Tuni, Andrea and Rentizelas, Athanasios (2017) Measuring the eco-intensity of the supply chain : a novel approach. In: 4th International EurOMA Sustainable Operations and Supply Chains Forum, 2017-02-27 - 2017-02-28, Politecnico di Milano. ,

Measuring the eco-intensity of the supply chain: a novel approach

Andrea Tuni (andrea.tuni@strath.ac.uk)
Department of Design Manufacture and Engineering Management,
University of Strathclyde, 75 Montrose Street, G1 1XJ, Glasgow, United Kingdom

Athanasios Rentizelas
Department of Design Manufacture and Engineering Management,
University of Strathclyde, 75 Montrose Street, G1 1XJ, Glasgow, United Kingdom

Abstract

More than 80% of the environmental impacts in a typical supply chain can arise beyond the focal firm, however models quantifying the environmental performance of supply chains typically measure only direct suppliers and customers rather than extended supply chains that represent the norm in the globalized competitive environment. This work aims to introduce an innovative quantitative approach to assess the eco-intensity of an extended supply chain, allowing to relate the environmental performance of a supply chain to its economic performance. The approach is based on multiple environmental indicators and a decentralized recursive mechanism, making it applicable to non-cooperative supply chains.

Keywords: Eco-intensity, Recursive indicators, Extended supply chains

Introduction

A number of factors, such as climate change, global warming and scarce natural resources, have recently become central to the agenda of the international community due to the impacts they have on both economies and people (Bloemhof et al., 2015; Montoya-Torres et al., 2015). As a result, policy makers are constantly introducing and updating regulations aimed to control the environmental impacts of industrial activities, with a specific focus on emissions (Björklund et al., 2012).

Companies are thus facing increasing environmental pressure from regulatory bodies, as well as experiencing pressure from the market due to an increased green awareness of customers, asking for more sustainable products and services. Other stakeholders, such as non-governmental organizations (NGOs) and local communities, are also in the forefront in pushing organizations towards sustainability initiatives by demanding increased transparency of companies' practices as well as improved sustainability reports to communicate actual and potential harm to the environment and the society caused by production activities (Björklund et al., 2012; Gerbens-Leenes et al., 2003).

These pressures were initially addressed to the focal firms, which are those companies that have a leading role within the network as they "rule or govern the supply chain, provide the direct contact to the customer, and design the product or service offered" (Seuring and Müller, 2008). These pressures later spread to other organizations part of the supply chain due to two factors. First, the current development of economic competition shifted from a company-versus-company form to a supply chain-versus-supply chain one, due to increasing specialization of companies and resulting outsourcing practices (Cabral et al., 2012; Fawcett and Magnan, 2002; Reefke and Trocchi, 2013). This trend often led to relocate part of the supply chain to countries with low production cost, often coupled with less strict environmental regulations and standards (Harris et al., 2011; Hauschild et al., 2008; Hutchins and Sutherland, 2008; Ukidwe and Bakshi, 2005). Coherently with the economic dimension, also environmental issues have expanded outside company's border, including both upstream and downstream networks and adopting a lifecycle perspective. Secondly, multiple sources show that the majority of the environmental impacts is not caused by the activities of the focal companies themselves, but arises in their supply chain. In certain instances, the environmental impact of organizations other than the focal firm was reported as high as 90% of the overall environmental impact of the supply chain (Beavis, 2015; Veleva et al., 2003; WBCSD and WRI, 2009).

The definition of Green Supply Chain Management (GSCM) reflects the expansion of the environmental aspects to the supply chain by integrating "environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life" (Srivastava, 2007). The definition of GSCM encompasses a wide set of operations and the existing research naturally developed into various streams focusing on more specific topics, including the measurement of the environmental performance of the supply chain (Taticchi et al., 2013). Even though the GSCM definition stresses that a holistic approach including all lifecycle stages and multiple supply chain tiers is required, this perspective has often been overlooked by supply chain environmental performance measurements, where metrics were applied only to focal firms despite the declared supply chain focus (Ahi and Searcy, 2015; Beske-Janssen et al., 2015). However, performance measurement systems addressing a single tier of the network are inadequate to provide an accurate understanding of the wider supply chain environmental performance; therefore, a holistic approach is needed (McIntyre et al., 1998). This work thus aims to introduce an innovative quantitative approach to measure the environmental performance of an extended supply chain, as part of an eco-intensity index that includes traditional economic performance as well.

The remaining part of this paper is structured as follows: literature review section briefly describes the concepts of eco-efficiency and eco-intensity as well as their applications in the supply chain contexts; methodology section outlines the key features of the model, such as the expected outputs and the methodological steps followed to build it. Finally, conclusion section highlights theoretical and practical contributions and identifies limitations of the model and future research directions.

Literature review

Eco-efficiency and eco-intensity integrate the environmental and economic dimensions of sustainability in a unique index. The Organisation for Economic Co-Operation and Development (OECD) refers to eco-efficiency as "the efficiency with which ecological resources are used to meet human needs" and defines it as a ratio of the economic value created and the sum of environmental pressures generated by an economic activity

(WBCSD, 2000). Eco-intensity is reciprocal to eco-efficiency, as the mathematical multiplication of the two values equals to one. Eco-intensity is thus the ratio of the environmental impact and the economic benefit generated by an economic activity (Schmidt and Schwegler, 2008). Eco-intensity proved to be more easily applicable to the supply chain context from a mathematical perspective as it allows the simple addition of environmental values of organizations part of the chain, which is not possible with eco-efficiency due to reciprocal positions of numerator and denominator (Schmidt and Schwegler, 2008).

Both concepts of eco-efficiency and eco-intensity are applicable to different systems, based on the systems' boundaries. Potential systems include single processes, firms, sectors or even entire economies. A number of eco-efficiency and eco-intensity models were applied to the supply chain context, despite the eco-intensity supply chain literature specifically is limited to few examples. Schmidt and Schwegler (2008) propose a recursive indicator for the supply chain of a company, but leave untouched the issue of the environmental measurements that need to be included in the assessment of the eco-intensity, whereas Joa et al. (2014) adopt a similar methodological construct to assess the water eco-intensity of the supply chain, which takes into account geographical differences of supply chain players.

Eco-efficiency models were applied with an increased frequency in the literature. Standing the broad scope of GSCM, models are applied to different supply chain extents offering support to a wide spectrum of managerial decisions. Tseng et al. (2013) and Mahdiloo et al. (2015) address the supplier selection and evaluation problem, limiting their attention to 1st tier suppliers. Despite not providing an actual eco-efficiency score of the suppliers, Tseng et al. (2013) evaluate them according to twenty eco-efficiency criteria adopting fuzzy sets to include uncertainties in the judgments of decision makers and adopt TODIM method (TOmada de Decisão Interativa e Multicritério - Interactive and Multicriteria Decision Making) to rank supplying alternatives. The use of linguistic variables favors the inclusion of qualitative values along with quantitative ones within the set of criteria, but the final output based on evaluations by decision makers is contingent on a certain degree of subjectivity (Tsoulfas and Pappis, 2008). On the other hand, Mahdiloo et al. (2015) adopted data envelopment analysis (DEA) to evaluate and select suppliers and ranked them based on their eco-efficiency score. The introduction of multi-objective linear programming along with DEA allowed them to overcome the issue of eco-efficient decision making units, which are not efficient from an economic or an environmental perspective. Wu and Barnes (2016) expand the problem of selecting partners to other supply chain members than the direct suppliers through analytical network process and later solve the green lot-sizing problem thanks to multi-objective programming. They adopt an eco-efficiency ratio as a tool to evaluate different supply chain structures and the outcome of improvement options in the environmental performance. Colicchia et al. (2015) also deal with the supply chain configuration, focusing on the distribution network: they present a bi-objective optimization of cost and CO_2 emissions, which are merged into a single objective eco-efficient optimization function through weighting. Quariguasi Frota Neto et al. (2009) develop a methodology to calculate an eco-efficient frontier in the waste electrical and electronic reverse chain considering the cumulative energy demand and the landfilled waste as environmental parameters and the profit as the single economic parameter. By adopting an ε-constraint heuristic multi-criteria decision method, the border between feasible and unfeasible solutions is determined as well as the curve of Pareto optimal solutions. The method offers the decision makers the possibility to select the most suitable option based on their preferences, thus being flexible in its applicability depending on the supply chain strategic targets.

Other authors remove the constraints of focusing on a limited portion of the supply chain by adopting a lifecycle perspective. This is the case of Michelsen et al. (2006) and Michelsen and Fet (2010) in their works on the furnishing sector, as well as of Saling et al. (2002). Michelsen, along with other scholars, adopt life cycle assessment (LCA) and life cycle costing as the eco-efficiency determinants in both papers. Despite an attempt to favor benchmarking through the method by selecting external normalization and weighting factors, the authors recognize that "all comparative use of LCA is questionable" due to the high number of assumptions embodied in the method, most noticeably the cut-off definition of the functional unit and durability of the products. Saling et al. (2002) instead develop a different method, which offers an aggregation of all environmental aspects in a single normalized index. Authors try to blend external reference factors to assess the relevance of each environmental aspect together with internal reference factors to include the viewpoint of experts and decision makers. The final outcome is a single eco-efficiency index of five possible alternatives for dyeing supply chain of blue jeans. Finally, Charmondusit et al. (2014) propose a socio-eco-efficiency index for the toy industry, which adds the social dimension of sustainability to the traditionally bi-dimensional eco-efficiency and boosts an increased applicability for small medium enterprises (SMEs).

Most methods outlined above perform some comparisons between different supply chains. The longitudinal comparison of the supply chain is a popular approach, aiming to track the efficiency of environmental improvements over time: the observation of eco-efficiency performance over multiple years is adopted for instance by Tseng et al. (2013) and Charmondusit et al. (2014). The comparison of different scenarios within a single supply chain is also a common approach. Mahdiloo et al. (2015) evaluates the eco-efficiency of potential suppliers and its effect on the supply chain performance, Wu and Barnes (2016) look at the eco-efficiency ratio of the same supply chain when different objectives are into practice, similarly to Colicchia et al. (2015). Finally, Saling et al. (2002) compare different technologies within a clothing supply chain, whereas Michelsen et al. (2006) and Michelsen and Fet (2010) compare various chairs on the basis of their functional units.

However, all eco-efficiency and eco-intensity models proposed by the literature are self-referential being applicable to a specific supply chain and exploring its behavior without any possibility of external comparison with other external supply chains, thus preventing any benchmarking possibility. This works thus aims to introduce an innovative quantitative approach to measure the eco-intensity of an extended supply chain allowing to relate the environmental performance of a supply chain to its economic performance. This approach:

1. Expands the coverage of the supply chain environmental performance measurement systems available in the literature both in terms of supply chain extent and of environmental aspects considered, paving the way for an effective supply chain-wide environmental assessment
2. Aims to be applicable to benchmark different supply chains thanks to publicly available reference factors of environmental aspects and by removing constraints introduced by functional units. The method could be used for environmental reporting and facilitates applicability by SMEs.

Methodology

The eco-intensity model presented in this section is aimed to be applicable for forward supply chains and adopts a cradle-to-gate approach. The model provides four major output levels, which are represented in the ovals in Figure 1: single company eco-intensities specific to the single environmental indicator, single company global eco-intensity, supply chain eco-intensities specific to the single environmental indicator and supply chain global eco-intensity.

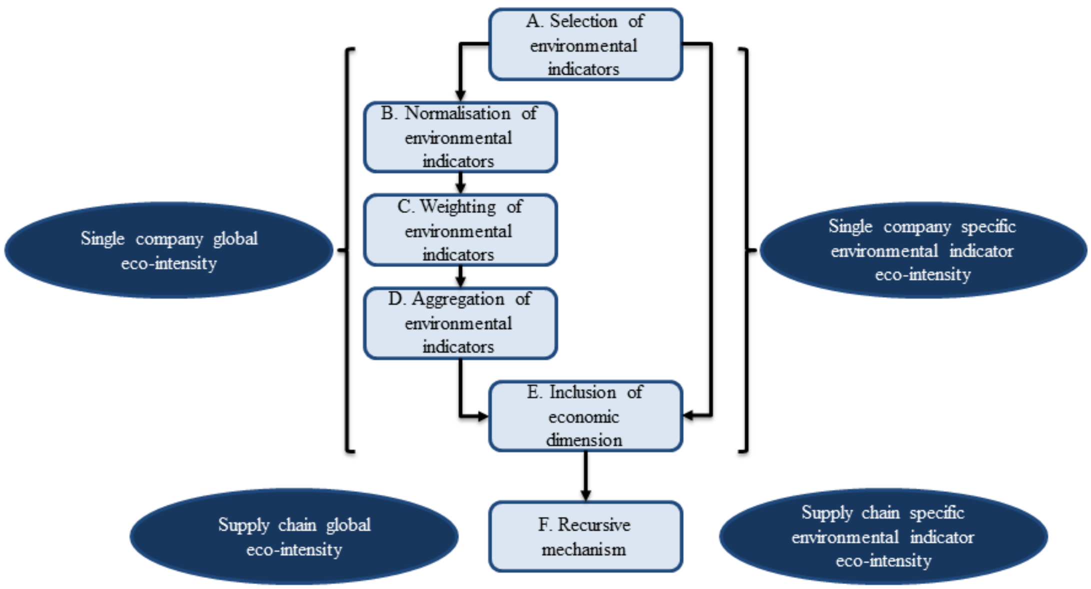

Figure 1– Six methodological steps and the resulting four outputs of the model

The construction of the model follows two separate streams, based on the level of aggregation in terms of coverage of the environmental dimension, as shown in Figure 1. Six methodological steps were identified, however steps B, C and D are performed to calculate only the global environmental performance, either to measure the single company global eco-intensity or the supply chain global eco-intensity. These steps are omitted when focusing on specific environmental aspects and their relative indicators. The six steps, performed in cascade, are:

A. Selection of environmental indicators: following a systematic literature review at the intersection of performance measurement and GSCM, the most frequent environmental aspects that are covered in the literature were identified and adopted as a reference for the development of the indicators. Seven areas were identified as the most frequently addressed in the literature as well as being applicable to virtually every type of industry, thus not being sector specific. Four areas refer to inputs to the supply chain operations, whereas three areas refer to the outputs arising from the productive activities of the supply chain:
   - Inputs: land occupation, use of materials, water consumption, energy consumption;
   - Outputs: emissions to air, emissions to water, emissions to land (solid waste).

B. Normalization of environmental indicators: the inclusion of multiple environmental indicators with different units of measurement poses a question about their comparability. A necessary preliminary step before aggregating different metrics is thus the normalization of the units of measurement into a single comparable scale (Dos Santos and Brandi, 2015; Kostin et al., 2015; Kravanja and Čuček, 2013; OECD, 2009). Normalization is also a necessary process to increase the benchmarking potential (Angelakoglou and Gaidajis, 2015; Jonsdottir et al., 2005; Tokos et al., 2012), when an external normalization factor, namely a generic reference value, is adopted (Tugnoli et al., 2008). A normalization factor was identified for each of the selected environmental indicators from publicly available database at the macro-economic level, transforming each environmental indicator in an absolute value between 0 and 1, with 1 being the maximum achievable score resulting in an excellent eco-intensity score.

C. Weighting of environmental indicators: equal weighting is assigned to each environmental indicator. Wang et al. (2009) proved the popularity of this weighting method thanks to simple applicability and near-optimal results of the final application of the method as well as reccognizing the low input of decision makers. Aiming the method to benchmark different supply chains, the latter does not constitute a drawback for the method, avoiding biases from subjective opinions (Tsoulfas and Pappis, 2008).

D. Aggregation of environmental indicators: the aggregation of the environmental indicators is the final step to obtain a single environmental index at the single company level, which is representing the overall environmental behavior of the organization. This is calculated as the weighted sum of the seven normalized environmental indicators.

E. Inclusion of economic dimension: contrary to the environmental dimension, a single economic indicator is included in the model which is the yearly turnover of the company. Despite the turnover does not give a complete picture of the economic performance of an organization, this data is the most suitable to be adopted in a supply chain environment as it is publicly available and thus applicable to non-cooperative supply chains as well (Schmidt and Schwegler, 2008). Alternative economic measures, widely applied in the literature, such as costs, profit and net present value, are typically confidential and not shared with other players in the chain as they may ultimately unveil and affect the competitive advantage of companies (Brandenburg, 2015; Caro et al., 2013). The adoption of turnover as the economic dimension indicator is used for both streams of methodology identified in figure 1 and leads to the first two outputs of the model: the single company eco-intensity referring to each specific environmental indicator and the single company global eco-intensity.

F. Recursive mechanism: the mathemathical formulation, adapted from Schmidt and Schwegler (2008), is identified in equation 1 and allows to pass the environmental impacts load from each tier of the supply chain to the next one till the last player in the chain, which will include its direct environmental impact on top of indirect impacts generated by the upstream supply chain:

$$EI_i = \frac{1}{T_i}\left(E_i + \sum_{j \in Supplier\,(i)} EI_j \sum_{k \in Supplies\,(j \rightarrow i)} Q_{ijk}\, P_{jk}\right) \quad (1)$$

Where EI_i is the eco-intensity of the company i, whose turnover and direct environmental impact are respectively T_i and E_i. The direct environmental impact in equation 1 can either be the overall environmental impact of the company after performing step B-E or a single environmental indicator out of the seven identified at step 1. Finally, Q_{ijk} is the quantity of product k being acquired by company i from supplier j at the price P_{jk} and EI_j is the eco-intensity of the j-th supplier.

Once the recursive mechanism is passed throughout the entire supply chain, the two final outputs are calculated: eco-intensity of the supply chain referring to each specific environmental indicators as well as the supply chain global eco-intensity. Both indexes are calculated by adding up the contribution of the various tiers building up the chain at the company level. This approach allows to evaluate the behaviors of organisations by considering all their operations and limits the potential of greenwashing by focusing on specific products that perform better in terms of environmental performance. However, it is still possible at this stage to obtain a calculation of the eco-intensity of a single product. Following the same methodological approach adopted in the recursive mechanism stating that the environmental impact is allocated proportionally to the economic value of products, the global eco-intensity of a product can be calculated as equation 2:

$$EI_P = EI_i \frac{P_p}{T_i} \qquad (2)$$

Where EI_p is the eco-intensity of the product, obtained as a the multiplication of the company-wide eco-intensity EI_i and the price of the product P_p, divided by the turnover T_i of the company. If the i-th company is the last tier of the supply chain selling the product to the final consumer, then the eco-intensity of the final product in a cradle-to-gate approach is obtained.

As outlined at the beginning of this section, the model provides four outputs: these can be disaggregated along the two axes of the matrix in figure 2, which are the supply chain extent coverage and the environmental aspects coverage. In the first case, the disaggregation of results at the single company level provides a picture of the eco-intensity behavior of each supply chain member, allowing informed supplier's selection and evaluation as well as identifying hotspots along the supply chain to target operational improvements. The aggregated results at the supply chain level provide a synthesized evaluation of the eco-intensity performance of the whole supply chain at the level of both single environmental indicators and overall environmental performance, which can be adopted for benchmarking purposes as well as for external reporting. Two levels of results are presented by disaggregating the results along the environmental aspects coverage axes. Considering single environmental indicators can help practitioners to focus on specific environmental aspects based on the decision-makers preferences, supply chain strategy or specific sector characteristics. On the other hand, an aggregated single eco-intensity index can better quantify the impact of trade-offs arising when considering simultaneously multiple environmental indicators and provide a holistic evaluation of the eco-intensity of a company and of a supply chain.

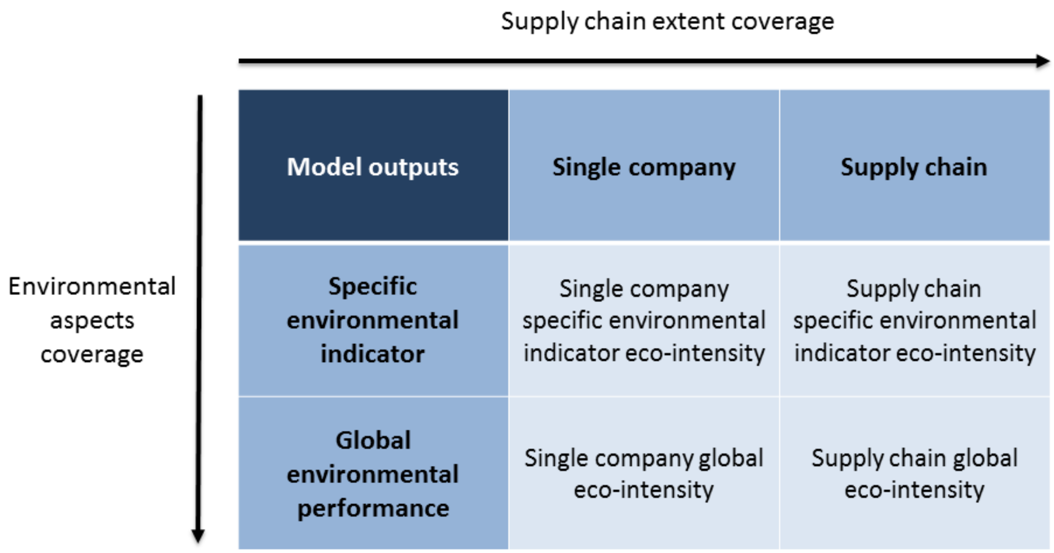

Figure 2– Four model outputs

Conclusion

Contribution

The proposed model is the first attempt to achieve a holistic environmental performance measurement of the supply chain, by simultaneously addressing the extended supply chain in a cradle-to-gate approach and covering multiple environmental aspects, leading the way for an effective supply chain-wide environmental assessment. Secondly, it is the first to adopt external reference values for the normalization of environmental indicators allowing for effective benchmarking between the eco-intensities of different supply chains. The absence of a specific functional unit avoids assumptions that limit the external comparability of environmental performance. The allocation of the environmental impact based on the economic dimension allows comparing the eco-intensities of any type of product. Thirdly, the proposed model, thanks to the recursive mechanism to pass information from one tier of the supply chain to the next one, is suitable for decentralized supply chains and applicable to contexts where the visibility of the supply chain is limited. This approach is particular valid in a competitive environment where global supply chains are becoming longer and the traceability of the main players in the chain is limited (Acquaye et al., 2014; O'Rourke, 2014). Furthermore, the approach is applicable to non-cooperative supply chains due to the limited exchange of information between players that does not require a developed relationship structure. Finally, the collection of the data at the company level significantly lowers the effort required by companies, and especially by SMEs, since data already available at companies such as bills of material or documents from the purchasing department for the use of materials or utility bills for water consumption, energy consumption and waste (emissions to land) can be adopted.

Limitations and future research direction

Some limitations of the proposed model need to be mentioned. A number of challenges refer to the practical applicability of the model in an operating supply chain. Since the model is based on a recursive mechanism, a player in the supply chain needs to kick-off the mechanism on a voluntarily basis, as already acknowledged by Schmidt and Schwegler

(2008). This could potentially be the focal firm of the supply chain, which, thanks to positive balance power along the supply chain, is more likely to introduce favorably the mechanism within its business partners. Additionally, some supply chain partners may not be willing to communicate or be able to collect the environmental data and this would lead to an incomplete evaluation of the supply chain. A technique to overcome the issue of truncated data still needs to be identified.

From a methodological perspective, the allocation of the environmental impacts to products based on the economic performance is surely facilitating the allocation process thanks to a black-box approach, but can lead to an underestimation or overestimation of the eco-intensity of the single products from a strictly environmental perspective. High value products are indeed allocated a higher environmental load despite not necessarily carrying the biggest polluting contribution. Additionally, the overall environmental performance of a company, obtained after normalization and aggregation of single indicators, is useful for external reporting and to consider trade-offs between different environmental aspects, but does not inform decision makers about the direction to take in terms of operational improvements. A subsequent analysis of the single environmental indicators is necessary to identify the environmental performances that need to be targeted by improvement plans. Therefore, outputs both aggregated and disaggregated in terms of environmental aspects coverage need to be considered simultaneously by decision makers. Finally, the model offers an increased applicability for external reporting and benchmarking compared to other methods developed in the literature, but at the expense of the inclusion of decision makers and other relevant stakeholders in the process. The choices of pre-determined indicators, adopting external reference values for normalization, and equal weighting minimize the subjectivity of the method, leading to a wide range of applications in different sectors. However, being the method generic, it cannot be specifically tailored for each case and linked directly to the strategy of the supply chain.

References

Acquaye, A., Genovese, A., Barrett, J., Koh, S.C.L., 2014. Benchmarking carbon emissions performance in supply chains. Supply Chain Management: An International Journal 19, 306–321. doi:10.1108/SCM-11-2013-0419

Ahi, P., Searcy, C., 2015. An Analysis of Metrics Used to Measure Performance in Green and Sustainable Supply Chains. Journal of Cleaner Production 86, 360–377. doi:10.1016/j.jclepro.2014.08.005

Angelakoglou, K., Gaidajis, G., 2015. A review of methods contributing to the assessment of the environmental sustainability of industrial systems. Journal of Cleaner Production. doi:10.1016/j.jclepro.2015.06.094

Beavis, L., 2015. M&S takes an interest in its suppliers' green credentials [WWW Document]. The Guardian. URL https://www.theguardian.com/sustainable-business/2015/apr/30/ms-takes-an-interest-in-its-suppliers-green-credentials (accessed 12.22.16).

Beske-Janssen, P., Johnson, M.P., Schaltegger, S., 2015. 20 Years of Performance Measurement in Sustainable Supply Chain Management – What Has Been Achieved? Supply Chain Management: An International Journal 20, null. doi:10.1108/SCM-06-2015-0216

Björklund, M., Martinsen, U., Abrahamsson, M., 2012. Performance measurements in the greening of supply chains. Supply Chain Management: An International Journal 17, 29–39. doi:10.1108/13598541211212186

Bloemhof, J.M., van der Vorst, J.G. a. J., Bastl, M., Allaoui, H., 2015. Sustainability assessment of food chain logistics. International Journal of Logistics Research and Applications 18, 101–117. doi:10.1080/13675567.2015.1015508

Brandenburg, M., 2015. Low carbon supply chain configuration for a new product - A goal programming approach. International Journal of Production Research 53, 6588–6610. doi:10.1080/00207543.2015.1005761

Cabral, I., Grilo, A., Cruz-Machado, V., 2012. A decision-making model for Lean, Agile, Resilient and Green supply chain management. International Journal of Production Research 50, 4830–4845. doi:10.1080/00207543.2012.657970

Caro, F., Corbett, C.J., Tan, T., Zuidwijk, R., 2013. Double Counting in Supply Chain Carbon Footprinting. Manufacturing & Service Operations Management 15, 545–558. doi:10.1287/msom.2013.0443

Charmondusit, K., Phatarachaisakul, S., Prasertpong, P., 2014. The quantitative eco-efficiency measurement for small and medium enterprise: A case study of wooden toy industry. Clean Technologies and Environmental Policy 16, 935–945. doi:10.1007/s10098-013-0693-4

Colicchia, C., Creazza, A., Dallari, F., Melacini, M., 2015. Eco-efficient supply chain networks: development of a design framework and application to a real case study. Production Planning & Control 7287, 1–12. doi:10.1080/09537287.2015.1090030

Dos Santos, S.F., Brandi, H.S., 2015. Model framework to construct a single aggregate sustainability indicator: An application to the biodiesel supply chain. Clean Technologies and Environmental Policy 17, 1963–1973. doi:10.1007/s10098-015-0919-8

Fawcett, S.A., Magnan, G.M., 2002. The rhetoric and reality of supply chain integration. International Journal of Physical Distribution & Logistics Management 32, 339–361. doi:10.1108/02656710210415703

Gerbens-Leenes, P.W., Moll, H.C., Schoot Uiterkamp, a. J.M., 2003. Design and development of a measuring method for environmental sustainability in food production systems. Ecological Economics 46, 231–248. doi:10.1016/S0921-8009(03)00140-X

Harris, I., Naim, M., Palmer, A., Potter, A., Mumford, C., 2011. Assessing the impact of cost optimization based on infrastructure modelling on CO2 emissions. International Journal of Production Economics 131, 313–321. doi:10.1016/j.ijpe.2010.03.005

Hauschild, M.Z., Dreyer, L.C., Jørgensen, a., 2008. Assessing social impacts in a life cycle perspective-Lessons learned. CIRP Annals - Manufacturing Technology 57, 21–24. doi:10.1016/j.cirp.2008.03.002

Hutchins, M.J., Sutherland, J.W., 2008. An exploration of measures of social sustainability and their application to supply chain decisions. Journal of Cleaner Production 16, 1688–1698. doi:10.1016/j.jclepro.2008.06.001

Joa, B., Hottenroth, H., Jungmichel, N., Schmidt, M., 2014. Introduction of a feasible performance indicator for corporate water accounting – a case study on the cotton textile chain. Journal of Cleaner Production 82, 143–153. doi:10.1016/j.jclepro.2014.06.075

Jonsdottir, H., Sparf, A.M., Hanssen, O.J., 2005. Environmental Benchmarking. A tool for continuous environmental improvements in the SME sector.

Kostin, A., Guillén-Gosálbez, G., Jiménez, L., 2015. Dimensionality reduction applied to the simultaneous optimization of the economic and life cycle environmental performance of supply chains. International Journal of Production Economics 159, 223–232. doi:10.1016/j.ijpe.2014.09.018

Kravanja, Z., Čuček, L., 2013. Multi-objective optimisation for generating sustainable solutions considering total effects on the environment. Applied Energy 101, 67–80. doi:10.1016/j.apenergy.2012.04.025

Mahdiloo, M., Saen, R.F., Lee, K.H., 2015. Technical, environmental and eco-efficiency measurement for supplier selection: An extension and application of data envelopment analysis. International Journal of Production Economics 168, 279–289. doi:10.1016/j.ijpe.2015.07.010

McIntyre, K., Smith, H., Henham, a, Pretlove, J., 1998. Environmental performance indicators for integrated supply chains: The case of Xerox Ltd. Supply Chain Management 3, 149–156. doi:10.1108/13598549810230877

Michelsen, O., Fet, A.M., 2010. Using eco-efficiency in sustainable supply chain management; A case study of furniture production. Clean Technologies and Environmental Policy 12, 561–570. doi:10.1007/s10098-009-0266-8

Michelsen, O., Fet, A.M., Dahlsrud, A., 2006. Eco-efficiency in extended supply chains: A case study of furniture production. Journal of Environmental Management 79, 290–297. doi:10.1016/j.jenvman.2005.07.007

Montoya-Torres, J.R., Gutierrez-Franco, E., Blanco, E.E., 2015. Conceptual framework for measuring carbon footprint in supply chains. Production Planning & Control 26, 265–279. doi:10.1080/09537287.2014.894215

O'Rourke, D., 2014. The science of sustainable supply chains. Science 344, 1124–1128.

OECD, 2009. Eco-Innovation in Industry.

Quariguasi Frota Neto, J., Walther, G., Bloemhof, J., van Nunen, J.A.E.E., Spengler, T., 2009. A methodology for assessing eco-efficiency in logistics networks. European Journal of Operational Research 193, 670–682. doi:10.1016/j.ejor.2007.06.056

Reefke, H., Trocchi, M., 2013. Balanced scorecard for sustainable supply chains: design and development guidelines. International Journal of Productivity and Performance Management.

Saling, P., Kicherer, A., Dittrich-Krämer, B., Wittlinger, R., Zombik, W., Schmidt, I., Schrott, W., Schmidt, S., 2002. Eco-efficiency analysis by BASF: the method. The International Journal of Life Cycle Assessment 7, 203–218. doi:10.1007/BF02978875

Schmidt, M., Schwegler, R., 2008. A recursive ecological indicator system for the supply chain of a company. Journal of Cleaner Production 16, 1658–1664. doi:10.1016/j.jclepro.2008.04.006

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

Srivastava, S.K., 2007. Green supply-chain management: A state-of-the-art literature review. International Journal of Management Reviews 9, 53–80. doi:10.1111/j.1468-2370.2007.00202.x

Taticchi, P., Tonelli, F., Pasqualino, R., 2013. Performance measurement of sustainable supply chains: A literature review and a research agenda. International Journal of Productivity and Performance Management.

Tokos, H., Pintarič, Z.N., Krajnc, D., 2012. An integrated sustainability performance assessment and benchmarking of breweries. Clean Technologies and Environmental Policy 14, 173–193. doi:10.1007/s10098-011-0390-0

Tseng, M.-L., Tan, K.-H., Lim, M., Lin, R.-J., Geng, Y., 2013. Benchmarking eco-efficiency in green supply chain practices in uncertainty. Production Planning & Control 7287, 1–12. doi:10.1080/09537287.2013.808837

Tsoulfas, G.T., Pappis, C.P., 2008. A model for supply chains environmental performance analysis and decision making. Journal of Cleaner Production 16, 1647–1657. doi:10.1016/j.jclepro.2008.04.018

Tugnoli, a., Santarelli, F., Cozzani, V., 2008. An approach to quantitative sustainability assessment in the early stages of process design. Environmental Science & Technology 42, 4555–4562. doi:10.1021/es702441r

Ukidwe, N.U., Bakshi, B.R., 2005. Natural versus Economic Capital in Industrial Supply Networks – Implications for Outsourcing and Sustainability. Spectator 39, 9759–9769.

Veleva, V., Hart, M., Greiner, T., Crumbley, C., 2003. Indicators for measuring environmental sustainability: A case study of the pharmaceutical industry. Benchmarking: An International Journal 10, 107–119.

Wang, J.J., Jing, Y.Y., Zhang, C.F., Zhao, J.H., 2009. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and Sustainable Energy Reviews 13, 2263–2278. doi:10.1016/j.rser.2009.06.021

WBCSD, 2000. Eco-efficiency. Creating more Value with less Impact, World Business Council for Sustainable Development.

World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI), 2009. The Greenhouse Gas Protocol Initiative: Scope 3 Accounting and Reporting Standard. Geneva, Switzerland.

Wu, C., Barnes, D., 2016. An integrated model for green partner selection and supply chain construction. Journal of Cleaner Production 112, 2114–2132. doi:10.1016/j.jclepro.2015.02.023