

MULTICRITERIA ANALYSIS TO EVALUATE INFLUENCE OF GREEN PRACTICES ON SUPPLY CHAIN PERFORMANCE

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Accepted 30 January, 2012

ABSTRACT

The consideration of environmental issues has a tremendous impact on the development and operations of a supply chain. The aim of the present work is to propose a systematic approach that a firm may use to evaluate its own supply chain environmental performances. The approach integrates index methods for Environmental Performance Evaluation (EPE) and Life Cycle Assessment (LCA) with a multi-criteria model based on the Analytic Network Process (ANP) and BOCR Analysis (Benefits, Opportunities, Costs and Risks). A key aspect of the model is the consideration of environmental directives such as the Waste Electrical and Electronic Equipment and the Restriction of the use of certain Hazardous Substances to evaluate and prioritize which green initiatives with respect to environmental performance

KEYWORDS: ANP, BOCR Analysis, Green Supply Chain, WEEE, EPE.

INTRODUCTION

Green supply chain management (GSCM) is an emerging research area, thus there are limited conceptual models on this important subject. This work develops a conceptual model for the successful greening of a supply chain that also takes into consideration environmental directives such as Waste Electrical and Electronic Equipment – WEEE (European Parliament, 2003a); and Restriction of the use of certain Hazardous Substances – RoHS (European Parliament, 2003b).

The useful life of consumer electronic products is relatively short, and decreasing as a result of rapid changes in equipment features and capabilities (Kang and Schoenung, 2004). The growing importance of Information and Communications Technology (ICT) to the world economy has brought about a surge in demand for electronic equipment (Macauley et al., 2001). Waste from electrical and electronic equipment, EEE (WEEE) is one of the highest priority streams in waste management because of its major challenges (Yla-Mella et al., 2004). As a result of the sheer variety of product models, size changes, compatibility issues, etc., the recovery of WEEE is very challenging (Kumar et al., 2005). WEEE has also become an issue of concern to solid waste management professionals (Musson et al., 2000). These policies and legislation are almost all based

on the principles of extended producer and entire supply chain responsibility. This concept has become an established principle of environmental policy in many countries. (Kibert, 2004).

To improve management of WEEE it is essential a proper evaluation of whole supply chain and in particular it is essential the optimization of Green Supply Chain. Various similar terminologies have emerged to describe GSCM. Some authors (Handfield et al., 2005) state that environmental supply chain management consists of the purchasing function's involvement in activities that include reduction, recycling, reuse and the substitution of materials. More widely they define GSCM as the formal system that integrates strategic, functional and operational procedures and processes for employee training and for monitoring, and summarising and reporting environmental supply chain management information to stakeholders of the firm.

A crucial aspect of a GSCM is the integration of the operational procedures and processes of Reverse Supply Chain Management (RSCM). The main goal of RSCM is to accommodate two-way material flows across the supply chain in order to provide products with opportunities for reuse and recycling (Kocabasoglu et al., 2007). According to the US Council of Logistics Management (Sarkis, 2001), RSCM should encompass two flows. The first is a divergent flow, known as an open-loop system, using traditional SCM skills. The other is a convergent flow, or a closed-loop system, which is a backward linkage that processes all end-of-life products throughout the entire supply chain from end-customers to the original suppliers (De Felice and Petrillo, 2011). The basic driving forces behind RSCM are the increasing pressure from the public for eco-friendly products, the potential financial returns from reuse, recycling, and recovering materials, and the requirements from environmental regulations such as the Waste Electrical and Electronic Equipment (WEEE) (Lysons and Gillingham, 2003; Eckerth, 2004). While reverse logistics in and of itself is becoming increasingly important in the context of analyzing the waste accumulation on the downstream supply chain (Prahinski and Kocabasoglu, 2006; Sundarakani et al., 2010; Hua et al., 2011), RSCM is a really a sub-set of GSCM. Although GSCM enables the maximization of the value of residual assets, attention should be drawn to the

challenges which arise from managing the reverse supply chain activities, the inter-firm relationships, and/or the cross-functional supply chain activities.

The present work proposes a multi-criteria based approach for supporting environmental sustainability analysis of the entire supply chain. The approach is based on the integration of Environmental Performance Evaluation (EPE) with a multi-criteria tool based on the well known Analytic Network Process (ANP) methodology and a BOCR Analysis (Benefits, Opportunities, Costs and Risks). The aim of our work is to develop the ANP/BOCR model through the definition of EPE to identify significant factors on environmental aspects; in this way, the ANP/BOCR model could supply valuable information about critical factors/areas throughout the whole supply chain in order to reduce its environmental impact. This study focuses on the supply chain of a typical cathode ray tube of computers (and televisions).

The paper is organized as follows: in section 2 the theory and research model is explained. Then, in section 3, the proposed approach is applied in a specific case study. Finally in section 4 conclusions and results are analyzed.

2. RESEARCH MODEL AND THEORY

While our understanding of a green supply chain has been expanded there is still a great deal of latitude in how it is defined. Currently, there is an imbalanced scenario within the research, which when considered together provides synergies and contradictions at the same time. The green supply chain could be viewed as a system, with interlocking elements or sub-systems (suppliers and customers), that aims to minimize wastes in the supply chain. Practices and changes within the sub-system(s) will have direct and indirect effects on the subsequent sub-system(s).

It is very difficult for a company to guarantee a complete environmental directive compliant component and manufacturing flow due to the limited capabilities and influence within the entire supply chain. The alternative strategy is to combine the operational strategy of the whole product supply chain to ensure the overall capabilities match the environmental requests, some examples include: new green products design and development, environmental performance assessment, green purchasing, eco-friendly materials, green SCM, environmental information management system, and recycling of end-of-life products (De Felice et al., 2011).

The aim of our work is to incorporate these considerations into a strategic decision framework for GSCM. This approach highlights the components and elements for GSCM and how they serve as a foundation for the decision framework. Next, we analyze the theoretical background of Analytic Network Process and its application in the conceptual model (De Felice and Petrillo, 2010).

3.1 Analytic Network Process – ANP: Theoretical background

The Analytic Network Process (ANP) is the successor of the popular Analytic Hierarchy Process (AHP) model devel-

oped by Saaty (1980). The AHP is a Multi-Criteria Decision Making (MCDM) tool at the core of which lies a method for converting subjective assessments of relative importance to a set of overall scores or weights. The AHP is a top-down decision model and, therefore, the criteria and alternatives are assumed independent. However, bias could occur when the criteria and subcriteria are correlated with each other. Fifteen years after the publication of pioneering work in the field of AHP, Saaty (1996) developed the ANP model, which could handle this situation of inner dependence among elements in a network.

Details on the Analytic Network Process (ANP) model can be found in Saaty (1999); the fundamentals are summarized here for completeness. An ANP model consists of the control hierarchies, clusters, elements, interrelationships between elements, and interrelationships between clusters. The modeling process is better understood by dividing it into several steps which are described as follows:

Step 1: Pairwise comparison and relative weight estimation. Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion based on the principle of AHP. Saaty suggested a scale of 1-9 when comparing two components

The result of the comparison is the so-called dominance coefficient a_{ij} that represents the relative importance of the component on row (i) over the component on column (j), i.e., $a_{ij} = w_i / w_j$. The pairwise comparisons can be represented in the form of a matrix (Saaty, 2007). The score of 1 represents equal importance of two components and 9 represents extreme importance of the component i over the component j.

After all pairwise comparisons are completed the priority weight vector (w_i) is computed as the unique solution of $Aw = \lambda_{\max} w$, where λ_{\max} is the largest eigenvalue of matrix A.

Matrix A is defined as:

$$A = \begin{bmatrix} w_1/w_1 & \dots & w_1/w_n \\ \vdots & \ddots & \vdots \\ w_n/w_1 & \dots & w_n/w_n \end{bmatrix} = \begin{bmatrix} 1 & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{n1} & \dots & 1 \end{bmatrix}$$

Step 2: Consistency index estimation. To more accurately represent judgments the comparisons need not be entirely consistent. However, if a set of comparisons are too inconsistent one could just as well have used random entries and the information from the comparisons would not be useful. In order to provide a balance the consistency index (CI) of the derived weights could then be calculated by: $CI = (\lambda_{\max} - n) / (n - 1)$. In general, if CI is less than 0.10, one may be satisfied with the judgments that were derived (Saaty, 2005).

Step 3: Formation of the initial supermatrix. Elements in ANP are the entities in the systems that interact with each other. The determination of relative weights mentioned above is based on pairwise comparisons as in the standard

AHP. The weights are then put into the supermatrix that represents the interrelationships of elements in the system. The general form of the supermatrix is described here below where C_N denotes the N^{th} cluster, e_{Nn} denotes the

n th element in the N th cluster, and W_{ij} is a block matrix consisting of priority weight vectors (w) of the influence of the elements in the i^{th} cluster with respect to the j^{th} cluster.

		C_1				C_2				...	C_N			
		e_{11}	e_{12}	...	e_{1n}	e_{21}	e_{22}	...	e_{2n}		e_{N1}	e_{N2}	...	e_{Nn}
C_1	e_{11}	W_{11}				W_{12}				...	W_{1N}			
	e_{12}													
	...													
	e_{1n}													
...			
C_N	e_{N1}	W_{N1}				W_{N2}				...	W_{NN}			
	e_{N2}													
	...													
	e_{Nn}													

Step 4: Formation of weighted supermatrix. The initial or “unweighted” supermatrix consists of several eigenvectors each of which sums to one. The clusters in the initial supermatrix must be weighted and transformed to a matrix in which each of its columns sums to unity.

Step 5: Calculation of global priority vectors and weights. In the final step, the weighted supermatrix is raised to limiting power to get the global priority vectors as in Equation (1):

$$\lim_{n \rightarrow \infty} (w)^n$$

3.2 Research Conceptual Model

Approaches for analyzing the environmental sustainability of a supply chain could be classified into two main types: *top-down models* based on global level analysis and *bottom-up models* based on performance of individual companies in a supply chain. The first type is essentially based on a Life Cycle Analysis (LCA) approach which allows one to measure sustainability from a system perspective. On the other hand, bottom-up models such as climate change, related fossil energy use, or ISO 14000 guidelines are focused on measuring the environmental performances of a single company (Gerbens-Leenes et al, 2003). Environmental in-

dicators in this category represent an effective approach for managing the supply chain (SC) sustainability level (Tsoulfas and Pappis, 2008). Index methods based on a predefined set of environmental indicators are usually simple and easy to use tools which provide relevant information for Green Supply Chain Management (Henri and Journeault, 2008).

The importance of collaboration and supplier partnership as a value-added strategy is discussed in great detail by Vachon and Klassen(2008). From a more operational point of view, several papers consider an analysis of a parameter which could mainly affect the Environmental Performance Evaluation (EPE) process.

From this point of view the aim of our model is to integrate different techniques: first, index categories are evaluated in order to define a reference model as an environmental reporting system; then, a multi-criteria model, based on Analytic Network Process (ANP), is developed which reflects the priorities of the influences on the supply chain environmental sustainability level. The primary focus is to assess strategic and/or operational alternatives which could improve the environmental sustainability level of a supply chain. The result is a prioritized set of potential alternatives. The conceptual model developed is presented in Figure 1.

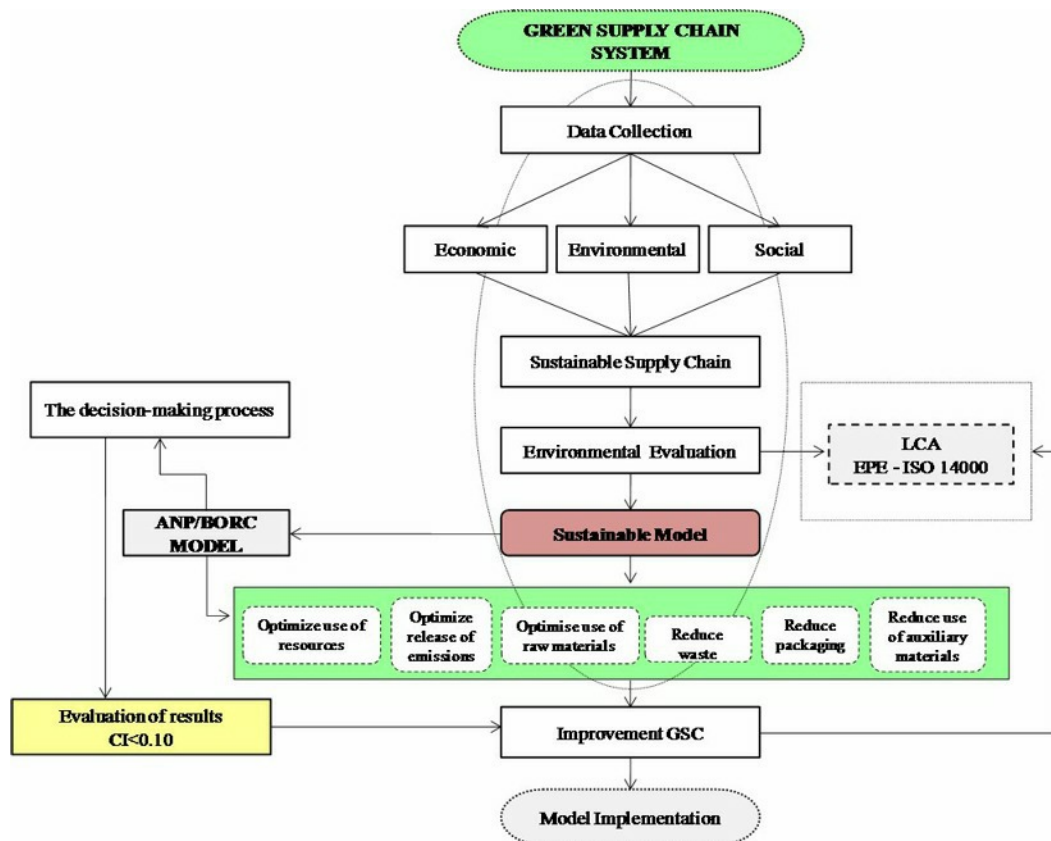


Figure 1: Conceptual model

The conceptual model was developed on the basis of a range of anecdotal and empirical evidence from the literature.

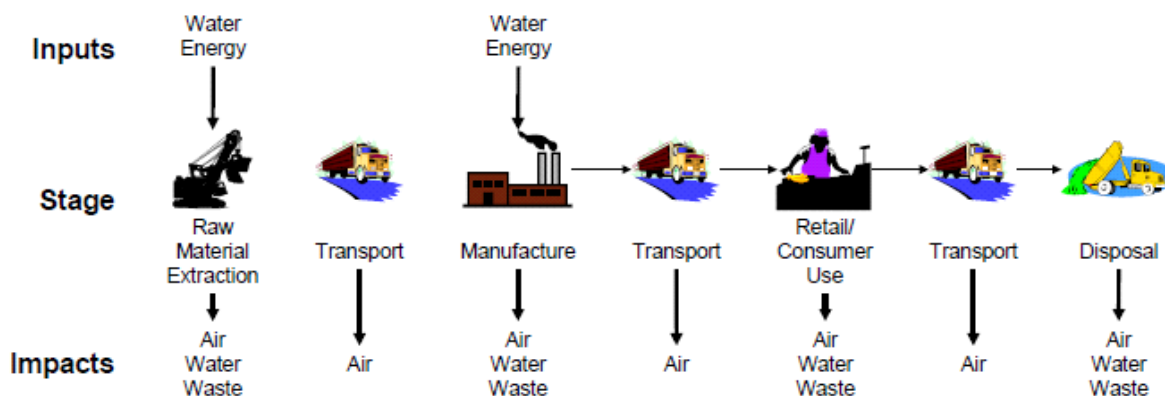
1. **Environmental collaboration with suppliers:** This is the interaction between organizations in the SC relating to joint environmental planning and shared environmental know-how or knowledge, having a positive effect on delivery and flexible performance.
2. **Environmentally friendly purchasing practice:** Although the purchase of green materials represents a cost, it can create economic value such as reduced disposal and liability costs, while improving the resource conservation and public image of the organization. Adopting green purchasing practices avoids buying in waste and reduces environmental costs.
3. **Minimizing waste:** This can be accomplished by handling and minimizing waste after it has been generated. This green practice is also incorporated into lean practices for the elimination of waste or non-value adding activities throughout the chain. Therefore, along with its contribution to the reduction of environmental costs, it also decreases business waste and promotes efficiency improvements in the SC process and cost reduction.
4. **Decreasing the consumption of hazardous and toxic materials:** This helps to minimize the cost of eliminating and treating hazardous and toxic materials, just as it limits business waste. This kind of practice can only be implemented if all partners throughout the SC share the same environmental concerns.
5. **ISO 14001 certification:** ISO 14001 is an internationally recognized standard which defines the criteria for an environmental management system, requiring commitment to compliance with applicable legislation, regulations and continuous improvement.
6. **Reverse logistics:** Despite the environmental gain from minimizing business waste (through product recovery as well as the collection and transportation of recovered products), it represents an environmental cost for organizations. Minimizing such a cost is important in order to increase the total environmental gain from recovery.
7. **Environmental collaboration with customers:** An effective customer relationship allows SC cost reduction and maintains the reliability of operations, thereby increasing quality and customer satisfaction. This green practice increases the level of environmental awareness and makes customers environmental partners, maximizing the return volumes while reducing business waste and environmental costs and increasing customer satisfaction. This helps to increase responsiveness to customers' environmental concerns as well as to improve the fulfillment rate and on-time delivery.
8. **Environmentally friendly packaging:** This is among the most visible indications of an organization's environmental commitment. It is expected that the application of environmentally friendly packaging initiatives will reduce environmental costs and business waste while improving customer satisfaction.
9. **Working with customers to change product specifications:** This helps to establish product specifications that are compatible with process modifications, increasing process efficiency and input substitution while having a positive influence on product conformance with respect to specifications and durability. It also contributes to improved customer satisfaction, since it reduces the customer rejection rates.

According to ISO 14031 (ISO, 1999), three main subcategories are proposed in order to evaluate sustainability of supply chain: the Operational and Management Performance Indicators (OPI - Operational Performance Indicator and MPI - Management Performance Indicator respectively, ECI - Environmental Condition Indicators). The first category refers to aspects regarding facilities and equipment such as energy flows, waste and emissions, etc. The second is focused on the management’s efforts to influence process oriented environmental performances and the last provides information about the condition of the environment which may be useful for the implementation of environmental performance evaluation within an organization. These indicators are fundamental to the development of the BOCR multi-criteria decision support system as they point out critical intervention areas for SC environmental sustainability assessment.

3. THE CASE STUDY

The proposed model is applied in a full scale case study regarding a TV & AUDIO VIDEO production supply chain (Figure 2). Usually, this sector is a resource intensive sector; thus, TV & AUDIO VIDEO manufacturers and processors are under ongoing pressure to maximize efficiency in all areas of production. Supply chain management in this context is a complicated due to the particular nature of the product: bulky, fragile, and difficult to deliver intact while meeting stringent requirements for high quality and safety.

The supply chain structure is quite linear; it consists of a company which produces TV & AUDIO VIDEO products, with a low number of first-tier suppliers and several intermediate customers (i.e. the final product is an intermediate material for different applications). A schema is proposed in Figure 2 which highlights the main parameters that influence its environmental sustainability level.



The proposed model has been applied to evaluate the SC environmental sustainability level and areas where intervention must have priority. Whenever possible the SC structure has been analyzed by applying the metrics system from the EPE process.

3.1 Collection and aggregation of information

To collect the information we used the database made available by the company and with information from managers in the areas of interest (see Table 1, 2, 3 and 4). This data is used to provide weightings in the model under these criteria which is explained in greater detail below.

Table 1. Consumption data

Description	Unit/total
Production	66,273.31ton
Electric Energy	53.499,67 MWh
Cogeneration Electric Energy	71.395,00 MWh
Thermic Electric Energy	80.319,38 MWh
Natural Gas Consumption	10.896.127,84 Nm3
Water Consumption	1,892,000.0 m3
CO2 emissions Consumption per unit	1.3 Ton per ton produced
Auxiliary materials (sodium hydroxide for the production of demineralized water)	855.700 kg
Raw materials	80.000 kg

Table 2. Waste data

Description	Unit/total
Hazardous Waste	8,800 kg
Other wastes	665,135 kg
Waste	5,469,336 kg

Table 3. Packaging data

Description	Unit/total
Paper and carton packaging	3674816 kg
Plastic packaging	57644.5 kg
Wood packaging	1282278 kg
Iron packaging	8900 kg

Table 4. LCA data

Description	Unit/total
Acidification	6.55 g SO ₂ /kg products
GWP 100	0.855 kg CO ₂ eq/kg product
Ecotoxicity	14.2 cgPbeq/kg product

3.2 ANP/BOCR model

In this section we analyze ANP/BOCR Model and its elements .The process of developing an ANP/BOCR model follows these practical steps:

1. Structure the problem with respect to its goal;
2. Create the benefits, opportunities, costs and risks networks;
3. Establish control criteria to evaluate the benefits, opportunities, costs, and risks;
4. Define the decision subnets for each control criteria;
5. Complete the pairwise comparisons on cluster elements;
6. Evaluate the rating model to combine the benefits, opportunities, costs, and risks;
7. Synthesize/Combine the model with respect to the strategic criteria;
8. Perform sensitivity analysis to test the stability of the results.

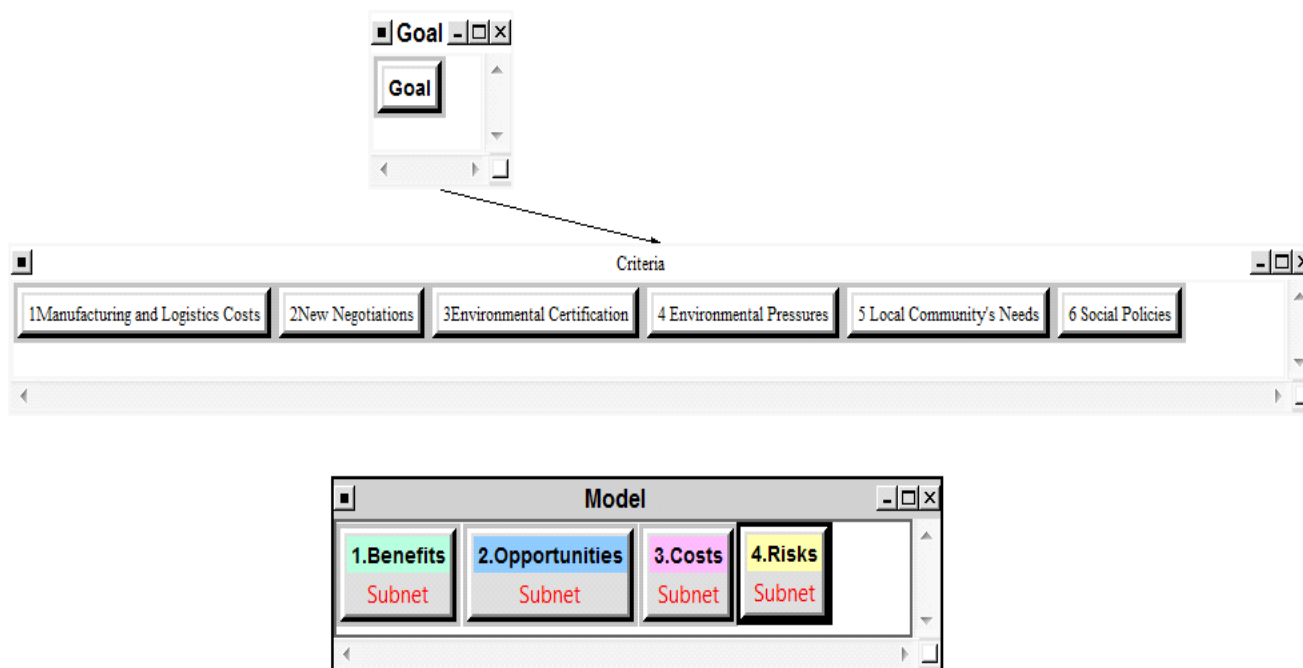


Figure 3. ANP/BOCR Model

The ANP model has been developed by a specific software tool, Super Decisions Software for Decision-Making®. To build an Analytic Network Process (ANP) network, you need to:

1. Think about the elements in it and decide what kind of logical groupings of nodes and clusters would best describe the problem;
2. Build a cluster first, then create the nodes within it;
3. Select one node as a potential parent node and examine all the clusters in turn to determine if they have nodes that the parent node either influences or is influenced by to select its children nodes in that cluster.
4. Create the links between the parent node and all its children nodes in each cluster – this is how the comparison sets of nodes are created.
5. Clusters are linked automatically when nodes are linked.
6. Make sure the influences or is influenced by question is posed in a consistent way throughout this network. Make pairwise comparison judgments on nodes and clusters and synthesize.

3.2.1 Alternatives

The **alternatives** cluster is represented by the following specific alternatives (A1) Installation of emission abatement, (A2) Installation of evaporative towers to recycle water, (A3) Installation of solar panels, (A4) Reuse packaging and (A5) Reuse of second hand materials.

3.2.2 Criteria

The criteria are described below:

- Manufacturing and Logistics Costs: These encompass the costs throughout the entire supply chain.
- New Negotiations: Changes that come about because of negotiations from other members of the supply chain, e.g. a company demanding a 25% reduction in packaging.
- Environmental Certification: The need to satisfy the requirements for ISO certification and of legislation, e.g. catalytic converters.
- Environmental Pressures: Similar to environmental certification but for issues that have not been mandated, e.g. hydraulic fracking chemicals.
- Local Community Needs: Requests from the community that are not mandated by law, e.g. noise pollution.
- Social Pressures: When a group or organization push for change within the supply chain. This is especially important for market share considerations, e.g. (coffee and deforestation initiatives).

3.2.3BOCR Network

Here below, in Table 5, we described a Decision Network and BOCR Analysis control criteria, clusters, elements and alternatives for a **general model**. Then in last column we pointed out elements for our **specific model**.

Table 5: Decision Network for BOCR Analysis

BENEFITS				
Model	Control Criteria	Clusters	General Elements	Specific Elements
Benefits	Economic	Advantages Activities can build value through sustainable methods	Company's value increase Costs saving Profitable green Relation benefits	/
		Sustainable Targets The evaluation and implementation of actions to reduce environmental impacts.	Optimize use of resources Optimize use of raw materials Reduce waste Reduce use of auxiliary materials Reduce packaging Optimize release of emissions	/
	Social	Society Social benefits achieved from the development of sustainability level	Damage Prevention Improvement local community's relationship	/
		Individual Evaluation of actions to improve health care and reduce environmental damage.	Health care Damage Reduction Improvement employees' relationship	/
	Environmental	EPE – MPI Assessment of the status of environmental performance measures.	Implementation of policies and programs Conformity Financial performance Employees performance Management and planning Purchases and investments Health and safety Community relations	MPI - N° of green initiative MPI – N° of green investments
		EPE – ECI Assessment of the status of environmental performance measures.	Air Water Land Flora Fauna Humans Natural heritage and culture	ECI – CO2 ECI – Natural Gas ECI – Waste ECI – Water ECI – Electricity ECI – Emissions
		EPE – OPI Assessment of the status of environmental performance measures.	Materials Energy Services to support the operation of the organization Products to support the operation of the organization Design Installation Operation Maintenance Land use Transportation Products supplied by the organization Services provided by the organization Waste Emissions	OPI – Auxiliary Materials OPI – Total Energy OPI – Raw Materials OPI – Packaging OPI - Cogeneration

OPPORTUNITIES				
Model	Control Criteria	Clusters	General Elements	Specific Elements
Opportunities	Economic	Process Processes associated with planning, scheduling, and coordinating supply chain activities	Improvement of production process Customers' satisfaction Improvement stakeholders' relationship Improvement bank's relationship Adaptability – Be Creative Development of environmental economic and social culture	/
	Social	Resources Processes associated with the development of territory and Human Resources e.g. lifelong learning.	Promotion of territorial identity Develop new professional skills Stimulate the establishment of quality products	/
		Law Identification and quantification of energy and resource use and environmental releases to air, water, and land according to European or National decrees	New sustainable regional planning European/National Policies enforcement Sustainable production methods	/

COSTS				
Model	Control Criteria	Clusters	Elements	Specific Elements
Costs	Economic	Infrastructure Activities that require economic investment to ensure a green supply chains.	Increase in infrastructure costs Increase counseling costs	/
	Social	Human Resources Activities that require economic investment to ensure safeguard of employees, citizen, etc	Training costs Health care survey costs	/
	Environmental	Joint Venture Agreements with suppliers that define the levels of "sustainability" or resource upside available within state	Partner skills	/

RISKS				
Model	Control Criteria	Clusters	Elements	Specific Elements
Risks	Economic	Profitability Evaluation of the ability to earn a profit.	Net profit Margin Standardization	/
	Social	Social Risks Loss of competitiveness	Legal Penalties Paternalism Stigma	/
	Environmental	Environmental Risks Actual or potential threat of adverse effects arising out of the organization's activities.	Data Collection Implementation of failure Introduction of indirect Problems	/
		LCA - Analysis of inventory Qualitative and quantitative characterization and assessment of the consequences on the environment.	Global warming potential - GWP Ozone Consumption of non-renewable resources Acidification Eutrophication Photochemical smog Ecotoxicity	Acidification Global warming protection Ecotoxicity

These criteria were ranked according to the BOCR. The control criteria are used to generate the weights of the BOCR with a ratings model (Figure 4).

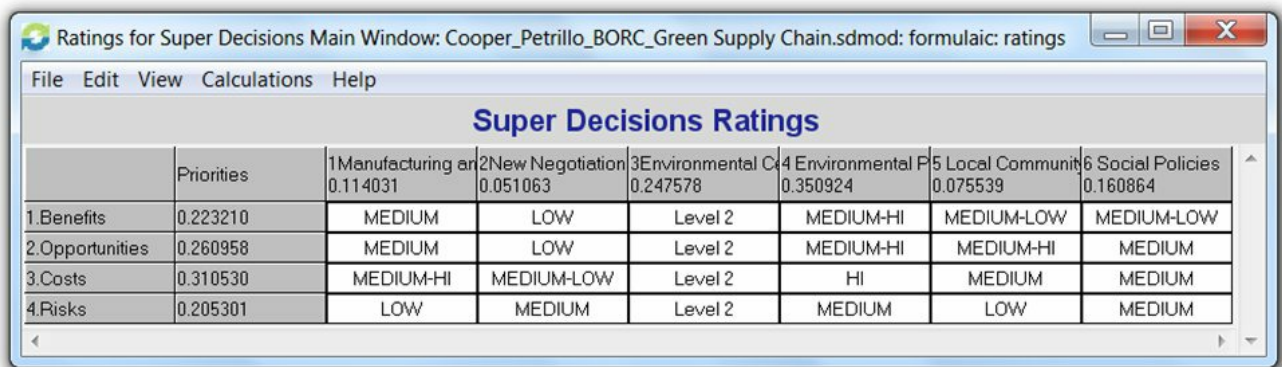


Figure 4. ANP/BOCR Model

Local Priorities for Benefits, Opportunities, Costs and Risks are:

1. Installation of emission abatement (0.206); (0,292); (0,175); (0.281);
2. Installation of evaporative towers to allow recycling of water (0.209); (0.254); (0.239); (0.171);
3. Installation of solar panel (0.299); (0.164); (0.130); (0.202);
4. Reuse packaging (0.133); (0.138); (0.130); (0.223);
5. Reuse of second hand materials (0.150); (0.150); (0.344); (0.121).

Global Priority (Additive Formula) is: Installation of emission abatement (0.126); Installation of evaporative towers to allow recycling of water (0.070); Installation of solar panel (0.206); Reuse packaging (-0.119); Reuse of second hand materials (-0.477).

Global Priority (Multiplicative Formula) is: Installation of emission abatement (0.215); Installation of evaporative towers to allow recycling of water (0.229); Installation of solar panel (0.329); Reuse packaging (0.130); Reuse of second hand materials (0.095).

The alternative to install solar panels is best alternative within the Benefits cluster; for the most opportunities installing the installation equipment if the preferred alternative. The reuse of packaging is the least costly alternative, while the reuse of second hand materials is the least risky. When the model is synthesized in both the short term (multiplicative) and long term (additive) models the best option is to install solar panels.

5. CONCLUSIONS AND RESULTS

The model is an integrated approach to evaluate the environmental sustainability of a supply chain. The proposed approach involves the evaluation of the entire supply chain: the environmental performance of a product or a producer depends not only on its production process, but the whole life cycle has to be evaluated starting from the first supplier to distribution to the final customer and final recovery activities. The approach integrates index methods for Environmental Performance Evaluation (EPE) and Life Cycle Assessment (LCA) with a complex multi-criteria model, the Analytic Hierarchy Process (AHP).

This proposed approach aims to optimize the development of the AHP model through a previous definition of EPE and LCA to identify significant factors of environmental aspects; in this way, the AHP model supplies effective information about critical factors/areas in the entire supply chain in order to optimize the sustainability level.

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