Multicriteria Evaluation of Sustainability within Supply Chains

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Abstract

The increasing activity in the industrial sector, and the consequent increase in the consumption of goods and services, rose awareness on modern society about the consumption of energy, raw materials and environmental impacts, which is manifested by increasing pressure to implement more sustainable solutions. This context leads organizations to higher levels of competition and sustainability, and since supply chains have a central role in companies' business strategies, they end up becoming more competitive and sustainable.
The Triple Bottom Line is a necessary and useful approach to combine management with the subject of supply chains, giving birth the concept of managing sustainable supply chains. However, the literature reveals that there is a lack of an approach that evaluates sustainability in supply chains in a sustainable manner. To bridge this gap, appropriate indicators were identified in the three dimensions of sustainability.
Through these indicators two MCDA models were developed with the help of M-MACBETH software in order to evaluate sustainability in two supply chains from different sectors. The application and analysis of these models are illustrated in two supply chains, making it possible to evaluate sustainability within supply chains.

Keywords: Supply Chain, Sustainability, Sustainable Development, Multiple Criteria Decision Analysis, MACBETH

1. Introduction

The increasing activity in the industrial sector, and the consequent increase in the consumption of goods and services, rose awareness on modern society about the consumption of energy, raw materials and environmental impacts. This growing concern stems from the unsustainable situation that is being created due to excessive and abusive exploitation of natural resources. Considering this new paradigm and the pressure from society, the industry needs to achieve a balance between the negative impacts of their activities, and the positive benefits that produces for society. Thus, organizations trying to achieve this new goal seek more sustainable solutions, increasing demand for more sustainable operations within firms (Pagell & Wu, 2009).

Supply chains have played an important role in companies' business strategies. Through an efficient and effective management of these elements, an organization can develop competitive advantages over the competition, especially in terms of reducing business costs, responsiveness to customer demand, and increase the quality of their products (Cooper et al., 1997). As such, the demand for more sustainable solutions in business is transmitted to their supply chains (Seuring & Müller, 2008). With this new perspective, the achievement of long-term economic sustainability in supply chains is no longer sufficient to assess the sustainability as a whole. Organizations should also incorporate environmental and social dimensions, forcing organizations to get out of their comfort zone (Bai & Sarkis, 2010). Economic growth is the key to success in organizations, however, it is sustainable only if it takes into account social and environmental considerations into their economic activities (Epstein, 2008). It is in this context that there is a need for a model that assesses sustainability in supply chains in all dimensions in an equivalent way. Although many authors have sought to establish a universally acceptable method to assess the sustainability and performance in supply chains, this feat has not yet been achieved (Corbière-Nicollier et al., 2011). There is no consensus on how to measure sustainability in supply chains, leading to faulty identification of processes and activities to improve, which sometimes causes an imbalance in the weighting of the dimensions of sustainability. One reason is the fact that there is the use of different metrics and a large group of sustainability indicators suggested in different contexts (Krajnc & Glavič, 2005). This work aims to fill this gap and build a model that assesses sustainability in supply chains in all dimensions appropriately, gathering indicators of various methods and formulating an appropriate multiple criteria model.

2. Literature review

2.2 Supply Chains

The concept of supply chain is associated with the transformation of raw materials into final product, including its respective distribution (Ahi & Searcy, 2013).

With the evolution in the area of supply chains, new ideas and needs have emerged, leading to the expansion and evolution of the initial concept of supply chains. This development and advancement were responsible for the diversification of Traditional Supply Chain in various latest models such as the Reverse Supply Chain, Closed-Loop Supply Chain, Green Supply Chain, and finally the Sustainable Supply Chain.

2.3 Sustainable Supply Chain Management (SSCM)

Despite the history of sustainability, its application to supply chains only emerged in the late 1980s (Maloni & Brown, 2006). In general, studies in supply chain management are focused on economic issues (Goetschalcks & Fleischmann, 2008), for example, seeking to minimize operating costs (Nagurney, 2010a) or maximize profits (Nagurney, 2010b). Until recently, most research on the management of supply chains addressed issues such as the environment, security and human rights independently, without considering the potential interrelationships between these and other aspects of social responsibility (Carter & Jennings, 2002).

Both the research and the practical application of sustainability in the management of supply chains has also been growing steadily in the last decade (Ahi & Searcy, 2013; Carter & Easton, 2011; Seuring & Müller, 2008). Sustainable Supply Chain Management (SSCM) enables companies to implement corporate responsibility practices and achieve greater efficiency in logistics performance and use of resources (see, e.g., Gold et al. (2010) and Carter and Easton (2011)), while the three dimensions of sustainability are considered (Triple Bottom Line), i.e., the environmental, economic and social dimensions. A driver for such business practices is the constant change in the structure of supply chains.

According to the definition given by Seuring and Müller (2008), SSCM can be defined as the management of material, information and capital flows, as well as cooperation between companies along the supply chain, incorporating the objectives of the three dimensions of sustainable development. Seuring and Müller (2008) stress the importance of cooperation with partners in the supply chain.

The markets that target customers with high level of knowledge of all three dimensions of sustainability are exposed to dynamic changes in perceptions and expectations of the customer. In these markets, the theory of strategic management of SSCM can help achieve high performance in companies (Beske et al., 2013).

2.4. Multiple Criteria Decision Analysis

It arises the need for a model to assess the performance in terms of sustainability in supply chains.

It is in this context that it is decided to use multiple-criteria decision analysis (MCDA). Although there are other possible methods such as Cost-Benefit Analysis, MCDA is often cited as a suitable approach to support decision making because of its capacity to rank remediation alternatives based on an assessment of criteria associated with the environmental, socio-cultural as well as the economic domains of sustainable development (Volchko et al., 2014). MCDA allows the evaluation of alternatives, taking into account complex qualitative and quantitative information in a systematic and consistent manner, based on objective and subjective data and their relative importance (Hanan et al., 2013). Although other MCDA approaches may be used (see, e.g. Figueira et al. (2005)), Hanan, et al. (2013) summarizes that a decision support process, a group of key actors (which may include specialists, lay or a combination of the two), that constitutes a decision group, identifies the criteria that are relevant to the decision making problem, assesses the criteria weights, scores the options on each criterion and determines an aggregate value score for each option.

In order to interact with the decision makers, an MCDA approach generally needs the existence of an external actor, a decision analyst, which aids decision makers in the evaluation process. The way this expert plays its role is determined by the methodology MCDA being employed: in a normative approach the expert solves the problem without the direct involvement of the client; in a prescriptive approach the expert acts as an analyst who solves the problem together with the client; and in a constructive approach acts as a facilitator whose goal is to increase customer knowledge to the problem and in the process of solving the problem (Zeleny & Cochrane, 1982).

A key feature of MCDA consists in the fact that the decision group is also responsible for the selection of objectives/criteria, the assessment of criteria weights and, to some extent, to assess the contribution of each option on each criterion performance. MCDA brings a degree of structure and analysis that are beyond the practical reach of mono criterion methods such as Cost-Benefit Analysis (Figueira et al., 2005).

3. Proposed Methodology

The use of discrete multiple criteria methods is suitable for the problem of assessing sustainability in supply chains, because the alternatives are finite in number and hardly exists an alternative that dominates all others in all perspectives of sustainability. The methodology selected for the evaluation of sustainability in supply chains model is based on Multi-Attribute Value Theory (MAVT) (Belton, 1999). The goal of a MAVT method is to build an environment that associates a real number to each alternative in order to produce a preference order on the alternatives consistent with the value judgments of the decision maker. The underlying principle of a MAVT model is of disaggregation/synthesis. Instead of assessing preferences about the alternatives available on a holistic basis, the preferences of the decision group are synthesized by individual building blocks, where each block describes the preferences of the key factors that have been identified (Belton, 1999). Thus, instead of directly evaluating the overall value $V(A)$ of an alternative *A* the decision maker focuses on evaluating the performance of this alternative on each one of the *n* criteria using a partial value function $v_i(A_i)$ (*i* = 1, ..., *n*) that describes the preferences of the decision maker with respect to criterion *i* (see equation [1]).

The simplest and most widely used form of the MAVT methodology is the additive model, which is represented by the following equation:

$$V(A) = \sum_{i=1}^{n} w_i \, v_i(A_i) \text{ with } \sum_{i=1}^{n} w_i = 1 \text{ and } w_i > 0 \quad [1]$$

Where:

- $V(A)$ is the overall value score of alternative *A*;
- A_i is the performance of alternative A on criterion *i* (*i* = 1, ..., *n*);
- $v_i(A_i)$ is the partial value score of the performance of alternative A on criteria *i* (*i* = 1, ..., *n*);
- w_i is the weight of criterion *i* (*i* = 1, ..., *n*), which allow transforming units of partial value $v_i()$ in overall value units *V*().

MACBETH is the MCDA approach selected, because it is more accessible to evaluators or decision makers with lower numeracy (Fasolo & Bana e Costa, 2014), since it only requires qualitative judgments from evaluators. The decision support system M-MACBETH, which implements MACBETH, is also a reason to select this approach, because it allows to validate the consistency of the judgments of decision makers and enables the accomplishment of extensive sensitivity and robustness analyses.

An approach based on MAVT and on the additive aggregation model, like MACBETH, attempts to sort a list of options according to the preference of the decision maker and is constructed through a process consisting of three main phases: structuring, evaluation, and testing

(Figure 1) (Bana e Costa et al., 2008).

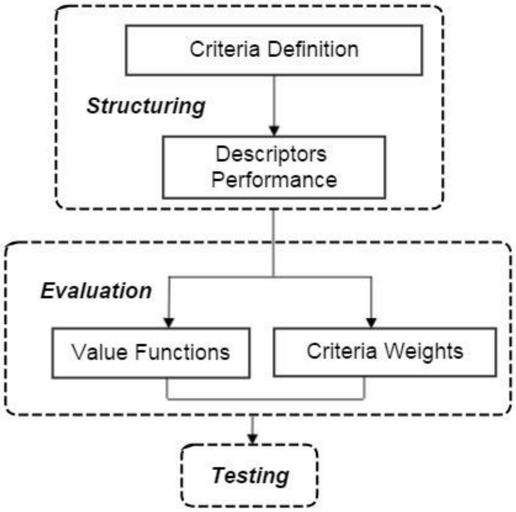

Figure 1 - Tasks to build an MCDA model like MACBETH

4. Methodological Implementation

4.1. Identification and selection of sustainable indicators

To implement the methodological aproach, emerges a necessity to look for indicators that evaluate all of sustainability's dimensions in the supply chain, and lead to a sustainable vision and environment.

The indicators for the economic dimension were selected through the junction of the indicators present in Global Reporting Initiative, IChemE and Eurostat, as these institutions promote sustainability worldwide and have indexes that include crafted indicators that are known to work well. Performance data produced by these indicators are intended to illustrate the flow of capital between different stakeholders and the main economic impacts of the organization of society.

For the environmental dimension, it was considered the environmental indicators grouped from the twelfth most relevant Life Cycle Impact Assessments (LCIA) methods present in Carvalho et al. (2014). From these grouped indicators it was retrieved and further selected a group of criterions that were later merged with the indicators present within the Global Reporting Initiative.

For the economical dimension it was analysed the indicators selected on the work of Simões (2014), where 1500 indicators and 250 articles were scrutinised and grouped into groups together with the indicators provided by the Global Reporting Initiative. There are categories of social impact associated with specific stakeholders (such as employees or customers). However, the social impacts of organizations are also linked to interactions with market structures and social institutions that establish the social environment in which stakeholders interact. These interactions, as well as the organizations' approaches to deal with social groups such as communities, represent an important component of sustainability performance in the supply chain.

After identifying the evaluation criteria it is necessary to associate to each criterion a descriptor of performance. To prepare this task, and before the meetings with the decision-makers, there was an analysis in order to determine what could be the possible descriptors and which reference levels ("good" and "neutral") could be defined upon them.

The first phase of this work examined whether the MCDA model should be developed for the supply chain as a whole, or if it would be necessary to build models depending on the sector in question. As such, we used sustainability reports present in the Business Council for Sustainable Development of Portugal as a source of information to collect data to select descriptors of performance for the evaluation criteria stipulated before. After some extensive investigation and collection of data in the sustainability reports of several Portuguese supply chains, it was recognized that the magnitudes of performances on the criteria vary considerably depending on the sector, making it difficult to find a clear pattern for them all. A clear example is presented in Table 1, where the evaluation criterion "Energy Consumption" shows different orders of magnitude regarding the amounts of energy consumed.

Table 1 - Energy consumed by several supply chains in 2012

Supply Chain	A	B	C	D	E
Energy Consumption (10^3 GJ)	422	197 723	1 811	29 475	44

To solve this problem it was considered the possibility of acquiring a global common denominator for each indicator, however, this solution only hinders the perception of the indicators by the decision makers. Witnessing this range of values between different supply chains, it was decided to set another sample that considered the division of the model in upstream, midstream and downstream companies. Again data was collected in order to determine whether this partitioning was possible.

However, by collecting the data it was found, again, a disparity in the values collected from the sustainability reports. Using the same example for the evaluation criterion Energy Consumption, it is visible that the variations between supply chains make it impossible to determine a common pattern (Table 2).

Table 2 – Energy consumed by several supply chains from different streams in 2012

Stream	*Midstream*		*Upstream*	
Supply Chain	B	I	C	F
Energy Consumption (10^3 GJ)	197 723	24 976	1811	44

With these successive data collections and analyses, it was realized that the performances on the evaluation criterion vary depending on the size, type and extent of the supply chains. Which means that a supply chain dedicated to the distribution of energy and another supply chain dedicated to food distribution have different ideals, missions and objectives, promoting different attractiveness's in identical criteria. Therefore, it was proposed to build a different model two sectors, promoting not only the solution of the problem of the supply chains type, but also enabling the comparison between supply chains. However, if two supply chains belong to the same sector, they may have different dimensions, which would make impossible the selection of proper descriptors of performance for the evaluation criteria. Therefore, it was determined to evaluate the evolution of the sustainability of the supply chain taking into account a reference year, i.e., the model would assess the performances in comparison with a base year, eliminating the problem of the size of the supply chain. Consequently, the descriptors of performance would use percentages of variation upon the base year as measuring units. It can be seen from Table 3 that although the B and J belong to the same sector (energy distribution) they have different magnitudes of consumption. However, if the variation in power consumption of one year is observed in relation to the other, in this case the power consumption of 2013 compared to 2012, it is visible that there is a reduction of 6.6% for supply chain J and 13.5% for supply chain B, enabling the extraction of descriptors for the evaluation criteria since a pattern is visible.

Table 3 – Energy Consumption and its variations on two supply chains

Supply Chain	J	B
Energy Consumption (10^3 GJ) in 2013	574	170 977
Energy Consumption (10^3 GJ) in 2012	615	197 723
Energy Consumption variation in 2013 compared to 2012 (in %)	-6.6	-13.5

This was the selected path and therefore the objective is to analyse the evolution of sustainability on supply chains. Upon this new path the data for the descriptors of performance were collected.

4.2. Selection of the Decision Makers

In order to be able to develop a MCDA model to assess the sustainability evolution of supply chains it is essential the presence of specialists or experts working in the area of sustainability of supply chains. This allows not only a greater reliability of the model, but also that this originates proper results.

Therefore, the structure and construction of the models were developed with the support of the Director responsible for Environment, Sustainability and Business Continuity at supply chain X and the Environment Affairs & In Store Food Safety Corporate Director at supply chain Y. Both are in direct contact with the areas of sustainability and supply chains in the workplace every day, something fundamental to the election and appointment of experts for constructing this MCDA model.

4.3. Structuring the Value tree

After the specialists selected the criteria for each of the two models, M-MACBETH software was used to integrate them in areas of concern that can be seen in the value trees depicted in Figures 2 and 3.

Figure 2 - Value Tree for the energy distribution sector model

The decision makers selected different evaluation criteria from the previously selected sustainability indicators, because some criteria were not applicable to the context of supply chains in question or simply because they were not quantifiable. However, some of the evaluation criteria not selected, namely in the model related to the food distribution sector, were not considered in the model due to the fact that they are not fully reported by the supply chains in this sector, despite some of these evaluation criteria are present in those supply chains. In both models there is no rejection criterion.

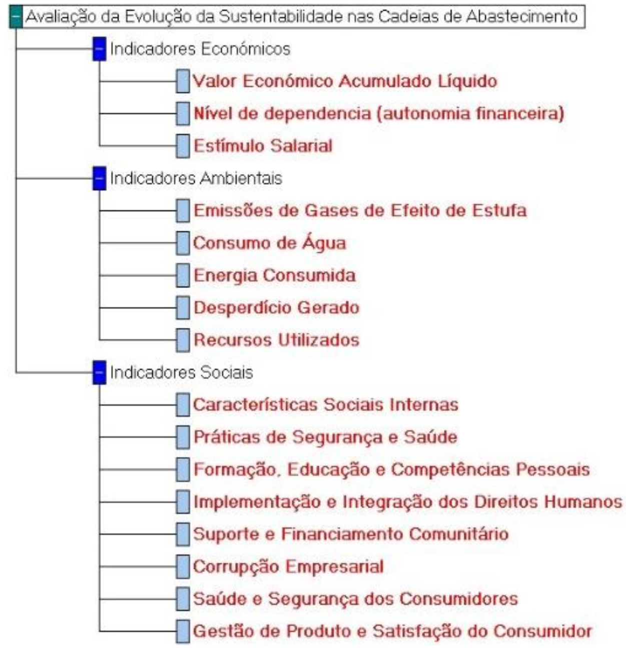

Figure 3 - Value Tree for the food distribution sector model

4.4. Descriptor of impacts and levels of impact

The next structuring step is to define the descriptors of impact and their levels of impact. In each descriptor, it was defined two reference levels of intrinsic value: the performance level of "good" (green) and the performance level of "neutral" (in blue). The "good" level corresponds to a significantly positive performance in the evaluated criteria, while the "neutral" level corresponds to a satisfactory or unsatisfactory performance or the evaluated criteria (see Table 4). In some descriptors were also defined other levels, to be later used in the construction of the value scales of the respective criteria.

The levels were defined for each criterion of each model. There were different levels for shared criterions on both models.

Table 4 - Performance levels on the descriptor for the criterion Estímulo Salarial

Impact levels (variation in %)	
	3.75
Bom	2.5
	1.25
Neutro	0
	-1.25

The next step for the development of multiple criteria model is to build a value function for each criterion using the M-MACBETH software, based on the judgments expressed by decision makers with regard to differences in attractiveness between levels of performance on each criterion. This procedure was performed through meetings with the decision makers. The decision maker is asked to qualitatively assess the attractiveness between pairs of levels of performance, using the semantic categories MACBETH (Very Weak, Weak, Moderate, Strong, Very Strong and Extreme).

As each judgment is entered in the MACBETH matrix of judgments, its consistency is tested, and each time that appears an inconsistency, suggestions are given by the software. After the matrix is complete and without inconsistencies, a quantitative scale is displayed by the software. This scale can be discussed and adjusted by decision makers.

The value functions in the case study were defined completing the judgment matrix for each performance indicator. Each matrix was filled out asking to the decision maker questions to compare the different pairs of levels through the 6 semantic categories. An example of the questions made is: "what is the difference of attractiveness between a supply chain that has 9% reduction in energy consumed and have 0% variation in the same performance indicator?". Figure 4 and Figure 5 have an example of judgment matrix and thermometric scale obtained by MACBETH, respectively.

	3.75	2.5	1.25	0	-1.25	Escala actual
3.75	nula	forte	mt. forte	mt. forte	extrema	157.14
2.5		nula	forte	forte	mt. forte	100.00
1.25			nula	mod-fort	forte	42.86
0				nula	moderada	0.00
-1.25					nula	-42.86

Figure 4 – Judgment Matrix on the criterion Estímulo Salarial

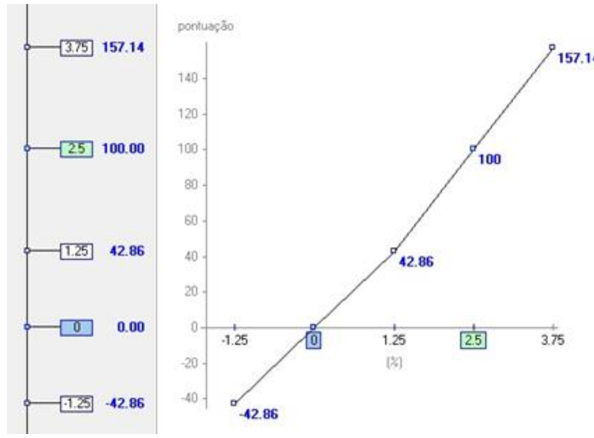

Figure 5 – Thermometric Scale on the criterion Estímulo Salarial

4.5. Weighting

After the identification of the value function, the next step is to obtain the weights for each criterion. The weights assure the importance of each criterion possesses in the model evaluation. Therefore, in this stage the actors in the decision conferences begin to rank the criteria in terms of attractiveness.

The second step to determine the weightings consisted on the completion of the weights matrix, according to the ordering defined above. At this stage the decision maker is asked to draw judgments about the difference in attractiveness between the intervals of good-neutral criteria using semantic scale again MACBETH.

Thus, decision makers assess once again through qualitative judgments the attractiveness of each swing, starting to compare in first place the swing most attractive with the second most attractive, applying the same six semantic categories used in the judgment matrix used in the determination of the value functions. This process continues until all the matrix is fulfilled (Bana e Costa et al., 2008).

After the matrix is completed and without obtaining inconsistencies, the weights are obtained by the M-MACBETH software as shown in Figure 6 and Figure 7.

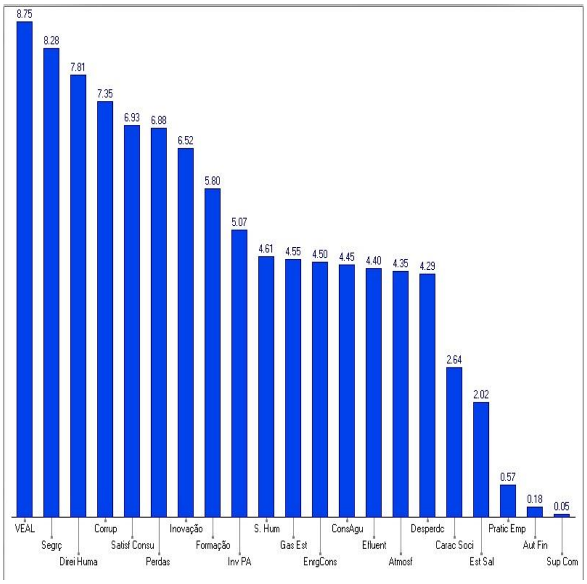

Figure 6 - Histogram with the weights of the criteria for the model of energy distribution sector

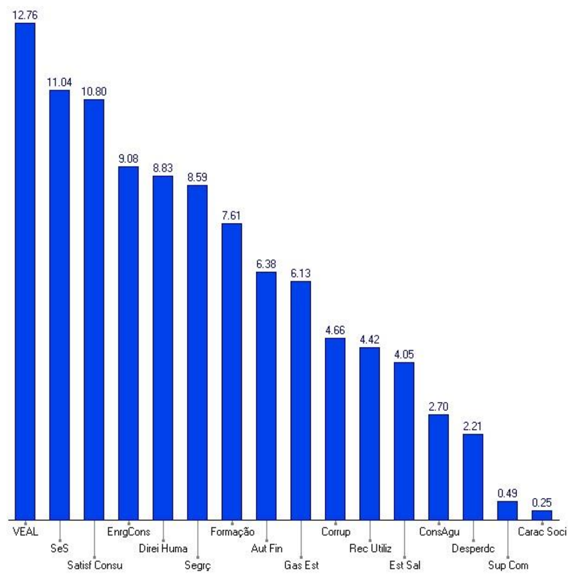

Figure 7 - Histogram with the weights of the criteria for the model of food distribution sector

5. Analysis of Results

5.1. Alternatives

For the model correspondent to the evaluation of the sustainability evolution in supply chains of the energy distribution sector, the options were extracted from the X's supply chain. This is, the options are the results obtained in 2010, 2011, 2012 and 2013 compared to the base year 2009. In this manner it is possible to evaluate the evolution of the supply chain X since the year 2010 until 2013, based on the year 2009.

For the model correspondent to the evaluation of the sustainability evolution in supply chains of the food distribution sector, the options used were extracted from the Y's supply chain. As there was a lack of information prior to 2012 results, the only option will be the results obtained in 2013 compared to the base year 2012, determining if there was a sustainable development in Y's supply chain in 2013 compared to 2012.

5.2. Performance Analysis

At last, after the introduction of the alternatives in the model and their performances for all the criteria, results are analyzed, using the results generated by the software MACBETH.

In Figure 8 and Figure 9 it is presented the thermometric scales resulting from the overall performance of the alternatives in the models relative to the food distribution sector and energy distribution sector, respectively.

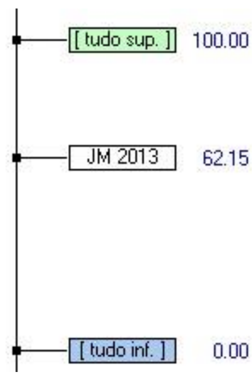

Figure 8 - Global thermometer for the food distribution model

Figure 9 - Global thermometer for the energy distribution model

In regards to the model corresponding to the food distribution sector, it was possible to conclude that in 2013 there was an evolution on sustainability in Y's supply chain when compared to 2012.

The year 2011 was the year where there was a more significant evolution on sustainability in the X's supply chain compared to 2009, in regards to the model corresponding to the energy distribution sector. The sensitivity analysis came verify this fact and that it would be needed a significant change in the weight of the criterion of Inovação e Competitividade for another year (except 2011) to obtain a higher score. The robustness analysis performed certified that 2011 alternative additively dominates all other alternatives.

6. Conclusions

With this models application it is possible to state that the objectives were achieved. It was possible to build two multiple criteria models that assess sustainability in supply chains in different sectors. The results, as the analysis themselves, have demonstrated that the model is sound and strong and that it is possible to evaluate sustainability in various sectors of supply chains. This article shows how to develop a methodology to assess the sustainability of supply chains, something not yet present in the literature. Thus, the work within this article enables assessing and monitoring sustainability in supply chains, indicating if they have sustainable behaviors and their evolution over time.

For future development it would be interesting to apply the developed model to other sectors of supply chains to test its consistency and fitness. Different supply chains may use different evaluation criteria, and as such, the creation of a database where the evaluation criteria for each sector supply chains are present would be something positive. It would then be possible to assess the sustainability on different supply chains regardless of their sector.

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