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Developing sustainable supply chains in developing countries

Noha M. Galal[a,*], Ahmed F. Abdul Moneim[a]

[a]College of Engineering and Technology, Arab Academy for Science, Technology, and Maritime Transport, Alexandria P.O. Box 1029, Egypt

* Corresponding author. Tel.: +2-03-562-2366; fax: +02-03-562-2525.*E-mail address:*noha.galal@staff.aast.edu

Abstract

Sustainability of supply chains is achieved through the consideration of the economic, environmental and social aspects in the decision making process. The majority of research concentrates on integrating two out of these three aspects, with limited inclusion of the social aspect. In developing countries, where the production supply chains are usually labour intensive, and where environmental regulations are still developing, both social and environmental aspects should be given considerable importance. This work presents a supply chain assessment model integrating the three dimensions of sustainability. An illustrative numerical example demonstrates how the proposed model may aid in the assessment and improvement of supply chain sustainability.

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*Keywords:*Sustainability; assessment; developing countries; supply chain;

1. Introduction

With the rise of globalization the role and importance of supply chain management has increased. Global supply chains commonly extend between industrialized and developing countries. Differences in economy, legislations, regulations and standards pose difficulties in managing such supply chains. Developing countries, usually playing the role of raw material suppliers or manufacturers, face problems which affect the performance of supply chains [1]. Common problems with developing countries include instability of governments and policies, corruption, labor intensive industries, deteriorated infrastructure and limited use of new technologies, underemployment, child labor, and low education level of the population [1]. Due to customer pressure and legislation in industrialized countries, sustainability of the supply chain is a main goal to achieve. Sustainable supply chain management is defined as "the management of material, information and capital flows as well as cooperation among companies along the supply chain while integrating goals from all three dimensions of sustainable development, i.e., economic, environmental and social, which are derived from customer and stakeholder requirements" [2]. To achieve sustainability targets a coordination between the supply chain members is necessary. To preserve their position and role in the supply chain, each member has to conform to the environmental and social goals, while competitiveness would be achieved through the fulfillment of customer requirements and economic aspects [2]. Failure of one stage or player in the supply chain will affect the overall performance and competitiveness of the supply chain. Developing countries encounter additional challenge since their economic benefit relies on the exploitation of natural resources. Social implications of the production activities are highly neglected [3].

Thus there is a need to assess the performance of the whole supply chain with respect to the three dimensions of sustainability: economic, environmental, and social. Having such a collective measure, strategic, tactical, and operational

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decision making will be facilitated to increase supply chain sustainability.

The remainder of this paper is structured as follows. In the following section a literature review concerning sustainability assessment in supply chains with an emphasis laid on the triple bottom line approach and its application to developing countries is presented. Section 3 describes the proposed methodology for assessing supply chains sustainability in global supply chains and proposes a set of indicators to measure the economic, environmental and social performance of the supply chain. To illustrate the implementation of the proposed approach, a numerical example is given in Section 4 and the results are presented and discussed. Finally, conclusions are drawn and future research avenues are highlighted in Section 5.

2. Literature review

Numerous research efforts have been dedicated to the assessment of the sustainability of supply chains. Few have considered all three dimensions of sustainability aspects. The majority have added the environmental aspect to the traditional economic dimension, leaving the social aspect the least addressed in the literature [4, 5]. This is in part due to the qualitative nature of social aspects and the difficulty encountered in quantifying it [6]. The purpose of the current review is twofold. First, it reviews the existent research which has considered all three pillars of sustainability in supply chain. Second, it presents a state of the art of sustainable supply chains in developing countries.

2.1. Measuring sustainability in supply chains

A number of sustainability measures have been presented in the literature and used in the context of supply chains to aid stakeholders in making tactical and strategic decisions. In [7] an optimization supply chain network design model is proposed. The objective was to maximize sustainability expressed as linear benefit function of three components representing the economic, social and environmental dimensions of sustainability. Environmental measures used were based on energy consumption in the different supply chain echelons. The social indicator used is the one for health and safety, which covered worker safety for technologies and community safety for sites. A multi-objective linear programming model was formulated in [6] to design and plan a closed loop supply chain.

An analytical model is proposed in [8] to assess the sustainability of the supply chain via a triad. The developed assessment framework focused on supply chain practices and how they affect the sustainability of the supply chain. The framework included fifteen indicators representing the three dimensions of sustainability. These were broken down to sixty seven subfields covering economic contribution, environmental impact and social responsibility.

A fuzzy inference system was used in [9] to assess the sustainability of suppliers in medical device industry regarding the three dimensions of sustainability. Three scores measuring the three dimensions of sustainability are derived, and their average represents the overall supplier performance.

A probabilistic model for assessing sustainability of supply chain over time is presented in [10]. In their model the sustainability of a supply chain is defined by the probability that a supply chain strength exceeds its challenges.

The supply chain operation reference (SCOR) model has been extended by the Logistics Management Institute (LMI) to GreenSCOR which includes the environmental aspects of the supply chain [11]. Yet, the application of GreenSCOR is still scarce [12]. A number of SCOR metrics have been devised by the Supply Chain Council. These are categorized in five performance attributes: reliability, responsiveness, agility, costs, and assets management efficiency. These consider the customer and the internal operation of the supply chain. It is evident that a measure for sustainability considering the triple bottom line approach is not present.

2.2. Sustainable supply chains in developing countries

The research on sustainable supply chains in developing countries is scarce [14]. The main challenge faced in supply chain management is the coordination between developing and industrialized countries in view of the difference in legislations. Two challenges in decision making for supply chains are present [3]: First, firms tend to build stronger relationships with their suppliers since more design and production activities may be delegated to them. Second, an increasing number of organizations are incorporated in the supply chain due to the focus on core competencies. With the focal company considered responsible for the performance and actions of their suppliers affecting the environment and society [15], the assessment of each supply chain actor and the overall supply chain sustainability seems vital for decision making.

A number of empirical research exists for sustainability practices in supply chains in developing countries [14]. In [16] it is argued that in developing countries the dynamicity and uncertainty of business environments and the lack of institutions prevent supply chains from learning, innovating and thus hinder the sustainability target achievement. Through a case study in Brazil, four characteristics of developing countries affecting the performance of supply chains are identified: corruption, lack of infrastructure, pressing social problems in urban areas, and informality [16]. Akamp and Müller [1] concluded that supplier selection and evaluation, supplier development and supplier integration directly affect the supplier performance in developing countries.

In summary, a limited number of measures have been developed for assessing sustainability of supply chains considering the triple bottom line. Such measures are vital to aid in the decision making process on both strategic and tactical levels. The barrier to incorporating all three dimensions is the difficulty in quantifying the social aspects and the integration of all three pillars. Aggregation methods encompass multi-objective optimization and multi-criteria decision making. Global supply chains extending between industrialized and developing countries face additional complexity of coordination in view of the differences in legislation and the prevailing economic and uncertain business environments.

The main contribution of this paper is to devise a sustainability measure applicable to supply chains in general and which considers the specific aspects of developing countries. To this end, a set of quantitative indicators and sub-indicators are suggested for assessing the three dimensions of sustainability across the supply chain.

3. Sustainability Assessment Model

3.1. Assessment model

The main characteristic which needs to be addressed in the proposed measure is its capability to reflect the triple bottom line approach of sustainability and to allow for differences between actors in the supply chain with respect to their role and location. To this end, a measurement index is proposed based on the modular structure of the supply chain. The authors have in a previous work [17] suggested a sustainability index (*SI*) used for assessing a manufacturing facility. The proposed approach was based on the triple bottom line concept. It modelled the sustainability as a three dimensional vector whose three components represent the economic, environmental and social performance of the facility. A hierarchal structure breaking down the three dimensions of sustainability to a set of indicators and sub-indicators was suggested. All indicators and sub-indicators were designed to be dimensionless and to extend over the range of [0, 1]. This property allows the aggregation of all the indicators to a single index, *SI*. Furthermore, the proposed assessment method considered the relative importance of each indicator in achieving the sustainability goals of the manufacturing system under study through using the Analytical Hierarchy Process (AHP).

The current work builds on the concept introduced in [17] and introduces some modifications to extend its application to the supply chain. In fact a supply chain is a coordination of a set of players: suppliers, manufacturers, distributors, and retailers to produce and deliver products to consumers. Each actor may be presented as an entity or system having inputs, outputs and some operations to perform. These three elements of inputs, outputs and operations have direct and indirect impact on the entity itself, other supply chain stakeholders, the environment, and the society as illustrated in Fig.1. Thus the performance of each entity affects its own sustainability and does also shape the sustainability of the supply chain as a whole.

In order to assess the supply chain sustainability, the proposed framework (Fig. 2) starts with the assessment of the entities constituting the supply chain. Each of these has a specific role to fulfil, and contributes differently to achieving the supply chain goals and sustainability. The assessment of each actor is then aggregated to identify the overall supply chain sustainability.

The proposed two-stage assessment framework is composed of the following five-step procedure.

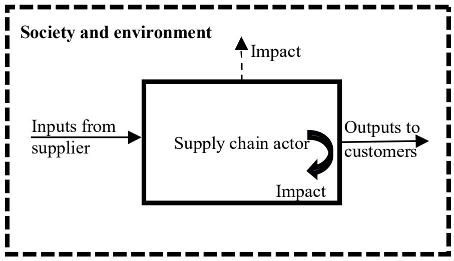

Fig.1. Inputs and outputs for a supply chain actor *k*.

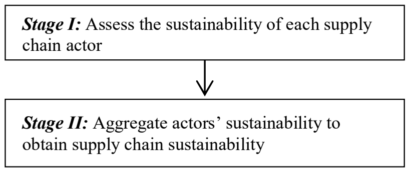

Fig. 2. Proposed framework.

- For each supply chain actor, a set of indicators and sub-indicators are identified and evaluated. These are categorized to economic, environmental, and social measures of sustainability performance of each actor. The proposed set of indicators and sub-indicators is described in detail in Section 3.2. These indicators contribute differently towards attaining sustainable performance, depending on the actor's role, size, location, and industry type. The relative importance of each of the indicators and sub-indicators may be assessed by eliciting information from experts by means of the Analytic Hierarchy Process (AHP). Experts shall identify the importance of each indicator and sub-indicator in achieving the sustainability of a specific actor. Thus, different weights result according to the activities each actor performs, the goals of the specific actor, its location and the prevailing business environment.
- For each actor *k*, the weighted sum of indicators and sub-indicators of each of the three dimensions is calculated to give the economic I_{eck}, environmental, I_{evk} and social I_{sck} indicators, respectively.
- A sustainability index SI_k of each actor *k* is calculated according to (1) as the resultant vector of the three sustainability dimensions, I_{eck}, I_{evk}, and I_{sck}. The role of the denominator is to enforce the upper bound of SI_k to be one. I_{eck}^{max}, I_{evk}^{max}, and I_{sck}^{max} present the highest possible value the economic, environmental, and social indicator may take on. These calculations are repeated to determine the sustainability index for all actors of the supply chain.

$$SI_k = \frac{\sqrt{(I_{eck})^2+(I_{evk})^2+(I_{sck})^2}}{\sqrt{(I_{eck}^{max})^2+(I_{evk}^{max})^2+(I_{sck}^{max})^2}} \quad (1)$$

- The overall supply chain sustainability index (*SSI*) is calculated by calculating SI_{ei} for each echelon, then aggregating the results across echelons. For an echelon of *m* actors, the echelon sustainability index is the geometric mean of sustainability index of all the *m* actors (2).

$$SI_{ei} = \sqrt[m]{SI_1 SI_2 \ldots SI_m} \qquad i=1,\ldots,n \qquad (2)$$

- Similarly, the sustainability across the echelons (*SSI*) is identified by the geometric mean of the sustainability indices of the echelons. The geometric mean has been chosen to reflect the dependency of the sustainability of each echelon on succeeding echelons and its impact on preceding ones. The geometric mean penalizes the inclusion of any actor with low sustainability level in the supply chain. This in turn encourages collaboration and coordination between the different supply chain actors. For a supply chain with *n* echelons, the overall sustainability is given by (3).

$$SSI = \sqrt[n]{SI_{e1} SI_{e2} \ldots SI_{en}} \qquad (3)$$

The *SSI* will take on values between zero and one, where one indicates the highest sustainability. The fact that the *SSI* value is dimensionless facilitates the comparison between different actors and different industries.

3.2. Developing the indicators and sub-indicators for measuring supply chain sustainability

The proposed framework relies on the evaluation of the economic, environmental and social dimensions of sustainability for each supply chain actor separately (SI_k). The individual sustainability assessments are then aggregated to obtain the overall supply chain sustainability index (*SSI*). In this section, a set of indicators and sub-indicators is proposed to be used in assessing the sustainability of each actor k. All the indicators are expressed as a ratio ranging in value from zero to one. This property is essential to allow for aggregation. Table 1 demonstrates the proposed indicators structure used for assessing the sustainability of each actor k. The economic dimension encompasses three indicators: added value, ratio of delivered products, and product diversification. The environmental dimension is presented by four indicators which are further broken down to sub-indicators. The selected categories target the assessment of the inputs (resources) and the resulting impact (emissions and waste) [17]. The renewable energy indicator is the ratio of renewable energy used to total energy consumption. Energy intensity ratio is the calculated by dividing energy consumed to total inputs. The water indicator assesses the ratio of the water wasted to total water consumed. Similarly, the material and emissions indicators consist of the ratio of the respective material or emission type to total material input or emissions generated.

The social dimension is presented by three indicators based mainly on the social sustainability indicators framework suggested by the United Nations Division for Sustainable development (UNDSD) [18]. Since these indicators are generally directed towards application on national or regional levels, there is a necessity to select among these indicators to arrive at a set which may be applied on supply chain level. The indicators selected are the ones which express the impact caused by the supply chain. These include the impacts generated by the different actors and influencing the labor as well as the society. One key issue in selecting the indicators is its measurability and the readiness of data required for the assessment. To ensure the sustainability of the assessment method, it should not entail great effort in data collection with consideration of the lack of data associated with developing countries. The selected indicators are: gender equality, labor development, healthcare delivery, and employment. The selected social indicators address major problems arising in developing countries as gender discrimination, underemployment, and low education level of the population. Table 2 and Table 3 give a brief description of the indicators and sub-indicators for the economic and social dimension, respectively.

Table 1: Proposed indicators for supply chain sustainability assessment

Sustainability dimension	Indicator	Sub-indicator
Economic	Added value	
	deliverable product	
	product diversification	
Environmental	energy	renewable energy
		energy intensity
	water	
	material	recycled
		hazardous
		waste
	emissions	direct
		indirect
Social	gender equality	
	labor development	
	healthcare delivery	
	employment opportunity	

Table 2: Description of economic indicators

Indicator	Description
Added value	Ratio of (selling price-cost of inputs) to selling price
Delivered Product	Ratio of good products delivered to the customer to total production
Product Diversification	Ratio of product variety offered to maximum possible products offered by the actor type

Table 3: Description of social indicators

Indicator	Description
Gender equality	Ratio of average female wage to male wage
Labor development	Ratio of training budget to total expenditure
Healthcare delivery	Ratio of health expenditure per employee to target national health care expenditure per capita
Employment opportunity	Ratio of job offering to number unemployed in the facility location.

4. Numerical illustration

4.1. Description

In this section a hypothetical numerical example is given to illustrate the application of the proposed assessment framework. The example is applicable to different supply chains as for example those of the manufacturing and distribution of electric appliances. This industry is generally characterized by having a global supply chain, typically extending between developing and industrialized countries. Sustainability of this type of products is critical since the manufacturing usually exploits valuable raw materials and energy and the wastes generated are critical to manage. Furthermore, these products are considered essential and exhibit high demand worldwide.

The network under study is assumed to consist of three echelons as depicted in Fig. 3. A total of eight actors build up the supply chain: three suppliers, two manufacturers, and three distributors. It is further assumed that both suppliers and manufacturers are located in developing countries; while the distribution is partially in industrialized and developing countries.

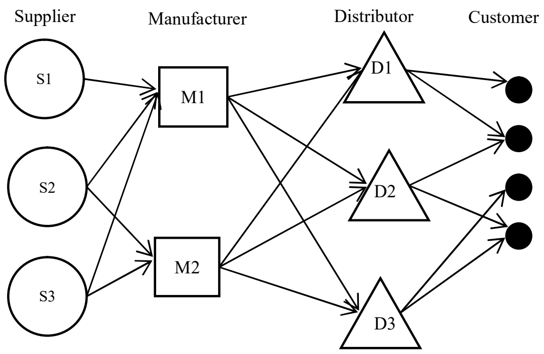

Fig. 3. Supply chain structure for the numerical example.

The set of indicators and sub-indicators described in Section 3.2 is calculated for each actor. Additionally, the weight of importance of the indicators and sub-indicators towards sustainability achievement is identified based on experts' opinion using AHP. The weight of importance, expresses how strongly the specific indicator affects the sustainability. The weights vary according to the industry type and the role of the specific actor. For example, for an energy intensive manufacturing process, the energy intensity may have a high contribution towards sustainability when compared to hazardous material (if no hazardous materials are used in this industry). On the other hand, for a distributor, the emissions are of more value to achieve sustainability than the water wasted (if the water consumption is negligible). A sample of the weights and values of the economic (E1, E2, and E3), environmental (V1,..., V8), and social (C1,…,C4) indicators for actor S1 is given in Table 4. The indicators are listed in the same sequence introduced in Table 1.

The weighted sum of the indicators results in the economic, environmental and social indicators I_{eck}, $I_{evk,}$ and I_{sck}, respectively. The sustainability index SI_k for each actor can now be determined according to (1). Next, the sustainability of each echelon is determined via (2); finally, the overall supply chain sustainability index *SSI* may be obtained by (3).

Table 4. A sample of indicator weight and value for actor S1

indicator	E1	E2	E3	V1	V2
weight	0.502	0.25	0.01	0.013	0.04
value	0.6	0.95	0.1	0.1	0.1
indicator	V3	V4	V5	V6	V7
weight	0.053	0.002	0.007	0.001	0.035
value	0.3	0.1	0.2	0.2	0.2
indicator	V8	C1	C2	C3	C4
weight	0.004	0.015	0.003	0.003	0.062
value	0.4	0.3	0.1	0.4	0.6

4.2. Results and discussion

A summary of the results is displayed in Table 5. The table shows the weighted sum of the economic (I_{eck}), environmental (I_{evk}), and social (I_{sck}) indicators for each actor, together with the sustainability index on actor, echelon, and supply chain levels. It can be observed that the dimension with the highest sustainability is the economic dimension, followed by the environmental and social dimensions. This reflects that it is mainly the traditional economic goal of the actor which is given a high priority.

Table 5: Supply chain actors' sustainability assessment

SC Actor	Economic (I_{eck})	Environmental (I_{evk})	Social (I_{sck})	SI_k	SI_{ei}
S1	0.540	0.032	0.043	0.694	0.539
S2	0.395	0.044	0.052	0.513	
S3	0.338	0.041	0.042	0.439	
M1	0.521	0.064	0.055	0.696	0.666
M2	0.473	0.073	0.059	0.637	
D1	0.464	0.088	0.042	0.641	0.723
D2	0.569	0.091	0.037	0.781	
D3	0.527	0.173	0.052	0.754	
				SSI	**0.638**

Each of the economic, environmental and social indicators may be broken down into a set of indicators and sub-indicators. As an example, the breakdown of the social indicator (I_{sck}) is presented graphically in Fig. 4. Since all indicator values are normalized, a comparison of the different indicators across the supply chain actors is possible. For the social indicators, the highest indicator value is the employment indicator for M2. Gender equality indicator has generally better achievements for the suppliers and manufacturers than labor development. This may be due to the fact, that for labor intensive industries requiring manual assembly work or inspection, the female workers are generally preferred due to their skills. Thus gender equality in such cases may be fulfilled. At the distributor, operations as warehousing, material handling, and transportation are generally performed by male workers, which may interpret the low indicator values at the distributor. Similar analysis is possible for the economic and environmental indicators, and may help in identifying strategies to improve individual actor as well as overall supply chain sustainability.

The results further allow the comparison between the different supply chain actors with respect to their sustainability index. This may help identifying the actors with critical sustainability level. In this example it is noticed that supplier S3 has the least sustainability among all supply chain actors followed by supplier S2 (Table 5). Thus measures need to be taken to improve sustainability for both actors. Investigating the sustainability components of each actor reveals that this low value originates from the social dimension. Based on the weight assigned to the contribution of each indicator towards sustainability, priority can be given to a specific indicator to improve the actor's sustainability.

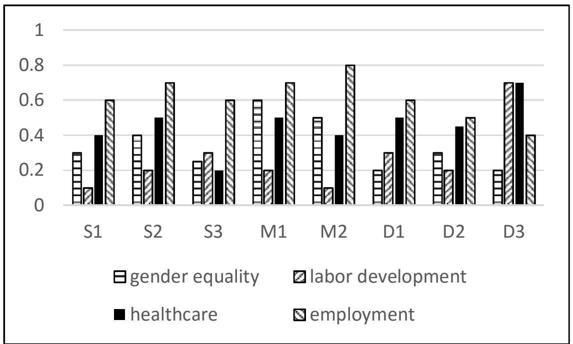

Fig. 4. Social indicators results

5. Conclusion

This work has proposed a model for assessing the sustainability of global supply chains. The supply chain is considered as a system of entities whose performance determines the overall supply chain sustainability. The suggested approach allows for the separate consideration of each supply chain actor in order to evaluate the total supply chain sustainability. To this end a set of normalized economic, environmental, and social indicators have been proposed. The fact that the indicators are normalized allows comparing the different entities of the supply chain, as well as aggregating the three sustainability dimensions to a single index. Furthermore, the inclusion of the relative importance of each of the indicators for each supply chain actor addresses the problem of global supply chain extending between industrialized and developing countries. This weight differs according to the location, goals, and role of the actor and is determined by AHP. This flexibility allows for the consideration of both industrialized and developing supply chain members. Thus the proposed model is generic and in fact applicable to any supply chain; yet the selection of the indicators, especially the social indicators, and the weight assigned to them facilitates addressing the specific characteristics of the supply chains in developing countries. The proposed model is flexible in that it can use different indicators as the supply chain context mandates. It may also handle more complex network structures.

Future research may include the application of the proposed framework to different industry sectors. Furthermore, the effect of specific supply chain strategies such as postponement, electronic data interchange, and consignment inventory on sustainability performance may be studied.

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