Product Environmental Quality Assessment: An Appraisal Model for Corporate Decision-Makers

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Abstract
Environmental quality of products is determined by several intrinsic characteristics and other characteristics that are not related to the product itself but rather to the supply chain process.
In this paper we present a mathematical model that illustrates the impact of several factors related to the activities of the supply chain on the environmental quality of the products to be manufactured. This model allows the determination of environmental quality of each product, thus its effect on the environment. For this purpose, we have adopted the most cited indicators in literature that significantly influence environmental quality of products to better reflect this quality.
This model is based on the aggregation of the adopted indicators. During the aggregation we faced a difficulty that affects the inequality of indicators importance (corporate strategy, type of industry, ...) which leads us to weight these indicators to express their relative importance. To do this, we have used the principle of weighting of Analytic Hierarchy Process method which is simple to use and allows to take into account both the quantitative and qualitative criteria.
By this work, our ambition is to provide for corporate decision-makers a real tool which will allows to know precisely the quality environmental of each manufactured product, thus it will be less difficult to know the actions to be taken to increase company's profit and to reduce its negative impact on the environment.

Keywords
Product, Environmental quality, Supply Chain, Indicator, Performance.

1. Introduction
The collective awareness of the environment and the increasing weight of regulatory constraints and environmental taxes applied by governments are pushing companies to think more carefully about the configuration of their supply chains and the environmental quality of their products.
Recently, customers have been increasing their attention to environmental issues. They are increasingly looking for products that respect the environment and do not harm the ecosystem. It is obvious that sensitivity to environmental problems differs according to customers. Some are more sensitive to environmental problems than others. They are known in the literature as "green" customers. These latter are mainly interested in the environmental quality of the product. Other customers are more sensitive to product prices. These customers are characterized as "ordinary" clients (Chen 2001). Others seek a compromise between the two criteria: environmental quality and price. The market then became segmented by a clientele sensitive to the environment.
Supply chain configuration and the definition of environmental characteristics of manufactured products are two interdependent aspects and should not be considered separately but rather simultaneously. Indeed, supply chain activities such as purchasing, production, and delivery have a great impact on the environmental quality of the product.
In the literature, very important work is concerned with aspects of design and definition of products considering environmental factors (Ljungberg 2007); (Gehin et al. 2008); (Borchardt et al. 2011). Most of this work does not consider supply chain configuration.
In addition, work on the supply chain in general and even those relating to the green supply chain often ignore the issues of environmental characterization of developed products (decisions concerning the environmental quality of proposed products) as well as the characteristics of the different market segments.
It is therefore very useful to complete existing approaches in the literature with an approach which integrates the supply chain configuration and the characterization of finished products considering environmental aspects. This work wants to be a contribution to this problematic.
In this paper, after a very broad literature review on the relationship between supply chain activities and the environmental quality of the products and on environmental regulations, we propose a mathematical optimization

model that chooses manufacturing processes (traditional and/or greens), product components (traditional and/or greens) and other factors under environmental constraints. The objective function is to find the value of the environmental quality of products to better position oneself on the market and maximize profits that consider sales revenue of green products. The constraints are of several types and mainly include environmental constraints.

2. Literature Review

An environmental impact can be defined as a modification of the environment, because of the proven or supposed human intervention, direct or indirect, which can have a detrimental effect on the sustainability of the natural environment and ecosystems, and a priori, consequently, on the human health (Baumann 2011).
It is certain that company's activities have impacts on the natural environment. These impacts can be related to the use of resources by company, the generation of pollution, the consequences of its activities on the natural habitats, ... To reduce their environmental impact, companies should adopt an integrated approach that considers the wider implications of their decisions from an environmental point of view.
Thus, to develop our model, it is first necessary to understand what it is a green product and the environmental performance indicators of a product.

2.1 Environmental product performance indicators

The environmental quality of a product is generally defined as a set of environmental attributes (qualities) for which customers have different preferences (Shi 2001); (Chen 2001). The integration of environmental attributes can be considered at the different phases of products design, for example, in components selection, packaging design and the choice of the type of energy (Chen 2001).
There is no product whose impact on the environment is zero (Ottman 2006). "Green Product" or "Environmental Product" are terms commonly used to refer to products that are intended to protect or enhance the natural environment by conserving energy and resources and reducing pollution, wastes and the use of toxic agents (Ottman 2006). This definition highlights the key issues on which the development of environmental products, namely energy, resources, emissions and wastes, must be focused.
Other green product definitions focus on the phases of the product life cycle during which environmental quality can be expressed. A green product is a product whose environmental and societal performance during the phases of production, use and end-of-life are significantly improved compared to other competitive products (Peattie 1995). This definition highlights the relativity of the green product notion.
Indicators of the environmental performance of products are two categories:

1. Intrinsic indicators that are related to product characteristics (lifetime, recyclability, reusability, recycled content, consumed energy and emissions generated during the use phase). etc.).
2. Indicators that are not related to the characteristics of the product itself, but rather depend on the supply chain activities. For example, the number of kilometers traveled by a product (indicated on some products and which represents one of the environmental quality assessment criteria for green customers) does not change its intrinsic characteristics but reflects the supply chain characteristics. The traditional polluting and green manufacturing technologies (which differ in terms of generated emissions during the product manufacture or in terms of the total amount of consumed energy) may give rise to finished products that are identical in terms of functionality but possess each a different environmental image. These criteria do not affect the functioning of the product but impact the environmental image of this later.

2.2 Environmental regulations

Different types of laws and environmental legislations are described in the literature (Dobos 1999); (Radulescu et al. 2009); (Chen et Monahan 2010). Environmental legislations refer to laws and regulations imposed by governments to encourage firms to minimize the impact of their activities on the environment.
Depending on the type of emissions and their environmental impact, these laws may, in some cases, consist of strict regulations with threshold values which the violation is strictly prohibited.
In other cases, the laws are more flexible: the exceeding of the thresholds determined by the governments is possible but in this case the government applies same sanctions and taxes on the companies. In other situations, emission allowances may be negotiated. In fact, to encourage companies to act on their emissions, governments offer companies the opportunity to sell these pollution permission allowances when they pollute less than the allowed threshold. This takes the form of a financial incentive. In the opposite case, when the company exceeds the threshold, it can buy permission allowances to pollute. This takes the form of a penalty. More details and ample examples of this type of regulation are given in the works of (Letmathe et Balakrishnan 2005). There are other types of legislations that are not

based on emission thresholds but that instead require companies to introduce recycling and/or re-manufacturing activity. It is also important to mention that these laws differ according to the country and the sectors of activity.

3. Product evolution in the supply chain

Several authors have studied the relation between the configuration of a product and that of its supply chain in a general context without considering the environmental aspect. The design of products and production processes should not be considered as two separated decisions and sequential over time but rather as two coordinated and interrelated decisions (Rungtusanatham et Forza 2005). Fixson argues that product features and architecture influence logistical decisions at the strategic, tactical and operational levels (Fixson 2005). The degree of standardization and the interactions between the product components impact the different logistical decisions. The number and type of components making up a product usually guide decisions concerning the number and location of different suppliers, the level of service and the delivery frequencies. The use of common components, for example, reduces the level of stocks. Some authors consider that product families, their production processes and the supply chain must be studied in an integrated way (Lamothe et al. 2006); (El Hadj Khalaf et al. 2009); (Haddach 2019 (a)); (Haddach 2019 (b)); (Haddach et al. 2016). In general, several authors consider that the product architecture guides logistics decisions and that the supply chain must adapt to the requirements of the product architecture.

Considering the relation between the supply chain and its products in an environmental dimension, Chen considers that to determine the real environmental performance of a supply chain, it is important to study the environmental quality of its products (Chen 2001). Conversely, the supply chain with its different decisions and activities impacts the environmental quality of its products.

There is therefore an interdependent relation between the environmental performance of supply chains and the environmental performance of products.

In the environmental context, it is important to consider environmental activities as mainly recycling and remanufacturing (generally considered in the framework of reverse logistics).We must also consider traditional activities such as the purchasing (cooperation with suppliers with environmental certification, selection of suppliers that are geographically close together), the production (choice of manufacturing processes with low pollutant emissions and green technologies to minimize energy consumption or the use of renewable energy resources) and the transport (optimization of deliveries, choice of less polluting means of transport). All these activities have a great impact on the product environmental quality.

4. Methodology

Value of product environmental quality is very essential for decision-making, but it is very difficult to evaluate because of too many indicators (Table 1). Our model reduces these indicators by aggregating them into a composite index (I_{EQ}) which reflects the product environmental quality as follow:

1. Indicators normalization
2. Weighting of indicators (using AHP method)
3. Product environmental quality (I_{EQ})

Table 1 (1). Adopted indicators for the determination of product environmental quality

Issue	N°	Indicator	Symbol	Impact	Unit	I_{inf}	I_{sup}
Resources use	1	Quantity of energy consumed to produce one unit of product p using all processes	Q_E	Negative	Joule (J)	0	Maximum quantity of energy consumed to produce one unit of product p using all processes in the last year;
	2	Quantity of water consumed to produce one unit of product p using all processes	Q_W	Negative	Cubic meter (m^3)	0	Maximum quantity of water consumed to produce one unit of product p using all processes in the last year;
	3	Percentage of green components needed to produce one unit of product p using all the processes	G_C	Positive	(%)	0 %	100%

Table 1 (2). Adopted indicators for the determination of product environmental quality

Issue	N°	Indicator	Symbol	Impact	Unit	I_{inf}	I_{sup}
Pollution	4	Quantity of solid waste generated to produce one unit of product p using all processes	S_W	Negative	Kilogram (kg)	0	Maximum quantity of solid waste generated to produce one unit of product p using all processes in the last year;
	5	Quantity of liquid waste generated to produce one unit of product p using all processes	L_W	Negative	Cubic meter (m^3)	0	Maximum quantity of liquid waste generated to produce one unit of product p using all processes in the last year;
	6	Quantity of noise generated to produce one unit of the product p using all the processes	Q_{dB}	Negative	Decibel (dB)	0	Maximum quantity of Decibel generated to produce one unit of product p using all processes in the last year;
	7	Quantity of CO_2 generated to produce one unit of the product p using all the processes	Q_{CO2}	Negative	Kilogram (kg)	0	Maximum quantity of CO_2 generated to produce one unit of product p using all processes in the last year;
	8	Quantity of CO_2 generated to transfer one unit of product p till the final consumer	Q'_{CO2}	Negative	Kilogram (kg)	0	Maximum quantity of CO_2 generated to transfer one unit of product p to the final consumer in the last year;

Environmental indicators are divided into two groups:

- Indicators whose increasing value has a positive impact (I_A^+) on product environmental quality:

1. Energy consumed
2. Water consumed
3. Solid wastes
4. Liquid wastes
5. Noise pollution
6. Quantity of CO_2 generated to produce one unit of the product
7. Quantity of CO_2 generated to transfer one unit of product p to the final consumer

- Indicator whose increasing value has a negative impact (I_A^-) on product environmental quality:

8. Percentage of green components needed to produce one unit of product p using all the processes

For example, increased value of CO_2 clearly has a negative impact on product environmental quality, while increased percentage of green components needed to produce one unit of product p using all the processes has a positive impact on it.

The main problem of aggregating indicators into I_E is the fact that indicators are expressed in different units. One way to solve this problem could be normalizing each indicator i by dividing its value over studied time t with its average value over all the time measured (Equations (1) and (2)).

$$I_{N,it}^+ = \frac{I_{A,it}^+}{\bar{I}_{A,i}} \quad (1) \qquad I_{N,it}^- = \frac{I_{A,it}^-}{\bar{I}_{A,i}} \quad (2)$$

Where $I_{N,it}^+$ is the normalized indicator i (with positive impact) and $I_{N,it}^-$ is the normalized indicator i (with negative impact).

Thus, the possibility of incorporating different kinds of quantities, with different units of measurement is offered. Among advantages of proposed normalization of indicators is the clear compatibility of different indicators, since they are normalized.

Next procedural part of I_E calculation involves weights determination, which should be combined with each indicator. Indicators weights can be obtained from environmental expert surveys or from public surveys about environmental themes. Therefore, to derive the weights practically, Analytic Hierarchy Process (AHP) method was used for this model.

We build a matrix A = (n x n) (in our case n=8); where indicators are compared 2 by 2 by decision maker. The comparisons are made by posing the question which of two indicators i and j is more important from environmental point of view. The intensity of preference is expressed on a factor scale from 1 to 9 (Table 2).

Table 2. Comparison scale of AHP method (Hafeez et al. 2002)

Preference factor, p	Importance definition
1	Equal importance
3	Moderate importance of one over another
5	Strong or essential importance of one over another
7	Very strong or demonstrated importance of one over another
9	Extreme importance of one over another
2,4,6,8	Intermediate values
Reciprocal, 1/p	Reciprocal for inverse comparison

Value of 1 indicates equality between the two indicators while a preference of 9 indicates that one indicator is nine times more important than the one which it is being compared. This scale was chosen, because in this way comparisons are being made within a limited range where perception is sensitive enough to make a distinction. In the matrix A, if indicator i is "p-times" of importance compared by indicator j, then necessarily, indicator j is "1/p-times" of importance compared by indicator i, where the diagonal $a_{ii} = 1$ and reciprocal property $a_{ji} = \left(\frac{1}{a_{ij}}\right)$ $such\ as\ i, j = 1.., n.$

Weight of indicator i (W_i) is given by the formula:

$$\mathrm{W_i} = \frac{\sum_{k'=1}^{n} \frac{\mathrm{a_{ik'}}}{\sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{a_{kk'}}}}{\mathrm{n}} \qquad (03)$$

One disadvantage of AHP method outlined in literature (Dyer 1990) is the problem of intransitivity preferences. Indeed, pair wise comparison may lead to non-transitivity which cannot be removed as part of AHP method.

However, perfect consistency rarely occurs in practice. In AHP method the pair wise comparisons in a judgment matrix are considered to be adequately consistent if corresponding Consistency Ratio (CR) is less than 10% (Saaty 1980). CR coefficient is calculated as follows: first a Consistency Index (CI) needs to be estimated. This is done by adding the columns in judgment matrix and multiply resulting vector by vector of priorities (i.e., approximated eigenvector) obtained earlier.

This yields an approximation of maximum eigenvalue, denoted by λ_{max} . Then, CI value is calculated by using the formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (04)$$

Next, CR is obtained by dividing CI by random consistency index (RI) as given in Table 3.

Table 3. RI VALUES for different values of n

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Otherwise matrix A should be evaluated:

$$CR = CI/RI \qquad (05)$$

Finally, composite index (I_E) can be derived as shown in equation (06):

$$\mathrm{I_{EQ}} = \sum_{\mathrm{i=1}}^{1} \mathrm{W_i} \times \mathrm{I_{N,i}^{+}} + \sum_{\mathrm{i=1}}^{7} \mathrm{W_i} \times \mathrm{I_{N,i}^{-}} \quad \text{where} \quad \sum_{\mathrm{i=1}}^{8} \mathrm{W_i} = 1 \ \text{ and } \ \mathrm{W_i} \geq 0 \qquad (06)$$

4. Findings and discussion

(I_{EQ}) purpose is to provide a simplified and quantified expression for a more complex composition of several indicators. It can be used to inform decision-makers of development trends in company. However, it may also be included in a more targeted context, such as reflecting firm status regarding sustainability, providing information to critical decision processes, or possibly forming basis for company to head in a certain direction. This model helps to highlight improvement opportunities and where best practices might be found. It provides early warning information and tracks to improve product environmental quality produced by company.

Decision-makers could easily interpret (I_{EQ}) than trying to find a trend in many separate criteria of sustainable development. If included in annual sustainability report, (I_{EQ}) could be used to present company's progress in terms of environmental performance to the various stakeholders of company. Also, this evaluation model if would be applied to different companies, it would be possible to compare and rank them in terms of products environmental quality.

Based on our evaluation model, company's leaders can decide if apply or not a given best practice following its effect on product environmental quality calculated by (I_{EQ}).

By this model, decision maker has a tool which allows him:

1. To analyze current and potential value of implemented activities and to consider actions to strengthen this value such as implementation of sustainable best practices. This analysis allows him to define activities scope and to consider several options for this end, as part of differentiation strategy by CSR (Corporate Social Responsibility).
2. To diagnose the global performance profile related to company's decisions during planning phase, choose company's configuration and the way to exploit it in advanced and optimized manner to ensure target level of company environmental performance.
3. To know additional investment which should be engaged to achieve desired level of product environmental quality.
4. To have qualitative indicators which could be used to control company environmental performance and for purposes of communication.

6. Conclusion

Companies have made tremendous progress in environmental protection abreast of recent years. Faced with popular and regulatory pressures, they have had no choice to develop an environmental management strategy increasingly rigorous. However, in many organizations, environmental issues remain on the margins of activities producing value. This is one reason why environmental protection is seen even today as an additional production cost.

Applying sustainable development principles in industrial management stills a difficult task. In this sense, companies have a little tools and consulting firms are often helpless against the demands of companies that want to engage in CSR strategy.

In the origin of this paper, was the problem of environmental impacts of manufactured products. In this context, our goal has been to provide an assessment model of product environmental quality. It was also for us, to assist in the definition of targeted axis of the progress allowing to evolve evaluation systems of environmental performance in company.

The first goal of this work is to lay the foundations for a new generation of environmental indicators which permit the determination of product environmental quality. The model presented in this paper promises advance in environmental performance assessment of products and makes environmental information more useful for decision-makers. Any company and based on this model, can know environmental qualities of their products and therefore their achievements towards environment. Even though further development is called for, it is evident that this model has the potential to become very useful as one of the available tools.

The combination of better assessment methods is likely to continue this movement towards a new generation of integrated sustainability performance reports.

Among the limitations of this model is the need to integrate other indicators (recycling, remanufacturing ...) that will improve the accuracy of measuring the product environmental quality.

In our next works we seek to develop this model considering the different aspects mentioned above. Our ambition is ultimately to provide real decision support tools that can be useful for the company and its stakeholders.

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Biography

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