# Sustainability Evaluation for an Industrial Supply Chain: A Data Envelopment Analysis Approach

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## Abstract

Over the last decade, there has been an increased pressure on enterprises to broaden the focus of sustainability and accountability in business performance beyond that of financial performance. Benefiting from a performance measurement system is an inevitable necessity for any supply chain to direct the business operations towards the maximal efficiency. Demands for sustainability management includes a variety of sources, including societal mandates incorporated into regulations, fear of loss of sales, and a potential decline in reputation if a firm does not have a tangible commitment to sustainable management. The sustainability paradigm calls for balancing economic, environmental, and social needs. Thus, this paper focuses on the evaluation of industrial supply chain operations, maximizing economic returns, minimizing environmental impacts, and meeting social expectations. The objective of this work is to expand the understanding of the measurement of sustainability management by introducing a data envelopment analysis (DEA) technique. By employing the approach of cross efficiency, we present a new model to measure sustainability management. The new proposed model and the findings contribute to the body of knowledge in sustainability management and its performance measurement.

**Keywords:**
Sustainability, Industrial supply chain, Performance measurement, Data envelopment analysis (DEA)

## Introduction

Understanding different aspects of sustainability, supply chain operations, and decision making policies and relating them to performance measurement have been increasingly investigated in the last decade(Hassini, Surti, & Searcy, 2012). Globalization brings about various pressures for multi-national enterprises to improve their environmental and social performance, as well as their economic efficiency, although they may be somewhat conflicting. Since the 1987 report Our Common Future commissioned by the World Commission on Environment and Development (1987) that offered a general definition of sustainable development as 'to meet the needs of the present without compromising the ability of future generations to meet their own needs', increasing number of companies have experienced the challenges of dealing with economic, environmental, and social issues at a practical level. One example of the incorporation of sustainability into business practices is the growing number of environmental and sustainability reports. Indeed, publication of such reports is increasingly becoming an essential part of corporate business activities at a global level. In a turbulent business environment, gaining competitive advantage based on business efficiency becomes a norm for any companies. Based on a three-dimension sustainability framework that deals with economy (profit), environment (planet), and society (people) (Elkington, 2004), both large and small initiatives have realized its profitable potential to create new revenue streams in the competitive world(Mincer, Chaudhry, Blankenship, & Turner, 2008). Furthermore, the importance of sustainability assessment has not been restricted to the academia and many practices have been performed by international organizations and unions around the triple pillars of the sustainable development(Young, Wolfheim, Marsh, & Hammamy, 2012). In the literature, there are various analytical methods and mathematical approaches to cope with sustainability assessment. Saisana and Tarantola (2002) focus on composite indicators' (CI) characteristics and review the methods applied to create CIs. They define an indicator or measure as a piece of information that summarizes or highlights what is happening in a dynamic system. Consequently, a systematic integration of a set of such indicators, for which there is no obvious way of weighting them, is called an index or a CI. They list several mathematical and statistical approaches for determining CIs. Among these procedures, data envelopment analysis (DEA) has been one of the most effective methods to evaluate the performance of entities (either single organizations or business cooperation chains). DEA, developed systematically by Charnes et al. (1978), is a non-parametric technique to evaluate the relative efficiencies of a set of comparable decision making units (DMUs) by mathematical programming. This approach does not require any decision maker to prescribe weights to be attached to each indicator. Not only are the indicators' weights derived directly from the existing data in DEA, but also this method is capable to distinguish the benchmark entities based on an efficiency score and also identify the sources and amounts of inefficiency of the inefficient DMUs )Birney et al., 2007( Our motivation for this work stemmed from the need to have comprehensive supply chain performance measurement systems that can capture the total supply chain efforts in sustainability.

In business terms, the KBCSD describes corporate sustainability management as 'strategic business activities to minimize risks from environmental, economic, and social sustainability, at the same time, to maximize corporate value including shareholder value.' There are international standards and guidelines for integrating sustainability management into business organizations. Increasing number of companies adopted sustainability management related standards and guidelines including ISO 14000, Social Accountability (SA) 8000, ISO 26000, Accountability 1000, OECD Multinational Enterprises, Dow Jones Sustainability Index (DJSI) (2008), the United Nations Global Compact, and World Business Council for Sustainable Development (WBCSD) initiatives. The main hindrance of these standards and guidelines when it comes to helping companies implement the different concepts of corporate sustainability management is that they remain merely suggestions and recommendations on how corporate sustainability management (CSM) is to be taken into account in the company's goals and activities. Thus, in order to increase eco-efficiency, it is necessary either to reduce the environmental impact of a product or to increase its economic value. Although there is a substantial body of literature on ecoefficiency for corporate sustainability indicators and measurement, there are "no agreed rules or standards for recognition, measurement, and disclosure of environmental information" (Mincer et al., 2008).Data envelopment analysis (DEA), as introduced by Charnes et al. (1978) and expanded upon by Banker et al. (1984), is a linear programming procedure for a frontier analysis of inputs and outputs.

Our motivation for this work stemmed from the need to have comprehensive supply chain performance measurement systems that can capture the total supply chain efforts in sustainability. This need has arisen from the involvement of one of the authors with a project where one organization wanted to measure the sustainability of its procurement and was faced with the problem that they were not able to measure beyond their company. This difficulty is not only due to lack of supply chain data but also because there were no performance measurement systems that can capture indicators beyond their company. Using the capabilities of DEA to assess sustainable supply chains is the focus of this study. The purpose of this paper is to:

(i) review existing DEA approaches that evaluate the supply chains and propose a sustainable-based application,
(ii) develop a multi-stage assessment framework that includes all possible partners of a supply chain,
(iii) utilize the concept of the strong efficiency in the proposed model, which generally decreases the number of efficient DMUs.

## Literature Review

The supply chain concept has been defined in the literature using several viewpoints(Mentzer et al., 2001). We consider a supply chain as the integration of all parties and related processes that are involved in satisfying a customer order. Likewise, there is no unique definition of sustainability(Ahi & Searcy, 2013), and we define the business sustainability "as the ability to conduct business with a long term goal of maintaining the well-being of the economy, environment, and society"(Hassini et al., 2012). Tajbakhsh and Hassini (2013) review the state-of-the-art in evaluating sustainable supply chain management (SSCM) practices. They propose various sets of performance measures that include all major links in a supply chain as well as all three pillars of sustainability.
Supply chain managers need performance frameworks monitoring a set of the crucial indicators to improve the existing efficiency of their operations (Shepherd et al., 2006).However, they often prefer to deal with a concise amount of processed data reflecting the overall status of their business effectiveness and achieved amount of the predetermined objectives. Therefore, applying CIs, which are capable of summarizing dynamic and complex multi-entity environments and systematically combining a set of indicators, can be a helpful approach. As Saisana and Tarantola (2002) note, one of the difficulties of this process is the subjectivity in assigning weights to the sub-indicators and indicators. In spite of the availability of expert judgment to weigh measures, such a possibility may not be practical in real sophisticated cases, such as multi-partner supply chains. Data envelopment analysis (DEA) which is a data-oriented approach to evaluate the relative efficiency of a set of comparable entities could be applied to help with such a difficulty.
The inception of DEA is presented in Farrell (1957) where economic research motivations raise the need of developing better methods for evaluating productivity functions. However, Farrell did not carry his developments to a point which distinguishes between both Farrell efficient and Pareto-Koopmans efficient categories (Koopmans, 1951), referred to as weak efficiency and strong efficiency, respectively(Birney et al., 2007). The modern version of DEA originates from the ideas of Charnes, Cooper, and Rhodes (CCR) through mathematical formulations(Charnes, Cooper, & Rhodes, 1981). The fundamental idea behind DEA is to provide a methodology whereby a set of benchmark DMUs forms an efficient frontier and furthermore this methodology is able to measure the level of efficiency of inefficient units. The indicator set of the DMUs is divided into two input and output categories and DEA approach attempts to maximize the ratio of weighed outputs to weighted inputs, as a conventional efficiency criterion. Since the very beginning of DEA studies, several extensions of the CCR model have been developed, such as what Banker, Charnes, and Cooper (BCC) propose to the CCR model have been developed, such as what Banker, Charnes, and Cooper (BCC) propose to produce frontiers

spanned by the convex hull of the existing DMUs(Banker, Charnes, & Cooper, 1984). There have been several recent reviews that cover both practical and theoretical developments of DEA (Cook & Seiford, 2009)

As Lee and Billington (1992) argue, an important obstacle to the effective management of supply chains is the lack of effective performance measurement systems, especially when objectives conflict. Since DEA is able to characterize the performance and efficiency in the existence of multiple measures, it can be potentially an appropriate choice to be implemented in the supply chain assessment, beyond the evaluation of each member individually and the treatment of each one as a separate blackbox(Chen, Liang, & Yang, 2006). However, the existence of conflicting objectives among supply chain members with respect to specific measures makes the process of selecting inputs and outputs a sensitive issue. Zhu (2009) shows that conventional DEA approaches (which ignore the intermediate measures) cannot appropriately measure the efficiency of the whole supply chain.

## Proposed model

The proposed model is able to evaluate the overall efficiency of a sustainable supply chain containing an arbitrary number of suppliers, manufacturers, distributers, and retailers.

Therefore, each of the DMUs, or the supply chains in this context, is built of four stages and each stage includes a set of partners connected to the predecessor/successor stage's members by some sustainable intermediate measures. Moreover, each of the supply chain members is also monitored by its own direct indicators.

## Notation

We use the following symbols and notations in this Section:

### Indices and Sets

J = {1,….,n}: set of comparable DMUs to be evaluated, indexed by j

I = {1,….,m}: set of inputs into a DMU, indexed by i

 = {1,….,s}: set of outputs from a DMU, indexed by r

P∈J : index of the DMU under evaluation

Dis( I ): set of discretionary(direct)inputs into a DMU, indexed by i

Non( I ): set of non- discretionary (intermediate) inputs into a DMU, indexed by i

A = set of suppliers, indexed by $\alpha$

Π = set of manufacturers, indexed by $\pi$

H = set of distributers, indexed by $\eta$

Φ = set of retailers, indexed by $\varphi$

K = Sustainability index

Δ ∈ {Sup, Man, Dis, Ret}: stage index representing all four main echelons of a DMU

DI . Δ: set of direct inputs into a echelon Δ of a DMU, indexed by i

DR . Δ: set of direct outputs from an echelon Δ of a DMU, indexed by r

T : set of intermediates from a supplier into a manufacturer, indexed by t

M : set of intermediates from a manufacturer into a supplier, indexed by m

F : set of intermediates from a manufacturer into a distributer, indexed by f

G : set of intermediates from a distributer into a manufacturer, indexed by g

E : set of intermediates from a distributer into a retailer, indexed by e

N : set of intermediates from a retailer into a distributer, indexed by n

### *Parameters*

$x_{ij}$ : consumed amount of input i by $DMU_j$

$y_{rj}$ : produced amount of output r by $DMU_j$

$\varepsilon$ : infinitesimal amount (known as the non-Archimedean value)

$X_{ij\alpha}$: consumed amount of input i by S($\alpha$) of DMUj

$Z_{mj\pi\alpha}$ : consumed/produced amount of intermediate t from M($\pi$) into S($\alpha$) of DMUj

$z_{tj\alpha\pi}$ : consumed/produced amount of intermediate t from S($\alpha$) into M($\pi$)of DMUj

Decision Variables

$\theta_{p}$: efficiency score of DMUp

$\theta_p^{s(\alpha)}$, $\theta_p^{D(\eta)}$, $\theta_p^{M(\pi)}$ or $\theta_p^{R(\varphi)}$: efficiency score of $s(\alpha)$,Respectively ,DMUof $R(\varphi)$ ,, $M(\pi)$

$\lambda_j$ : indicator for DMUj determining whether it is a benchmark for DMUat the level of suppliers $p$

$\beta_j$ : indicator for DMUj determining whether it is a benchmark for DMUat the level of $p$ manufacturers

$\delta_j$ : indicator for DMUj determining whether it is a benchmark for DMUat the level of $p$ distributers

$\gamma_j$ : indicator for DMUj determining whether it is a benchmark for DMUat the level of retail $p$

**Supplier Stage**

$$\sum_{j\in J} x_{ij\alpha k}\lambda_j + s_{i\alpha}^- = \theta_p^{s(\alpha)} x \qquad \forall i \in \text{DI.Sup} \quad \forall \alpha \in A$$

$$\sum_{j\in J} y_{rj\alpha k}\lambda_j - s_{r\alpha}^+ = y_{rp\alpha} \qquad \forall r \in \text{D}\square\text{.Sup} \quad \forall \alpha \in A$$

$$\sum_{j\in J} z_{mj\pi\alpha k}\lambda_j + s_{m\alpha\pi}^- = z_{mp\pi\alpha} \qquad \forall m \in M \quad \forall \alpha \in A \ \forall \pi \in \Pi \qquad *$$

$$\sum_{j\in J} z_{tj\alpha\pi k}\lambda_j - s_{t\alpha\pi}^+ = z_{tp\alpha\pi} \qquad \forall t \in T \quad \forall \alpha \in A \ \forall \pi \in \Pi$$

$$\lambda_j, s_{i\alpha}^-, s_{r\alpha}^+, s_{m\alpha\pi}^-, s_{t\alpha\pi}^+ \ge 0$$

$\forall j \in J, i \in \text{DI.Sup}, r \in \text{D}\square\text{.Sup}, m \in M, t \in T, \alpha \in A, \pi \in \Pi$

**Manufacturer Stage**

$$\sum_{j\in J} x_{ij\pi K}\beta_j + s_{i\pi}^- = \theta_p^{M(\pi)} x_{ip\pi} \qquad \forall i \in \text{DI.Man} \quad \forall \pi \in \Pi$$

$$\sum_{j\in J} y_{rj\pi k}\beta_j - s_{r\pi}^+ = y_{rp\pi} \qquad \forall r \in \text{DR.Man} \quad \forall \pi \in \Pi$$

$$\sum_{j\in J} z_{tj\alpha\pi k}\beta_j + s_{t\alpha\pi}^- = z_{tp\alpha\pi} \qquad \forall t \in T \quad \forall \alpha \in A \ \forall \pi \in \Pi \qquad *$$

$$\sum_{j\in J} z_{mj\pi\alpha k}\beta_j - s_{m\alpha\pi}^+ = z_{mp\pi\alpha} \qquad \forall m \in M \quad \forall \alpha \in A \ \forall \pi \in \Pi$$

$$\sum_{j\in J} z_{gj\eta\pi k}\beta_j + s_{g\pi\eta}^- = z_{gp\eta\pi} \qquad \forall g \in G \quad \forall \pi \in \Pi \ \forall \eta \in H \qquad *$$

$$\sum_{j\in J} z_{fj\pi\eta k}\beta_j - s_{f\pi\eta}^+ = z_{fp\pi\eta} \qquad \forall f \in F \quad \forall \pi \in \Pi \ \forall \eta \in H$$

$$\beta_j, s_{i\pi}^-, s_{r\pi}^+, s_{t\alpha\pi}^-, s_{m\alpha\pi}^+, s_{g\pi\eta}^-, s_{f\pi\eta}^+ \ge 0$$

$\forall j \in J, i \in \text{DI.Man}, r \in \text{DR.Man}, t \in T, m \in M, g \in G, f \in F, \alpha \in A, \pi \in \Pi, \eta \in H$

**Distributer Stage**

$$\sum_{j\in J} x_{ij\eta k}\delta_j + s_{i\eta}^- = \theta_p^{D(\eta)} x_{ip\eta} \qquad \forall i \in \text{DI.Dis} \quad \forall \eta \in H$$

$$\sum_{j\in J} y_{rj\eta k}\delta_j - s_{r\eta}^+ = y_{rp\eta} \qquad \forall r \in \text{D}\square\text{.Dis} \quad \forall \eta \in H$$

$$\sum_{j\in J} z_{fj\pi\eta k}\delta_j + s_{f\pi\eta}^- = z_{fp\pi\eta} \qquad \forall f \in F \quad \forall \pi \in \Pi \ \forall \eta \in H \qquad *$$

$$\sum_{j\in J} z_{gj\eta\pi k}\delta_j - s_{g\pi\eta}^+ = z_{gp\eta\pi} \qquad \forall g \in G \quad \forall \pi \in \Pi \ \forall \eta \in H$$

$$\sum_{j\in J} z_{nj\varphi\eta k}\delta_j + s_{n\eta\varphi}^- = z_{np\varphi\eta} \qquad \forall n \in N \quad \forall \eta \in H \ \forall \varphi \in \Phi \qquad *$$

$$\sum_{j\in J} z_{ej\eta\varphi k}\delta_j - s_{e\eta\varphi}^+ = z_{ep\eta\varphi} \qquad \forall e \in E \quad \forall \eta \in H \ \forall \varphi \in \Phi$$

$$\delta_j, s_{i\eta}^-, s_{r\eta}^+, s_{f\pi\eta}^-, s_{g\pi\eta}^+, s_{n\eta\varphi}^-, s_{e\eta\varphi}^+ \ge 0$$

$\forall j \in J, i \in \text{DI.Dis}, r \in \text{D}\square\text{.Dis}, f \in F, g \in G, n \in N, e \in E, \pi \in \Pi, \eta \in H, \varphi \in \Phi$

**Retailer Stage**

$$\sum_{j\in J} x_{ij\varphi k}\gamma_j + s_{i\varphi}^{-} = \theta_p^{R(\varphi)} x_{ip\varphi} \qquad \forall i \in DI.Ret \quad \forall \varphi \in \Phi$$

$$\sum_{j\in J} y_{rj\varphi k}\gamma_j - s_{r\varphi}^{+} = y_{rp\varphi} \qquad \forall r \in DR.Ret \quad \forall \varphi \in \Phi$$

$$\sum_{j\in J} z_{ej\eta\varphi k}\gamma_j + s_{e\eta\varphi}^{-} = z_{ep\eta\varphi} \qquad \forall e \in E \quad \forall \eta \in H \quad \forall \varphi \in \Phi \qquad *$$

$$\sum_{j\in J} z_{nj\varphi\eta k}\gamma_j - s_{n\eta\varphi}^{+} = z_{np\varphi\eta} \qquad \forall n \in N \quad \forall \eta \in H \quad \forall \varphi \in \Phi$$

$$\gamma_j, s_{i\varphi}^{-}, s_{r\varphi}^{+}, s_{e\eta\varphi}^{-}, s_{n\eta\varphi}^{+} \geq 0$$

$$\forall j \in J,\ i \in DI.Ret,\ r \in DR.Ret,\ e \in E,\ n \in N,\ \eta \in H, \varphi \in \Phi$$

As part of this study, the guidelines were rigorously analyzed, synthesized, and organized into three key principles and dimensions, and five key areas of corporate sustainability performance (see Table 1).

The five key areas for corporate sustainability management identified in Table 1 are reflected in the development of a methodology to measure CSM performance in the industrial supply chain

The KPIs and associated measurement items are developed and summarized in Table 2. Arguably, superior corporate sustainability performance will bring relevant benefits to increase overall corporate value and performance. For example, transparent economic and financial activities will enhance trust and yield positive inputs from shareholders and investors (Lee & Saen, 2012) From a long-term perspective, companies that practice economic sustainability performance will, therefore, be able to secure capital through financial markets and investors. Similarly, employee training for social responsibility will increase the employee retention ratio and attract an increasing number of employees. Also, obtaining external sustainability-related awards and donations will return additional sales, grants, and tax benefits to firms that exercise corporate sustainability performance proactively. Developing 'green' and environmentally friendly new product development will bring another source of competitive advantage such as increased sales, cost reduction, and product differentiation in commercial markets.

Table 1 Key principles and key areas of corporate sustainability performance.

| Key principals and dimension | Key areas | Description |
|---|---|---|
| 1.Economic transparency and profitability | Corporate governance | The company recognizes the fiduciary duty of corporate boards and managers to focus on the interests of all corporate stakeholders. |
| | Corporate transparency and accountability | The company provides timely information disclosure about its products, services, and activities; the company discloses timely information about sustainability performance activities. |
| 2. Social Responsibility | Human rights | The company engages in human resource management activities that promote employee development and diversity. |
| | Social contribution | The company builds and fosters a mutually beneficial relationship between the corporation and community. |
| 3.Environmental sustainability | Environmental management and innovation | The company strives to protect and restore the environment and provides innovative products, processes, and services towards sustainable development. |

Table2

| Key principals and dimension | KPIs | Measures |
|---|---|---|
| 1.Economic transparency and profitability<br>2.Social responsibility<br>3.Environmental sustainability | Corporate governance<br>Corporate transparency and accountability<br>Human rights<br>Social contribution | No. of board meetings and stakeholder meetings.<br>Personnel<br>costs/expenses of communication and relevant meetings<br>Material costs—design and printing costs of communication<br>materials (e.g. annual sustainability reports, financial reports, etc.).<br>Personnel/administrative costs.<br>No. of employee training hours for corporate social responsibility (CSR).<br>Expenses to train and promote CSR internally.<br>No. of social events with local communities.<br>Amounts of donations<br>Volunteering hours/personnel costs.<br>No. of green technology development projects.<br>Expense of environmental management.<br>Costs of environmental product innovation (# of products patents, employee hours to develop product innovations) |

## Discussions

The aim of this paper is to provide new insights into corporate sustainability management and its performance measurement. International organizations including the United Nations, the OECD, and the GRI have published principles and guidelines in order to advance the notion of sustainable development globally at firm level. In addition, financial institutions and markets including the Dow Jones Sustainability Index (DJSI) and Financial Times Stock Exchange for Good (FTSE4Good) provide a corporate sustainability index and related management indicators at global level. These international developments are helping to persuade markets and industries to move proactively towards sustainable development. However, as discussed previously, it is a major challenge for firms to demonstrate their contributions to sustainable development not at least due to the difficulties in measuring corporate sustainability performance. In order to integrate CSM practices into business organizations at a firm and an industry level, developing indicators and measurement models is a key first step. Although business responses to corporate sustainability issues are varied, the core message is simple: corporate sustainability is a managerial issue as well as a strategic issue. Recent research also indicates that a company's decision to engage in corporate sustainability management is a strategic choice (Siegel, 2009). At a strategic level, strategic goals and tactics can be adopted by companies regarding strategic

CSM. For example, when some companies choose achievement of “an increased market share” as a strategic goal, they can use a certain range of tactics such as advertising CSM, CSM-related product and service innovation, and CSM application to raise rivals’ costs. In order to implement CSM-related strategies, in particular, corporate managers need to improve their understanding of both the implications of their decisions and the actions that they can take to produce improved performance in sustainability management. This requires a careful analysis of the performance measurement and the related indicators. Since few empirical studies have employed a DEA methodology for measuring corporate sustainability management, we developed a new model to measure corporate sustainability management based on advanced DEA approach. In particular, we employed cross-efficiency in the presence of dual-role factors as a means of reflecting some of the complexities of a real-world case and, in particular, the potential input/output role of donations for tax benefits. Although, as evidenced by the work of Chalmeta and Palomero (2011), there are some useful, available tools to support sustainability management in the form of standards, guidelines, and indicators; incorporating these tools to identify and measure sustainability management is a hard challenge for companies (Chalmeta and Palomero, 2011). This study provides some important contributions. First, the proposed DEA model for measuring corporate sustainability management considered a dual-role factor and cross-efficiency technique simultaneously. This gives a better decision making tool for measurement. Second, this paper is the first study to propose an advanced DEA model for measuring corporate sustainability management. There are also important managerial implications. First, firms may establish key criteria for corporate sustainability management in order to measure any progress towards sustainable business development. By employing the proposed DEA model, firms can monitor efficiency scores, which provide an indicationof the levels of corporate sustainability performance. By doing this, firms can set a strategic goal to achieve improved corporate sustainability in both the short-term and long-term. In practice, firms may engage in sustainable innovative product development, green marketing, and sustainability performance measurement to achieve such strategic goals. Second, the proposed DEA model can be applied to select suppliers within a supply chain network in manufacturing industries such as the electronics and automobile industries. Since such sustainable supply chain management requires monitoring and collaboration with suppliers in relation to their economic, social, and environmental performance, final manufacturers within the supply chain may apply the proposed DEA model to screen and select suppliers according to a ranking of a cross-efficiency and input–output matrix. By practicing this, final manufacturers, as well as buyers, can develop strategic partnerships with superior performers to achieve new product innovation or tackle environmental regulations such as climate change-related $CO_2$ reductions to meet their Kyoto compliance obligations. Finally, there are also practical issues that in relation to the application of the methods to measure corporate sustain-ability management. Since most of the practitioners are not familiar with Operations Research techniques, especially DEA technique, developing a decision support system (DSS) is likely to be an essential step in resolving this problem. By employing such a DSS, practitioner can measure corporate sustainability without having a detailed understanding of the underpinning mathematics. The problem considered in this study is at an initial stage of investigation and further research can be undertaken based on the results of this paper. Some avenues are as follows: _ Similar research can be repeated to deal with stochastic data. _ In this study, the proposed model has been applied to a problem related to corporate sustainability measurement. However, the same model could be applied, with minor modifications, to other problems related to selection of tech-nologies, selection of suppliers, selection of personnel, and many other selection-based problems. _ In order to generalize the findings from this study, it is also recommended that academics examine the model and methods in other industries such as automobile industry. Furthermore, it would be important to conduct comparative studies in different industries or different countries using the model and methods from this study in order to reinforce its claims to validity.

## Conclusions

In this paper, in addition to reviewing a vast range of existing DEA approaches that evaluate supply chain practices, a new multi-stage DEA model is proposed. This model presents both the overall efficiency score of a supply chain and the individual efficiency score of its partners at the same time. In addition, the condition that guarantees the equivalence of results obtained by centralized and non-cooperative approaches is described. More importantly, the developed multi-stage DEA approach could evaluate the efficiency of a (sustainable) supply chain when there exists an arbitrary number of suppliers, manufacturers, distributers, and retailers, allowing for the possibility of having unequal weights between stages as well as new inputs to intermediary stages. Although a centralized perspective has been introduced in this study, more complicated approaches of game theory could be integrated with the DEA technique in future studies. Furthermore, all indicators are assumed independent in the current paper, while they could be generalized for practical cases that deal with correlated and non-separable direct/intermediate measures. In addition, investigating the impact of the missed data of some DMUs on the overall score and also beneficiating the privileges of super efficiency models to overcome the infeasibility and multi-efficiency appearance could be analyzed in the future.

## References


Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of cleaner production, 52*, 329-341.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science, 30*(9), 1078-1092.

Birney, E., Stamatoyannopoulos, J. A., Dutta, A., Guigó, R., Gingeras, T. R., Margulies, E. H., . . . Thurman, R. E. (2007). Identification and analysis of functional elements in 1% of the human genome by the ENCODE pilot project. *Nature, 447*(7146), 799-816.

Charnes, A., Cooper, W. W., & Rhodes, E. (1981). Evaluating program and managerial efficiency: an application of data envelopment analysis to program follow through. *Management science, 27*(6), 668-697.

Chen, Y., Liang, L., & Yang, F. (2006). A DEA game model approach to supply chain efficiency. *Annals of Operations Research, 145*(1), 5-13.

Cook, W. D., & Seiford, L. M. (2009). Data envelopment analysis (DEA)–Thirty years on. *European Journal of Operational Research, 192*(1), 1-17.

Elkington, J. (2004). Enter the triple bottom line. *The triple bottom line: Does it all add up, 11*(12), 1-16.

Hassini, E., Surti, C., & Searcy, C. (2012). A literature review and a case study of sustainable supply chains with a focus on metrics. *International Journal of Production Economics, 140*(1), 69-82.

Koopmans, T. C. (1951). *Activity analysis of production and allocation*: Wiley New York.

Lee, K.-H., & Saen, R. F. (2012). Measuring corporate sustainability management: A data envelopment analysis approach. *International Journal of Production Economics, 140*(1), 219-226.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. *Journal of Business logistics, 22*(2), 1-25.

Mincer, H. H., Chaudhry, J., Blankenship, J. A., & Turner, E. W. (2008). Postmortem dental radiography. *Journal of forensic sciences, 53*(2), 405-407.

Shepherd, S. P., Zhang, X.-n., Emberger, G., Hudson, M., May, A. D., & Paulley, N. (2006). Designing optimal urban transport strategies: The role of individual policy instruments and the impact of financial constraints. *Transport Policy, 13*(1), 49-65.

Young, M., Wolfheim, C., Marsh, D. R., & Hammamy, D. (2012). World Health Organization/United Nations Children's Fund joint statement on integrated community case management: an equity-focused strategy to improve access to essential treatment services for children. *The American journal of tropical medicine and hygiene, 87*(5 Suppl), 6-10.

Mentzer, J.T., et al., *Defining supply chain management.* Journal of Business logistics, 2001. **22**(2): p. 1-25.

Ahi, P. and C. Searcy, *A comparative literature analysis of definitions for green and sustainable supply chain management.* Journal of Cleaner Production, 2013. **52**: p. 329-341.

Hassini, E., C. Surti, and C. Searcy, *A literature review and a case study of sustainable supply chains with a focus on metrics.* International Journal of Production Economics, 2012. **140**(1): p. 69-82.

Shepherd, S.P., et al., *Designing optimal urban transport strategies: The role of individual policy instruments and the impact of financial constraints.* Transport Policy, 2006. **13**(1): p. 49-65.

Koopmans, T.C., *Activity analysis of production and allocation*. 1951: Wiley New York.

Birney, E., et al., *Identification and analysis of functional elements in 1% of the human genome by the ENCODE pilot project.* Nature, 2007. **447**(7146): p. 799-816.

Charnes, A., W.W. Cooper, and E. Rhodes, *Evaluating program and managerial efficiency: an application of data envelopment analysis to program follow through.* Management science, 1981. **27**(6): p. 668-697.

Banker, R.D., A. Charnes, and W.W. Cooper, *Some models for estimating technical and scale inefficiencies in data envelopment analysis.* Management science, 1984. **30**(9): p. 1078-1092.

Cook, W.D. and L.M. Seiford, *Data envelopment analysis (DEA)–Thirty years on.* European Journal of Operational Research, 2009. **192**(1): p. 1-17.

Chen, Y., L. Liang, and F. Yang, *A DEA game model approach to supply chain efficiency.* Annals of Operations Research, 2006. **145**(1): p. 5-13.