, H. W. & COOPER, K. (1999) The health impact of solar radiation and prevention strategies. *Journal of the American Academy of Dermatology*, 41, 81-99.
- LIN, J. (2007) Energy conservation investments: A comparison between China and the US. *Energy Policy*, 916-924.
- LINTON, J. D., KLASSEN, R. & JAYARAMAN, V. (2007a) Sustainable supply chains: An introduction. *Journal of Operations Management*.
- LINTON, J. D., KLASSEN, R. & JAYARAMAN, V. (2007b) Sustainable supply chains: An introduction. *Journal of Operations Management*.
- LONGSTRETH, J., DE GRUIJL, F. R., KRIPKE, M. L., ABSECK, S., ARNOLD, F., SLAPER, H. I., VELDERS, G., TAKIZAWA, Y. & VAN DER LEUN, J. C. (1998) Health risks. *Journal of Photochemistry and Photobiology*, 20-39.

- MARKIS, T. & PARAVANTIS, J. A. (2007) Energy conservation in small enterprises. *Energy and Buildings*, 404-415.
- MASTERS, J. M. & POHLEN, T. L. (1994) Evolution of the logistics profession. *The Logistics Handbook*. New York, Free Press.
- MICKWITZ, P., MELANEN, M., ROSENSTRÖM, U. & SEPPÄLÄ, J. (2006) Regional eco-efficiency indicators - a participatory approach. *Journal of Cleaner Production*, 1603-1611.
- RAO, P. & HOLT, D. (2005) Do green supply chains lead to competitiveness and economic performance? *International Journal of Operations & Production Management*, 25, 898.
- REITH, C. C. & GUIDRY, M. J. (2003) Eco-efficiency analysis of an agricultural research complex. *Journal of Environmental Management*, 219-229.
- SARKIS, J. (2003) A strategic decision framework for green supply chain management. *Journal of Cleaner Production*, 397-409.
- SHAH, K. L. (2000) *Basics of Solid and Hazardous Waste Management Technology*, Prentice Hall.
- SHEU, J.-B., CHOU, Y.-H. & HU, C.-C. (2005a) An Integrated Logistics Operational Model for Green-Supply Chain Management. *Transportation Research Part E*.
- SHEU, J.-B., CHOU, Y.-H. & HU, C.-C. (2005b) An Integrated Logistics Operational Model for Green-Supply Chain Management. *Transportation Research Part E*.
- VOGTLÄNDER, J. G., BIJMA, A. & BREZET, H. C. (2002) Communicating the eco-efficiency of products and services by means of the eco-costs/value model. *Journal of Cleaner Production*, 57-67.