PROBLEM STRUCTURING METHODS AS AN INPUT TO LIFE CYCLE SUSTAINABILITY ASSESSMENT: THE CASE OF BRAZILIAN WEEE REVERSE LOGISTICS

R.G. SOUZA*, S.P. SALHOFER**, J. ROSENHEAD°, M.P.E. LINS* AND R.A.B. VALLE*

** Production Engineering Program, Federal University of Rio de Janeiro, Ilha do Fundao, Cidade Universitaria, Centro de Tecnologia, Bloco F, Sala 103, 21941-972, Rio de Janeiro-RJ, Brazil*
*** Institute of Waste Management, BOKU - University of Natural Resources and Life Sciences, Muthgasse 107, A- 1190 Vienna, Austria*
° Department of Management, London School of Economics and Political Science, Houghton Street, WC2A 2AE, London

SUMMARY: Life Cycle Sustainability Assessment (LCSA) is a useful tool for decision-making in waste management, but there are some important methodological issues that require attention. Two Problem Structuring Methods (PSMs) can be particularly supportive for LCSA modeling: Strategic Options Development and Analysis (SODA) and Soft Systems Methodology (SSM). The first enables to the capturing of different perspectives held by real-world stakeholders in a cause-effect structure, which is similar to LCSA impacts pathway. This helps in identifying more realistic impact categories for sustainability assessment, rather than relying on analysts' assumptions. SSM can be helpful on identifying and designing potential systems to be assessed in LCSA. We have applied both these methods to the development of Brazilian Waste Electric and Electronic Waste (WEEE) reverse logistics (collection and recycling) systems. Results show that PSMs can reveal innovative impact categories and processes, so enriching LCSA modeling for waste management.

1. INTRODUCTION

Life Cycle Sustainability Assessment (LCSA) has developed to be an important tool for supporting decision-making in waste management systems. Nevertheless, a formal methodological framework is still not established, as key steps have remained under discussion and development. Problem Structuring Methods (PSMs) are potentially useful tools for providing relevant inputs to some of these steps.

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Using LCSA to assess environmental, social and economic impacts is particularly important for waste management. Inadequate waste systems can provoke problems for the environment and human health, and for the formal sector. (UN-Habitat, 2010; Lundgren, 2012). On the other hand, good waste management can contribute to sustainability by supporting equity, decent work conditions, education, health improvement, environmental quality and global development (UN-Habitat, 2010).

This complexity of potential positive and negative impacts imposes critical challenges for LCSA analysts when assessing waste management systems. Key decisions have to be taken during LCSA modeling, which can significantly influence both results and ensuing decision-making about those systems. Restricting these critical LCSA decisions to the analysts (experts in the LCSA methodology) only can lead to incomplete, and over-general models, and possibly to unreliable assessment and results.

In complex societal problems, decision-making should be based on a structured understanding of the different perspectives involved in the real-world situation (Rosenhead and Mingers, 2001). Identifying these perspectives permits the fuller identification of key interests, conflicts, objectives, impacts, decision opportunities and alternatives.

Rather than constituting a difficulty, this methodological issue provides an opportunity for enhancing LCSA studies, with the support of PSMs. PSMs are tools designed to support decision-making in problem situations with multiple actors and perspectives, incommensurable or conflicting interests, and salient intangibles (Rosenhead and Mingers, 2001). They have been successfully applied both alone and in combination with traditional methods that employ optimization or other forms of quantitative analysis (Howick and Ackermann, 2011).

Two particular PSMs are of special interest for LCSA modeling. They are Strategic Options Development and Analysis (SODA), and Soft Systems Methodology (SSM). These two PSMs can also be deployed in a broad combined methodology (Howick and Ackermann, 2011), which enhances their potential contribution to sustainability assessment in complex waste management problems.

The objective of this paper is to discuss how SODA and SSM can be applied to support LCSA in waste management, and illustrate this by analysing the case of Brazilian Waste Electric and Electronic Equipment (WEEE) reverse logistics. These systems involve collection, recycling and final destination to products and residues. They have recently been under discussion and development, as a result of the Brazilian National Policy for Solid Waste (PNRS), established as mandatory in 2010.

2. DECISION-MAKING IN COMPLEX PROBLEMS

Nowadays, decision-making and its supporting activities of modeling systems and solving problems are immersed in a context of unprecedent complexity and uncertainty. *Complexity* refers to the densely interconnected networks and ramifications that cannot be ignored. *Uncertainty* relate to choices from other decision-makers and their consequent influences, to the dynamics of those turbulent networks, to the possibility of unforeseeable events, and to the fluidity of organisations and individuals' missions. This problematic environment exposes the limitations of traditional decision-support methods, which are typically based on mathematical modeling aimed at finding the 'best' solution for rather shielded and predictable decision problems (Rosenhead and Mingers, 2001).

2.1 *Tame* versus *wicked* problems

Based on the levels of complexity or predictability, a dichotomy of problems can be identified (Table 1).

Table 1. *Wicked* versus *tame* problems

Tame problems	*Wicked problems*
Individual components of complex systems	Complex systems of changing interacting problems
May be solved	Need to be managed
Can be consensually specified, do not change during analysis	Alternative types and levels of explanations and phenomena of concern
True or false solutions, judged by analyst	Good or bad solutions, judged by interested parties themselves
Relatively unimportant to society at large	Areas of greatest human concern
Essentialy independent of individuals' views and beliefs	Importance of participants' perceptions, values and interests

Source: Rosenhead and Mingers (2001)

2.2 *Traditional modeling methods* versus *Problem Structuring Methods*

The dichotomy of problems presented in Table 1 also implies a dichotomy of methodological approaches for decision support (Table 2). Traditional methods, based on mathematical models for finding the *optimum*, are more applicable to *tame* problems, while Problem Structuring Methods (PSMs) are designed to support decisions in *wicked* problems.

Observing Table 2, we can acknowledge that the traditional modelling approach may be appropriate to most Life Cycle Assessment (LCA) and waste management projects when policy issues are largely restricted to technical and economic issues. Nevertheless, sustainabilty-related problems are more *wicked*, which in principle makes them more amenable to PSMs at some stage of the decision-making process. In this latter case, stakeholders' interests are diverse and decision variables are unclear, as well as their effects on the real system.

Table 2. Characteristics of traditional modeling methods and Problem Structuring Methods

Traditional Modeling Methods	*Problem Structuring Methods*
Problem formulation in terms of a single objective and optimization. Multiple objectives are subjected to trade-off onto a common scale	Non-optimizing; seeks alternative solutions acceptable on separate dimensions, without trade-offs
Overwhelming data demands, with consequent problems of distortion, data availability and credibility	Reduced data demands, achieved by greater integration of hard and soft data with social judgements
Scientization and depolitization, assumed consensus	Simplicity and transparency, aimed at clarifying the terms of conflict
People are treated as passive objects	Conceptualize people as active subjects
Assumption of a single decision maker with abstract objectives from which concrete actions can be deduced for implementation through a hirearchical chain of command	Facilitates planning from the bottom-up
Attempts to abolish future uncertainty, and pre-take future decisions	Accepts uncertainty, and aims to keep options open

Source: Rosenhead and Mingers (2001)

2.3 *Alternative-focused thinking* versus *value-focused thinking*

Another relevant discussion regards the means by which decisions are taken. In most cases, decision-makers start by focusing on the alternatives available for a particular decision problem, and only then consider the objectives or criteria to assess them. This is called *alternative-focused thinking*. However, alternatives are only important because they are “means to achieve values”. Focusing first on values – *value-focused thinking* – can guide the creation of better alternatives, and the identification of key decision opportunities within the decision context (Keeney, 1996).

Eliciting stakeholders’ perspectives and identifying their core values in order to guide decisions should be the first step in a decision-support approach. A good way to make values explicit and to articulate them is by using causal maps. When organized in causal maps, decision-making discourses generate a means-ends structure (Figure 1). In this topology, decision-makers’ ends/goals are positioned at the top of the maps, with means/options at the bottom (Montibeller and Belton, 2006).

In order to assess the potential performance of decision alternatives, broader strategic objectives must be decomposed into more operational ones (Franco and Montibeller, 2009), or broken into their “logical parts” (Keeney, 1996). This *top-down* process can be followed by a *bottom-up* one, as reflexion on the importance of well-defined alternatives can also help identifying new objectives (Keeney, 1996).

A selected set of specific objectives to better assess decision alternatives must have the following properties:

- *Essential:* they should consider all the essential organizational objectives involved in the decision;
- *Understandable:* they should have clear meaning for all the members of the group involved in making the decision;
- *Operational:* it should be possible to measure the performance of decision alternatives against each of the fundamental objectives;
- *Nonredundant:* they should not measure the same concern twice;
- *Concise:* there should be the smallest number of objectives required to the analysis;

- *Preferentially independent:* if it is possible to measure the performance of decision alternatives on one objective disregarding the performance on all other objectives, then a simple aggregation function can be used to aggregate partial performances (Franco and Montibeller, 2009).

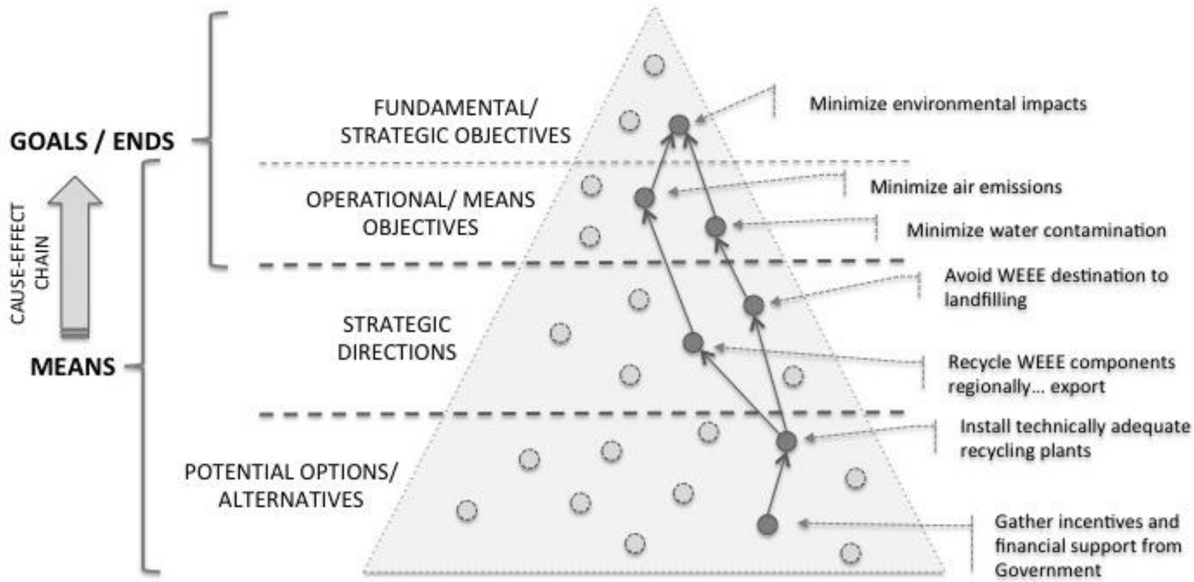

Figure 1. Structure of a causal map (Authors, based on Montibeller and Belton, 2006; Ackermann, Eden and Cropper, 2004)

3. CRITICAL DECISIONS IN LCSA MODELLING

Life Cycle Sustainability Assessment (LCSA) is an extension of traditional Environmental Life Cycle Assessment (LCA), which aims to assess environmental, social and economic impacts from a determined product system in an integrated way. While a standardized methodological framework is not yet defined, it should integrate assessments from the three streams: LCA, Social LCA (SLCA) and Life Cycle Costing (LCC). That, according to Finkbeiner et al (2010), can be expressed in the Formula (1).

$$LCSA = LCA + LCC + SLCA \qquad (1)$$

Decisions involved in LCSA modelling can be related to: goal and scope definition, system identification and boundaries, selection of impact categories, impact allocation, and other relevant parameters for the models (EC-JRC-IES, 2010). Thus, the analyst's decision can significantly influence assessment results. In this paper we will focus on issues and potential improvements regarding the selection of impact categories, the identification of systems to be analysed and definition of the processes within their boundaries.

3.1 Selection of impact categories

Impacts categories must represent key environmental, social and economic issues of concern to the product system of interest. These potential impacts must be measured in terms of their respective categories indicators.

The selection of impacts categories, as well as all other steps of an LCSA study, depends essentially on the goal definition (ISO, 2006; JRC-IES, 2010). The goal will make clear what are the Areas of Protection (AoP) of interest, i.e. the surrounding elements that need to be protected, what gives a hint of what are the *endpoint* impacts to be assessed (the ultimate consequences of the system which affect the AoP; *midpoint* are intermediate impacts that are means to provoke the *endpoint* ones). This hierarchy of levels represents a cause-effect network, which is called the *impact pathway* (Figure 2). An important modeling decision is if the impact categories will be of *endpoint* or *midpoint* levels.

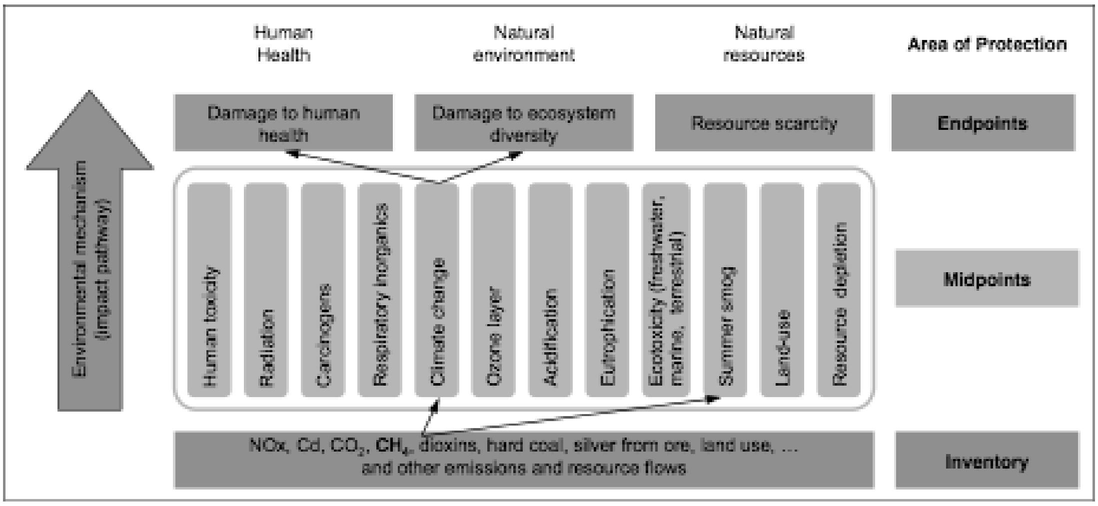

Figure 2. Impact pathway for Environmental LCA (EC-JRC-IES, 2010)

There is a clear association between the LCA impact pathway hierarchy (Figure 2) and the means-ends hierarchy illustrated in Figure 1 (item 2.3). Thus, value-focused thinking must be an appropriate approach to support the selection of impact categories in real, complex decision-contexts.

Not only are the impact categories related to fundamental and means objectives, but also the criteria to select impact categories, defined in ISO 14044 (ISO, 2006), are quite similar to those for selecting objectives to assess decision alternatives, discussed in Section 2.3 (Table 3).

Table 3. Association of criteria to select operational objectives to assess decision options, and criteria to select LCA impact categories

Criteria for operational objectives	*Criteria for impact categories*
Essential	Consider the essential objectives/goals
Understandable	Comprehensive, internationally accepted
Operational	Measurement indicators represents aggregated endpoint impacts
Nonredundant	Avoid double counting
Concise	Taking scope into consideration
Preferentially independent	Aggregation of impacts

Source: Adapted from Franco and Montibeller (2009); ISO (2006)

However ISO 14044 recommendations, which are focused on environmental LCA do not stimulate “value-choices and assumptions” on the selection of impact categories. This is because environmental impacts are well defined (see Figure 2), fairly comprehensive, and can be estimated using the natural sciences. Therefore, they involve relatively few subjective impact categories. However this is not true for the other two LCSA streams (S-LCA and LCC). For this reason the potential contribution of value-focused thinking is in principle higher for Social and Economic LCA than for Environmental LCA.

In Social Life Cycle Assessment (SLCA) there is no standardized methodology for the selection of impacts categories. Due to the complexity of social impacts, there are a number of approaches, each with its set of impact categories and indicators. As discussed by Jorgensen et al (2008), there is also an implicit cause-effect hierarchy of midpoint, endpoint and areas of protection, as in the Environmental LCA impact pathway (Figure 2).

The UNEP Guidelines for Social Life Cycle Assessment (UNEP-SETAC, 2009) highlights the importance of developing impact categories based on "social issues of interest to stakeholders and decision makers". According to the authors, "more experience needs to be gained in order to determine one, or several, final sets of generally accepted impact categories". Thus, experts must consider stakeholders' perspectives – and value assumptions - in their SLCA models.

According to UNEP-SETAC (2009), two important factors remain obstacles to obtaining well-established SLCA impact categories: a) there is still no characterization model between subcategories and impact category accepted by S-LCA practitioners; b) the causal models in social sciences are generally not well developed. They reinforce the need of considering stakeholders' perspectives case by case.

These guidelines describe two complementary approaches to the development of impact subcategories and characterization factors – in general, SLCA indicators:

- *Top-down*: This approach identifies broad social and socio-economic issues of interest, from which impact categories, subcategories and inventory indicators are derived;
- *Bottom-up*: asks the appropriate stakeholders at the organization and process level what would be relevant summary indicators and aggregation/summary methods according to their perspective. The result is an assessment of local level issues of concern and their relative importance according to the appropriate stakeholders' understanding (workers, community etc.) (UNEP-SETAC, 2009).

Those two complementary approaches have clear association to the impact pathway cause-effect hierarchy, and similarly, to the value-focused thinking top-down and bottom-up procedures. Thus, as in value-focused thinking, the iterative process of identifying SLCA impact categories must start by identifying broad issues of interest, analyzing their causes (top-down). Then, from the identifyied causes/means, the analyst must explore other potential consequences that can describe additional impact categories (bottom-up).

We can conclude that value-focused thinking is an approach with the potential to support the selection of impact categories, especially in SLCA and LCC, and is aligned to the formal requirements for this procedure. Causal mapping can be a useful tool in this process, by structuring stakeholders' perspectives in real-world decision contexts.

3.2 Identification of processes and definition of systems to be analysed

Selection of impact categories, discussed in item 3.1, is necessary for the assessment of product system. The system to be assessed, as well as its boundaries and set of processes, is defined in the scope definition, based on the study goal. For a detailed definition of the system or processes to be analysed, three central elements must be described: *function* (what does it deliver?); *functional unit* (what indicator best represents the function?); and *reference flow* (through which processes does the function operate?) (EC-JRC-IES, 2010).

From the above it follows that the essential decision is to chose whether or not to study the whole system, and if not, which of the single functions. Based on the selected function(s), it is necessary to define the system boundaries, which describes the parts of the life cycle and the processes required to provide the function. This also determines which processes characterize the *foreground* system (specific processes that deliver the function and can be managed) and *background* (processes with average effect across suppliers) (EC-JRC-IES, 2010).

4. SODA, SSM AND MIXING

As previously discussed, value-focused thinking is an interesting approach for the selection of impact categories, and SODA can be a useful tool in the process of problem structuring. SSM can support the identification of the system to be assessed . The following two subsections provide a quick explanation of these two PSMs.

4.1 Strategic Options Development and Analysis (SODA)

SODA is a tool to support decision-making on messy problems. Its main features are:
- The construction and analysis of a model representing the interconnected issues, problems, strategies and options which members of the team wish to address; and
- Facilitation for reaching workable and feasible agreements in group decision-making (Eden and Ackermann in Rosenhead and Mingers, 2001).

The main technique for building such models is *cognitive mapping*. Cognitive maps structure individual decision-maker's speech as a system of action-oriented 'concepts' connected by causal 'arrows', in a cause-effect structure, with ends or goals towards the top and means or causes below them. For group decision-making, individual maps are joined together as a *merged map*.

For a more detailed explanation of SODA, please refer to Rosenhead and Mingers (2001).

4.2 Soft Systems Methodology (SSM)

SSM is a methodology which uses systems concepts to learn about complex problematical human situations. Its purpose is to help to find accommodations between those holding different perspectives, so as to identify purposeful action for improvement which seems sensible to those concerned.

The stages of an SSM study are:
- Graphical representation of the complexity of interests, values, conflicts and issues in the problem situation (*Rich Picturing*);
- Naming human activity systems which are hopefully relevant to exploration of the problem situation (*Root Definitions*);
- Building activity models (*Conceptual Models*) of selected Root Definitions, each consisting of a set of activities essential for the system in the corresponding Root Definition to operate. The Conceptual Model serves as a logical machine for pursuing the Root Definition's purpose;
- Carrying out *multilevel analysis* to further explore specific activities in the Conceptual Model, by detailing specific activities within Root Definitions as Root Definitions themselves, with their own subset of activities;
- Comparing activity models with the real-world situation, so as to identify critical differences and stimulate and structure debate about possible changes (Checkland in Rosenhead and Mingers, 2001).

SSM is a rich and complex methodology, so for a deeper explanation, please refer to

Checkland in Rosenhead and Mingers (2001), Checkland (2000) and Checkland and Tsouvalis (1997).

4.3 Mixing methods

As shown by Howick and Ackermann (2011), SODA and SSM have been successfully mixed to support complex decision situations. More specifically, SODA maps can substitute for the *Rich Picturing* stage of SSM, aiding the identification of relevant human activity systems to be modeled.

5. APPLICATION: THE BRAZILIAN WEEE TAKEBACK SYSTEMS

To demonstrate the contribution of Problem Structuring Methods to LCSA (with methodological contribution from value-focused thinking in SODA application), we carried out an application based on the case of Brazilian Waste Electric and Electronic Equipment (WEEE) takeback systems. They have been currently under discussion and development, by enforcement of the Brazilian National Policy for Solid Waste (PNRS), establish by Law in 2010.

5.1 Decision-making process in the Brazilian WEEE systems modeling

In accordance to the PNRS, the main responsibility for the development and implementation of WEEE takeback systemslies with: EEE manufacturers, distributors, importers and retailers. Nevertheless, the Law establishes, through products' life cycles, a shared responsibility for all actors, including consumers, governments and waste pickers cooperatives (PNRS, 2010).

In order to develop the WEEE takeback system to be implemented in Brazil, at least representatives of manufacturers, distributors, importers and retailers must formalize, together with the public administration at different levels, a *sectoral agreement*. Additionally, representatives of waste pickers cooperatives, consumers-related entities and others can sign those sectoral agrements.

5.2 Research methodology

The methodology carried out in this research is illustrated in Figure 3. Key stakeholders (Table 4) were interviewed in order to understand and structure their perspectives in cognitive maps, and subsequently for validation and enrichment of the merged map. SODA maps supported the identification of LCSA impact categories, as well as potentially relevant systems to be modeled via SSM Root Definitions. SSM activity models are built and analysed to create alternative systems to be assessed in LCSA. We did not carry out the full LCSA study, but rather focused on modeling issues.

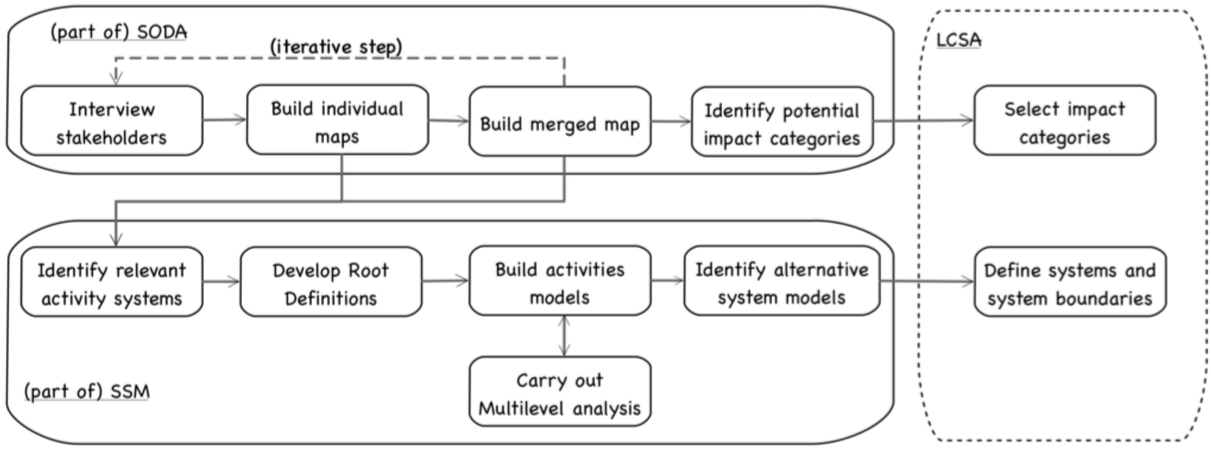

Figure 3. Research methodology

Table 4. Stakeholders interviewed

Decision-makers	State Government Environmental Agency; EEE Manufacturer; EEE Retailer
Specialists	Brazilian waste management; Takeback systems; WEEE management; Brazilian environmental legislation; Regulation agency; Environmental issues journalist.

5.3 Results and discussion

5.3.1 SODA and the selection of impact categories

After recording, transcribing and analysing each interview, individual cognitive maps were built. From these, a merged map was drawn (Figure 4), at the level of goals and some strategic directions (see Figure 1).

Observing the top-level concepts in the merged map, we could identify potential LCSA endpoint and midpoint impact categories. From these, we derived a suggested set of LCSA impact categories for the Brazilian WEEE takeback systems modeling (Table 5).

There are some interesting differences between these impact categories and those generated by other LCSA approaches in waste management (Obersteiner et al., 2011). First, it surfaces some goals or ends that are not usually considered in other approaches, such as *government election* and the *competitivity of national products*. On the other hand, it does not identify overall impact categories such as *non-discrimination*, which may not be a critical issue for the stakeholders involved.

Secondly, it reveals more realistic levels for some impact categories within the overall hierarchy. For example, *system costs*, which is a very common LCC impact category, proved to be just a lower-level goal, or even a strategic direction, to more relevant aspects such as *feasibility of activities* and *product price.* Nevertheless, it is one of the variables needed for the calculation of such impacts.

Table 5. Selected LCSA impact categories for the Brazilian WEEE takeback systems assessment

Areas of protection	*Endpoints*	*Midpoints*	*Inventory*
Environment	Environmental impacts	Air emissions Water and soil contamination Global warming	WEEE avoided to landfill Residues with adequate disposal
Brazilian Economy	Sell national products	New economic activities generated Competitiveness of the national product Brazilian companies' image	Feasibility of economic activities Relative price of the national product Brazilian companies' performance
Social development	Social inclusion Society awareness	Generated jobs and incomes Adequate working conditions Workers and society capacitation	Waste pickers' cooperatives enabled and engaged Elimination of informal pickers Digital inclusion
Government election	(re)elected governments' platform or members	Governments' image	Governments' performance

Finally, study of the merged map and the set of selected impact categories can provide insights both on missing aspects and on possible additional stakeholders to be interviewed. For example, by consulting an environmental or a health specialist, it would be possible to identify missing links between *air emissions* and *working conditions*, for example, and so reveal more specific impact categories. Similarly, interviewing other social and workforce representatives could provide a richer perspective on additional social aspects to be assessed.

5.3.2 SSM and the system definition

Based on SODA maps, we identified a number of potential systems to be modeled as *Root Definitions* (Table 6). In Table 7, we explore some activities that describe some of these RD's Conceptual Models. Table 8 illustrates a multilevel analysis (level down, detailing most elementary sub-activities) for some of these activities.

In Figure 5, we show how the RDs in Table 6 can be connected within a whole system, potentially relevant for LCSA modeling. This entire system is more adequate for LCSA than the one restricted to the boundaries of RD ENV.01, which would be adopted in the traditional approach. Processes from the other RDs, the complex flow of their inputs and outputs, are rich contributions for LCSA modeling decisions, especially the definition of system's function, functional unit and reference flow (see 3.2). By analyzing Figure 5, it is possible for modelers to define, for each LCSA stream (environmental, social and economic), different system's function, functional unit and reference flow, depending on the impacts under consideration.

It is important to notice that SODA's cognitive maps can also support SSM in this search for specific activities to carry out determined processes. In this case, we need to look at the bottom of the maps – strategic directions and potential options. Options can be activities within a single system model, or can describe alternative ones, what is interesting for developing LCSA scenarios.

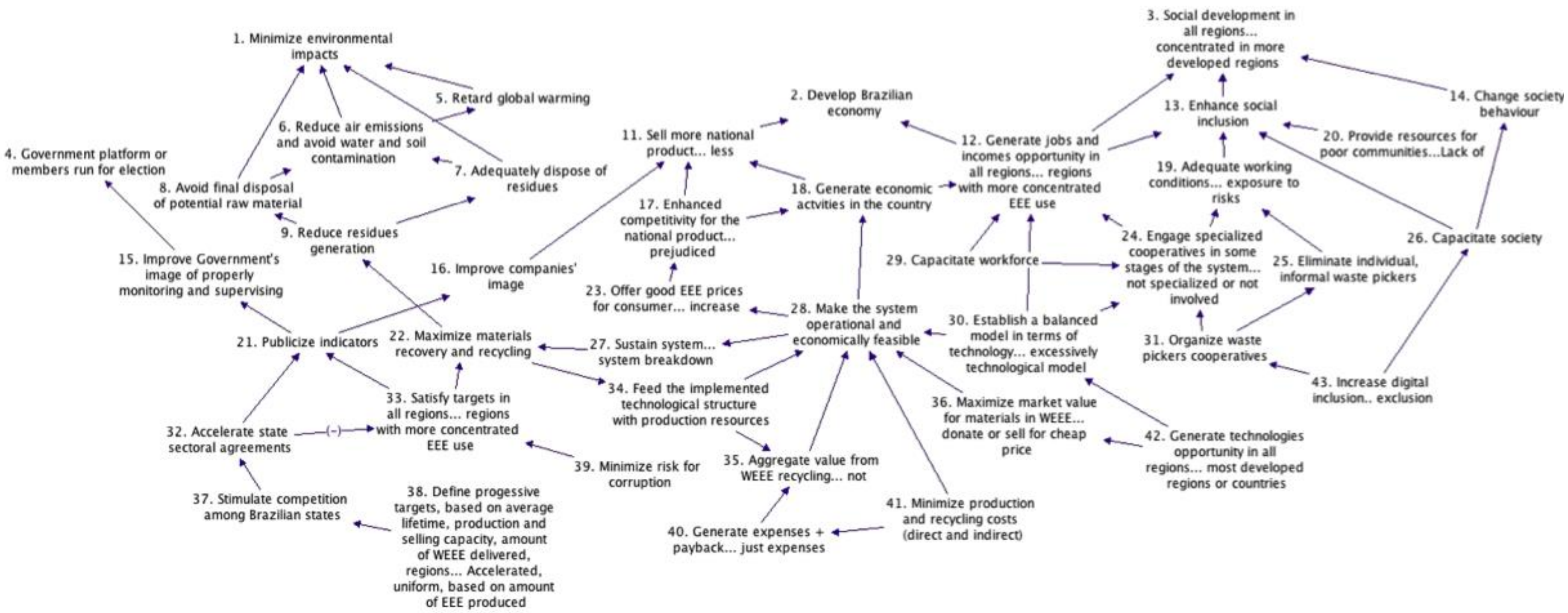

Figure 4. Top-level merged map for interviewed stakeholders

Table 6. Selected Root Definitions for system modeling

RD No.	A SYSTEM THAT…			TRANSFORMATION
	DOES…	BY…	IN ORDER TO…	
ENV.01	Minimizes water contamination, air emissions and raw material depletion	Adequately recycling WEEE and disposing of residues	Minimize environmental impacts	WEEE generated → WEEE recycled
SOC.01	Generates jobs and income opportunities with adequate working conditions	Organizing, capacitating and engaging specialized cooperatives in some stages of the system, generating more economic activities and establishing a balanced model in terms of technology	Enhance social inclusion	Unemployed or informal worker → Formal worker into WEEE system
ECN.01	Makes the EEE and WEEE chain operational and economically feasible	Feeding the system with production resources, aggregating value from recycling, minimizing costs, maximizing market value for recovered material, establishing a balanced technology system	Offer good EEE prices for consumers and generate economic activities in the country	Unfeasible EEE and WEEE chain → Feasible EEE and WEEE chain
ECN.02	Enhances price competitiveness for national EEE products	Making the EEE and WEEE chain operational and economically feasible	Generate more economic activities and sell more national product	National EEE products with bad price competitiveness → Good price
POL.01	Improves government's image	Meeting WEEE takeback system targets in all regions	Support reelection of government platform or members	Government's image → Improved image
ECN.03	Improves Brazilian EEE companies' image	Meeting WEEE takeback system targets in all regions	Sell more national product	Companies' image → Improved image
POL.02	Meet WEEE takeback targets in all Brazilian regions	Defining progressive and regionalized targets and adequately recycling WEEE	Improve governments' and companies images, and maximize material recovery and recycling	System with no targets → System with well defined and met targets
ECN.04	Aggregates value from WEEE recycling	Feeding the system with production resources, generating payback and minimizing expenses	Make the EEE and WEEE chain operational and economically feasible	Low value from recycling → Aggregate value from recycling

Table 7. Activities within some Root Definitions' models

RD No.	*Activities*
ENV.01	Acquire knowledge; establish WEEE segregation categories; define system capacity and technologies; establish locations for facilities; obtain and enable resources; deliver WEEE (consumers); receive WEEE (stations); sort and pretreat WEEE; treat WEEE; dispose of residues; deliver recovered material to clients; transport material
SOC.01	Identify unemployed and informal workers; identify current cooperatives; analyse risks and opportunities in WEEE system; determine functions and incomes for workers; organize, capacitate and engage cooperatives; stimulate WEEE market
ECN.01	Map available infrastructure and technology; assess financial and technical feasibility; minimize system costs; aggregate value from WEEE; design and implement WEEE takeback system; feed the system with WEEE

Table 8. Multilevel analysis for some Root Definitions' activities

System (RD No.)	*Sub-activities (one level down to Table 7 activities)*
Transport material (ENV.01)	Take WEEE to delivery stations; collect, transport and deliver WEEE to sorting and pretreatment facilities; transport pretreated material to treatment units; transport residues to final destination; transport recovered material to clients; consume fuel; generate air emissions
Minimize system costs (ECN.01)	Design initial WEEE system; assess initial costs; identify critical points for system costs; negotiate with suppliers; minimize taxes for the WEEE chain; optimize facilities' spatial distribution; balance workforce and technology

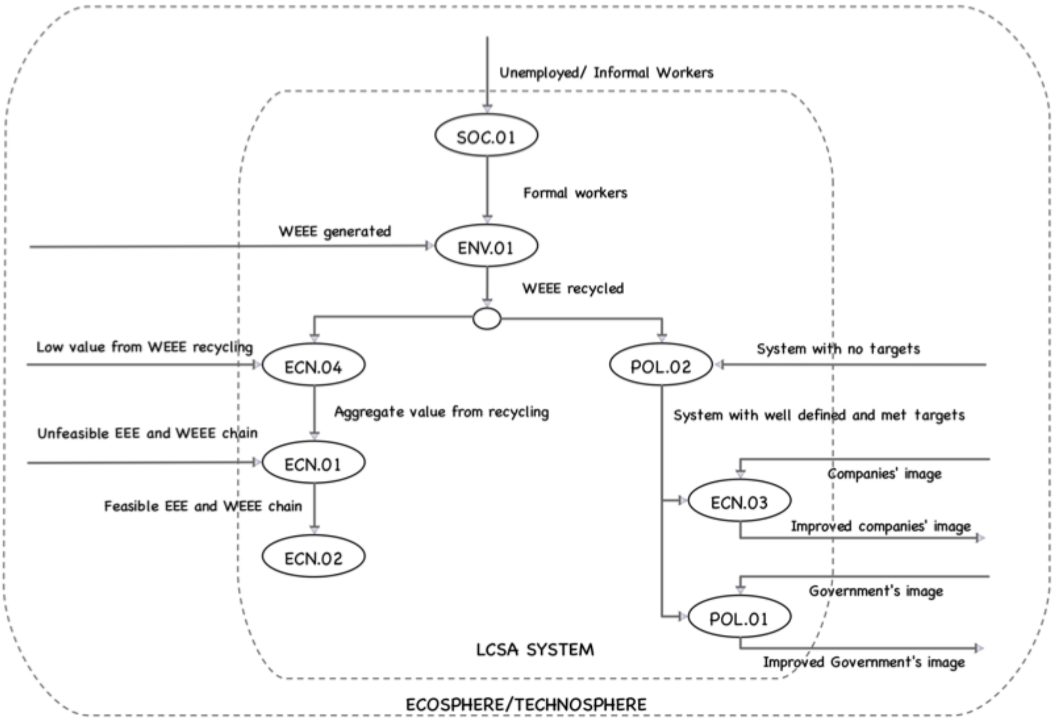

Figure 5. Potential system for LCSA modelling

Although the RDs in Table 6 are not exhaustive, they provide a rich understanding of the full set of processes that can be involved in a system to be assessed in LCSA. Many of these processes and respective activities are likely to be ignored in traditional LCA modelling, which is commonly concerned about processes within the boundaries of Root Definition ENV.01.

Social and economic impacts (e.g. job generation or costs) are typically associated to the processes of RD ENV.01. This ignores other relevant activities that characterize possible ways of 'how' can such impacts be produced by the real-world system. Some activities within other RDs in Table 7 can be at least as important for S-LCA and LCC than those within RD ENV.01 (e.g. organize and engage cooperatives; aggregate value from WEEE).

Activities in Table 8 give perspectives for potential variations by which a same RD transformation can be carried out. For example, material transportation can vary on: origins and destinations (location of delivery points, facilities, clients); actors (private company, public sector, waste pickers cooperatives); types of vehicles, etc. Combinations of all possible variations within the system illustrated in Figure 5 can provide the LCSA analyst with a rich set of potential scenarios to be assessed, broadening the horizons for decision-making.

A system such as the one illustrated in Figure 5 can support an important conclusion for LCSA studies: that foreground and background systems (see item 3.2) can vary, depending on the aspect being assessed. For example, ENV.01 must be the foreground system for Environmental LCA, as its main function is to provide adequate treatment to WEEE. Some "SOC" RDs may be foreground in S-LCA (e.g. the function of engaging cooperatives in the system), and the same applies to "ECN" RDs for LCC (e.g. aggregated value for WEEE as a functional unit). Thus, it is also true that SSM can help the definition of system *functions* and *functional units*, based on the transformation delivered by each RD (see Table 6) on the foreground system.

Although there is potentially good applicability of SSM for LCSA studies, some methodological issues must still be investigated: how to define rules for the allocation of impacts to such a complex set of processes; how to prioritize potential scenarios to be assessed and compared; and how to obtain inventory data to evaluate impacts from these scenarios.

6. CONCLUSIONS

So far, we can conclude that:

- There is good potential for contribution from SODA (supported by value-focused thinking) and SSM to LCSA studies;
- Impact categories derived from SODA maps are theoreticaly more useful to assess real cases than generic ones, especially those concerned with social and economic aspects;
- The quality of impact categories selected through the use of SODA depends on those stakeholders selected for interviewing. The process must be iterative, and major representatives must be consulted, in order to obtain a richer perception of the real problems' main issues;
- SSM is a useful tool to support the definition of processes to be modelled, foreground and background systems, as well as system functions and functional units;
- The application of SSM to LCSA remains to be investigated, in order to tackle methodological issues regarding impacts allocation, scenarios selection and data collection.

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