MCDA and LCSA—A Note on the Aggregation of Preferences

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Abstract Cost and social dimensions are now being added to the existing environmental Life Cycle Assessment (LCA), leading to Life Cycle Sustainability Assessment (LCSA). LCSA is very complex with deep uncertainties and, generally, involves several stakeholders. Therefore, the analysis and interpretation of the outputs of LCSA is a difficult and complex task, requiring aggregation of preferences. The work in progress here presented deals with a study regarding the use of open exchange interactive software packages dedicated to Multi-criteria decision aiding in the context of LCSA output analysis and interpretation.

Keywords Life cycle sustainability assessment · Complexity · Multi-criteria analysis · Aggregation of preferences procedures

1 Introduction

In recent years, Multi-criteria models have undergone great development, especially, in the field we are particularly interested in this study, interactive methods based on a progressive and selective definition of preferences. Roughly speaking, the aggregation of preferences, in most of the cases, includes one or several of the following procedures: optimisation of weighted sums of the criteria (or other function of the criteria), pairwise comparison of alternatives and minimizations of a distance to the ideal point, or to other reference point. Interactive procedures, especially those rooted in constructivism, avoid a final aggregation of the preferences of decision agents based on a unique criterion, in some cases proposing the

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combination of algorithmic protocols with the experience and intuition of decision agents in the process of preferences aggregation. We call them open exchange interactive procedures. As aggregation always implies loss of information, special care is needed. Ethical issues become very relevant. We believe that in the complex framework of LCSA, the most interesting Multi-criteria approaches have some kind of affinity with the Comparative Theory of Justice proposed by Amartya Sen [1]. So, interactive approaches should be favoured, and among them learning oriented tools, easier to accommodate to practical situations involving several stakeholders and not rarely also public opinion's points of view.

Preference aggregation is a widespread requirement in our societies. But perhaps the contemporary real life domain where they emerge in wider range and with greater intensity is in making decisions related to a sustainable way of life. Even though concerns with such decisions are not necessarily recent, sustainability remains a disputed concept. Yet, its association with development, as proposed by the Brundtland Report, has gathered an overwhelming acceptation, sustainable development being the one that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. Later, the notion has been incorporated into business and governmental decisions through a "triple bottom line" accounting framework that evaluates social, environmental and economic performance. Therefore, decisions about sustainability are inherently Multi-criteria, raising some theoretical and practical controversies. Moreover, it is consensual that sustainability assessment will be progressively more associated with the Life Cycle of the products. This means considering the whole set of cost, social and environmental impacts associated not only to the production, but also to the use and discard of goods, services and events, from the extraction of raw materials, through the several stages of transport and storage, till recycling, recovering or disposal in landfills. The tool to evaluate all those impacts is Life Cycle Sustainability Assessment (LCSA), which may help in public or private decisions on design options, transportation, and life use, etc. [3]. LCSA includes (environmental) Life Cycle Analysis (LCA), Social Life Cycle Analysis (SLCA) and Life Cycle Costing (LCC)—a complex procedure involving not only challenging uncertainty issues but also stakeholders with diverse backgrounds, interests, and points of view on the subject. The ISO LCA methodological framework is formalized since 2006. Now it is tentatively being extended to LCSA.

The major goal of this paper is discussing the potentialities and limitations of some Multi-criteria approaches when dealing with complex LCSA preference aggregation problems. Special emphasis is put in the application of a specific interactive package to a Social Life Cycle Assessment case.

2 Preference Aggregation in LCSA

The most relevant difficulties regarding Life Cycle Assessments are outlined and discussed in a paper by John Reap et al. [4]. The authors recognize that the methodology is still not very relevant in practice and give important hints on how to improve the available tools on the aggregation of preferences. Here we just outline the principal issues in short: defining impact indicators is not a simple task; impacts aggregation, usually based on the use of weights, tends to raise many controversies; the choice of adequate procedures of aggregation is conditioned by uncertainty associated with decision processes, and by the eventual existence of multiple actors; increasing time horizons leading to a bigger difficulty in measuring the socio-economical impacts; the interpretation of the results depending on the previously defined LCA/LCSA goals; the use of interfaces enabling a holistic evaluation is also a key issue.

3 MCDA Tools and Aggregation of Outputs in LCSA

This subject is methodologically discussed in [5, 6]. The phases of characterization and modelling of the process are crucial for the success of LCA and LCSA in practice: study goals and boundaries, data collection and management, definition of impacts, indicators/criteria and alternatives. In [5, 6] the potentialities of using problem structuring techniques in the LCA framework and the aggregation of outputs are discussed. It must be remarked that these issues are still more relevant in LCSA.

The aggregation of outputs in LCA is usually done using weighted sums of normalized outputs obtained by direct elicitation procedures. Many recent papers alert that the use of weights raises several questions/errors, still more relevant in LCSA. Compensatory procedures showed to be very problematic in these circumstances. Moreover, it must be remarked that the direct use of weights still involves normalization of the terms, which also may contribute to the distortion of the results in many situations. Multi-Attribute Utility Theory (MAUT) can help doing weights elicitation in a more scientific way, but it does not overcome the root of the problem. See, for instance, [4, 7, 8].

Taking into account the limitations of the additive model, some authors proposed to avoid total compensation approaches by using outranking methods such as those of the ELECTRE family, where the concepts of concordance and discordance are employed to build partial order outranking relations, followed by some kind of aggregation and exploitation of the results. Although avoiding the complete compensation, these approaches require fixing a large number of parameters, such as concordance and discordance thresholds, weights (even if here they are less problematic than in the additive model, because they just represent coefficients of importance of the criteria and not trade-offs, as in additive model), and in many cases indifference and preference thresholds to take into account uncertainty associated to the criteria scores. It must be remarked that, of course, changes in these parameters can influence drastically the results. See for instance [9]. Furthermore, simple non-compensatory procedures can also be useful in the aggregation of outputs in LCSA. Note that inter-criteria aggregation is particularly delicate in LCSA, considering that data can be either quantitative or qualitative. Moreover, uncertainty and lack of information can be dealt with by using different decision aiding tools that use several types of uncertainty representations. Sensitivity analysis and robustness analysis are very important approaches in LCSA framework and can be efficiently associated with Multi-criteria modelling. Finally, though the classical LCA is a "steady-state" assessment, real life cycles under study involve inter-connections and dynamic interactions and so dynamic system tools should be associated with MCDA [10].

4 On the Potentialities of Open Exchange Interactive Multi-criteria Procedures in the Aggregation of the Outputs of LCSA

The use of Multi-criteria analysis in the aggregation of outputs in LCSA is still very limited. Taking into account the difficulties associated with the use of many well-known methods in this context, the authors are testing flexible learning oriented Multi-criteria packages that seem to cope better with the problem. Reinforcing all previous remarks, we believe that the following issues should be considered carefully: the involvement of several stakeholders/actors (cooperating and/or negotiating); the desirable public participation in situations where public and private spheres and the evolution of their borders are important issues; the inevitability of coping with large uncertainties (see for instance, [11, 4]). In this section we outline the main characteristics of the open exchange interactive tools that we intend to test.

4.1 VIP-Analysis [12]

It is an interactive platform dedicated to the choice problematic regarding the evaluation of a discrete set of alternatives according to a Multi-Attribute additive value function. It does not require precise values for the weights. Rather, it can accept imprecise information (i.e. intervals and linear constraints) on these values. It enables the discovering of robust conclusions, i.e. those that hold for every feasible combination of the weights/scaling constants, and to identify what is the variability of the results resulting from the imprecision in the parameter values. This software is free.

As VIP Analysis does not requires accurate values for the weights, some of the drawbacks of using the additive model are really mitigated: the decision makers or stakeholders only need to identify linear constraints for the weights, normally by indirect ways (one example is by comparing equivalent swings); it is very appreciated, in the context of LCSA, the possibility of identifying which are the robust conclusions compatible with the use of incomplete information regarding the weights; this tool seems very adequate to support a group of stakeholders/actors meeting face to face around a computer, which is also very adequate in the LCSA context. However, a proficient use of VIP-Analysis requires the sharing of knowledge about the tool potentialities and limitations with the stakeholders, so a facilitator is required.

4.2 A Non-compensatory Software Package Integrating an Interactive Dashboard with an Extension of the Conjunctive Method [13]

The interactive package, based on an extension of the conjunctive method integrates an interactive multidimensional dashboard, in order to open options of analysis. However, here we do not follow the mainstream aggregation frameworks using weighted sums of normalized data regarding the considered dimensions, as in many situations when aggregating outputs of LCA/LCSA. We opted by a non-compensatory tool thence avoiding the most negative aspects of the additive model. The software of support to our proposal [13] is based on an interactive implementation of the conjunctive method, enabling the consideration of up to three performance thresholds, having in mind to classify the objects under evaluation. Quantitative and qualitative criteria are admitted. For details see [13]. The software is free.

For the applicability of this approach see the experiment reported below in paragraph 5. For details on the application of this tool in other type of applications see [14, 15].

4.3 ELECTRE Methods

The idea is using a non-conventional implementation of ELECTRE methods containing a control panel with slide bars that enables “continuous” variation of some parameters, providing real time sensitivity and robustness analysis. For instance, a simple visual inspection could allow a real time evaluation of the changes on the outranking relations graph according to parameter changes. This possibility is very suitable to our case because LCSA involves very high uncertainties. The choice of the adequate ELECTRE method depends on the problematic associated to the case under study. For details on ELECTRE methods see [16].

5 A First Experiment Based on a Brazilian Social Life Cycle Assessment Case Study

In this section we describe a first experiment regarding the integration of a Multi-criteria approach in a Social Life Cycle Assessment (SLCA) case. After outlining the case study (5.1), the software package referred to in 4.2 is introduced and applied to the case study (5.2). Although this experiment just deals with one of the three components of LCSA it is very relevant in the context of this paper because SLCA raises the most difficult problems regarding the aggregation of outputs in.

5.1 SLCA Case Study—on the Comparison of Wind and Thermo-Electric Power Stations

The case study refers to a wider on going research that analyses two energy production sites in Northern-East Brazil: a wind power plant (including a production equipment by company A and an installation, operation and maintenance of the equipment by a company B) and an oil thermal power plant (including plant installation by company C, oil supply by company D and operation and maintenance by company E) [17]. For illustration purposes, we restrict the social impacts here taken into account to those related to only one of the stakeholders, namely the local community of those companies. The considered SLCA subcategories are those of United Nations Environment Programme methodological guides, with exception of two of them that does not apply (respect of indigenous rights and delocalization and migration). For each one of them, three social indicators were taken from GRI (Global Reporting Initiative) guidelines, ISO 26000 and Ethos indicators were assessed. Data was collected in interviews, on-site observation and secondary sources (such as companies' sustainability reports).

Every Social Life Cycle impact Assessment must include a characterization procedure, i.e. inventory data attributed into a given subcategory must be modelled and expressed into a numeric indicator. The social impacts of each power plant correspond to an average value of the respective companies' scores (regarding the interviews and other sources), multiplied by a severity factor involving the social impact magnitude based on society consequences; the area of influence of the social impact in terms of space; the importance of each impact in the corresponding UNEP/SETAC category [18] (human rights, working conditions, healthy and safety, cultural heritage, governance and socio-economic repercussions); and the applicable legal requirements, or notifications from regulatory agencies. The calculation of those factors is beyond the scope of this paper. Details can be seen in [17]. The final outcome is the impact matrix presented in Table 1 (where an impact is better, when the corresponding value is smaller…).

Table 1 Impact matrix

Subcategories	Social impact indicators	Wind power plant	Thermal power plant
Access to material resources	When necessary and possible, the company helps improving its region public spaces (schools, health centers, green areas, etc.)	6	16
	Infrastructure and services provided primarily for public benefit through commercial activities, in-kind, or pro bono	24	18
	The organization has developed some project related to infrastructure with mutual community access and benefit	27	21
Access to intangible resources	Where necessary and /or possible, the company collaborates offering freedom of expression, access to information, community services, health, education, security	6	10
	The company organizes educational campaigns along with local companies in their community	6	10
	Presence/strength of community education initiatives	18	18
Cultural heritage	The organization is concerned about preserving its cultural heritage, mainly where the company activities have some impact	76	95
	The company promotes cultural activities such as appreciation of local cultures and cultural traditions	30	50
	Take action and support cultural activities enhancing minority, discriminated or vulnerable groups	63	78
Safe and healthy life conditions	Management effort to minimize use of hazardous substances	50	131
	The company promotes good health, contributing to access to medicines and vaccinations, encouraging healthy lifestyles (exercise, good nutrition, early diagnosis of diseases, etc.)	24	26
	The company seeks to eliminate negative impacts to health caused by any production process, any product or service supplied by the company	21	13
Community engagement	The company is concerned in maintaining contact with the surrounding community, seeking to minimize negative impacts their activities could cause	54	42
	The company invites local residents to attend meetings at which issues of collective interest are addressed	27	27
	Characteristics, scope and efficiency of any program or practice to assess and manage operation impacts in the community	84	56

(continued)

Table 1 (continued)

Subcategories	Social impact indicators	Wind power plant	Thermal power plant
Local employment	Hiring of employees residing in the neighborhood areas	72	36
	The company uses close NGO or cooperative services	18	22
	Proceedings for local hiring and proportion of high management positions from the local community in important operational units	81	66
Safe life conditions	Regarding the number of legal complaints per year against the organization with regard to security concerns	54	78
	Regarding the number of casualties and injuries per year ascribed to the organization	57	44
	The company has management policies related to private personal security	12	9

5.2 *On the Application of a Non-compensatory Software Package to the SLCA Case Study*

The software that supports our proposal [13] is based on an interactive implementation of the conjunctive method, enabling the consideration of up to three performance thresholds, having in mind to classify the objects under evaluation. Figures 1 and 2 present its interactive dashboard/control panel. In Fig. 1 a system of

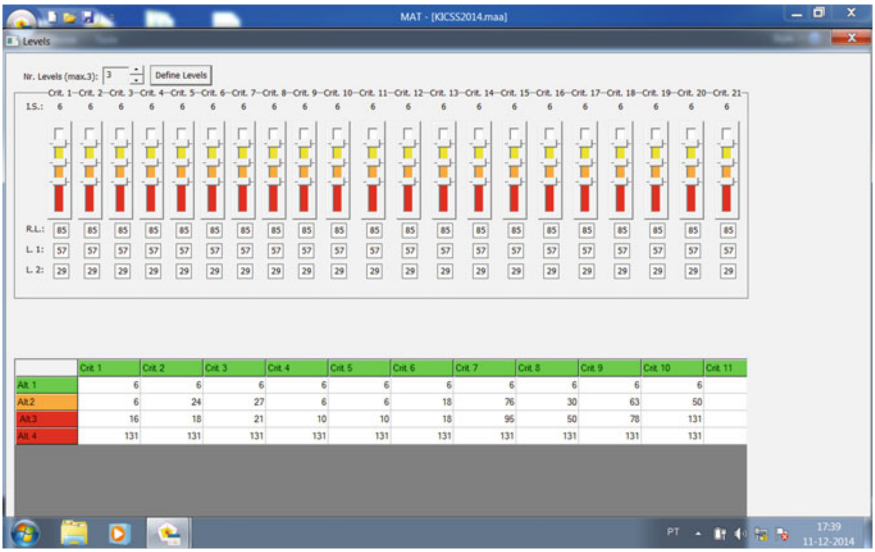

Fig. 1 Interactive dashboard: fixation of thresholds

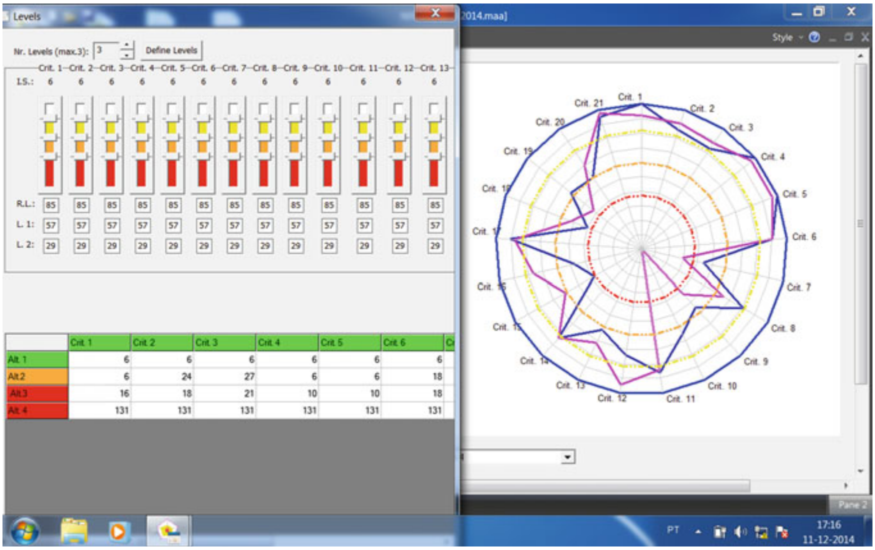

Fig. 2 Interactive dashboard: profile of each object

"elevator boxes" enables the fixation of thresholds for the various dimensions. In the bottom one find the matrix of the objects under evaluation with the corresponding performance on each dimension/attribute. In general, dimensions the evaluation of which is either quantitative or qualitative are admitted (note that Fig. 1 is a print screen showing just part of the criteria/indicators due to space limits; of course, an elevator is available enabling to see all of them). On the right of Fig. 2 the profile of each object concerning the evaluated dimensions is presented in a radar graphic. The fixation of each of the three thresholds which bound the four performance levels may be carried out through the "elevators" in Fig. 1. The representation of the thresholds in the radar graphic is made using coloured broken rings. The objects will appear with the following colours: red if at least one of the attributes of the object does not reach the red level; orange if every attribute satisfies the red level but at least one attribute does not reach the "good" threshold, yellow if every attribute satisfies the "good" threshold but at least one attribute does not reach the "very good" threshold and green if every attribute satisfies the "very good" threshold. Note that the described aggregation process is non-compensatory thence avoiding the problem that a weak performance in one dimension may always be compensated by a strong performance in another dimension, as in an additive model; there is no need to assume additive independence among the various attributes, an adequate property because that is a requirement too strong in the context of SLCA. Furthermore, it must be remarked that in the case of the proposed methodology there is no inter-criterion aggregation. This is very important to avoid the drawbacks related to the total compensation associated to the additive model.

The characteristics of this tool seem very appropriate to fulfill some requirements in SLCA, due to the intuitive aspect of the graphics, as well as to the simplicity of the user-oriented proposed approach, both conceptually and operationally.

It is also relevant that besides the classification of alternatives/scenarios, the system enables a holistic view of them. The combination of an analytic process with visual holistic views constitutes a remarkable added value, giving an important global feedback from the system to the stakeholders. Of course, this contributes to a global perception of the sustainability phenomena.

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In Figs. 1 and 2 are presented the data and some of the results provided by the non-compensatory package tool regarding the SLCA case above introduced. Note that alternatives 1 and 4 are virtual alternatives. Alternative 1 is the ideal solution (represented by the external contour limiting the radar graphic) and 4 is the anti-ideal solution (represented by the central point of the radar graphic), concerning the data of the two alternatives under evaluation (one regarding wind power generation and the other thermal power generation). So, the real alternatives under study are alternatives two and three of the figures. The thresholds that allow the classification of the alternatives were provided by specialists. They are the same for all the criteria. This is not very surprising because the scores generation procedure used in [17] led to normalized scores.

Regarding the spider web graphic in Fig. 2, we can conclude that alternative wind power (represented by the dark contour on the graphic) is classified as acceptable, because it passes the red threshold in all criteria but not all of them for the yellow one. So, it appears "orange" in the table on the right part of Fig. 2. On the other hand, the alternative 3 (represented by a pink contour on the sider web graphic) is unacceptable because it does not pass the red thresholds of criteria 7 and 10. So, it appears in "red" on the table on the right part of Fig. 2. Through an available very flexible and intuitive interactive manipulation of the performance thresholds the actors may acquire knowledge about possible variations in the classification of the objects under evaluation, taking into account the required levels for each attribute. This is particularly relevant for cases with a greater number of alternatives. Moreover, the holistic comparison of pairs of alternatives enables a visual inspection of the differences between them. Finally, a holistic view of the contours of the alternatives on the spider web graphic, together with the temporary exclusion of some criteria (which is very simple in operational terms) may help in the understanding of the process, forming global perceptions concerning the points of view of different actors involved in the study. We believe that schematic open and interactive systems can be useful for training people for thinking together and better, from the local and national political power agents to the corporation representatives, non-governmental organizations and other forms of public opinion expression, leading to a more creative society. This is particularly clear when we intend to join SLCA with environmental and economical LCA. Providing holistic views together with classical scientific analysis is crucial to promote a collective discussion in order to propitiate the evolution to a more creative way of living in our communities, not only from the technological point of view, but also considering the social and environmental dimensions.

6 Conclusion

In this paper we discussed the potentialities and limitations of some open exchange interactive Multi-criteria approaches dedicated to the aggregation of preferences, when applied to very complex problems, as the Life Cycle Sustainability Assessment problems. An illustrative example applying a non-compensatory software package to the analysis of the outputs of a SLCA study is presented.

References

1. Sen, A: Idea of Justice. Harvard University Press, Cambridge (2011)
2. Our Common Future–Report of the World Commission on Environment and Development: United Nations (1987)
3. Zamagni, A., Pesonen, H.L., Swarr, T.: From LCA to life cycle sustainability assessment: concept, practice and future directions. Int. Life cycle Assess. **18**, 1637–1641 (2013)
4. Reap, J., Roman, F., Duncan, S., Bras, B.: A survey of unresolved problems in life cycle assessment–part 2: impact assessment and interpretation. Int. J. Life Cycle Assess. **13**, 374–388 (2008)
5. Mazri, C., Ventura, A., Jullien, A., Bouyssou, D.: Life cycle analysis and decision aiding: an example of roads evaluation. http://sciencestage.com/d/1093635/life-cycle-analysis-and-decision-ainding-an-example-for-roads-evaluations-.html
6. Mietinen, P., Hamailainen, R.P.: How to benefit from decision analysis in environmental life cycle assessment (LCA). EJOR **102**, 279–294 (1997)
7. Benoit, V., Pousseaux, P.: Aid for aggregating the impacts in life cycle assessment. Int. J. Life Cycle Assess. **8**, 74–82 (2003)
8. Huppes, G., von Oers, L., Pretato, U., Pennington, D.: Weighting environmental effects: analytic survey with operational evaluation methods and a meta-method. Int. J. Life Cycle Assess. **17**, 876–891 (2012)
9. Cinelli, M., Coles, S., Kirwan, K.: Use of multicriteria decision analysis to support life cycle sustainability assessment: an analysis of the appropriateness of the available methods. In: 6th International Conference on Life Cycle, Gothenburg (2013)
10. Halog, A., Manik, Y.: Advancing integrated systems modeling framework for life cycle sustainability assessment. Sustainability **3**, 469–499 (2011)
11. Benetto, E., Dujet, C.: Uncertainty analysis and MCDA; A case study in life cycle assessment (LCA) practice. In: Proceedings of the 57th Meeting of the European Working Group on Multicriteria Decision Aiding. Viterbo (2003)
12. Dias, L., Clímaco, J.: Additive aggregation with interdependent parameters: the VIP analysis software. JORS **51**, 1070–1082 (2000)

13. Clímaco, J., Fernandes, S., Captivo, M.E.: Classificação MultiAtributo Suportada por uma Versão Interactiva do Método Conjuntivo (An Interactive version of the Conjunctive Method dedicated to Multiattribute Classification Problems). CIO—Working Paper 9 (2011)
14. Clímaco, J., Craveirinha, J.: Multi-actor multidimensional quality of life and sustainable impact assessment—discussion based on a new interactive tool. In: Proceedings of GDN 2013, Sweden (2013)
15. Valle, R., Clímaco, J.: Green economy in the state of rio de janeiro—a non-compensatory multidimensional interactive evaluation. In: XXII MCDM Conference, Malaga (2012)
16. Figueira, J., Mousseau, V.,Roy, B.: ELECTRE Methods, Multiple Criteria decision Analysis: State of the Art Surveys. In: Figueira, J., Erghot, M., Greco, S., Springer (2005)
17. Duarte, S.: Social impacts identification and characterization tool (SIICT): proposal and application for social LCA. SAGE/COPPE/UFRJ Internal Report (2014)
18. United Nations Environment Programme (UNEP). Guidelines for social life cycle assessment of products. Paris (2009)