A Multi-Criteria Methodology for developing a Sustainability Assessment Tool

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Abstract

No particular system is present to assess sustainability of products leading to incoherency and ad hoc evaluations which do not incorporate all potential criteria pertinent for examination. The paper aims to develop a methodological framework with a purpose of creating a tool to assess sustainability of products while solving a real-world problem and aiming to contribute to the literature. The proposed framework combines the principles of Multi Criteria Decision Analysis (MCDA) and Participatory Processes. The identification of criteria was achieved by employing, Welphi, a web-Delphi platform. The tool was constructed through a socio-technical interaction between the facilitator and the decision makers by implementing MACBETH approach for the creation an evaluation model aided by M-MACBETH, a decision support system. The framework was implemented with PLANETIERS as the case study to build the assessment tool that enabled the decision makers to assess performance of the products and evaluate their overall sustainability. The results obtained provided valuable addition to the literature regards to socio-technical interactions in sustainability assessment and employment of M-MACBETH and Welphi in decision aiding and participatory process. The methodology implemented has proved to be robust and allows forth adaptation towards products from various categories.

Keywords: Sustainability Assessment, MCDA, Participatory Processes, MACBETH, Delphi

1. Introduction

In regards to everyday commodities and household consumables a standardized tool for assessing their sustainability has not been developed leading to incoherency and ad hoc evaluations which do not incorporate all potential criteria pertinent for examination. PLANETIERS encompasses an extremely diverse product and in order to ascertain their sustainability, the products are evaluated on an individual basis. The resultant product analysis determines if the product is sustainable (or not) and is then allocated to their online platform (or rejected if it does not meet their standards). PLANETIERS intends to implement a system with an aim to ease the evaluation process and support the appraisal of their inventory with greater efficiency, accuracy and reliability, and incorporating greater deal of flexibility by standardizing the process and allowing the assessment of sustainability for distinct products. In order to achieve this objective, a robust and reliable tool needs to be developed that can evaluate their diverse range of products. The first and present chapter aims to provide the underlying objectives. The literature review is presented in the subsequent chapter. Section 3 elaborates on the design of the framework and implementation of the multi-criteria methodology. Results will be presented in Section 4.

Discussion are presented in Section 5 and finally, Conclusions will be provided in Section 6.

2. Literature Review

Sustainability of a system cannot be assessed by the use of a single criterion mainly because of its intrinsic multidimensionality characteristics thus an evaluation incorporates all three dimensions (economical, environmental and social) needs to be considered for a more comprehensive assessment of sustainability (Doualle *et al*., 2015). Environmental considerations have significantly raised the demand of sustainability assessment tools and are based on a wide number of methodologies focusing primarily on the economic outcomes. However, the social and environmental principles are often neglected or handled inappropriately.

Assessment methods such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Cost Benefit Analysis (CBA) evaluate potential impact on the environment by quantifying environmental impact and relies on measured data for calculations which can be problematic due to the scarcity and difficulty in retrieving relevant data (Finnveden *et al*., 2003; Belfield and Levin, 2010). Cost Effectiveness Analysis (CEA) is susceptible to the similar limitations of CBA, as relevant data is hard to collect (Belfield and Levin, 2010). Although these methods have been employed for analysis and impact assessment, they are not suitable for the present case study due to the multiplicity of factors and indicators concerning sustainability which are qualitative in nature and cannot be quantified. Measuring Attractiveness by a Category-Based Evaluation Technique (MACBETH) can accommodate quantitative and qualitative data amidst a heterogenous set of criteria and involvement of multiple stakeholders. The MACBETH approach requires pairwise comparisons on an interval scale with a strict consistency check and then uses linear optimization to calculate the priorities (Ishizaka and Siraj, 2018). The decision-maker's judgments are represented as a numerical scale and through a similar process it allows forth the creation of weighting scales for criteria (Bana e Costa and Chagas, 2004).

Participatory methods have established themselves as the prevailing approach in aiding social component of MCDA's technique. A decision conference is led by a neutral facilitator, whose role is to enhance communication between the participants and to get them to constructively deal with the conflicting issues at hand (Marttunen *et al*., 2013). Delphi is a very practical approach as it can incorporate a very large number of participants and also geographically dispersed members. The use of decision conferencing and Delphi process with the MACBETH approach has been found in (Rodrigues, 2014; Vieira *et al*., 2019).

3. Methodological Framework

A new methodological framework is proposed for building a sustainability assessment tool in order to appraise products. The tool is to be based on the term "sustainability", which is characterized by the three principles and can be measured through multiple criteria, hence justifying the use of MCDA framework to properly accommodate each criterion. Figure 1 depicts the framework for the development of the sustainability assessment tool.

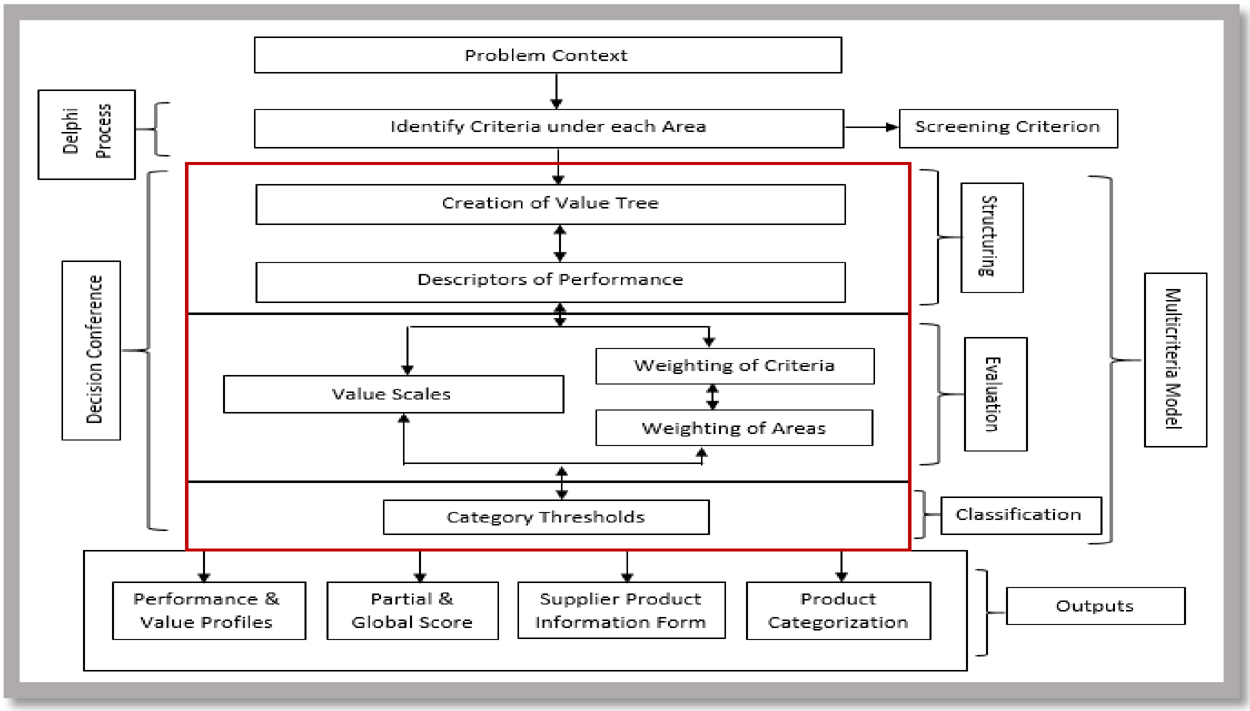


Figure 1 - Framework for Development of the Assessment Tool

3.1 Identifying Criteria

The recognition, measurement and employment of appropriate indicators concerning sustainability is of among the major challenges facing policy-makers, scientists, researchers, bureaucrats and citizens (McCool and Stankey, 2004). Extensive literature review was carried out on Google Scholar and Science Direct repository, on the subject matter sustainability to identify indicators. The criteria were also based on the PLANETIERS' principles as they were found to roughly cover the basic characteristics of sustainability with regards to product manufacture and disposal. The literature study and analysis of the principles yielded identification of 34 potential indicators grouped with 3 areas of concern. The list comprised of 23 environmental (67.65%), 5 social (14.70%) and 6 economic (17.65%) indicators.

3.2 Delphi Process

Exercising Delphi methodology (depicted in Figure 2) was most preferable as it allowed for consolidation of a wide range of opinions from geographically dispersed individuals with diverse backgrounds whilst ensuring anonymity. The most commonly used type of response scale in Delphi study surveys is a rank-ordered or Likert-type scale (Belton *et al.*, 2019), and this scale was employed in the eliciting the panel's response.

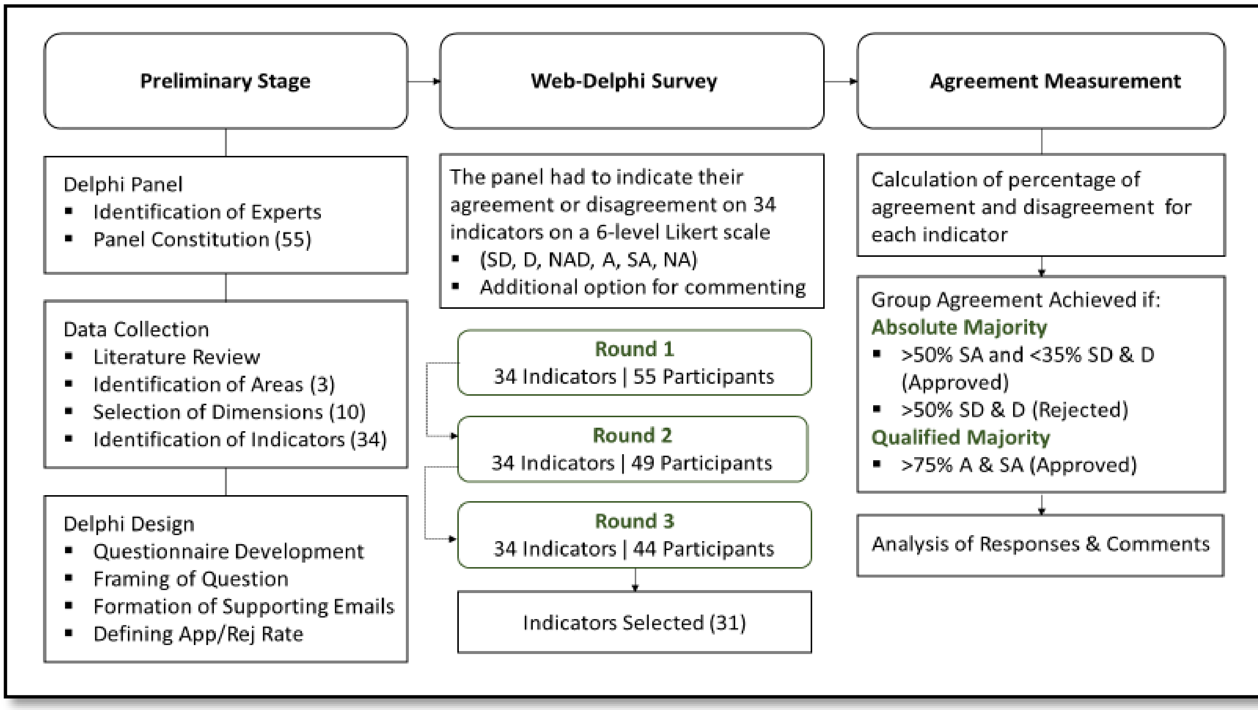


Figure 2 - Web-Delphi Process Flow Diagram

3.2.1 Delphi Application

The Delphi survey was employed by making use of the "ENERPHI" project, a platform for participatory processes in decision-making contexts established exclusively for students (ENERPHI, 2019). The Delphi process was conducted via a web platform "WELPHI", (https://app.welphi.com/welphi/Pages/LoginPage.aspx), for implementing and monitoring the participatory process involved in this dissertation. Panelists were required to indicate their agreement or disagreement with the following statement "*Is this indicator relevant in assessing the sustainability of a product?*" The panel would response on a 6-level Likert scale, with Disagree (D) and Strongly Disagree (SD) indicating disagreement and Agree (A) and Strongly Agree (SA) indicating agreement. Moreover, panelists could indicate their uncertainness by opting Neither Agree nor Disagree (NAD). Furthermore, if the panelist did not wish to answer or believed that certain indicator did not fall under their expertise, they could select the option No Answer (NA). In the 2nd round, panelists were presented with the results of the first round, and had the option to maintain or revise their response. In the third round, the same procedure was replicated as in the second round. Similarly, participants were invited to revise their previously given answers.

3.3 Evaluation Model Construction

A decision conference was conducted in order to validate the outcomes of the Delphi process and construct a multicriteria evaluation model. From now onwards the PLANETIERS' team was involved in the building of the evaluation model and M-MACBETH software was utilized in the decision conference.

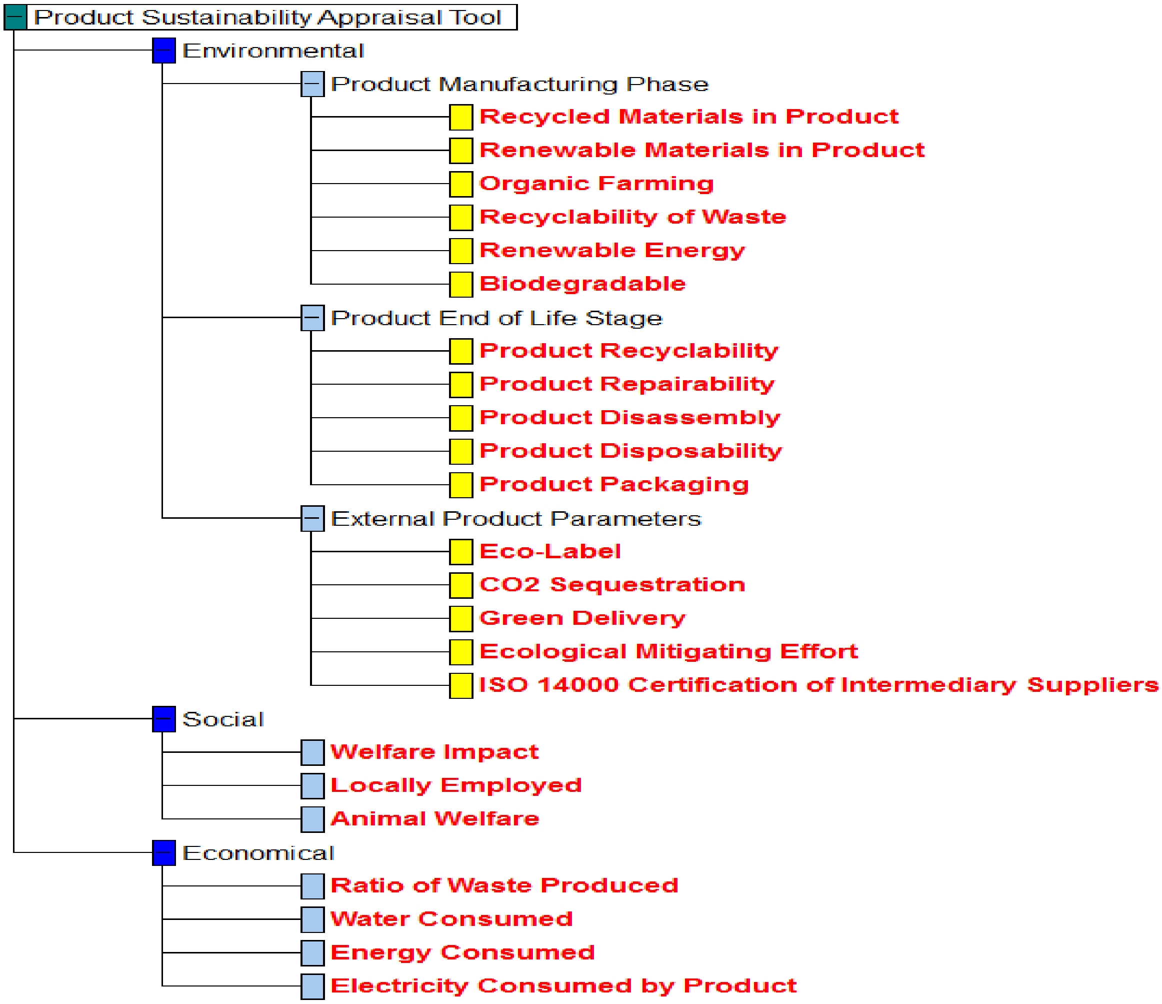


Figure 3 - Generic Value Tree - "Product Sustainability Assessment Tool"

3.3.1 Value Tree

The results of the Delphi process were needed to be analyzed for the creation of the Value Tree. On analysis of the identified criteria, it became apparent that the criteria would be defined in a hierarchical structure, based on the three pillars of sustainability, represented in Figure 3. The generic form of Value Tree was adapted into a product category specific value model using a bottom-up approach by analyzing the characteristics of the product categories to be evaluated. This was necessary as several criteria identified were relevant and pertinent to one particular category but inappropriate to the other. These criteria would have affected the result of the model hence were excluded from some models. The results of the generic model would have created disagreements on this basis and "lack of trust" with the results.

The evaluation criteria in the generic model were utilized as criteria for the models of specific categories, as they possessed the required properties such as non-redundancy and preferential-independence to ensure the creation of an adequate evaluation model. ‘‘Product Disposability’’ performance levels are provided in Figure 4. Table 1 defines the list of all criteria and their descriptions.

Performance levels:

- +	Qualitative level	Short
1	Product once disposed can be prepared for reuse	Reuse
2	Product once disposed can be recycled	Recycle
3	Product once disposed can be composted	Compost
4	Product once disposed can be converted into refuse derived fuel	RDF
5	Product is disposed by incineration	Incinerate
6	Product is disposed by dumping in landfill	Landfill

Figure 4 - Descriptors of Performance for the criterion "Product Disposability"

Table 1 - List of Criteria and their descriptions

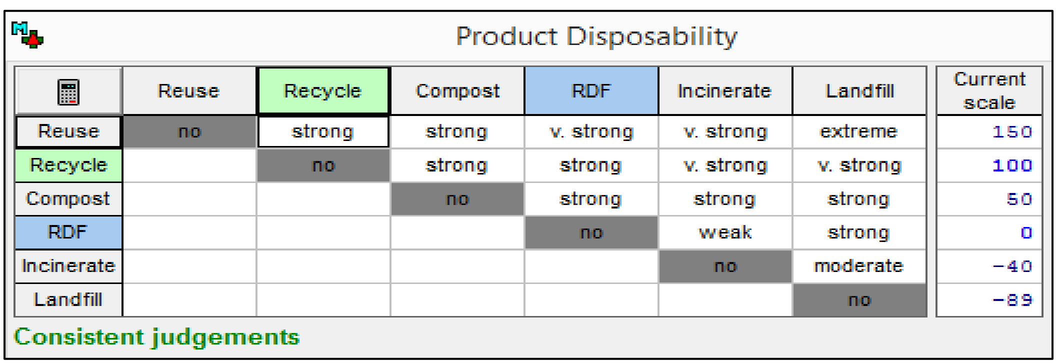
Criteria	**Description**
Recycled Materials in Product	Raw material used in the manufacture of product are obtained through recycling
Renewable Materials in Product	Materials used in the manufacture of the product which can be remade, regenerated or regrown
Organic Farming	The use of raw materials harvested through organic farming practices
Recyclability of Waste	Waste generated in the manufacture of the product can be recycled
Renewable Energy	Renewable energy consumed in the manufacture of the product
Biodegradable	The use of biodegradable raw materials in the manufacture of product
Product Recyclability	Degree of recyclability of product after it has reached its end of life
Product Repairability	The level of technical expertise required to repair the product
Product Disassembly	The level of technical expertise required to disassemble the product
Product Disposability	Disposal method of the product within waste management hierarchy
Product Packaging	The utilization and disposal of product packaging
Eco-Label	Accreditation of the Product
ISO 14000 Certification of Intermediary Suppliers	ISO 14000 Certification of Suppliers providing raw materials to the product manufacture
CO_2 Sequestration	Utilization of raw materials that have captured CO_2
Green Delivery	The use and disposal of packaging utilized in logistics of the product
Ecological Mitigation Effort	The manufacturing company of the product partakes in activities to minimize or reverse its impact on the environment
Welfare Impact	The product manufacturing company partakes in activities that promotes social and welfare development
Locally Employed	Product manufacture promotes local employment

Table 1 - List of Criteria and their descriptions (Continued)

Animal Welfare	**The manufacture of product involves testing on animals**
Ratio of Waste Produced	The ratio of waste produced to the product manufactured.
Water Consumed	Impact of product manufacture on water consumption
Energy Consumed	Impact of product usage on energy consumption
Electricity Consumed by Product	Type of energy source utilized in the consumption of electricity by the product

3.3.2 Value Scales

The judgement matrix (Figure 5) is filled by first requesting the stakeholders to express the magnitude of difference of attractiveness between consecutive performance levels. The question was phrased as, "Given two performance levels, with the first better than the second, describe the difference of attractiveness (value) between them is?" The panel had the option to respond from the seven semantic judgements; "*No*", "*Very Weak*", "*Weak*", "*Moderate*", "*Strong*", "*Very Strong*" and "*Extreme*". Figure 5 depicts the judgement matrix and value scale for "Product Disposability" criterion.



Product Disposability

	Reuse	Recycle	Compost	RDF	Incinerate	Landfill	Current scale
Reuse	no	strong	strong	v. strong	v. strong	extreme	150
Recycle		no	strong	strong	v. strong	v. strong	100
Compost			no	strong	strong	strong	50
RDF				no	weak	strong	0
Incinerate					no	moderate	-40
Landfill						no	-89

Consistent judgements

Figure 5 - Judgement Matrix and Value Scale for the criterion "Product Disposability"

3.3.3 Assigning Weights

The appraisers were asked the importance of improving the performance of their most preferred criterion with reference to the last column of the judgement matrix labelled "Neutral". They were then inquired to compare consecutive criteria and share the degree of importance of improving from "Neutral" to "Good" of performance level on each consecutive criterion. Once the judgement matrix is complete, an interval scale is generated. The M-MACBETH software generates the weight of the criteria through normalization of the scores on the interval scale. The next step is to weigh the areas in order to harmonize the weights of the criteria. Under the "Environmental" aspect of sustainability, the criteria are allocated to three areas with regards to "Manufacturing Phase", "Product End of Life" and "External Parameters". The panel was asked to indicate their most preferred criterion among the 3 highest weighted criteria in each area. They are then asked to express their desirability in improving the criterion from “Neutral” to “Good” performance level in comparison to the other. The final step is to weigh the three areas of concern. Exactly the same process is repeated and the same weighting procedure is applied.

3.4 Additive Model

The additive model consists of allocating a certain option, partial score on evaluation criteria, which are in turn multiplied by their respective weighting coefficients, yielding a global aggregate score for that option. The mathematical model, described below, enables the assessment of alternatives in obtaining an overall score.

$$v(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} k_i \times w_j \times v_j(x_j) \quad with \begin{cases} v_j\ (Good) = 100 \\ v_j\ (Neutral) = 0 \end{cases} \tag{1}$$

x_j represents the performance of a product on criterion j where j = 1,2,3… n (n being the total number of criteria). v_j being the partial score and $v_j(x)$ representing the partial score on the criterion j. w_j being the weight of the criterion and k_i depicting the weight of the area of concern where the criterion j resides and i = 1,2,3… m (m being the total number of areas of concern).

3.5 Category Thresholds

Alternatives scoring above the level “Good” would be approved and the ones scoring below the level “Neutral” would be rejected. The intermediary range between “0” and “100” was split into two categories, “Monitoring Zone” and “Grey Zone”, and a threshold between them had to be established. The approach utilized in (Bana e Costa and Oliveira, 2002), was implemented to determine the threshold based on the identification of “*reference profiles*” and was conducted by *Bottom-Up procedure*. This resulted in the score of “50” and was defined the threshold for separating the two categories. The products scoring between “50” and “Good” would be approved but will be monitored and the products scoring between “Neutral” and “50” would be assessed over certain criteria depending on the specific evaluation model. If a performance level of the product in the particular criterion is either at “Good” or a higher level, then the product is approved (otherwise rejected).

4. Results

4.1 Delphi Results

A total of 34 indicators were proposed to the panel, and amongst them 31 indicators (91.2%) reached group agreement and were approved as relevant to appraise product sustainability. The agreement results in the areas of concern are as follows: Environmental (22), Social (3) and Economical (6). Three indicators presented lack of agreement and were subsequently rejected. The results of the web-Delphi process were wielded to be fed in the construction process of the evaluation model.

4.2 Reusables Category Model Results

The evaluation of the products was carried out first on the "Reusables" model. Figure 6 depicts the standings obtained by the products on the Reusables sustainability assessment tool. The model proposed the product "*Plate*" as the most sustainable option in commensurate with the decision makers judgments. According to the category thresholds defined previously, *Plate* has scored an overall score of "111.02" is approved. The product "*Bag 1*" scored an overall score of "103.08" and is approved. The items labelled as "*Bottle 2*" and "*Bag 2*" have scored in the negative, "-6.32" and "-8.22" respectively hence were deemed non-sustainable and henceforth rejected. The products, "*Straw*" and "*Bottle 1*" scored in the range of 50 and 100, and were regarded sustainable but will be monitored. The product "*Notebook*" achieved an overall score of "32.62". The performance levels of *Notebook* were analyzed on the criteria "Social Welfare". As the performance level of item *Notebook* was equivalent to the "Good" reference level in criterion Social Welfare, it was approved. One of the outcomes of the methodological framework was the creation of a "Supplier Product Information" form. The purpose of this form will be to acquire product information to facilitate product appraisal. This proved to be an important component as this form greatly enhanced the efficiency and speed of the evaluation process. It formalized a standard set of information necessary for product appraisal further streamlining the process.

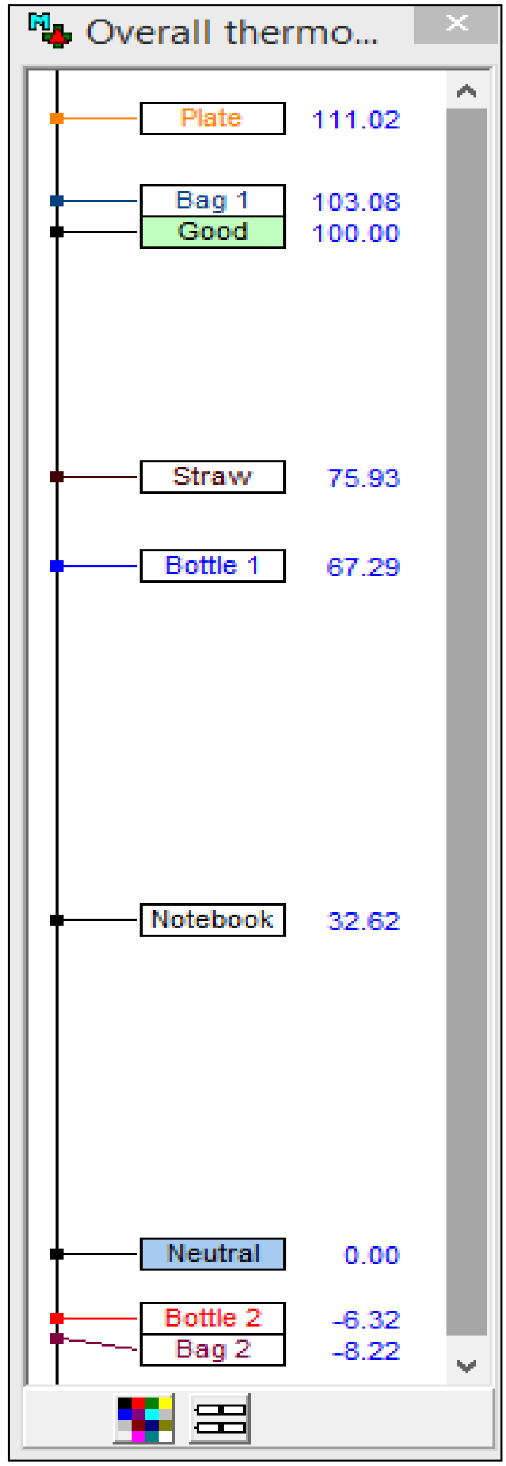


Figure 6 - Reusable Model Results

5. Discussion

The use of the Welphi platform to deliver the questionnaires greatly enhanced the speed of the Delphi process as the need for face to face interaction was eliminated hence saving time and resources. The recursive model development procedure under MACBETH's non-numerical approach offers an advantage of interactive verification of the reliability of the preference information elicited (Bana e Costa *et al*., 2012). A "Supplier Product Form" was designed with an aim to elicit product specifications from the supplier for product assessment. This proved to be an important component as this form greatly enhanced the efficiency and speed of the evaluation process. It formalized a standard set of information necessary for product appraisal further streamlining the process. The generation of multiple category specific models provided a much more accurate depiction of results and the sustainability score attained and eliminated irrelevant criteria for that category. This also facilitated in assigning higher weightages to certain criteria in one model and a lower weightage in another model in consideration of the category assessed. This capability was not present in the generic model which resulted in "lack of trust" with the results.

6. Conclusion

The paper adds to literature from a 1) practical aspect; by establishing a consensus among a diverse and geographically dispersed group of experts and stakeholders on which indicators are mostly relevant for appraising sustainability of products, from a 2) methodological standpoint, by proposing participatory methods that can be used in the field of sustainability assessment and from a 3) technological viewpoint, by presenting a web-platform and a decision support software, as a means to aid the use of participatory processes. The study presented, a real-world application, in Sustainability Assessment, a practical assessment tool for evaluating consumer products. The tool serves the purpose of standardizing the procedure of assessing sustainability and instilling coherence to the process. Findings from the study can inform future research on sustainability assessment and product appraisal and the developed framework can be tailored to not only different aspects of sustainability but also products from different industries.

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