MODELLING AND SUSTAINABILITY ASSESSMENT OF WASTE MANAGEMENT SYSTEMS BASED ON MULTIPLE STAKEHOLDERS' PERSPECTIVES

Ricardo Gabbay de Souza

Tese de Doutorado apresentada ao Programa de Pós-graduação em Engenharia de Produção, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Ciências em Engenharia de Produção.

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TESE SUBMETIDA AO CORPO DOCENTE DO INSTITUTO ALBERTO LUIZ COIMBRA DE PÓS-GRADUAÇÃO E PESQUISA DE ENGENHARIA (COPPE) DA UNIVERSIDADE FEDERAL DO RIO DE JANEIRO COMO PARTE DOS REQUISITOS NECESSÁRIOS PARA A OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS EM ENGENHARIA DE PRODUÇÃO.

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À minha amada família, Rui, Marilyn, Kátia e Popis (in memoriam), o mais puro reflexo da Luz e Amor Divinos em minha vida.

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MODELLING AND SUSTAINABILITY ASSESSMENT OF WASTE MANAGEMENT SYSTEMS BASED ON MULTIPLE STAKEHOLDERS' PERSPECTIVES

Ricardo Gabbay de Souza

Abril/2014

Orientadores: Marcos Pereira Estellita Lins
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Programa: Engenharia de Produção

A avaliação da sustentabilidade na gestão de resíduos sólidos é uma abordagem de importância crescente, mas que ainda não possui metodologia formalizada. A abordagem mais promissora ainda está em desenvolvimento: a Avaliação da Sustentabilidade do Ciclo de Vida (LCSA), cujas diretrizes existentes requerem o envolvimento de *stakeholders* na formulação dos modelos e avaliação dos impactos, algo negligenciado pelas aplicações atuais. O objetivo deste trabalho é elaborar uma metodologia de LCSA que permita a consulta a múltiplos *stakeholders* na definição de categorias de impacto e modelagem de sistemas. A metodologia foi aplicada ao caso da logística reversa de resíduos de equipamentos eletroeletrônicos (REEE) no Brasil. A partir da consulta a diversos *stakeholders* e especialistas no assunto, foram elaborados mapas causais. Analisando a hierarquia destes mapas, foram identificados objetivos estratégicos que podem ser interpretados como potenciais categorias de impacto de LCSA. Estas foram analisadas por *stakeholders* de forma a obter um conjunto final que revela categorias bem estabelecidas e outras inovadoras. Os mapas também permitiram a identificação e modelagem de potenciais sistemas para implementação. Alguns destes expandem a fronteira tradicionalmente adotada em modelos de Avaliação do Ciclo de Vida.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

MODELLING AND SUSTAINABILITY ASSESSMENT OF WASTE MANAGEMENT SYSTEMS BASED ON MULTIPLE STAKEHOLDERS' PERSPECTIVES

Ricardo Gabbay de Souza

April/2014

Advisors: Marcos Pereira Estellita Lins
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Department: Production Engineering

Sustainability assessment of complex systems such as waste management is an approach of increased relevance, but which yet has no formal methodology. Its most promising methodology is still under development: Life Cycle Sustainability Assessment (LCSA), whose existing guidelines require the involvement of stakeholders in the formulation of models and impacts assessment, what has been neglected in current applications. The aim of this study is to develop an LCSA methodology that allows for multi-stakeholder consultation in the definition of impact categories and system modelling. The methodology was applied to the case of Brazilian Waste Electric and Electronic Equipment (WEEE) reverse logistics. By consulting stakeholders and specialists in the area, causal maps were built. By analysing the hierarchy of these maps it was possible to identify strategic objectives that can be interpreted as potential LCSA impact categories. These were analysed with stakeholders in order to define a final set which reveals both well established and unforeseen categories. Maps also allowed for identifying and modelling potential systems for implementation. Some of these expand the usually adopted boundary in Life Cycle Assessment models.

SUMMARY

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LIST OF ABBREVIATIONS

ABINEE	Association of Brazilian Industries of EEE
ABREE	Brazilian Association of EEE Industry and Importers
AoP	Area of Protection
CATWOE	Clients, Actors, Transformation, World-view, Owner, Environment
CM	Conceptual Model
COMLURB	Rio de Janeiro Municipal Company for Urban Sanitation
DEA	Data Envelopment Analysis
DEA	Data Envelopment Analysis
DRZ	Demontage und Recycling Zentrum, Vienna
EEE	Electric and Electronic Equipment
EoL	End-of-Life
EPR	Extended Producer Responsibility
ETR	Waste Transfer Station
EU27	The 27 members of the European Union
GDP	Gross Domestic Product
GTT	Thematic Task Group in PNRS
INEA	RJ State Environment Institute
LCA; eLCA	(Environmental) Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LCSA	Life Cycle Sustainability Assessment
LCT	Life Cycle Thinking
MCDA	Multicriteria Decision Analysis; Multicriteria Decision Aid
MSW	Municipal Solid Waste
OR	Operational Research
OR	Operational Research
PCB; PWB	Printed Circuit Board; Printed Wire Board
PNRS	Brazilian National Solid Waste Policy (Law No. 12305/10)
PPE	Personal Protective Equipment
PQR	“Do P by Q in order to reach R”
PSM; PSMs	Problem Structuring Methods
RD	Root Definition
REEE	Resíduos de Equipamentos Eletroeletrônicos
RJ	State of Rio de Janeiro, Brazil
RMRJ	Metropolitan Region of Rio de Janeiro city
SEA	Secretary of Environment, State of Rio de Janeiro, Brazil
SLCA; sLCA; S-LCA	Social Life Cycle Assessment
SODA	Strategic Options Development and Analysis
SP	State of Sao Paulo, Brazil
SSM	Soft Systems Methodology
WEEE	Waste Electric and Electronic Equipment

1. INTRODUCTION

Sustainability assessment of complex systems such as waste management is a resourceful tool for decision-support. There is still no formal methodology established for this aim, but the most promising approach currently in development is Life Cycle Sustainability Assessment (LCSA). LCSA expands the standardized methodology of environmental Life Cycle Assessment (LCA), in order to comprehend the social and economic dimensions. In doing this, LCSA also increases its complexity. In LCA the assessed systems are rather objective and based on materials flows, and the assessed impacts can be measured quantitatively; in social and economic dimensions the assessment may also include rather subjective systems and impact categories. This is why some existing guidelines for LSCA recommend the involvement of relevant stakeholders during modelling and assessment stages of the applications; in LCA these can be and are usually carried out based only on specialists' analyses.

In LCSA, specialists need to facilitate elicitation and structuring of stakeholders' perspectives, in order to obtain realistic parameters for system modelling and sustainability assessment. This is a major gap in current LCSA applications, as LCA practitioners have not searched to facilitate such multi-stakeholder decision-making within their models. There are robust tools available in the field of Decision Science that can be adapted and combined to LCA standards and LCSA guidelines, in order to bridge this methodological gap. This is the case of Problem Structuring Methods (PSMs). Some well-established PSMs are Strategic Options Development and Analysis (SODA) and Soft Systems Methodology (SSM). These can be useful tools in stakeholder consultation for LCSA, especially in the tasks of defining social and economic impact categories, and in identifying and modelling potential relevant systems for implementation in real case problems. PSMs have supported decision-making in several complex problems during the last decades, many of them in the environmental area.

Waste management are complex systems currently demanding for such stakeholder-based LCSA approach, especially in Brazil. In 2010, the country established its National

Solid Waste Policy (PNRS), which adopts a complexity of principles such as Extended Producer Responsibility (PER), shared responsibility for products' life cycle and the social inclusion of waste pickers within the diverse waste chains. It also determines that reverse logistics systems are mandatory for some waste types, including Waste Electric and Electronic Equipment (WEEE). WEEE is complex in nature, because they comprehend many types of different appliances and components, including recyclables, precious metals and hazardous materials. The WEEE chain is also complex, because it involves several actors along many formal and informal trans-boundary stages, from raw material extraction to production of appliances, commercialization, use and waste recycling or disposal. This involves significant risks to human health and the environment.

PNRS establishes that responsibility for modelling and implementing WEEE reverse logistics in Brazil is shared by producers, importers, distributors and retailers of Electrical and Electronic Equipment (EEE) in the country. It also defines responsibilities for consumers, governments and waste management companies within this chain, which may include formalized waste pickers' cooperatives. This way, there is a complexity of actors with their responsibilities, interests and needs. This is thus a relevant problem with potential to be supported by combined LCSA and PSMs, in order to define the best reverse logistics model to be implemented in Brazil.

1.1. Objectives

The main objective of this research is to propose a methodology for systems modelling and for the definition of social and economic impact categories in LCSA that considers multiple stakeholders' perspectives.

Some specific objectives are:

- To combine Problem Structuring Methods (PSMs) and LCSA principles and approaches within a methodology for decision-support in waste management;
- To elicit and structure stakeholders' perspectives in the case of Brazilian WEEE reverse logistics using causal maps;
- To define systems models and LCSA impact categories for Brazilian WEEE reverse logistics.

1.2. Structure of the thesis

This work is structured as follows:

- Chapter 2 comprehends a literature review on the following topics: Waste Electric and Electronic Equipment (composition, market, generation estimates, risks, formal and informal chains, main stakeholders, regulation); Life Cycle Management and Life Cycle Sustainability Assessment (main concepts, involved methods and respective challenges); complex decision problems and potential decision-support tools for sustainability (definition of complex decision problems, Problem Structuring Methods, Multimethodology, applications in sustainability-related problems); WEEE reverse logistics and the Brazilian National Solid Waste Policy;
- Chapter 3 presents the proposed methodology, with explanation of each step;
- Chapter 4 presents results of the application in the case study (causal maps, defined LCSA impact categories, alternative system models for sustainability assessment), and discussion by the analysis of the obtained results with validation in the literature and with specialists and stakeholders;
- Chapter 5 draws conclusions on the case study and on the quality of the proposed methodology after application, and suggests further steps for research in the same field.

2. LITERATURE REVIEW

2.1. Waste Electric and Electronic Equipment (WEEE)

Waste Electrical and Electronic Equipment (WEEE), also known as *e-waste*, are "*electrical and electronic equipment* (EEE) which are waste (…), including all components, subassemblies and consumables which are part of the product at the time of discarding" (EC, 2002). They are discarded either because they reached the end of their lifespan or because their usage was discontinued (ABNT, 2013).

WEEE is as diverse as the variety of electrical and electronic equipment. In Brazil, EEE are categorized into four *product lines*:

- "Brown" line: TV, screens, DVD/VHS, audio products;
- "White" line: Refrigerators, freezers, ovens, air conditioning, washing machines;
- "Blue" line: mixers, blenders, irons, drills;
- "Green" line: desktops, laptops, printers, mobiles (ABDI, 2013).

The Directive 2002/96/EC (also known as the *WEEE Directive*) by the European Commission defines ten categories of WEEE:

- Large household appliances (refrigerators, freezers, etc.);
- Small household appliances (vacuum cleaners, irons, toasters etc.)
- IT and telecommunications equipment (computers, printers, telephones etc.);
- Consumer equipment and photovoltaic panels (TV, audio, musical instruments etc.);
- Lightning equipment (lamps);
- Electrical and electronic tools (drills, saws etc., with the exception of large-scale stationary industrial tools);
- Toys, leisure and sports equipment (video games, sports equipment etc.);
- Medical devices (with the exception of all implanted and infected products);
- Monitoring and control instruments (thermostats, smoke detectors etc.);

- Automatic dispensers (EC, 2012).

All these sorts of equipment have their own characteristics of size, lifespan and composition (Table 1). This complexity poses a challenge for an adequate WEEE management.

Table 1. Characteristics of EEE lines as defined in Brazil

Characteristic	Brown line	Green line	White line	Blue line
Average lifespan	5 - 13 years	2 - 5 years	10 - 15 years	10 - 12 years
Weight	1 - 35 kg	0.09 - 30 kg	30 - 70 kg	0.5 - 5 kg
Main component	Plastics and glass	Plastics and metals	Metals	Plastics

Source: ABDI (2013)

2.1.1 The EEE market and WEEE generation in Brazil

WEEE is the fastest growing waste stream in the world. It grows about 4% per year. Annually 40 million tonnes of WEEE are generated (Lundgren, 2012), and WEEE generation is expected to jump to 65 million tonnes in 2017 (STEP, 2013). Some reasons for such high volumes and growth rate are: increasing market penetration of products in developing countries; development of a replacement market in developed countries; a generally high product obsolescence rate; decrease in prices; and the growth in internet use (Lundgren, 2012).

A study based on data from Europe showed that the generation of WEEE is directly related to population income (**Figure 1**). Considering Brazilian growing economy (**Figure 2**) and the average income of formal workers (**Figure 3**), we can assume that EEE consumption and WEEE generation also tend to grow in the country during the next years. Based on overall worldwide correlations, **Figure 4** presents estimates of the amount of WEEE generated in Brazil in comparison to some developed and developing countries, based on their Purchasing Power Parity (PPP: a measure of the relative value of currencies and the purchasing power of consumers based on the amount of money needed in each country to purchase a fixed basket of goods and services). Considering the average of 7 kg/capita of WEEE generated in Brazil in 2012 (**Figure 4**) and the total population of 193,946,886 in that time (IBGE, 2012), approximately 1,36 million tonnes of WEEE were generated in Brazil in that year. This is 38% more than the estimate of 980 thousand tonnes calculated by ABDI (2013) using the method of *Market Supply* for the same year. This method calculates the amount of EEE inserted in the market (t) in a year, and assumes average lifespans for these products (in years) to estimate the amount of WEEE generated further. One problem with this methodology is to assume average lifespan values for a variety of products along different years, in a complex context were informal economy plays a significant role and lifespan of electronic products is constantly extended by reuse or resell. For this reason, we prefer to adopt the estimate of 1.2 million tonnes of WEEE in 2012 based in **Figure 4**. We make estimates for the Brazilian regions in Chapter 4.

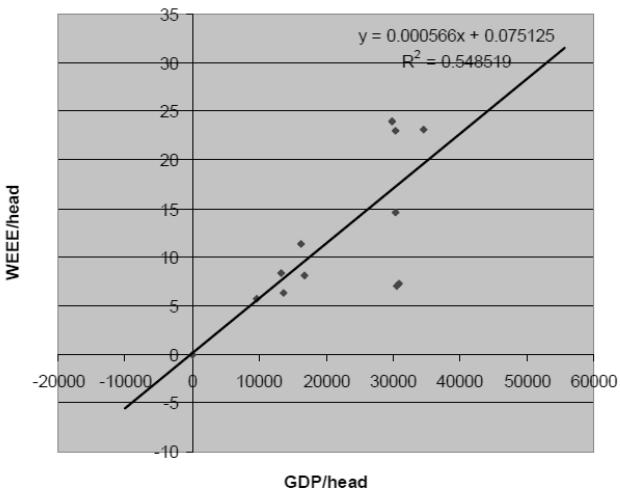


Figure 1. Plot of WEEE/head (in kg) versus GDP/head (in US$)

Source: Huisman et al. (2008)

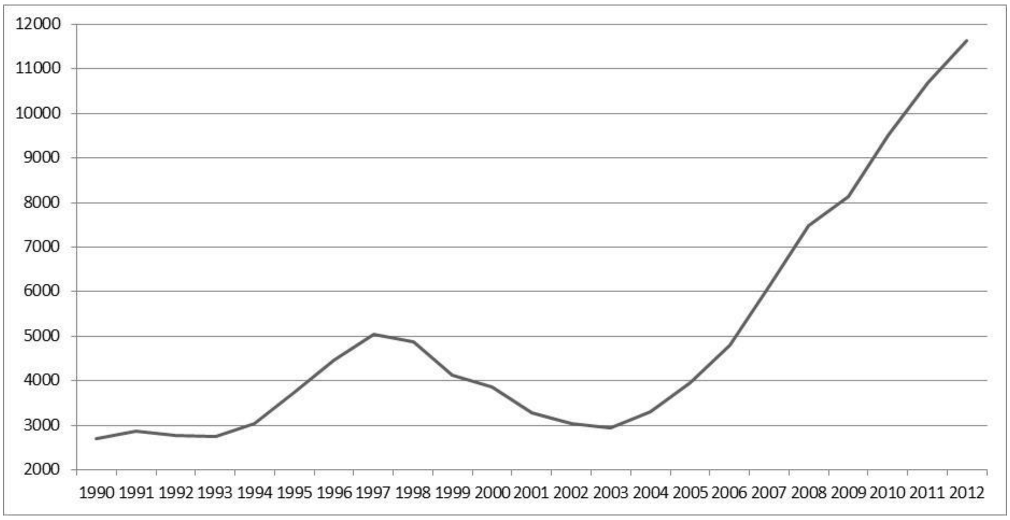
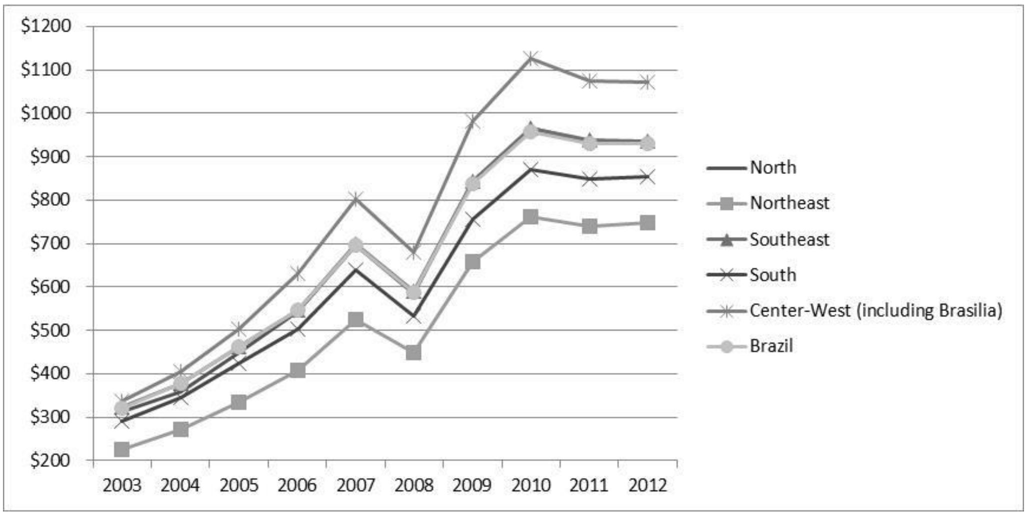


Figure 2. Evolution of Brazilian GNI per capita (in US$)

Source: The World Bank (2013)



Note: Figures in US$ calculated based on the official exchange rate in December 31st of each year

Figure 3. Evolution of average income of Brazilian formal workers per region (in US$)

Source: Authors, based on RAIS (2013) and CANADA (2013)

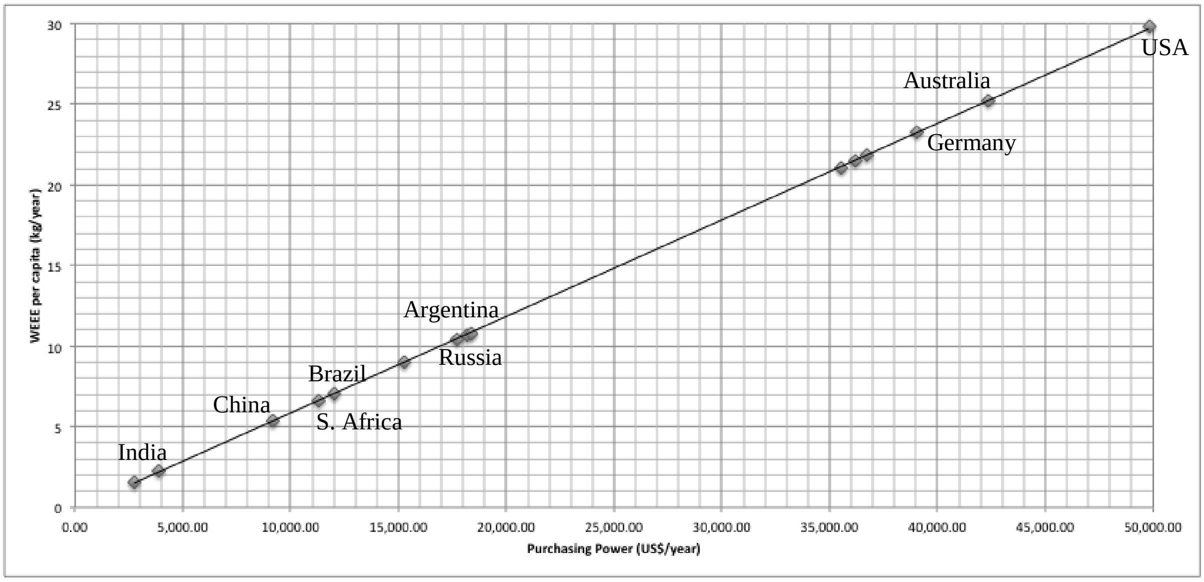


Figure 4. Estimates of WEEE generation in different countries in 2012 based on the correlation with Purchasing Power Parity

Source: Authors, based on STEP (2013)

It is estimated that 2 million tonnes of EEE (10.5 kg/capita) were put into the Brazilian market in 2012 (ABINEE, 2013a). The percentage of households with computers in relation to total households in Brazil has increased from 19% in 2005 to 43% in 2011 (**Figure 5**), what confirms the growing demand for technology and internet. As seen in **Figure 5**, except by radios and freezers, all other EEE investigated are consumed at a large or rapidly increasing rate by Brazilian households.

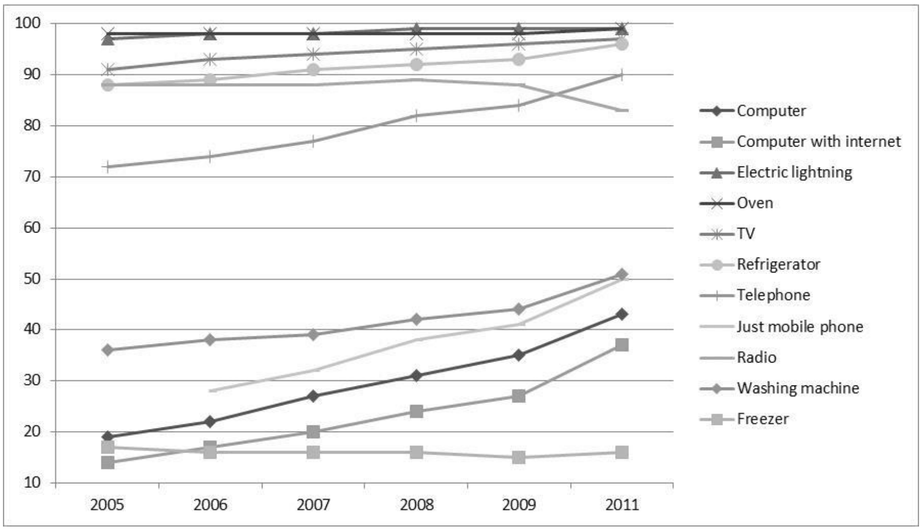


Figure 5. Percentage of Brazilian households having different types of EEE

Source: ABINEE (2013a)

Growth in the acquisition of computers in the country is illustrated in **Figure 6**. **Figure 6** also indicates the contribution of unofficial market, i.e. informal chains for distribution and commercialization of EEE, to such growth in consumption. These unofficial chains do not pay correspondent taxes, promote falsification of products and pose challenges to WEEE quantification and management. Regarding mobile phones, consumption has increased from 47.5 million units in 2005 to 59.5 million in 2012, establishing an average of 1.33 mobiles per person in 2012 (ABINEE, 2013a).

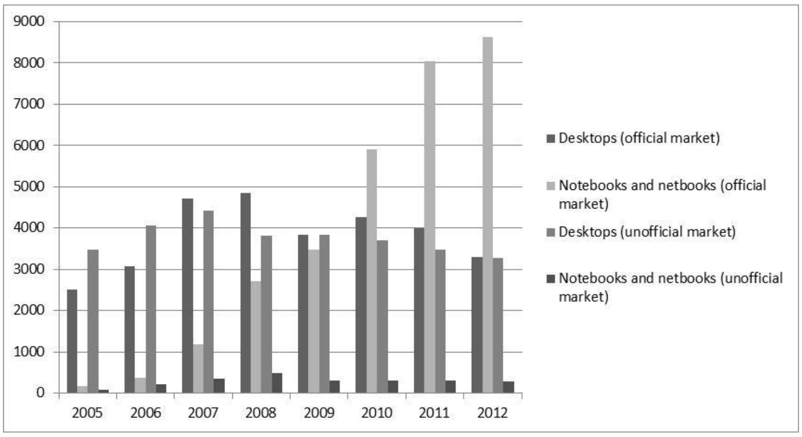


Figure 6. Acquisition of computers from official and unofficial markets in Brazil
Source: ABINEE (2013a)

Regarding the Brazilian EEE industry, there is slight increase in total turnover, reaching US$ 71 bi in 2012 (based on the exchange rate as in December 31st, 2012), 5% more than in 2011. The main products that contribute to this turnover are informatics (30%) and telecommunication appliances (16%), and industrial equipment (15%). The commercial trade (exports minus imports) presented a deficit of 32.5% in 2012, same value as in 2011. Main imported equipment are electric and electronic components (55.5% of import costs), specially components for telecommunications, informatics and semiconductors (ABINEE, 2013b). 53% of Brazilian EEE companies have reported an increase in demand for products in October, 2013, while 30% reported decrease, in relation to the same month in the previous year. From April to October 2013, only a few of these companies have reported difficulties in acquiring production resources and raw material (15% average), but many (52% average) informed there is pressure on the prices of such materials (ABINEE, 2013c). Competition with countrywide WEEE recycling could possibly reduce such pressure in prices and stimulate production and commercialization with higher turnover, as EEE demand has increased.

The end of EEE production chain is the use of products, and after that there are the stages of managing End-of-Life (EoL) products (in our case, WEEE). Effective measurement of amounts of WEEE generated is a worldwide problem. As there is no absolute control of WEEE flows, it is only possible to have a notion of such dimensions based on estimations and some specific indicators that are available. WEEE arising across the EU27 (the 27 member countries of the European Union) were estimated between 8.3 and 9.1 million tonnes for 2005, growing at a rate of 2.5% to 2.7% per year and reaching 12.3 million tonnes in 2020. The average compositional breakdown for the European Union is shown in **Figure 7**. From the total WEEE produced, it was estimated that just 40% of larger appliances and 25% of medium sized appliances were adequately collected and treated in 2005.

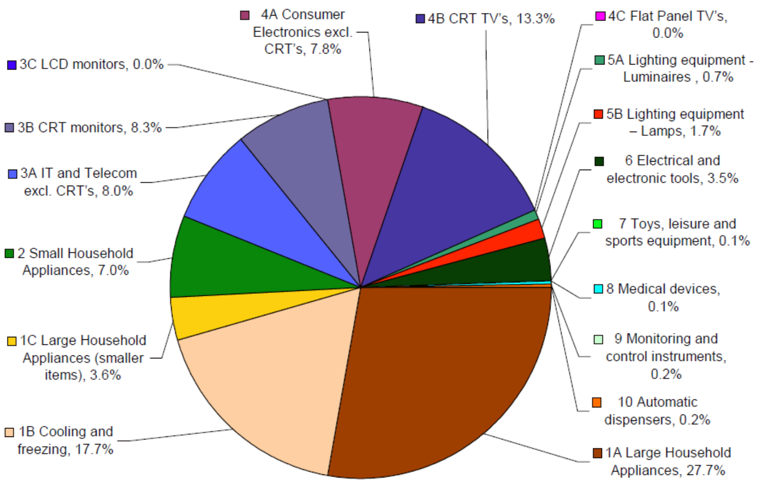


Figure 7. Breakdown of WEEE arising 2005 in EU27

Source: Huisman et al. (2008)

A relevant aspect in WEEE generation is the procedure adopted by users when disposing of it. Even where there is formal system available to collect such equipment separately from other kinds of waste, lack of information or education may lead some people to send WEEE to other waste chains, either formal or informal. This can represent loss of valuable resources, overload of other waste streams, and increased environmental risks due to hazardousness in WEEE. Such risks are expanded when informality takes place in WEEE collection and rough treatment for extracting valuable material (see Sections 2.1.2 and 2.1.3). In Figure 8, we observe the amount of WEEE that is found mixed to household waste in the city of Rio de Janeiro, Brazil. Total amount of WEEE found amongst household waste increased from 2 thousand tonnes a year in 2009 to 3.7 thousand tonnes in 2012 (COMLURB, 2013a). Regarding public waste (from the streets), WEEE was not found into samples taken during 2013 (COMLURB, 2013b), what indicates the possibility of interception from informal waste pickers.

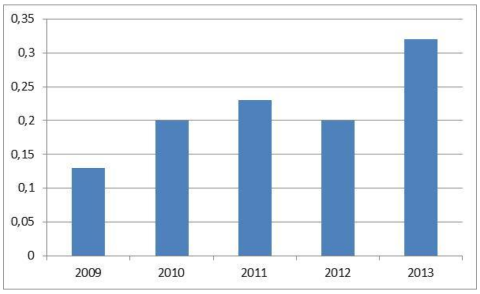


Figure 8. Percentage of WEEE found mixed to household waste in Rio de Janeiro

Source: COMLURB (2013)

2.1.2 Composition, market values and risks associated to WEEE

Besides EEE market and WEEE generation aspects, another characteristic of WEEE that increases complexity in its management is diverse composition of its materials. Table 2 presents an overview of the sort of materials that can be found in WEEE. During EEE production, these materials are glued, welded or assembled together, what makes it difficult to separate them at recycling processes. Many of these are hazardous, so such difficulty in disassembly and separation can pose risks to environment and human health. The Brazilian Standard for WEEE management (ABNT, 2013) has identified 41 substances or groups of substances that pose hazardousness to diverse WEEE. **Figure 9** shows that some of the most hazardous components correspond both to rare materials and to the most present ones found in Information and Technology appliances, the later due to their high volumes.

Table 2. Some materials found in WEEE and respective market prices per kg as in Europe in 2007

Fe (in components) (€0.22)	Co (€20.22)	PC (€2.72)	Glass (white) (€0.05)
Magnetic steel (€3.96)	Cr (€2.11)	PE (HD) (€1.07)	Glass (LCD) (€0.05)
Stainless steel (€3.96)	Hg (€11.31)	PE (LD) (€1.23)	Other/inerts
Steel low alloyed (€0.22)	Li (€0.66)	PET (€0.66)	Felt
Cu (€4.02)	Mn (€2.63)	PMMA (€2.92)	Paper
Ag (€326)	Ni (€27.97)	PP (€1.30)	Wood
Au (€15,721)	Pb (€1.25)	PS (HI) (€1.17)	Flame retardants
Pd (€7,990)	Sb (€3.90)	PUR (polyurethane) (€3.50)	PCB
Al (general) (€2.06)	Sn (€9.34)	PVC (€1.25)	Liquid crystals
Al cast (€2.06)	Zn (€1.49)	Rubber (EPDM)(€7.29)	Oil (fridges)
Al wrought (€2.06)	Plastics general (€0.40)	Ceramics (€0.04)	Cyclopentane
Mg (€1.58)	Plastics FR (€1.37)	CRT rim (PbO) (€0.40)	Br (€0.55)
As (€10.40)	ABS (€1.54)	CRT-glass complete (€0.30)	CI
Be (€259.4)	ABS/PC (€2.84)	CRT-glass cone (€0.30)	Isobutaan (€0.10)
Bi (€15.40)	Epoxy	CRT-glass screen (€0.35)	CFC11
Cd (€2.83)	Other plastics (€0.30)	Fluorescent powder	CFC12

Source: Huisman et al. (2008)

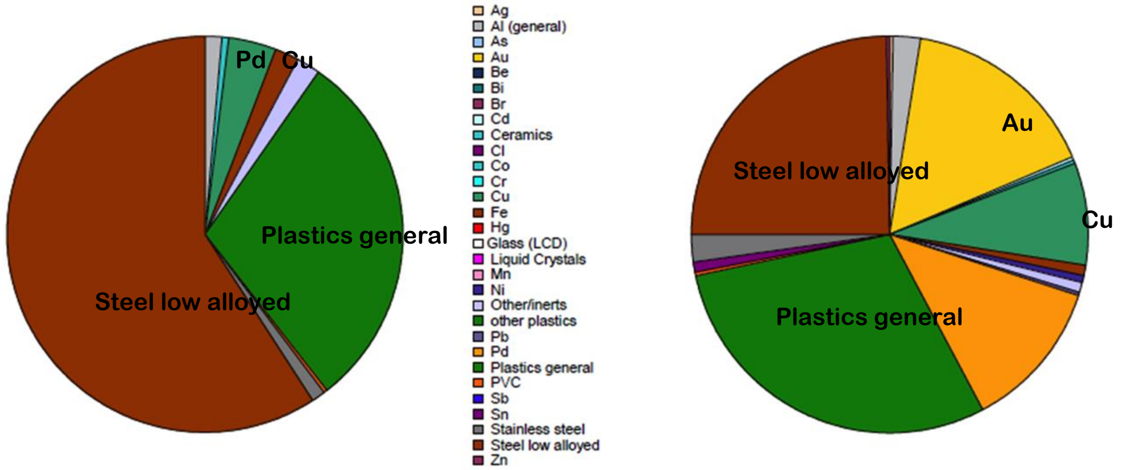


Figure 9. Weight vs. environmental weight (EI'99) - IT appliances (except CRT)
Source: Huisman et al. (2008)

Separation of different kinds of material from WEEE can be of significant relevance not just for environmental reasons, but also economically. In **Table 2** we can see market prices for some materials found in WEEE, as in 2007 in Europe. The non-separation of such materials with adequate techniques can result in environmental and health risks, but also in the wastage of valuable resources. In Brazil, informal waste pickers usually sell WEEE as scrap, which is worth much less than the sum of prices of separate components.

Certainly not all components in WEEE are worth some market value, but all of them need to be managed and adequately treated and disposed of. **Figure 10** exhibits the total operational costs of a formal WEEE management system, in this case the systems running in Europe in 2005. These costs are broken down into the different stages of WEEE management, as for the five main WEEE collection categories in Europe: LHHA (Large Household Appliances); C&F (Cooling and Freezing); SHA (Small Household Appliances); CRT+FDP (Cathode Ray Tube and Flat Display Panels); and Lamps. We can see that costs per stage can vary considerably from one WEEE category to the other. For LHHA, for example, larger costs correspond to transport, while for other categories they correspond to pretreatment processes. Lamps recycling provoke extra charges, while for the other categories recycling is a source of revenue (negative costs).

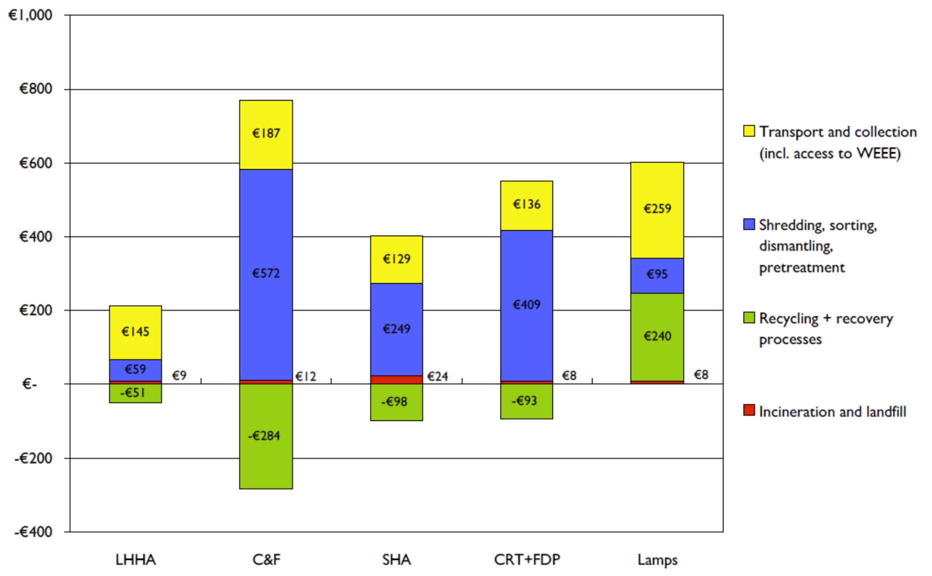


Figure 10. Breakdown of technical costs for the 5 main collection categories in 2005

Source: Huisman et al. (2008)

Either if WEEE is not recycled (increasing the use of raw material in EEE production), if it is disposed of mixed to household waste, or if it is processed for extraction of valuable materials using improper techniques (see Section 2.1.3), it can pose significant risks to human health and the environment. Usually, specialists on Life Cycle Assessment of WEEE systems take into consideration the impact categories: global warming, acidification, human toxicity, eutrophication, summer smog, and resource depletion (SOUZA, 2014). Such impacts arise from the presence in WEEE of heavy metals, persistent organic pollutants (POPs), flame retardants and other hazardous substances. There are three groups of substances that may be released during WEEE recycling and material recovery, that are of concern: original constituents of the equipment (e.g. lead and mercury); substances that may be added during some recovery processes, such as cyanide; and substances that may be formed by recycling processes, such as dioxins (LUNDGREN, 2012).

Risks to human health can arise from elevated concentrations of heavy metals and particulate matter in the air, combined with exposure of workers and local residents through inhalation, dust ingestion, dermal exposure and oral intake. There can also be exposure to dioxins, lead, copper, cadmium, mercury and other metals and carcinogens. Another risk regards to electrical shocks. All those risks may provoke human diseases such as: breathing difficulties, respiratory irritation, coughing, choking, pneumonitis, tremors, neuropsychiatric problems, convulsions, coma and death. Other potential hazards are physical injuries and chronic ailments such as asthma, skin diseases, eye irritations and stomach disease. Air contamination may lead to inflammatory response, oxidative stress and DNA damage. All those risks are increased when WEEE flows by the informal chains (LUNDGREN, 2012).

2.1.3 Formal and informal WEEE flows and their main stakeholders

As discussed above, proper WEEE management can contribute to economy, while it avoids numerous risks to the environment and human health. Main risks to human health arise from emissions provoked by improper activities:

- leachates from dumping activities;
- particulate matter (coarse and fine particles) from dismantling activities;
- fly and bottom ashes from burning activities;
- fumes from mercury amalgamate “cooking”, desoldering and other burning activities;
- wastewater from dismantling and shredding facilities; and
- effluents from cyanide leaching and other leaching activities (LUNDGREN, 2012).

Usually such irregular activities are promoted by informal WEEE chains worldwide. Up to 80% of WEEE generated in developed countries that is sent for recycling is shipped (often illegally) to developing countries (**Figure 11**), to be processed by thousands of informal workers. Assuming that most (if not all) developing countries still lack adequate WEEE recycling capacities, we can conclude that WEEE generated worldwide is predominantly sent to informal chains, exposing thousands of people to the aforementioned risks. This raises an equity issue of developing countries receiving a disproportionate burden of a global problem, without having the technology to deal with it. **Figure 12** illustrates the WEEE flow within India, where just a smaller part of (internal) WEEE is taken to a formal chain, because of market prices, something similar to what happens to developed countries that have available adequate technology to recycle WEEE (Lundgren, 2012).

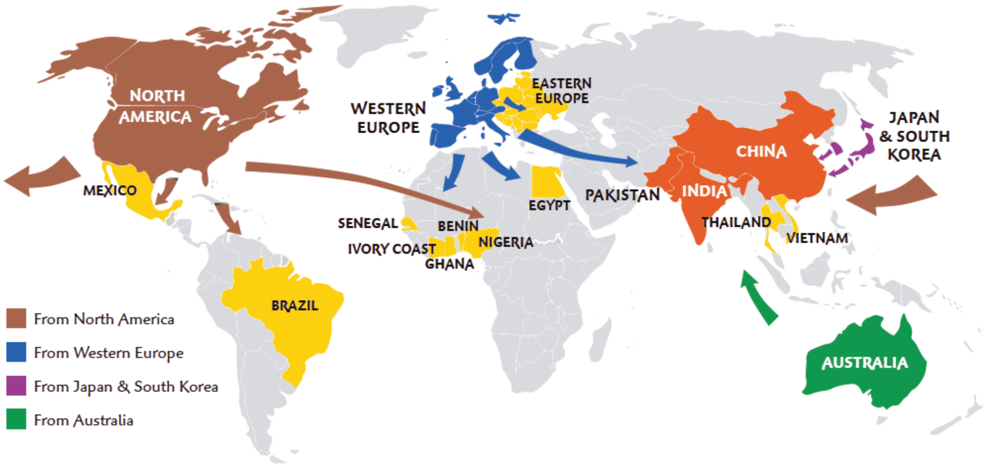


Figure 11. Export of WEEE

Source: LUNDGREN (2012)

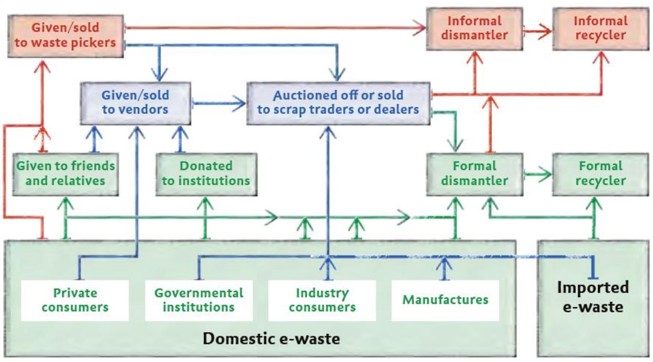


Figure 12. WEEE flow in India

Source: LUNDGREN (2012)

As explained by Lundgren (2012) the WEEE recycling sector in developing countries is largely unregulated and the process of recovering valuable materials takes place in small workshops using simple recycling methods, of which the most delicate are the manual disassembly and the recovery of valuable components from wires and cables, CRTs and PCBs. Regarding manual disassembly, largest risks are upon breakage of shell, implosion of CRT due to vacuum inside, and inhalation hazard. Recovery of materials from WEEE may involve processes such as: heating printed circuit boards to recover solder and chips; acid extraction of metals from complex mixtures; melting and extruding plastics; and burning plastics to isolate metals. Another inadequate procedure is open-air storage (Lundgren, 2012).

According to Lundgren (2012), an environmentally sound e-waste recycling chain contains the following steps:

- demanufacturing into subassemblies and components – this involves the manual disassembly of a device or component to recover value;
- depollution – the removal and separation of certain materials to allow them to be handled separately to minimize impacts, including batteries, fluorescent lamps and cathode ray tubes (CRTs);
- materials separation – manually separating and preparing material for further processing
- mechanical processing of similar materials – this involves processing compatible plastic resins, metals or glass from CRTs to generate market-grade commodities;
- mechanical processing of mixed materials – this involves processing whole units followed by a series of separation technologies; and
- metal refining/smelting – after being sorted into components or into shredded streams, metals are sent to refiners or smelters. At this stage, thermal and chemical management processes are used to extract metals (LUNDGREN, 2012).

Despite of the large dominance of informal WEEE chains worldwide, there is a promising formal market for WEEE recycling. The most complex and value-adding activities regard to the recovery of Rare Earth Metals (REM) from Printed Circuit Boards (PCBs). One of the most recognized companies capable of such activities is UMICORE, whose main plant is located in Belgium. The industrial processes applied by this company to recover valuable metals (**Figure 13**) are based in two integrated chains: the *Precious metals operations (PMO)* for refining REM, and the *Base metals operations (BMO)* for processing by-products from PMO. In search to expand its market in Brazil, UMICORE has settled a business unit in the State of Sao Paulo, which acquires, collects and transports Brazilian WEEE to the main industrial units in Belgium and Sweden. UMICORE Brazil *plus* UMICORE Belgium and Sweden is then an example of a formal WEEE chain, with adequate environmental and working conditions.

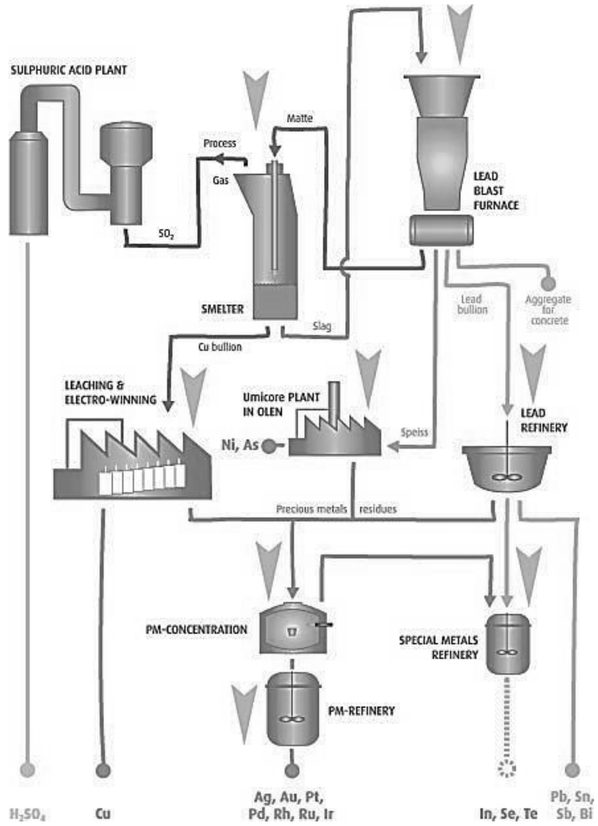


Figure 13. Industrial processes to recover precious and base metals from WEEE
Source: UMICORE (2014)

2.1.4 WEEE regulation

Due to associated risks and for economic reasons, WEEE flow needs to be regulated and controlled worldwide. However, only few countries and the European Union have specific legislation regarding WEEE management. Some of the countries that have specific WEEE regulation are Brazil (to be discussed further), China and India. Even bigger and rich countries like the USA or Russia still do not have a countrywide legislation in this sense. Many other countries have ratified multilateral conventions regarding hazardous materials, like the Bamako Convention, Basel Convention, as specifically the WEEE Directive in Europe. Despite of the existence of such laws and conventions, enforcement of implementation is still a major gap for WEEE management (LUNDGREN, 2012).

2.2. Life Cycle Management and Life Cycle Sustainability Assessment

As stakeholders and specialists concern about interconnected social, economic and environmental issues of a system such as WEEE's, what is being concerned are actually sustainability impacts, either positive or negative, of the focused system. This is why sustainability assessment has developed to be an important approach to support decision-making in waste management and other decision contexts (Kaufmann et al. 2010; Wagner 2011; Menikpura et al. 2012; Aparcana and Salhofer 2013). Considering environmental, economic and social aspects related to WEEE as briefly described in Section 2.1 leads to the idea that sustainability assessment is of major importance for developing and implementing adequate collection and recycling systems to manage such waste.

2.2.1. Product Life Cycle and Life Cycle Thinking

A key notion for sustainability assessment of systems is the concept of a product's or a service's *life cycle*. A product life cycle is a chain of "consecutive and interlinked stages of a *product system*, from raw material acquisition or generation from natural resources to final disposal". A product system is, in turn, a "collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product" (ISO, 2006a). **Figure 14** illustrates the stages or processes usually involved in a product's life cycle. **Figure 15** exemplifies a product system and **Figure 17** illustrates a set of unit processes within a product system. The *WEEE life cycle* chain is described in **Figure 16**.

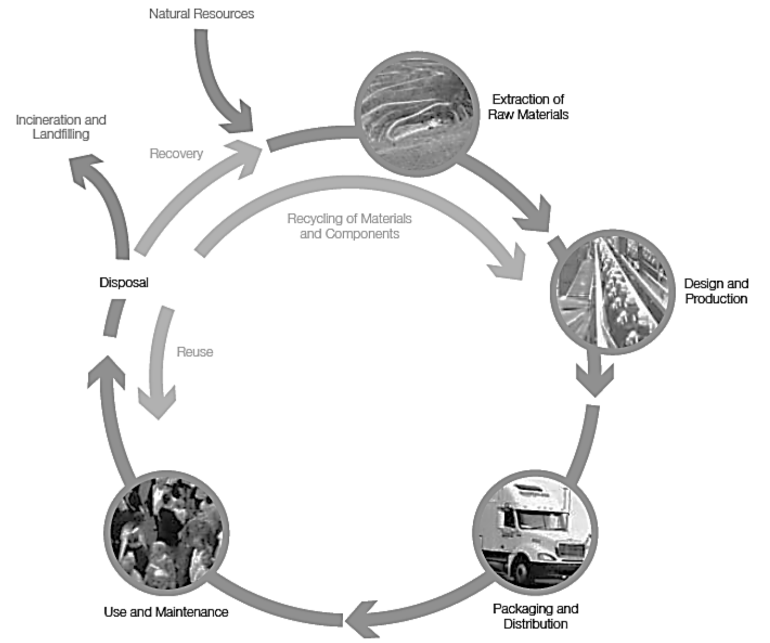


Figure 14. A product life cycle

Source: Benoit & Mazijn (2009)

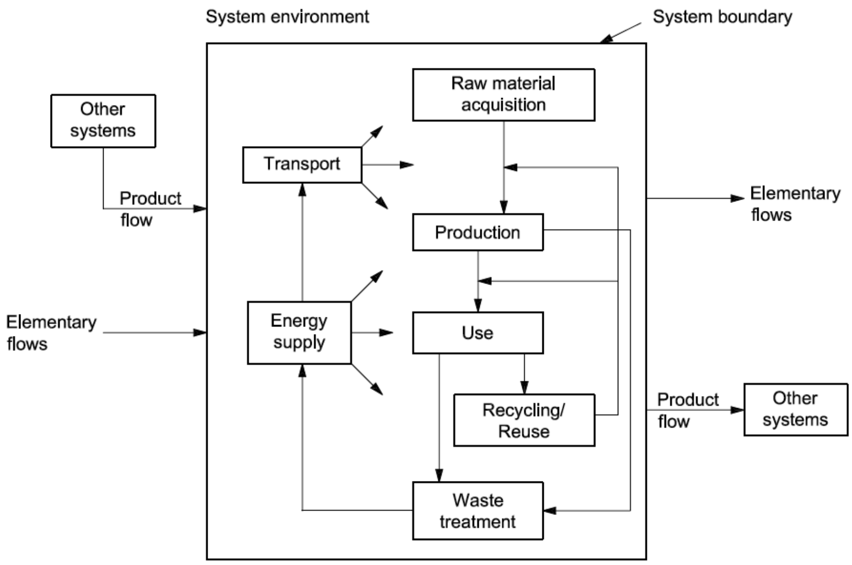


Figure 15. Example of a product system

Source: ISO (2006a)

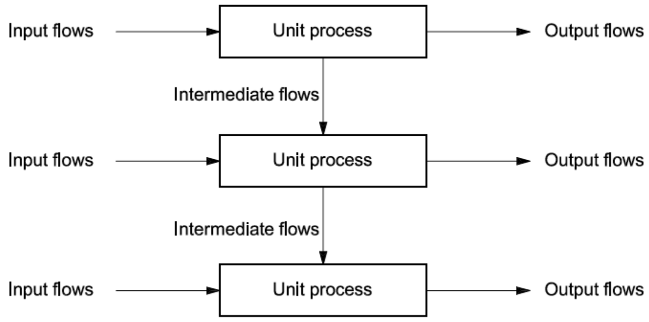


Figure 17. Set of unit processes within a product system

Source: ISO (2006a)

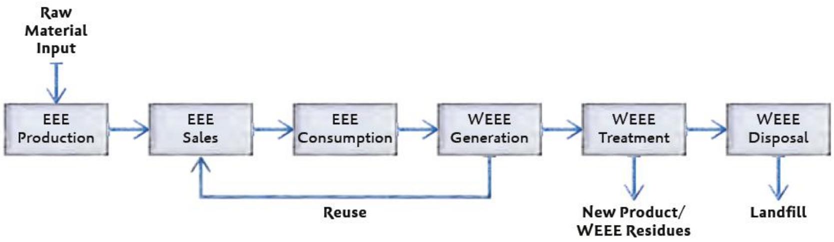


Figure 16. The WEEE life cycle

Source: Lundgren (2012)

As commented by specialists (EC-JRC, 2010), "to achieve more sustainable production and consumption patterns, we must consider the environmental implications of the whole supply-chain of products, both goods and services, their use, and waste management, i.e. their entire life cycle from 'cradle to grave'". Such strategic concern of a product's life cycle is called *Life Cycle Thinking* (LCT). LCT expands the traditional focus on production site and manufacturing processes to comprehend the environmental, social and economic impacts of a product and its respective flows along its life cycle. The main goals of LCT are: to reduce a product's resource use and emissions to the environment; and to improve its socio-economic performance throughout its life cycle. (REMMEN et al, 2007).

A vision that is directly related to LCT is the principle of *Extended Producer Responsibility* (EPR), by which producers need to develop products with improved sustainability performance, going beyond cleaner production (production phase only). Another principle related to LCT is the *polluter-pays*, by which actors who provoke the entrance of a new product into the market, including producers, retailers and consumers, are responsible for the environmental burdens related to it. This principle is a basis for many environmental laws worldwide, including Brazilian Law for Environmental Crimes (BRASIL, 1998).

2.2.2. Life Cycle Management

To turn Life Cycle Thinking into practical results, a product life cycle needs to be managed by producers and involved stakeholders. *Life Cycle Management* (LCM) "is a product management system aiming to minimize environmental and socioeconomic burdens associated with an organization's product or product portfolio during its entire life cycle and value chain" (UNEP, 2007). LCM puts LCT into practice, bringing its principles to the organisational environment and its processes.

LCM is transboundary; its effectiveness lie on a successful supply chain management, developing, implementing and controlling processes of all relevant actors: suppliers of raw material and product components, producers, transporters, retailers, consumers, governments, waste managers and recyclers. The latter supply the first actors with material and energy, closing the supply chain (as illustrated in Figure 13). Such an integrated management system consists of reciprocal communication and collaboration among actors.

LCM may involve different steps and tools, as presented in **Figure 18**. It starts with the formulation of a strategy, which is a business case with long-term view for sustainability. This strategy is a basis for the development and improvement of systems and procedures along the chain. Data, information and models for performance and impacts assessment are used for systems controlling. Robust tools and techniques support data analysis and assessment of processes, leading to improvements of the strategy and the whole system. Although **Figure 18** presents interesting tools for decision support in LCM, it still does not include recent improvements in Life Cycle Assessment methods, such as Social Life Cycle Assessment (SLCA) and Life Cycle Sustainability Assessment (LCSA), which are discussed in Section 2.2.3.

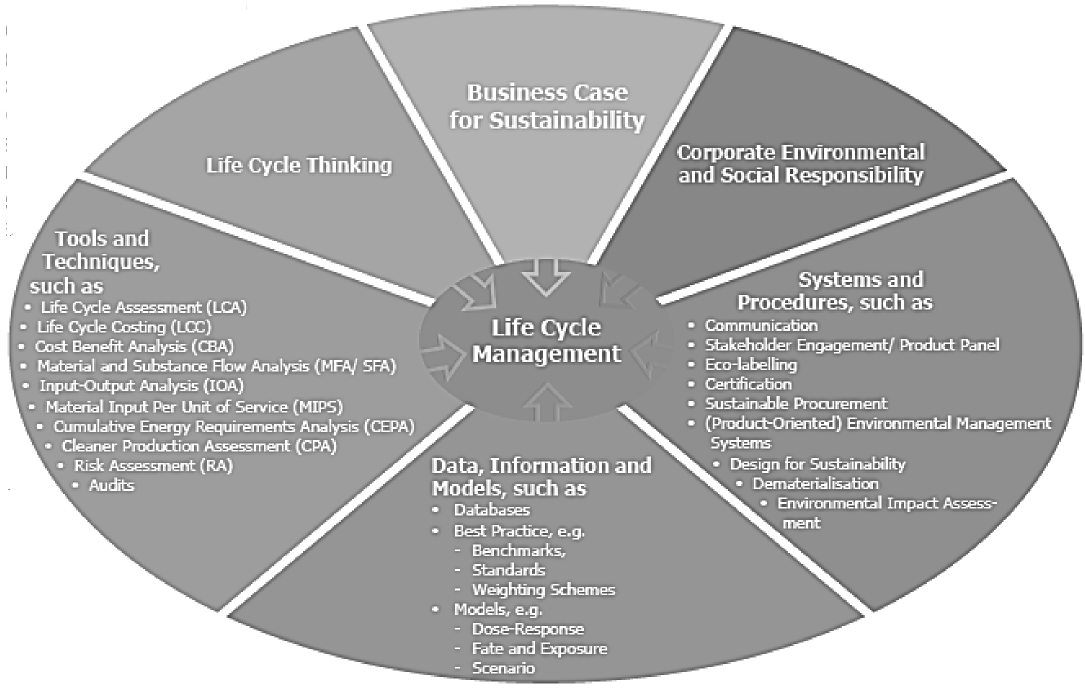


Figure 18. Concepts and tools for Life Cycle Management

Source: UNEP (2007)

All departments of an organization, as well as all actors involved in a supply chain management, can implement LCM. **Figure 19** shows that different functions within a product system play significant roles for successful LCM implementation. The activities executed by each function describe a wider product system, not only the core, production processes, but also development and marketing systems, all integrated to accomplish with strategy objectives.

LCM may involve several interconnected operational, development and marketing management processes. A good way to represent such processes to be modelled is by structuring a product's *value chain*, i.e. the system of processes that produces the value for a product. This value can be economic, social, environmental, or in general what does the organisation strategically define *value*. In **Figure 20** we present a generic value chain for reverse logistics systems. This value chain can be a useful reference to the organisation of companies entering the reverse chain markets, including waste pickers' cooperatives, or existing production companies that are incorporating reverse logistics within their chains of processes. By drawing their particular value chains or by finding their strategic position within the reference chain in **Figure 20** or other references, reverse logistics companies can play a significant role for Life Cycle Management of products, adopting its principle of systems and models.

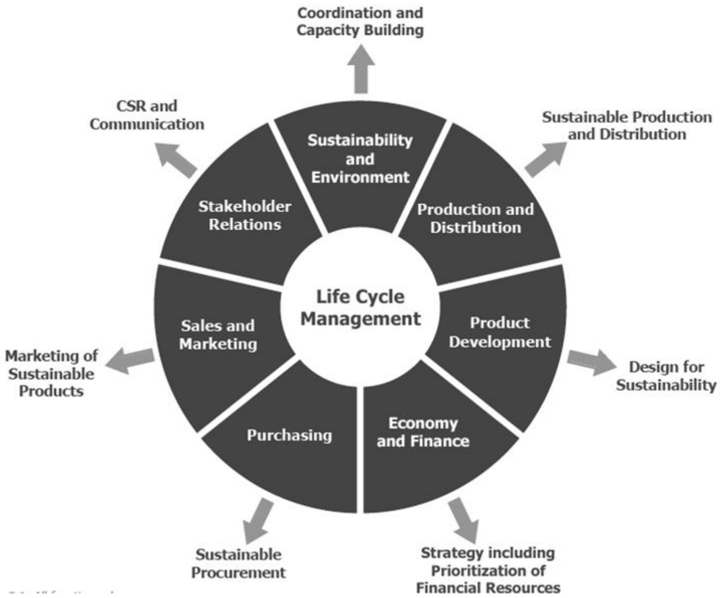


Figure 19. Functions within and organization playing their roles to LCM
Source: UNEP (2007)

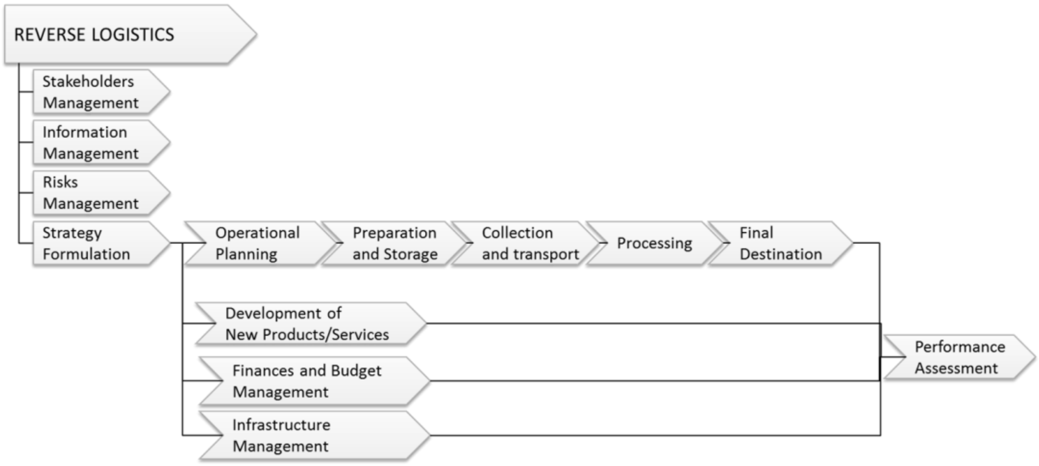


Figure 20. The reverse logistics value chain
Source: Valle & Souza (2013)

2.2.3. Life Cycle Sustainability Assessment

As explained previously, sustainability assessment is a modern and useful tool for LCM. Probably the most promising methodology for sustainability assessment, in terms of rubstness, is Life Cycle Sustainability Assessment (LCSA). It consists in evaluating and often comparing potential social, economic and environmental impacts that can be provoked by alternative systems that are considered for implementation within a product chain. The currently operating system is usually regarded as one of the options, in order to assess impacts of the system ‘as is’.

LCSA, which can be expressed by: LCSA = LCA + LCC + SLCA (Jorgensen et al 2013), aggregates evaluated impacts from three complementary methodological streams:

- LCA (sometimes eLCA - environmental Life Cycle Assessment), the environmental stream whose methodological framework is well established, being standardized in ISO 14040 to 14044 and richly developed in the ILCD Handbook (EC-JRC 2010). LCA is the basis for further development of LCC, SLCA and LCSA;
- LCC (Life Cycle Costing) usually focuses on costs for different actors along the chain; this is not yet standardized, but some suggested methodological guidelines do exist (Swarr et al. 2011); and
- SLCA (Social Life Cycle Assessment), still under development due to its higher levels of subjectivity but also provided with some suggested guidelines (Benoit & Mazijn 2009).

Despite of particularities of each methodological stream, representing specificities of each sustainability dimension, it is assumed that sLCA and LCC approaches must be anchored to the “root” LCA standard (Swarr et al. 2011; Benoit & Mazijn 2009). In other words, social and economic assessments need to be an adaption of the LCA standardized methodology.

2.2.4. Life Cycle Assessment (LCA)

LCA standard methodology is illustrated in Figure 21. It consists of four major iterative phases. The first phase is to define the goal and scope of the LCA study. The goal of an LCA states: the intended application; the reasons for carrying out the study; the intended audience; and whether the results are intended to be used in comparative assertions intended to be disclosed to the public (ISO, 2006a).

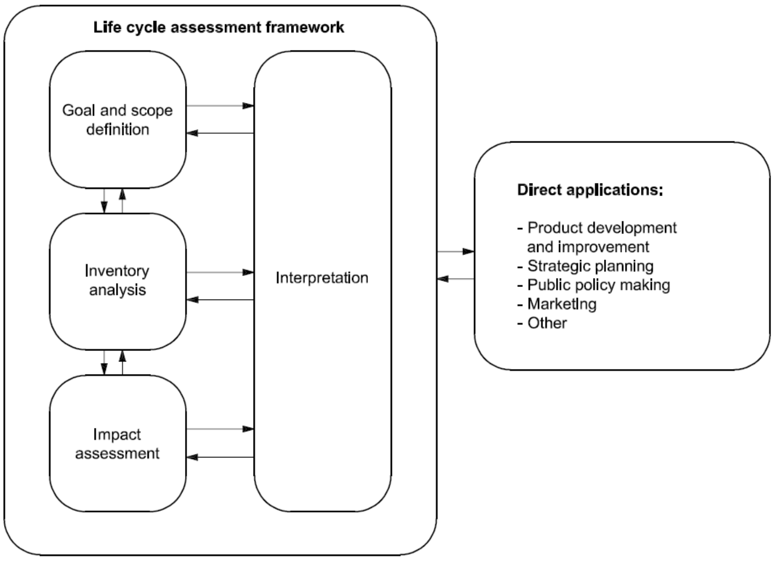


Figure 21. Stages of an LCA
Source: ISO (2006a)

The scope comprehends:

- the product system to be studied;
- the *functions* (performance characteristics) of the product system or, in the case of comparative studies, the systems;
- the *functional unit* (quantification of the function, as a reference to which the inputs and outputs are related);
- the *system boundary* (unit processes to be included in the system);
- *allocation* procedures (partitioning of input or output flows of a process or a product system between the product system under study and one or more other product systems);
- *impact categories* selected (classes representing environmental issues of concern to which results of life cycle inventory analysis may be assigned), and methodology for impact assessment with subsequent interpretation to be used;
- data requirements; assumptions; limitations; initial data quality requirements; type of critical review, if any; and type and format of the report required for the study (ISO, 2006a).

Life Cycle Inventory Analysis (LCI), the second phase, is an iterative process that involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. While doing such quantification, it is possible to gain more understanding of the system, data requirements and limitations, and also arising issues that can provoke a review of goal and scope (ISO, 2006a). One issue in LCI regards allocation of flows and releases. Data collection is also a critical task within LCI, as there can be practical constraints regarding data availability. These constraints are sometimes overcome by using LCI databases such as EcoInvent, which is a library of unit and group processes with respective inventory flows, as measured by specialists based in real cases (most from China, Europe and the United States). Some of them can be adapted to other contexts by adjusting parameters in the source model. Main data necessary in LCI are:

- energy inputs, raw material inputs, ancillary inputs, other physical inputs;
- products, co-products and waste;
- emissions to air, discharges to water and soil; and
- other environmental aspects (ISO, 2006a).

The third phase of LCA is Impact assessment (LCIA), which evaluates the significance of potential environmental impacts using the LCI results. LCIA associates inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts. LCIA can also provoke a redefinition of goal and scope of the study, in search to align results with the objectives. There can be subjectivity in the LCIA phase, especially regarding choice, modelling and evaluation of impact categories. Selection of impact categories is a key issue under study in our research, as detailed further. The elements of LCIA are illustrated in **Figure 22**. Table 3 presents the environmental impact categories suggested by a highly used LCIA method called ReCiPe. These impact categories correspond to environmental issues connected in a cause-effect chain. *Endpoints* refer to the ultimate impacts of inventory flows to the three Areas of Protection (AoP's): *Human Health*, *Ecosystems*, and *Resources*. *Midpoint* impact categories are the intermediate effects from inventory flows that are aggregated to characterize the *endpoint* categories. This cause-effect structure of inventory flows, environmental impact categories (endpoints and midpoints) and AoP's describes an Environmental Mechanism called the *impact pathway* (**Figure 23** and **Figure 24**).

Areas of protection depend on the decision context, and so are defined by the scope of the study. Based on the impact pathway it is possible to select an adequate set of impact categories that are likely to affect each AoP. Impact categories can be defined by the ultimate impacts on the AoP, i.e., at the *endpoints* of the impact pathway. But they can also be defined at *midpoint* levels, direct consequences of inventory emissions and resource flows that converge and aggregate to configure the endpoint impacts. Individually or combined, those midpoint impacts will provoke the effects described by the endpoints. This is why an LCA study should not combine endpoint and midpoint categories together, as they would present redundancy on the impacts assessment. Actually, midpoints are usually preferred in eLCA, as "on midpoint level a higher number of impact categories is differentiated and the results are more accurate and precise compared to the three Areas of Protection at endpoint level that are commonly used for endpoint assessments" (EC-JRC 2010).

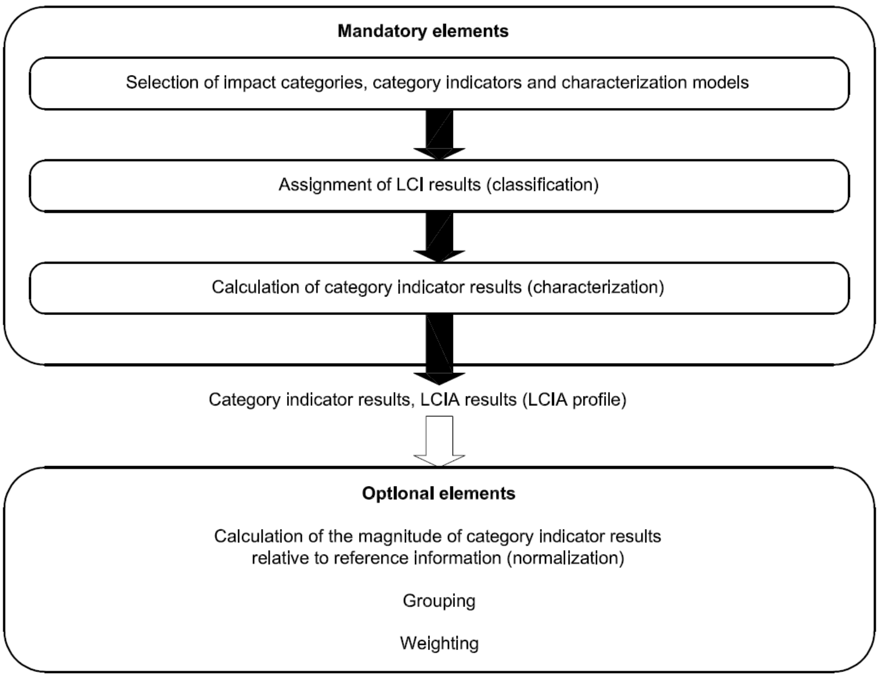


Figure 22. Elements of the LCIA phase

Source: ISO (2006a)

Table 3. Environmental impact categories suggested by the ReCiPe method

Level	Impact categories
Endpoint	1. damage to human health (HH); 2. damage to ecosystem diversity (ED); 3. damage to resource availability (RA)
Midpoint	1. climate change (CC); 2. ozone depletion (OD); 3. terrestrial acidification (TA); 4. freshwater eutrophication (FE); 5. marine eutrophication (ME); 6. human toxicity (HT); 7. photochemical oxidant formation (POF); 8. particulate matter formation (PMF); 9. terrestrial ecotoxicity (TET); 10. freshwater ecotoxicity (FET); 11. marine ecotoxicity (MET); 12. ionising radiation (IR); 13. agricultural land occupation (ALO); 14. urban land occupation (ULO); 15. natural land transformation (NLT); 16. water depletion (WD); 17. mineral resource depletion (MRD); 18. fossil fuel depletion (FD)

Final phase of LCA is interpretation of results, in which the findings from the inventory analysis and the impact assessment are considered together. It delivers results that are consistent with the defined goal and scope. They reach conclusions, explain limitations and provide recommendations. The interpretation should reflect the fact that the LCIA results are based on a relative approach, that they indicate potential environmental effects, and that they do not predict actual impacts on category endpoints, the exceeding of thresholds or safety margins or risks (ISO, 2006a).

A full explanation on LCA would be too extensive for the purposes of this work. We recommend deeper study of the references mentioned in this Section. We prefer to present an overview of the framework, as well as methodological issues that can be tackled in researches focused in waste management systems (scope of this study). Particularly interesting issues we would like to discuss in this work are: critical decisions in LCA modelling; and common mistakes found in LCA applications in waste management (**Table 4**). Some critical decisions, which are mostly taken in the Goal and Scope phase, are:

- Clear initial goal definition;
- Precise and unambiguous definition of intended application;
- Drivers, motivations and decision-context of the study;
- System: function, functional unit, reference flow, boundaries;
- LCI modelling framework and method approach;
- LCIA impact categories;
- Data and comparison requirements (EC-JRC, 2010).

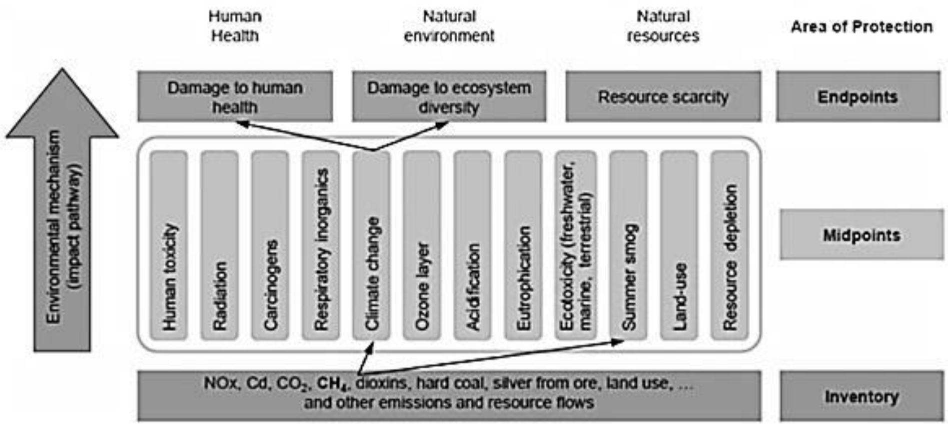


Figure 24. The impact pathway

Source: EC-JRC (2010)

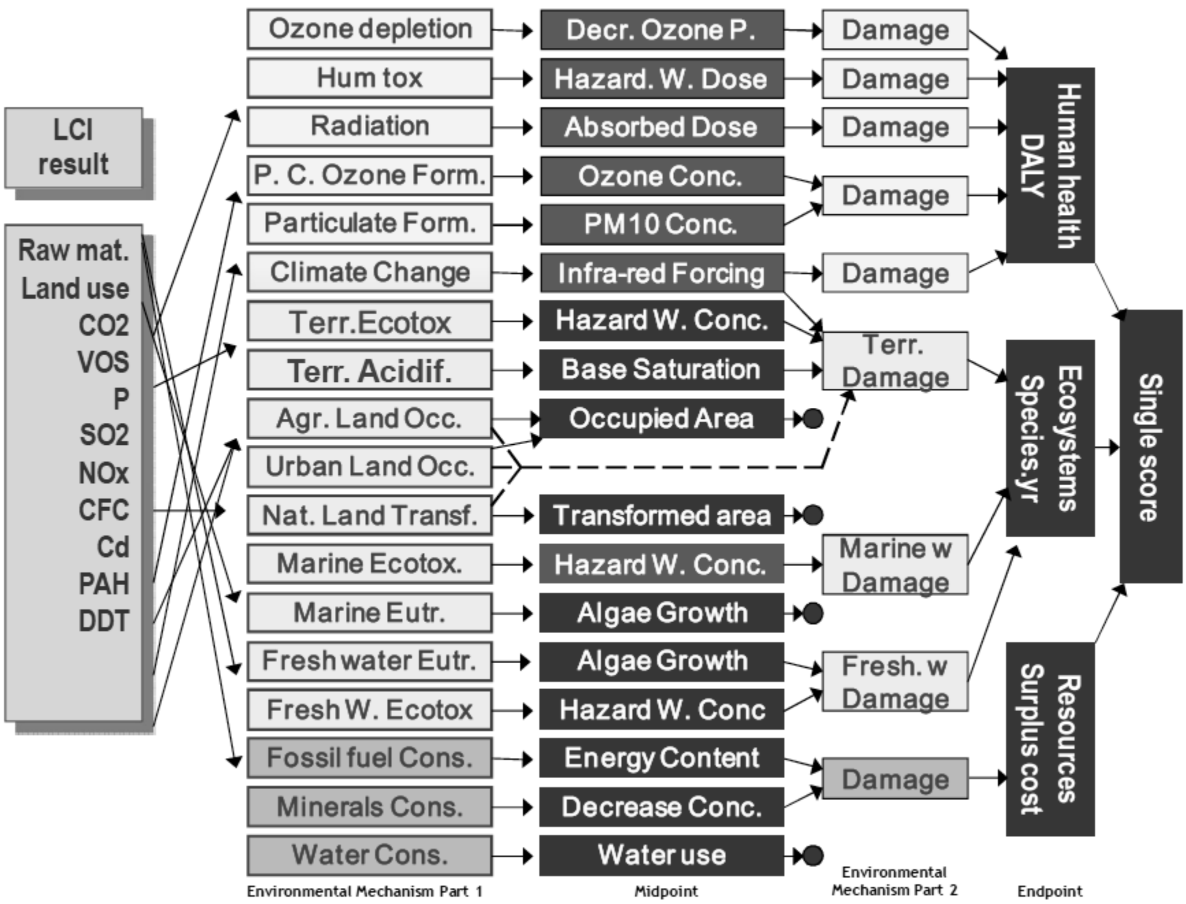


Figure 23. Relationship between LCI parameters, midpoint and endpoint indicators in ReCiPe 2008

Source: Goedkoop *et al* (2012)

These decisions are usually taken in LCA by the analysts themselves, disregarding stakeholders' perspectives, while their involvement is recommended in most of the LCA decisions. In this research we are focusing stakeholder consultation for two of these decisions: system definitions and selection of impact categories.

Table 4. Common mistakes of LCA applications in waste management

Issue	Description
Mapping of studies	- Developing countries: ○ Lack of waste treatment LCAs ○ Lack of primary data ○ under-representation of the life cycle thinking concepts
Waste systems assessed	- Studies do not cover: ○ Open dumps in low-income countries ○ Waste prevention systems ○ Specific waste streams: Construction & Demolition; WEEE
Findings of LCA studies	- Apparent trends: ○ Favour recycling over landfilling and thermal processes ○ Generalisation of LCA results ○ Disregard local conditions
LCA methodology	- Inconsistencies: ○ A frequent neglect of the goal definition ○ A frequent lack of transparency and precision in the definition of the scope of the study ○ A truncated impact coverage ○ Difficulties in capturing influential local specificities such as representative waste compositions into the inventory ○ A frequent lack of essential sensitivity and uncertainty analyses

Source: Adapted from LAURENT et al (2013)

Table 4 presents common methodological issues usually found in LCA studies. Some of them can be directly associated to the case of WEEE management in Brazil: the overall lack of studies and primary data in developing countries like Brazil; the non-coverage of WEEE among the commonly assessed waste streams; and the inconsistent goals, scopes, and local specificities. In Section 2.2.5 we present some LCA studies of WEEE systems applied worldwide and discuss their methodological approaches to tackle some of those issues.

2.2.5. LCA studies in WEEE reverse logistics

Swiss researchers are among the pioneers of LCA studies, and specifically on WEEE systems. Hischier et al. (2005) combined LCA and Material Flow Analysis (MFA) to compare two possible scenarios for WEEE management in Switzerland: the first involved WEEE take-back (or reverse logistics) and recycling systems, and the second, the baseline scenario, was consisted in WEEE incineration with energy recovery. The boundaries of this second scenario included the primary production of raw material as compensation to the amount of WEEE that would be recycled in the first scenario, which includes secondary production of materials. The definition of these boundaries is in line with the functional unit of the study, which corresponds to the total WEEE accumulated in the year of 2004 in the country. The schemes of both scenarios and some results of this research can be found in ANNEX 1. Their results presented clear environmental advantages of WEEE take-back and recycling instead of incineration with primary production of raw material. This advantage remains even when incineration is ignored in the baseline scenario. However, they concluded it is impossible to recycle WEEE without provoking any environmental impact.

Updated scenarios for WEEE management in Switzerland were analysed by Wager et al. (2011), based on the abovementioned study by Hischier et al. (2005). One of them is the WEEE recovery scenario for the year 2009, shown in **Figure 25**. The second and third scenarios adopt respectively incineration and landfilling, including primary production. All scenarios included some additional energy production in order to have the same amount of usable energy (heat/electricity). This was calculated based on the "average grid electricity production and a 50:50 mix of systems based on natural gas and heating fuel, respectively". The functional unit defined to represent the main outputs of the three scenarios is based on the so-called "basket-of-products" approach, which makes the scenarios comparable by extending them to cover a common set of products and/or services. In this study the "basket-of-products" corresponded to "the total amount of resources recovered from 1 t of WEEE (in the Swiss WEEE recovery scenario), plus all the energy produced in the case of complete incineration of the same amount of WEEE" (in the first baseline scenario). All scenarios can be found in ANNEX 1, as well as detailed results.

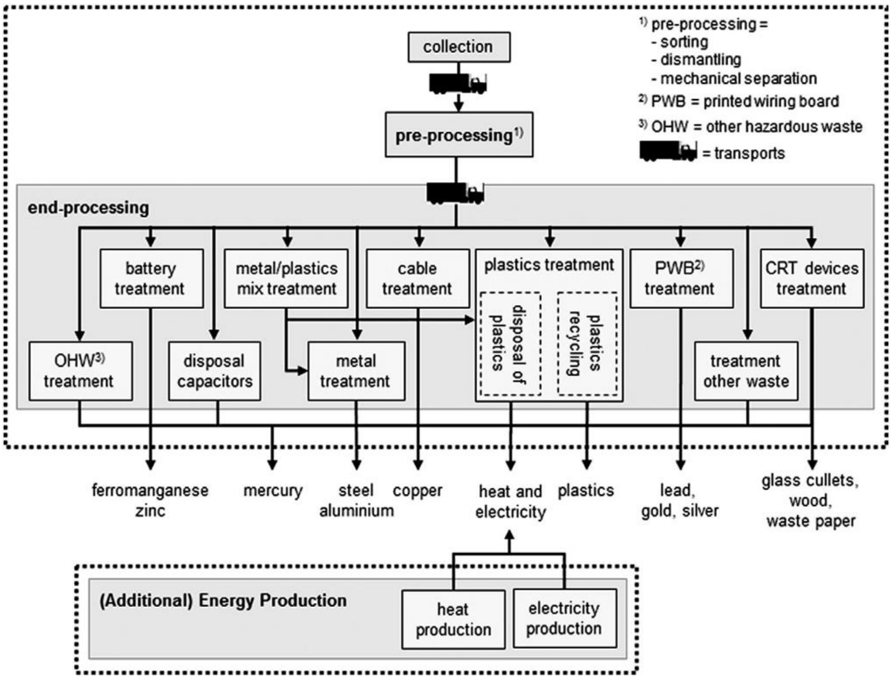


Figure 25. WEEE recovery scenario for Switzerland in 2009

Source: Wager et al. (2011)

In general, the WEEE recovery scenario presented once again higher environmental performance than the two baseline scenarios, as depicted in **Figure 26**. The environmental impacts from each scenario were calculated in the frame of the Eco-Indicator'99, which aggregates the three endpoint impact categories: Ecosystem quality; Human health; and Resources. As explained by the authors, the main impacts of the recovery scenario come from the processes of metal treatment, followed by CRT devices treatment and plastics treatment (incineration and recovery, respectively). The contribution of collection and pre-processing is marginal. Regarding the baseline scenarios, main contribution is again related to metals: highest impact (with almost 90% of the total) comes from the Freshwater Aquatic Ecotoxicity Potential (FAETP), a midpoint impact category which is almost exclusively a consequence of the direct emissions of copper and nickel to water. "For several other factors, the metal treatment used is responsible for about 60% of the overall impact — among them, the Eutrophication Potential (EP) and the Stratospheric Ozone Depletion Potential (ODP)". "The only exception, i.e. the only category not dominated by the metals treatment, is the Human Toxicity Potential (HTP), where the main contribution comes from the plastics treatment, more precisely from the incineration of a part of the plastics fraction". In comparison to the study of 2004 (Hischier et al., 2005) there was an overall increase of

20% in the total impacts, due to the availability of more detailed models for a variety of WEEE fractions (cables, CRTs etc.). On the other hand, the recovery scenario lowered its impacts in 14%, apparently due to improvements in the treatment of plastics (more recovery, less incineration) and metals.

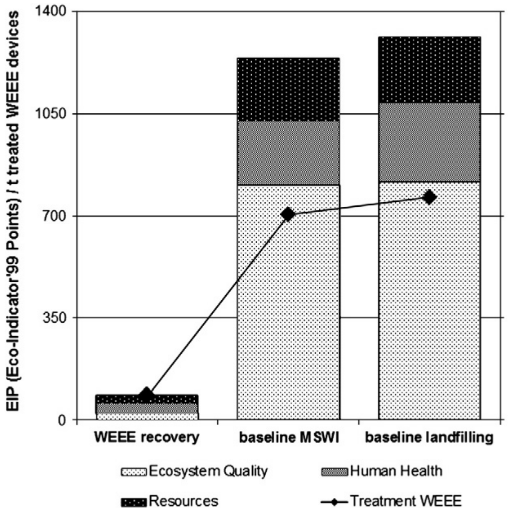


Figure 26. Environmental impacts of three scenarios for Swiss WEEE management in 2009

Source: Wager et al. (2011)

As instructed by ISO (2006b), LCA impact categories must be defined technically, rather than based on stakeholders' perspectives. Many other LCA studies for WEEE reverse logistics systems have been carried out by LCA and WEEE specialists worldwide (Hischier et al. 2005; Wager et al. 2011; Bigum et al. 2012; Traverso et al. 2012; Rocchetti et al. 2013). Those studies allow for the identification of a standard set of WEEE LCA impact categories:

- Endpoint impact categories: damage to human health; damage to ecosystem diversity; resource scarcity;
- Midpoint impact categories: global warming; acidification; human toxicity; eutrophication; summer smog; resource depletion.

2.2.6. Life Cycle Costing (LCC)

Differently from LCA, LCC impact categories need to be based on stakeholders' perspectives. As defined by Swarr et al. (2011), *Life Cycle Costing (LCC)* "summarizes all costs associated with the life cycle of a product that are directly covered by one or more actors in the product life cycle (e.g. supplier, producer, user or consumer, end-of-life agent). LCC considers the term *costs* in a narrow meaning: they must relate to real money flows. A second requirement in LCC is costs are covered directly by actors in the considered life cycle (*internal costs*). Costs usually disregarded in LCC are those borne by other actors, such as society or competitors (*external costs*). However some of these externals can be included in LCC studies if they are expected to be internal in the decision-relevant future. The usual LCC boundary is illustrated in **Figure 27**. In the case of WEEE LCC studies, costs with resources and final disposal can be included within the boundary, as these life cycle stages are usually regarded in WEEE LCA studies (Section 2.2.5).

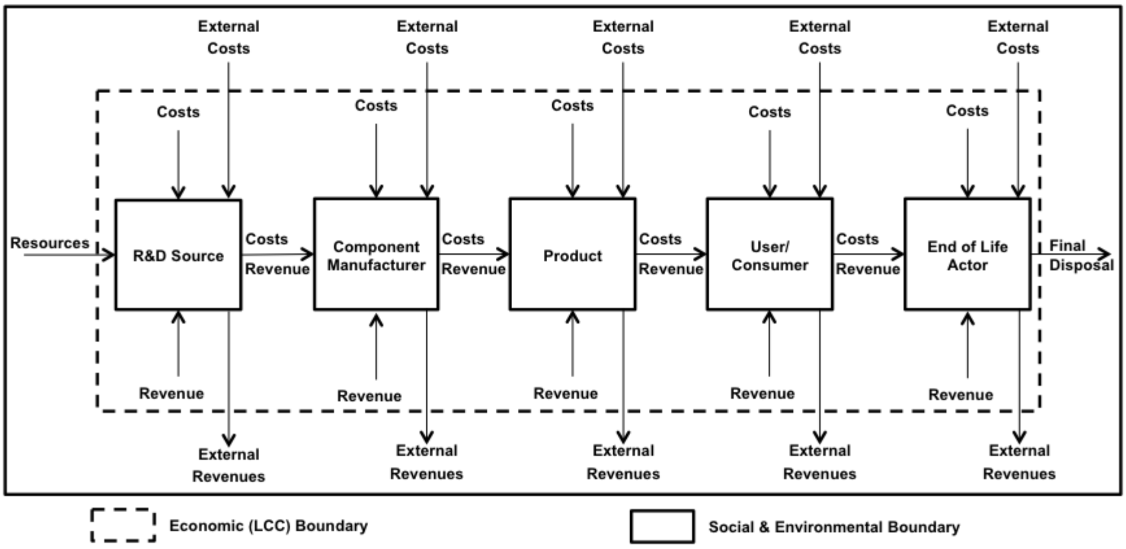


Figure 27. Conceptual framework of LCC

Source: Swarr et al. (2011)

LCC impact categories are defined based on the perspective of actors along the chain. They also vary depending on the life cycle stage being concerned. **Table 5** presents a reference set of LCC impact categories.

Table 5. LCC categories

Life stage	Perspective		
	Producer	Consumer	Society
Research and development	Market research Test equipment Wages, salaries, benefits Subscription to technical databases	School taxes	Public education buildings, salaries Investment subsidies
Component manufacture	Materials Energy Capital equipment Facility O&M Logistics Wages, salaries, benefits	Taxes Health insurance	Waste treatment Water treatment Health impacts Brownfield remediation Infrastructure
Product manufacture	(Same as component manufacture)	(Same as component manufacture)	(Same as component manufacture)
User	Distribution & logistics Warranty Customer support services	Taxes Transportation Consumables Energy Maintenance and repair	Waste disposal Pollution Health impacts Infrastructure
End of life	Take-back program	Disposal fees Recycling deposit	Recovery and disposal Pollution and remediation Landfill development, closure Health impacts

Source: Swarr et al. (2011)

One issue to be developed in LCC is that it only refers to costs. Therefore it does not cover richly the economic dimension of sustainability, which also includes other aspects like profits, economical benefits, and impacts on the market, regional, national and international economies. As discussed in Section 4, these broader aspects can be highly important for LCSA in WEEE systems.

2.2.7. Social Life Cycle Assessment (SLCA)

Social Life Cycle Assessment (SLCA) also follows the LCA stages shown in Figure 21, where goal and scope definition are the basis for all other stages. Regarding impacts assessment, SLCA also requires stakeholders engagement in the assessment of social and socio-economic impacts of products life cycle (Benoit & Mazijn, 2009). Similarly to LCIA in LCA, sLCIA (Social Life Cycle Impacts Assessment) phase consists of three mandatory steps:

- Selection of impact categories and characterization methods and models;
- Linkage of inventory data to particular sLCIA subcategories and impact categories (classification);

- Determination and/or Calculation of subcategory indicator results (characterization) (Benoit & Mazijn 2009).

SLCA impact categories must relate to social issues of interest to stakeholders and decision makers. As in LCA, their choice must be in accordance with the goal and scope of the study. They also correspond to logical groupings of SLCA results, arranged in a cause-effect hierarchy where Life Cycle Inventory data is aggregated and characterized in subcategories, and these into impact categories (**Figure 28**). But as commented by Benoit & Mazijn (2009), "both in environmental impact assessment and when evaluating social and socio-economic impacts, situations occur where such cause-effect relationships are not simple enough or not known with enough precision to allow quantitative cause-effect modelling". There are indeed causal chains connecting social impacts themselves, as well as others connecting social, environmental and economic ones, these chains are "at present usually disregarded" and need to be investigated.

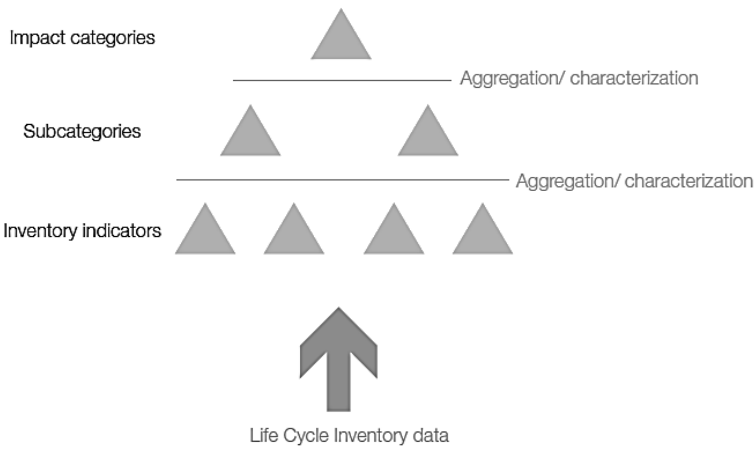


Figure 28. Concept of SLCA subcategory
Source: Benoit & Mazijn (2009)

According to Norris (2013) "Midpoints and Endpoints exist at different points along a 'social impact pathway' that begins with a social intervention and leads to different levels of impacts. However in social assessment there are very few demonstrated cause-effect chain models".

Discussing SLCA, Finkbeiner et al. (2010) argue that the "selection of social criteria and their quantification is still one of the major challenges", as "there is currently no uniform usage of a standardized set of indicators". According to the same authors, "there are still research needs and consensus needs of the involved stakeholders".

The choice of impact categories, subcategories and characterization models shall be made in accordance with the goal and scope of the study. Reference frameworks can serve as a library of potential SLCA categories to be considered in sLCIA. Norris (2013) suggested a set of 31 methodological sheets, one for each impact subcategory defined by Benoit & Mazijn (2009) according to *stakeholder categories* (**Table 6**). The selection of subcategories was achieved by looking at international agreements, standards and guidelines that have been developed by multi-stakeholder groups, as they capture consensus of wide audiences. These sheets were designed to provide measurement sources and background information sources for SLCA baseline data, as well as a "measurement recipe" for each subcategory in the SLCA framework (Norris, 2013). Detailing of potential indicators and data sources for some of these SLCA subcategories can be seen in ANNEX 2.

Table 6. SLCA subcategories for each stakeholder category as suggested in literature

Stakeholder category	SLCA Subcategories
Local community	Delocalization and migration; Community Engagement; Cultural Heritage; Respect of Indigenous Rights; Local Employment; Access to Immaterial Resources; Access to Material Resources; Safe and Healthy Living Conditions; Secure Living Conditions
Value Chain Actors	Fair Competition; Respect of Intellectual Property Rights; Supplier Relationships; Promoting Social Responsibility; Health and Safety; Feedback Mechanism; Privacy; Transparency; End-of-Life Responsibility
Worker	Freedom of Association and Collective Bargaining; Child Labour; Fair Salary; Hours of work; Forced Labour; Equal opportunities/Discrimination; Health and safety; Social Benefit/Social Security
Society	Public Commitment to Sustainability Issues; Prevention and Mitigation of Conflicts; Contribution to Economic Development; Corruption; Technology Development

Source: Norris (2013)

Selection of the functional unit in SLCA models can follow the guidelines defined for LCA functional units, as suggested by Weidema *et al* (2004) *apud* Benoit & Mazijn (2009). It consists of five iterative and possibly concurrent steps:

1. Describe the product by its properties including the product's social utility;

2. Determine the relevant market segment;

3. Determine the relevant product alternatives;

4. Define and quantify the functional unit, in terms of the obligatory product properties required by the relevant market segment;

5. Determine the reference flow for each of the product systems (Weidema *et al*, 2004 *apud* Benoit & Mazijn, 2009).

In S-LCA, the definition of the function (Step 1-2-3) needs to consider both the technical utility of the product and the product's social utility, which can be described as "a range of social aspects such as time requirement, convenience, prestige etc." (Griesshammer *et al.*, 2006 *apud* Benoit & Mazijn, 2009). The overall properties of a product may be related to:

- *Functionality*, referring to the main function of the product;
- *Technical quality*, such as stability, durability, ease of maintenance;
- *Additional services* rendered during use and disposal;
- *Aesthetics*, such as appearance and design;
- *Image* (of the product or the producer);
- *Costs* related to purchase, use and disposal;
- *Specific environmental and social properties* (Benoit & Mazijn, 2009).

2.2.8. System modelling in LCA and SLCA

Benoit & Mazijn (2009) explain that a product life cycle is not a single, objective thing, but an idea or an abstract system that can be defined differently by different people and their world-views. Decisions for the modelling of an SLCA product system are influenced by drivers like: (individual) world-view; (conception of the) overall goal of the study; realities of our existing databases, software, and professional practice; study budget, goal & scope; data quality goals, and results of sensitivity analysis. These subjective aspects constrain the ideal system "we wish we could model", defining a system we actually use and seek data to model (**Figure 29**). The data we actually use to construct our model is therefore a simplification of the complex reality of the system, representing a particular frame of a broader decision context consisting of interconnected social, economic and environmental aspects, as well as cognitive concepts and rules.

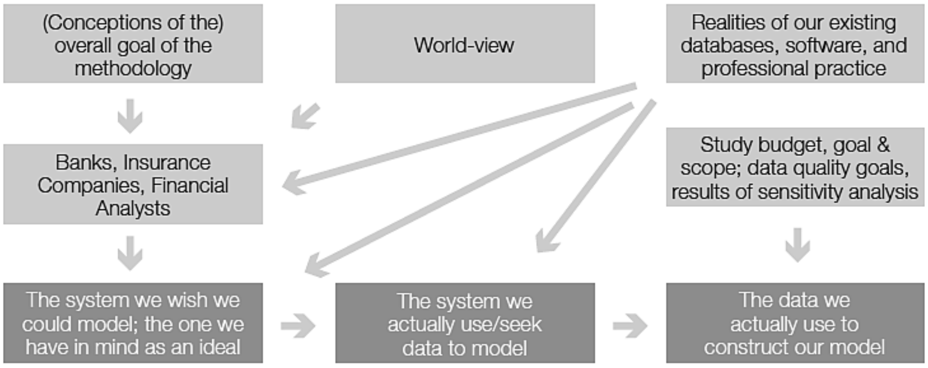


Figure 29. Influences of drivers on the conceptual system (incl. model and data) in a study area

Source: Benoit & Mazijn (2009)

Either in LCA and SLCA, the product system should be modelled in such a way that only elementary flows cross the system boundaries, i.e. no product or intermediate product flows (economic flows) enter or exits the system. System boundaries must be defined and refined iteratively during modelling, applying sensitivity assessments. While explaining choices it is suggested to use E-LCA system boundary setting and building upon it for S-LCA. This is because SLCA studies have usually adopted *attributional* modelling, while care should be taken in *consequential* assessments, where "important consequences arise as a result of an action or decision may differ". "As experience is acquired through increasing S-LCA practice, the reasons why S-LCA system boundary may or may not differ from E-LCA system boundary will become clearer" (Benoit & Mazijn, 2009).

The choice of *attributional* or *consequential* modelling is one of the most important in the scope definition. *Attributional* modelling depicts the system as it can be observed/measured, linking the single processes within the technosphere along the flow of matter, energy, and services (i.e. the existing supply-chain). The *consequential* LCI modelling framework aims at identifying the consequences of a decision in the "foreground" system on other processes and systems of the economy and builds the to-be-analysed system around these consequences.

The analysed system has boundaries (dashed border in **Figure 30**), separating it from the remainder of the technosphere and from the ecosphere. The system may be divided into the *foreground* system of processes that are specific to the analysed system i.e. own operations and fixed suppliers. The processes in the *background* system are not specific but purchased via a (theoretically fully homogenous) market. The system is the exact sum of the background and the foreground systems. Quantitatively irrelevant flows can be excluded, i.e. cut-off (dotted arrows) (EC-JRC, 2010).

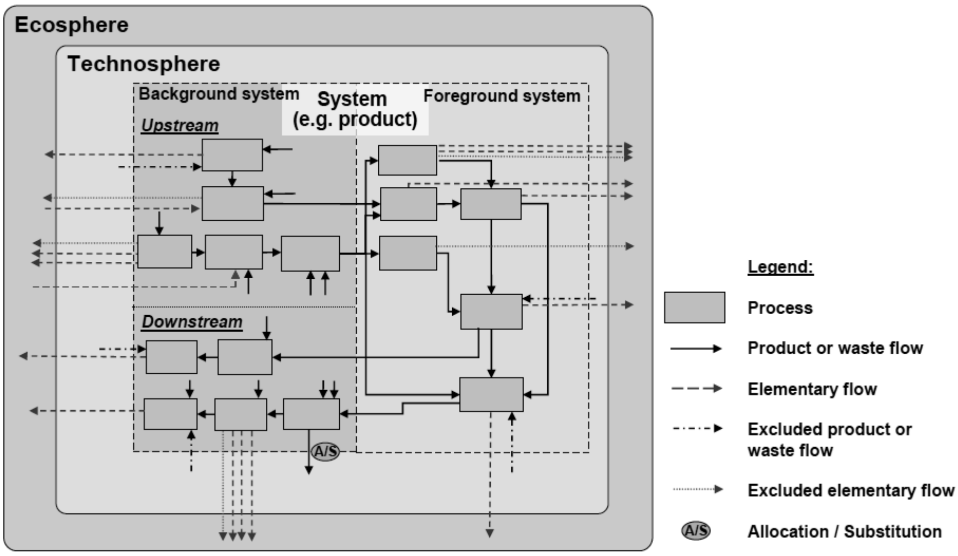


Figure 30. Analysed system divided into foreground and background systems
Source: EC-JRC (2010)

The *foreground* system (**Figure 30**) is defined by those processes that are regarding their selection or mode of operation directly affected by decisions analysed in the study. In contrast, the *background* system comprises those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good (or operator of the service, or user of the good). In consequential modelling the background system comprises everything except processes at the producer/operator and those “tier-one” suppliers with which long-term contractual relations exist and which hence cannot be changed (EC-JRC, 2010).

After modelling the actual system, it is relevant to ask the questions:

1. Where are the processes located in the World?
2. a) What is (or who are) the enterprise(s) or organization(s) involved in each of the processes? b) Who are the other stakeholders (society, local

community, workers, consumers, value chain actors) involved in each of the processes? (Benoit & Mazijn, 2009).

2.2.9. LCC and sLCA studies in waste management

A good example of an SLCA application to waste management is the study by Aparcana and Salhofer (2013), focused in the development of an SLCA methodology for recycling systems in low-income countries. Based on a literature review, the authors have selected 26 semi-quantitative indicators related to impact categories (**Table 7** and ANNEX 3. Social impact categories, subcategories and indicators for recycling systems in low-income countries) that represent social problems of informal recyclers. Two alternative system models are described, one representing a typical waste management system in low-income countries (**Figure 32**), and the second describing a formalisation approach based on cooperation with recycler's association (**Figure 31**). One restriction about this approach is that no stakeholder was involved during the selection of impact categories or the system modelling phases of SLCA.

Table 7. SLCA impact categories and subcategories for recycling systems

Category	Sub-category
Human rights	Child Labour; Discrimination
Working conditions	Freedom of association and collective bargaining; Working hours; Minimum income, fair income; Recognised employment relationships and fulfilment of legal social benefits; Physical working conditions (health, security, working equipment); Psychological working conditions
Socio-economic repercussions	Education

Source: Aparcana and Salhofer (2013)

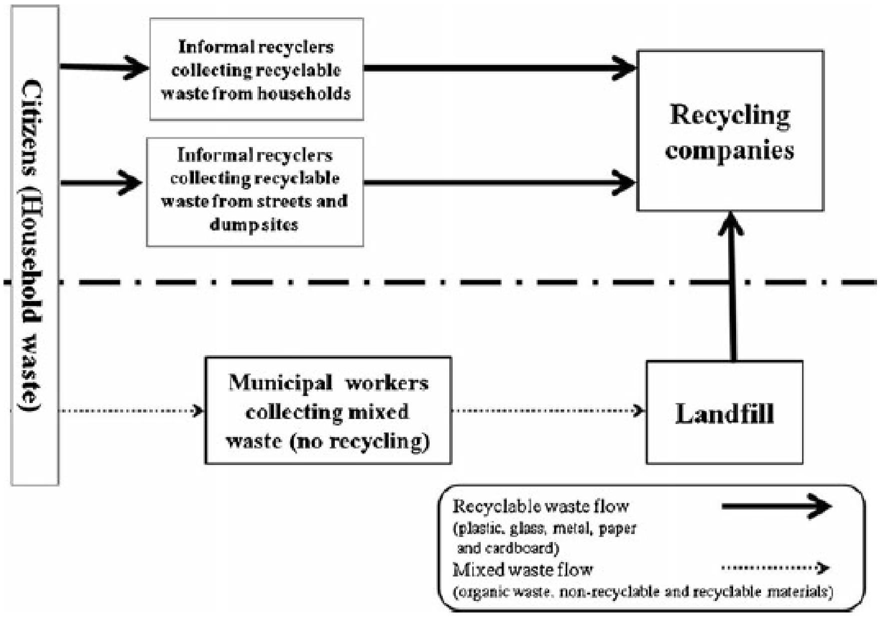


Figure 32. Typical waste management system in low-income countries

Source: Aparcana and Salhofer (2013)

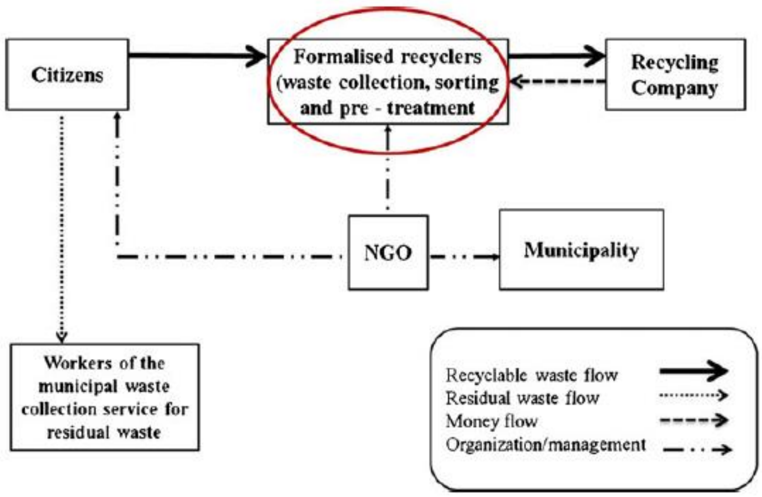


Figure 31. Formalisation approach based on cooperation with recyclers' association

Source: Aparcana and Salhofer (2013)

There are few but interesting LCC applications in waste management (Reich 2005; Kim et al. 2011; Massarutto et al. 2011). An interesting feature in some of them is that they consider expanded system boundaries based on the usual LCA system boundaries, by including processes of resources or energy supply to support allocation of costs. All of them have compared financial costs to environmental impacts or costs. Reich (2005) compared diverse scenarios for MSW management in Sweden. Their financial costs are presented in Figure 33, detailed in terms of stages of the waste management system.

They have also calculated the costs for the external system, i.e. processes within the extended boundary (Figure 34). They have also calculated environmental costs using three different methods, one of which being EPS 2000, which is based in LCA results (Figure 35). Observing their results, it is clear that landfilling was the worst option both in economic and environmental terms, while other solutions like incineration, anaerobic digestion (AD) and recycling are balanced.

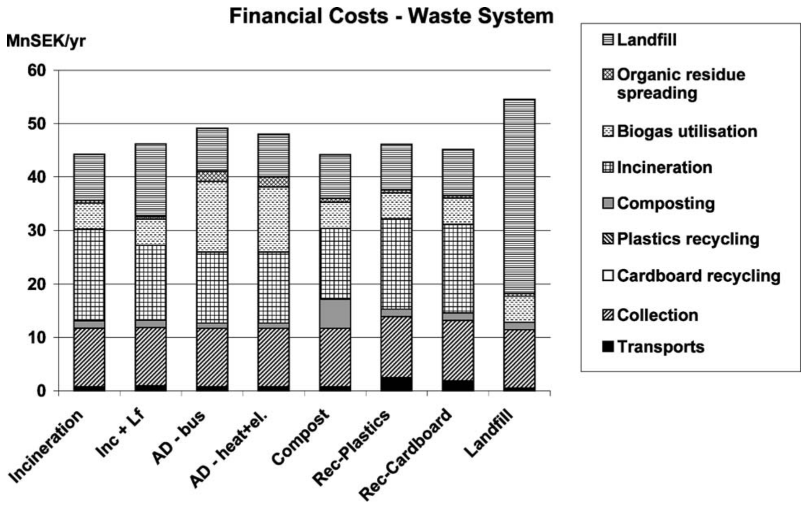


Figure 33. Financial costs of alternative MSW systems in Sweden

Source: Reich (2005)

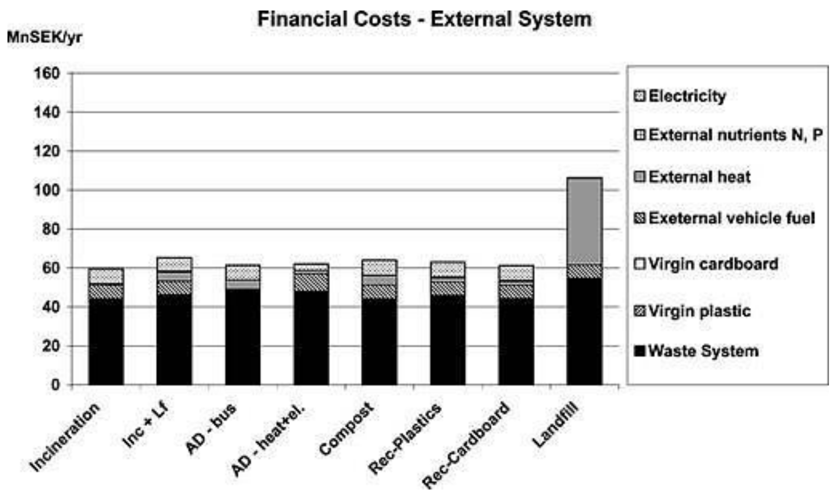


Figure 34. External costs of alterntive MSW systems in Sweden

Source: Reich (2005)

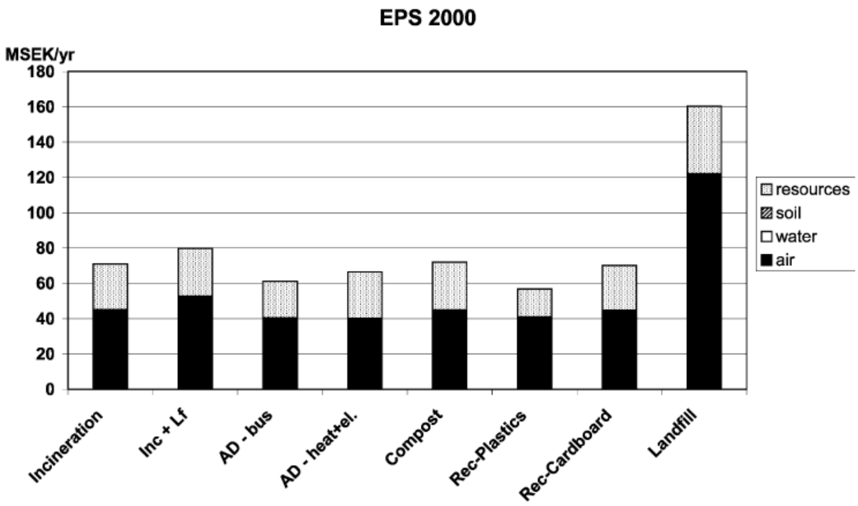


Figure 35. Environmental costs of MSW systems in Sweden
Source: Reich (2005)

2.2.10. Principles and challenges for an LCSA framework

As introduced in Section 2.2.3. Life Cycle Sustainability Assessment, Life Cycle Sustainability Assessment corresponds to the integrated application of LCA, SLCA and LCC approaches. While LCA is standardized with richly developed methodology, LCC and SLCA frameworks are still in their early stages although some pathway has been established in recent years. The establishment of a standard LCSA framework depends on the consolidation of SLCA and LCC, whilst following improvements on their root reference (LCA standards).

It is possible to assume that the main challenges to LCSA are related to: reviews and improvements in LCA; development of SLCA and LCC standards; and the integration (or aggregation) of the three streams within an overall framework. Regarding the last topic, some main references in LCSA suggest an approach based in the aggregation of social, economic and environmental scores into the calculation of a final sustainability index (Figure 36) or endpoint composite indicators representing each dimension (Figure 37). Researchers selected the impact categories in Figure 37 focusing on municipal solid waste (MSW) management systems. One problem with aggregation of indicators is the reduction of a complex reality into a simple narrower representation of reality, based on mathematical modelling assumptions, usually in models developed by specialists disconnected to each particular problem situation. This is the case of the weighting scheme of social, economic and environmental factors proposed in Figure 36.

Another issue with aggregation approaches is that they can hardly deal with qualitative indicators. This issue has been dealt with by the use of dashboards or multicriteria methods (discussed in Section 2.3). The Life Cycle Sustainability Dashboard (LCSD) suggested and applied by Traverso et al. (2012) and illustrated in **Figure 38**, where performance in each indicator is presented qualitatively, and a sustainability index is calculated based in the aggregation of indicators within each dimension. Although the visual representation of dashboards can be useful for stakeholder consultation in decision-support, if aggregation is still to be adopted, parameters like weights and tolerance thresholds need to be determined also with stakeholders, what can lead to significant variations of suggested values. There are other methods like multicriteria approaches that do not fall into a final overall index, but can provide a rank of best to worst or a classification of assessed options.

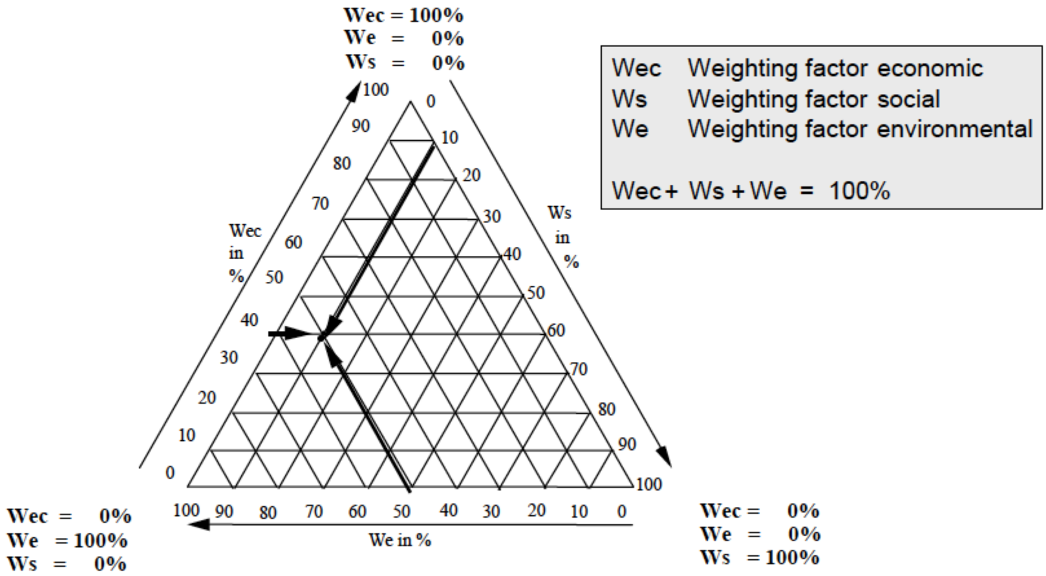


Figure 36. Life Cycle Sustainability Triangle (LCST) graphical scheme

Source: Finkbeiner et al (2010)

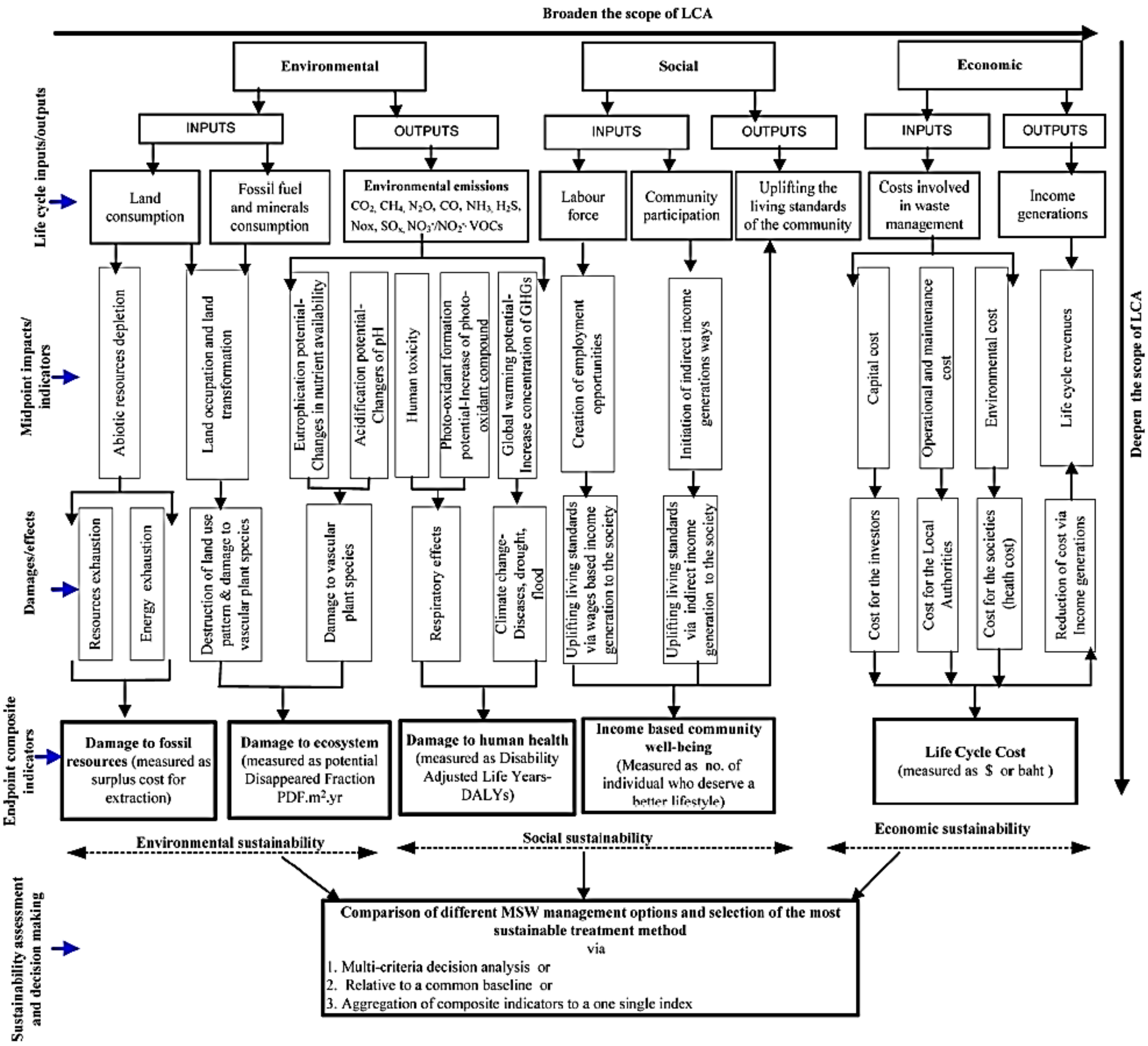


Figure 37. Framework for LCSA of MSW management systems

Source: Menikpura et al (2012)

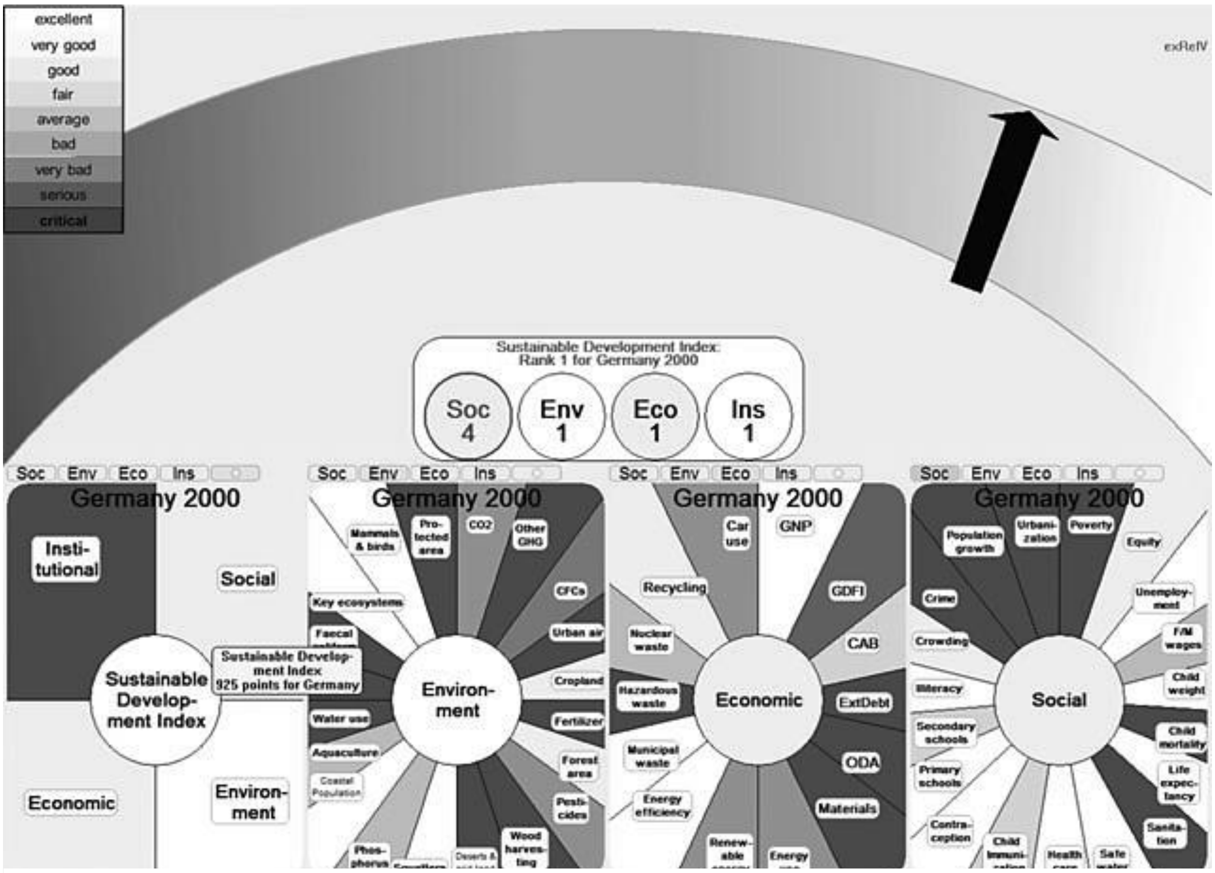


Figure 38. Sample results on Germany for a use of the Dashboard of Sustainability

Source: Traverso et al. (2012)

One problem with this and all aforementioned LCSA applications is that they did not consider stakeholder perspectives in the selection and evaluation of impact categories, what is needed especially for LCC and SLCA, according to what was discussed about their methodological guidelines. These approaches need to be reviewed and adapted if they are to be integrated within a formal LCSA framework that considers all methodological recommendations.

Other issue to be developed within a formal LCSA framework is the definition of foreground and background systems within a scope of the study, their respective functions and flows with consequent reference flows and functional units. Despite the need for considering stakeholder perspectives in determining these system models, there is a trend in following the same usual structure adopted for LCA systems, i.e. based on material flows (**Figure 39**). However, in SLCA and LCC there can be other flows like actors, capital, information and other resources, which are integrated to the LCA usually-modelled systems, describing a broader life cycle chain of product systems like

WEEE's. All those flows are considered and external in **Figure 39**, meaning that the processes that produce them are occult within the simplified context of background systems. Rather, they should be put in evidence, as variations of these "background" processes can influence significantly the quantity or quality of these flows, what in turn influences SLCA and LCC results. A potential methodology to support system modelling in LCSA is SSM, as discussed in Section 2.3.

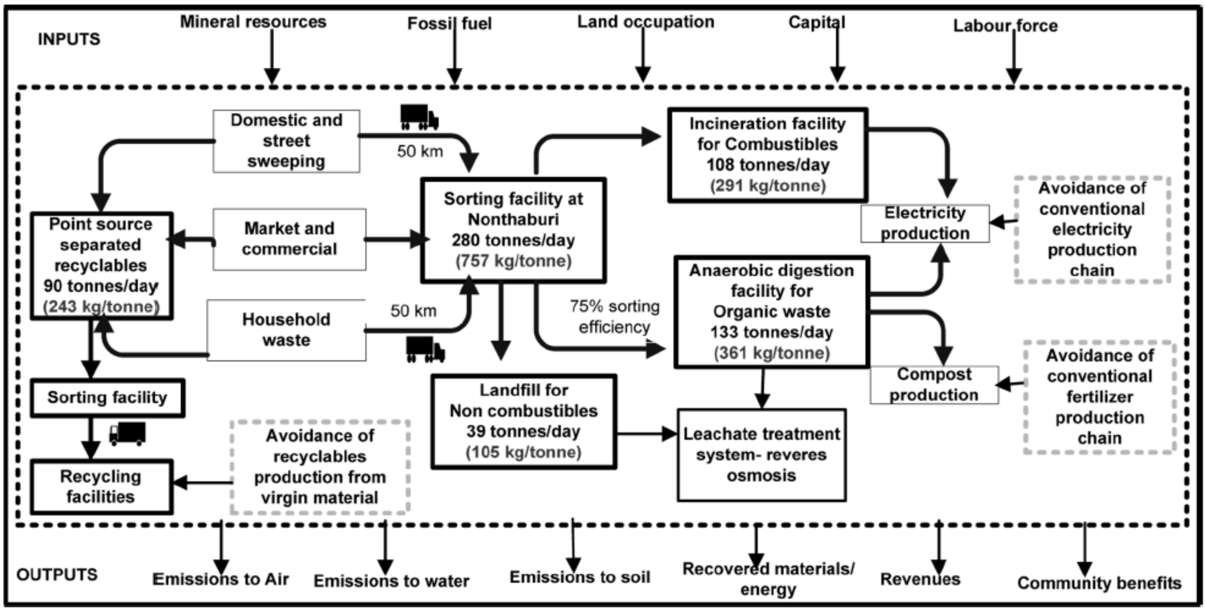


Figure 39. LCA framework of an intented MSW management system in Thailand

Source: Menikpura et al (2012)

2.3. Complex decision problems and potential decision-support tools for sustainability

Many researches have focused on decision-support tools able to manage the complexity of waste management systems. Morrisey and Browne (2004), in their survey paper on waste management models, found a variety of decision-support methods and tools that have been applied to waste management, such as risk assessment, environmental impact assessment, cost benefit analysis (CBA), multicriteria decision-making and Life Cycle Assessment. They identified the shortcomings of each of these methods, as described in **Table 8**. Most models assume that all options and decision criteria have already been identified, and that the most important stage is the evaluation of alternatives. The type of tool selected also depends both on the decision being made and on the profile of the decision-makers who are the clients for such decision-support project (Morrisey and Browne, 2004).

The authors concluded that:

- None of the published models have considered the complete waste management cycle, from prevention to disposal. Most are concerned, rather, with refining the actual multicriteria technique or with comparing the environmental aspects of WM options;
- No model examined environmental, economic and social aspects together and none considered the intergenerational effects of the strategies;
- The non-involvement of all relevant stakeholders in the decision making process is a major shortcoming;
- Important steps in decision making for municipal solid waste management are the formulation of the problem and the involvement of stakeholders (Morrisey and Browne, 2004).

Table 8. Shortcomings of traditional methods for modeling in waste management

Method	Shortcomings
Cost benefit analysis (CBA)	- Environmental decision-making usually involves competing interest groups, conflicting objectives and different types of information and CBA is not suitable for these decisions; - CBA allows improvements in one dimension, to compensate for deterioration in another, which is not a strong sustainability approach.
Life cycle assessment (LCA)	- LCA has not been subject to public involvement, being a specific and highly technocratic tool. Because it is incapable of dealing with health effect predictions, it has partial relevance to public deliberation; - LCA cannot predict actual effects. It is a comparative tool that reduces data to mass loading based on simplifying assumptions and subjective judgements, and hence it can add independent effects into an overall hazard score; - It cannot easily deal with localised environmental impacts which become a public priority, or with effects that cannot be quantified as outputs; - Cannot deal with time dependant impacts; - Models which consider the full life cycle are complex and very detailed, and potential users (decision-makers) often lack the expertise and data, tending to look at financial data.
Multicriteria decision analysis (MCDA)	- Allocation of weights in outranking methods (ex. ELECTRE), are not concerned with the way criteria or alternatives are selected; - The number of criteria/alternatives can be very large.

Source: Adapted from Morrisey and Browne (2004)

Those conclusions reinforce the necessity of considering stakeholders' perspectives in a proper formulation of a decision problem regarding waste management, covering environmental, social and economic aspects. This is a potential contribution from Problem Structuring Methods to waste management.

2.3.1. Complex decision problems and Problem Structuring Methods (PSM)

Nowadays, decision-making, and its supporting activities of systems modeling and problem solving 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, the dynamics of those turbulent networks, unexpected and unpredictable events, and the fluidity of organisations and individuals' missions. This complexity of contemporary problems exposes the limitations of traditional decision-support methods, usually based on mathematical modeling which aims to find the 'best' solution for rather shielded and predictable decision problems (Rosenhead and Mingers, 2001).

Various authors from different disciplines have observed a dichotomy of problem structures (Rosenhead and Mingers, 2001). Their characteristics are given in **Table 9**.

Table 9. Tame versus Wicked decision 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 specified in consensus, do not change during analysis	Alternative types and levels of explanations and phenomena of concern
True or false solutions, judged by analyst	Good and bad solutions, judged by interested parties themselves
Relatively unimportant to society at large	Greatest human concern
Essentially independent of individuals' views and beliefs	Importance of participants' perceptions

Source: Rosenhead and Mingers (2001)

The dichotomy of problems presented in **Table 9** also suggests that a dichotomy of methodological approaches for decision-making support is appropriate (**Table 10**). 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 decision-making in *wicked* problems.

Table 10. Traditional modeling methods versus 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)

Observing **Table 8**, **Table 9** and **Table 10**, we can acknowledge that most waste management analyses are based on the traditional modelling perspective associated with 'tame' problems. This includes most LCA, LCC and SLCA models, as discussed previously. However, sustainability-related problems are more *wicked*, which suggests the adoption of PSMs at some level of decision-support.

In PSMs, an important methodological step is usually to draw diagrams that can visually represent stakeholders' perceptions about the decision context. The use of maps as diagrams to support reasoning is a feature in several areas of knowledge. Methods which are quite widely used are Concept Maps (Novak and Cañas 2008), Thinking Maps (Hyerle 2008) and Mind Maps (Buzan, 1994). Mostly they are used to enhance meaningful learning and critical thinking, and are helpful in uncovering "unknown unknowns".

2.3.2. Strategic Options Development and Analysis (SODA)

One of the most used PSM is 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 (*causal maps*), with ends or goals towards the top and means or causes below them (**Figure 40**). For group decision-making, individual maps are joined together as a *merged map*.

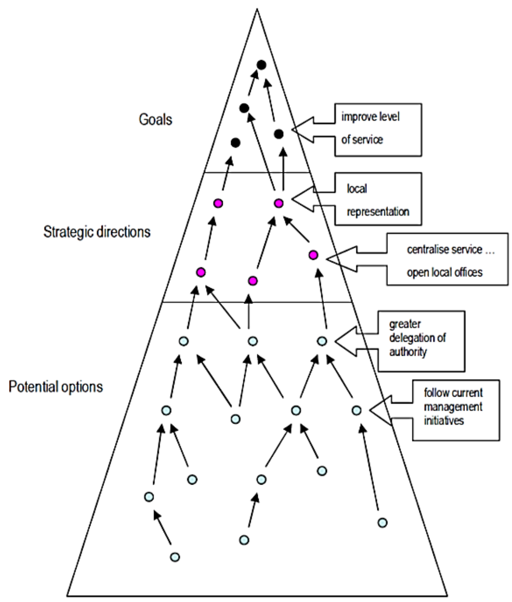


Figure 40. Common structure of cognitive maps

Source: Eden and Ackermann (1992)

Cognitive maps are built based on the stakeholders' discourses on the decision problem, either simultaneously to the interviews, or by recording and transcribing them. The stages for building a cognitive map are:

1. Separate sentences into distinct phases;
2. Build up the hierarchy (potential goals at the top, supported by concepts indicating strategic direction and further on with potential options);
3. Watch out for goals: the most superordinate concepts, regarded by the stakeholder as good things per se;
4. Watch out for strategic directions, that have such characteristics: long term implications, high cost, irreversible, need a portfolio of actions to make them happen, may require a change in culture. Potential options are concepts that explain (and thus suggest potential solutions to) the key issues to which they are linked. Links (arrows) between concepts can be interpreted as "may lead to" or "may imply";
5. Look for opposite poles. These clarify the meaning of concepts, and are usually represented in causal maps after three dots (…);
6. Add meaning to concepts by placing them in the imperative form and where possible including actors and actions. Through this action perspective the model becomes more dynamic;
7. Retain ownership by not abbreviating but rather keeping the words and phrases used by the problem owner (or the interviewed stakeholder);
8. Identify the option and the outcome between each pair of concepts, and build links (arrows) between them;
9. Ensure that a generic concept is superordinate to specific items that contribute to it;
10. Code the first pole as that which the problem owner sees as the primary idea (idea first started). The first pole tends to stand out when reading a map. A consequence of this is that links may be negative (signed with "-") even though it would be possible to transpose the two poles in order to keep links positive;
11. Tide up in order to provide a better more complete understanding to the problem. Ensure to ask why isolated concepts are not linked in to the main parts of the map. This is often an important clue to the problem owner's thinking about the issues involved;

12. Start mapping about two thirds of the way up the paper in the middle and try to keep concepts in small rectangles of text rather than as continuous lines of text (Eden and Ackermann, 1992).

When organized in causal maps, stakeholders' decision-making discourses can be used to generate a means-ends structure (**Figure 41**, based on Keeney 1996; Ackermann et al. 2004; Montibeller and Belton 2006). 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), as in **Figure 41** (The causal chain shown by the arrows in **Figure 41** represents a segment of the merged map built in our case study, see Section 4). In comparison with **Figure 23**, it is possible to realise that the structure in **Figure 41** resembles the LCA impact pathway. If the impact pathway is analysed with a strategic perspective (elements interpreted towards action), avoiding midpoint and endpoint impact categories might be operational and strategic objectives, respectively.

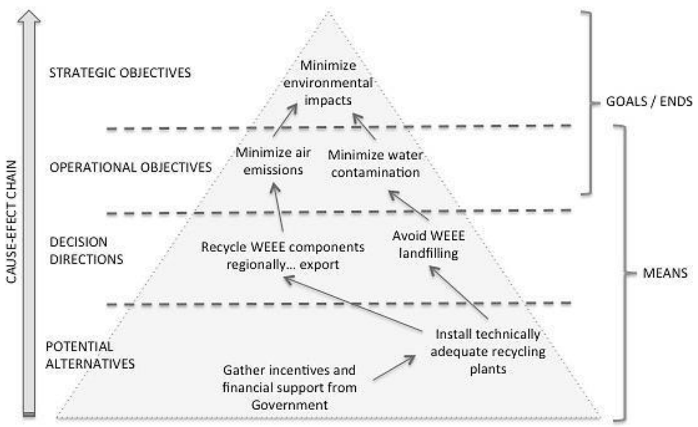


Figure 41. Structure of a causal map, case study Brazilian WEEE reverse logistics
Source: Souza et al. (2014)

One of the main contributions of causal maps is the support they provide for the selection of decision criteria. In order to assess decision alternatives, broader strategic objectives at the very top of the maps must be decomposed into more "operational" ones (Franco and Montibeller 2009), or broken into their "logical parts" (Keeney 1996). Such operational objectives are defined as *criteria* to measure the degree of attainment of the concern expressed by broader objectives. As such, they can be translated into performance indicators, and adopted as *decision criteria* to assess alternatives (Franco and Montibeller 2009).

Both the impact categories in the impact pathway (**Figure 23**), and fundamental and operational objectives in causal maps (**Figure 41**), measure the levels of good or bad *effects* provoked by lower-level decision alternatives, or, in LCSA, alternative systems with their respective inventory flows and emissions. The basic value of causal maps for LCSA is then to identify desirable and undesirable effects reflecting implicit or explicit issues of social and economic concern for the stakeholders.

Decision objectives can be translated into decision criteria to assess options. An adequate set of criteria needs to satisfy some desired properties, as presented in **Table 11**. This is also true for a set of LCA impact categories. Despite differences of terminology, there is a high degree of convergence between decision science and LCA main references, when it comes to the expected characteristics of a coherent set of decision criteria – or, in our case, the set of LCSA impact categories.

Table 11. Comparison of expected properties of a set of decision objectives and of LCA impact categories

Properties of decision objectives	**Properties of impact categories**
Essential: consider all essential objectives in the decision	Consider the essential objectives/goals
Understandable: clear meaning for all the members of the decision group	Comprehensive, internationally accepted
Operational: it should be possible to measure the performance of decision alternatives against each of the fundamental objectives	Measurement indicators represents aggregated endpoint impacts
Nonredundant: they should not measure the same concern twice	Avoid double counting
Concise: the smallest number of objectives required for the analysis	Only environmentally relevant categories
Preferentially independent: performance measurement of decision alternatives on one objective disregarding all other objectives, allowing for the use of an aggregation function	Aggregation of impacts

Source: Souza et al. (2014)

Because cognitive maps and the merged map are able to represent stakeholders' perspectives on a problem situation, they are usually adopted as tools to structure decision problems in order to analyse its complexity towards accommodations and decision-making. For this property, SODA is usually applied combined with other *hard* or *soft* methods. A common combination is between SODA and Soft Systems Methodology (SSM).

2.3.3. Soft Systems Methodology (SSM)

Another of the most widely used PSM is Soft Systems Methodology (SSM). Its main feature is the development of alternative models to represent the system from a range of different perspectives. Although dealing with the same problem situation, these SSM models will each describe a different set of processes seen as relevant from that particular perspective, and consequently different inputs and outputs, resources, actors and purposes. Traditional model-based waste management methods reflect only a few of the possible perspectives on the system. SSM can provide analysts and decision- makers with richer descriptions of the real-world system, allowing for a better understanding and assessment.

SSM operates by developing a set of models to be compared to the real situation, in order to stimulate debate about change. As defined by Checkland and Poulter (2006), SSM is "an organized, flexible process for dealing with situations which someone sees as problematical (…) an organized process of thinking your way to taking sensible 'action to improve' the situation, and, finally, it is a process based on a particular body of ideas, namely systems ideas".

Figure 42 illustrates the seven stages of an SSM application. It is in stage 2 (Rich Picturing) that SODA is usually combined to SSM. In more detail, SSM's steps 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 those Root Definitions, which serve as logical machines consisting of a set of the essential activities required to pursue the purpose specified in the Root Definition;
- Carrying out multilevel analysis, by detailing specific activities within a conceptual model as Root Definitions themselves, with their own subset of activities;
- Comparing activity models with the real-world situation, identifying critical differences and conducting debate about these possible changes (Checkland *in* Rosenhead and Mingers, 2001).

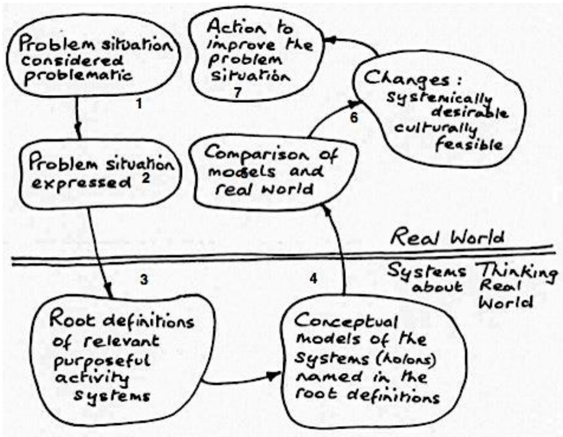


Figure 42. The SMM seven stages
Source: Checkland (2000)

In summary, the main elements in SSM are:

- A problematical real-world situation seen as calling for action to improve it;
- Models of purposeful activity relevant to this situation (not describing it);
- A process of using the models as devices to explore the situation;
- A structured debate about desirable and feasible change (Checkland and Poulter, 2006).

In SSM, potential strategies for a problem situation are described by *Root Definitions* (RD). SSM starts with the problem structuring into a *Rich Picture*, from which the analysts are able to identify purposeful activities systems with potential implementation in the situation. In the Figure 1, we present a Rich Picture for the problem of reverse logistics implementation in Brazil. The next step is the systems thinking phase, which is the description of RDs.

A *Root Definition* is a purposeful action (*holon*), structured as *human activity systems*, which might transform the perceived situation expressed in the *Rich Picturing* (where the problem in the real world is expressed). The core element of a RD, which allows for the conceptual modeling, is a *Transformation Process* (T) which best describes the purposeful transformation of an *entity* - the main input of T, not to be confused with the resources necessary for its transformation. These relevant purposeful systems are defined in the RDs, but modeled in *Conceptual Models* (CMs), where the Transformation T is detailed in its elementary activities (Checkland & Tsouvalis, 1997).

There are two different kinds of RD. *Primary task* RDs express a notional human activity system whose system boundary might be expected to coincide with real-world organizational boundaries, may these be the whole organization or some department or section. The second kind of RDs are *Issue-based*, so their boundaries do not in general coincide with a real world manifestation (Checkland & Tsouvalis, 1997).

The most effective way to describe a RD is by the analysis PQR, what means to describe the RD as “a system that does ‘P’ by doing ‘Q’ in order to achieve ‘R’. PQR ensures system thinking at three levels, placing T at the level of “system” or “what?”; its contributing activities as “sub-systems” or “how?”; and a “wider system” or “why?” which comprehends the system, at the level of its “owner” (Checkland 2000). Analysis of SSM RDs is detailed by CATWOE, which is an acronym for aspects of each RD that must be analysed and described: Clients (who receives the output), Transformation, World-view (what gives the RD a meaning to exist), Owner (who can make the system no longer exist), Environment (surrounding context). CATWOE can also be sometimes be adapted to BATWOVE, were Beneficiaries (B) or Victims (V) of the system are adopted instead of Clients (C).

The process of modeling RDs into Concept Models (CMs) is presented in **Figure 43**. It is done by using verbs to describe activities, and by assembling a handful of such activities structured in terms of logical dependency. The purpose of the conceptual model is notionally to accomplish what has been defined in the Root Definition

(Checkland & Tsouvalis, 1997). There must always be activities of monitoring and control of efficacy, efficiency and effectiveness (the 3 E's) criteria.

In order to gain clarity on the relevant purposeful activity which is being modeled in RDs and respective CMs it is stimulated to analyze the possible variations of T, and one way to do this is through *multilevel analysis* (Checkland, 2000). This involves a perception of a causal hierarchy through transformation processes and activities, in which a determined system describes 'what' has to be done, and a set of subsystems or activities describe 'how' this 'what' must be done. By moving the level of T up and down this hierarchy, we can reveal new possible RDs to be modeled, as much as we can better contextualize the RDs actually being modeled.

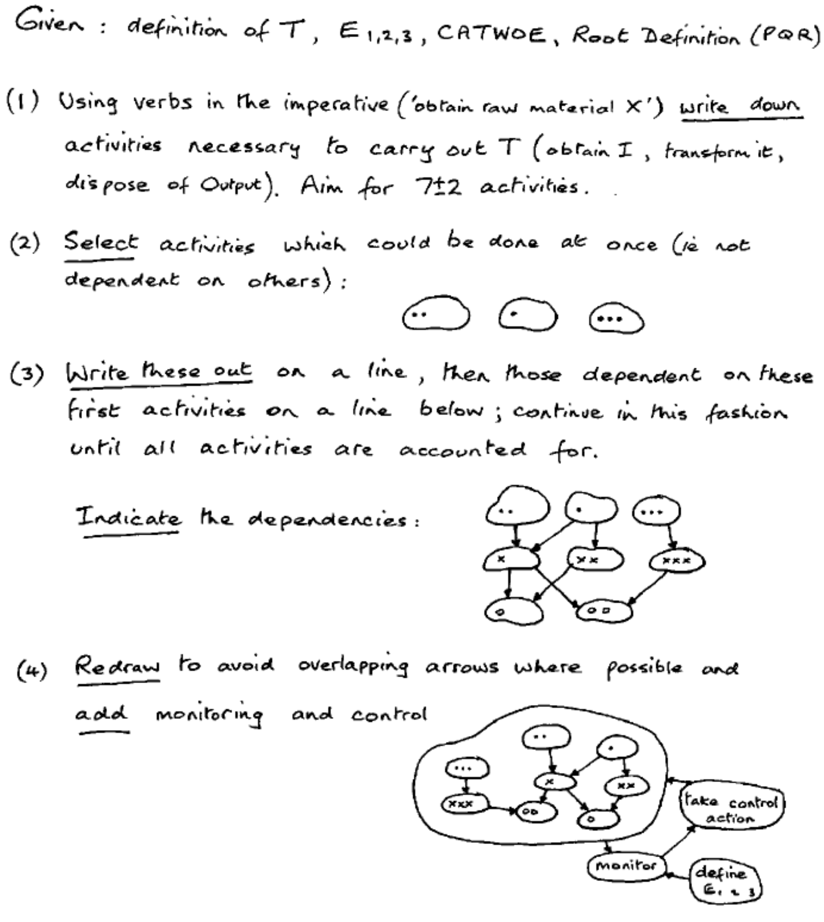


Figure 43. Modelling Root Definitions into Concept Models
Source: Checkland (2000)

A common problem in SSM may appear in the multilevel analysis or even before it: the fact that different CMs may be modeled for the same RD. As explained by Mingers (1990) *apud* Checkland and Tsouvalis (1997), "there can be no single, logically determined expansion of and RD – any CM must involve some selection from valid alternatives". Schregenberger (1982) *apud* Checkland & Tsouvalis (1997) explains this occurs because while RDs express 'macro-activities', CMs are representations of abstract stored knowledge, which can vary from one person to other. This way, we cannot expect CMs to behave deterministically. According to Checkland and Tsouvalis (1997), the 'relevant' systems are selected following a particular world view, what allows for multiple possible interpretations of the purposeful activity. Hence it is normal to work with a number of models, not a single one.

If there can be CM variations, such that each of them receives the same main input and produces the same main output, so there might be *alternative* CMs, what means that they are alternatives for the same transformation and purpose (or '*Weltanschauung'* is SSM). Woodburn (1995) *apud* Checkland and Tsouvalis (1997) suggests activities in a model must be connected in such a way that the next activity needs to receive the output produced by a former one. By multilevel analysis, each of these activities may be modeled as new RDs, with their own set of activities, so *alternative* CMs may have very different configurations, while producing the same transformation of an input into an output.

SSM can be a useful tool to support system modelling in LCSA, and thus helping in the definition of foreground and background systems, identification of their functions and flows, as well as a richer description of the systems by CATWOE and other SSM analysis. A comparison of SSM CMs and LCA product systems is illustrated in **Figure 44**.

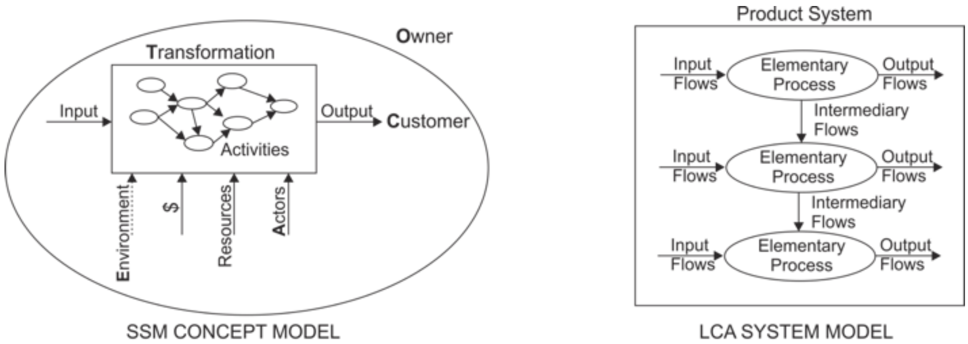


Figure 44. Comparison of SSM CMs and LCA product systems

Source: Authors

2.3.4. Multimethodology: combining "Soft" and "Hard" Operational Research methods

Some decades after showing up in the 1940 years, Operational Research (OR) was a research area still restricted to approaches that use mathematical models for performance assessment, simulations and projections of future scenarios. However, in the past decades a new OR area emerged, which takes care of more subjective aspects involved in the perception of complex decision contexts. The first, traditional OR area can be called *Hard OR*, while the second is called *Soft OR*, which includes PSM. In Figure 45, Checkland (2000) illustrated the difference of OR Hard and Soft. In the first, the analyst sees the world systemically, and identifies a system in which specialized engineering will be applied. In Soft OR, the analyst sees complexity, but searches for a systemic approach to explore such complexity.

Although in most researches these streams have been approached independently, lately researchers have found means of combining different Hard and Soft OR methods, exploring their potentials in an integrated frame. Mingers (2010) explains that usually problems related to situations in the real world are complex and have diverse dimensions – technical, social and personal. Thus, projects normally go through diverse stages, in which determined methods can be more appropriate than others. The author also mentions that methods can be used in many ways, i.e. they can model situations in different dimensions.

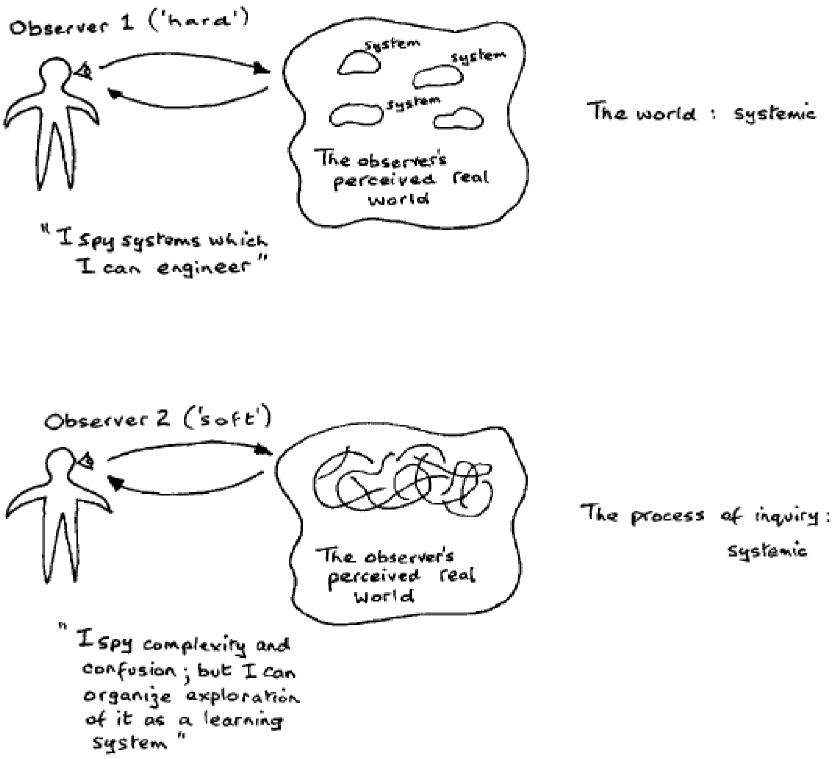


Figure 45. *Hard* OR versus *Soft* OR

Source: Checkland (2000)

Multimethodology corresponds to the use of multiple methods to approach a complex problem in the real world. It is a deliberate search to combine a diversity of methods, possibly hard and soft, in search to equate the richness of the problem situation and effectively deal with the different stages of a project (Mingers, 2010). Mingers (2010) presents some arguments for the use of multimethodology:

- Each method reveals certain aspects of the situation, but is completely blind to others. These aspects can be found in the material, social or personal world;
- An OR Project is not a discrete event, but a process that has diferente stages or different types of activities prevailing in different times. Particular methodologies and techniques are more useful in some stages than in others, so a combination of approaches can be necessary to provide a reasonable result.

As mentioned, different methods can be more applicable each to a determined stage of a project. According to Mingers (2010), the four stages of an OR project are:

- *Perception* of the situation as experienced by involved actors and expressed by participants in the situation. This involves an initial identification of concerns to be approached; conceptualization and design of the study; and generation of basic data using methods such as observation, interviews, experiments, surveys or qualitative approaches;
- *Analysis* of the produced information allowing to comprehend and explain why the situation is as it is. What are the fundamental structures and constraints that shape the situation? This involves methods for analysis that are appropriate to the objectives of the intervention and to the information produced in the first stage;
- *Assessment* of possible explanations and potential changes to the situation. This involves generating alternative arrangements or courses of action and an evalauation of them being desirable and feasible;
- *Action* to bring changes, if necessary or desirable, or to relate and disseminate results if the project is merely research (Mingers, 2010).

According to Howick and Ackermann (2011), there are different ways to combine OR techniques:

- Direct comparison of methods;
- Improve a method by bringing elements of other method;
- Creation of a new method by integrating elements from different methods;
- Combination of entire methodologies; and
- Combination of partitioned methodologies (Howick and Ackermann, 2011).

Howick and Ackermann (2011) identified a large number of combinations of a complexity of OR methodologies, such as SODA, SSM, Data Envelopment Anaysis (DEA), MultiCriterial Decision Analysis (MCDA), Data Mining and many others.

Franco and Montibeller (2010) presented diverse tools (including PSM) that can be applied to different stages of an MCDA model. A summary of these activities and their respective PSM applicable is shown in Table 12. In this research we do not emphasize

MCDA methods and applications, but we consider sustainability as a multicriteria decision problem, as it involves several social, environmental and economic criteria that lead to a decision.

Table 12. Tasks and tools for structuring MCDA models

Phase 1: Problem Structuring		
Activity	Task	Supporting tools
Defining the Problem	Capture the different understandings about the multicriteria problem and facilitate a definition of the problem that is shared by the client (or client group).	Cognitive mapping; Dialog mapping; SSM; Strategic Choice Approach (SCA); Group model building; Decision framing
Scoping participation	Determine the type and level of participation of different stakeholders required for the intervention.	Power-interest grid, star diagrams e stakeholder influence diagrams; stakeholder-issue interralation diagram and problem-frame stakeholder maps
Phase 2: Structuring the MCDA Evaluation Model		
Activity	Task	Supporting tools
Structuring Value Trees	Organize the objectives to be considered in the evaluation as a hierarchy.	Top-down or bottom-up approaches; Checklist and grouping of ideas; Means-ends objective networks; Cognitive maps; Qualitative influence diagrams; Checklist of properties for a value tree
Defining Attributes	Specify, for each bottom level objective in the value tree, an associated attribute.	Keeney's and Gregory's decision model for selecting attributes and Parnell's preference ranking for selecting attributes; Kirkwood's classification of attributes and guidelines for their development; Checklist of properties for an attribute
Identifying Decision Alternatives	Define/identify/create decision alternatives to be assessed by the MCDA model.	Brainstorming; Laddering-down in a cognitive map; Dialog maps; Focus on the objectives to be achieved; Ideation techniques; Strategy tables; Analysis of interconnected decision areas

Source: Franco and Montibeller (2010)

In case of problems involving a group of decision-makers, Franco and Montibeller (2010) argue it is not enough to choose best PSM techniques to integrate with MCDA. It is necessary that the analyst have ability to facilitate processes in group, regarding the definition of the problem, once they are influenced by power and interests of stakeholders. The authors also point out other challenges for this branch of multimethodology:

- Development of Problem-Structuring Methods. While the field of problem-structuring methods (PSMs) is already well-established in management science, more research could be conducted on tools that could be tailored specifically for MCDA interventions;

- Integrated Use of PSMs. The use of standard PSMs with MCDA requires transitions from a problem-structuring model to a multicriteria decision analysis model, which may prove challenging. Consequently, a direction of research is the development of methods that could provide a seamless transition. The reasoning maps method and the use of means objectives to assess the performance of decision alternatives on fundamental objectives are examples of research in this direction;
- Tools for Supporting Structuring MCDA Tasks. The paper reviewed some tools that could be employed for structuring value trees, defining attributes and identifying decision alternatives. The development of new tools is, however, still a potentially area of research—particularly if it were based more on psychological aspects [e.g., how to spark off creativity when creating alternatives; how to identify/display complex options to a group of decision makers (Franco and Montibeller, 2010)

2.3.5. Example of a multimethodology application combining SSM and DEA

A multimethodology application of particular interest to this study is the combination of SSM with DEA (a "hard" OR method). Mingers et al (2009) developed an application and detected there is good potential for combining these methods together. According to the authors, SSM is relevant to determine, in a comprehensive and systemic approach, indicators to be further evaluated by DEA. This study is particularly relevant also for LCSA applications, as it shows how SSM can support the definition of system models, inventory flows and performance indicators, as illustrated in Figure 46.

Mingers et al (2009) state there are determined links between SSM and DEA that are based in the perception of *inputs-transformation-outputs* (system modelling) and in the three 'E' (Efficacy, Efficiency and Effectiveness), which are part of the SSM methodology. However, they inform there is still need for researches to develop aspects of this combination of methods (with particular interest to an SSM-LCSA combination):

- Develop SSM in terms of input/resources distinction and the value-added versus absolute outputs distinction;

- In combination with DEA, using several SSM models each representing different viewpoints about the nature and purpose of the operational unit under consideration, for example different views on the type of education a school should provide;
- Developing better ways of moving from the specification of a wide range of possible performance indicators to the smaller subset to be used within the DEA modelling;
- Also within DEA, consider the difference between efficacy and effectiveness. Should DEA consider two levels of efficiency, operational efficiency in terms of the direct outputs of the process (efficacy/resources), and strategic efficiency in terms of the achievements of the objectives of the wider system (effectiveness/resources)? (Mingers et al, 2009).

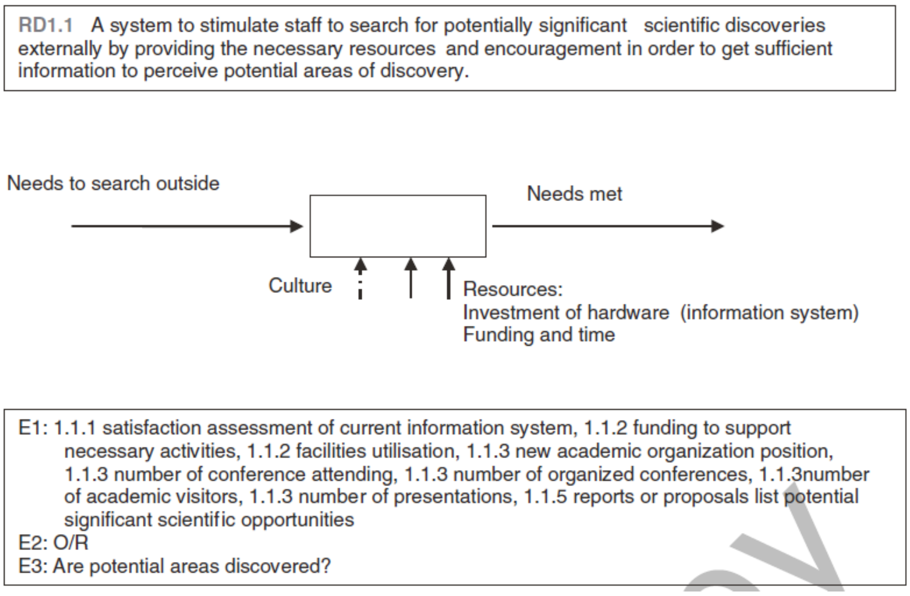


Figure 46. SSM Root Definitions as a support to define performance indicators

Source: Mingers et al (2009)

2.3.6. Potential for multimethodology applications in sustainability problems

Sustainability and its related problems can be considered complex social problems. Therefore, this is a challenging field for multimethodology approaches. Scoones et al (2007) state that a critical point for the sustainability of complex dynamic systems, such as waste management, in the comprehension of their dynamic and interactive processes.

The authors suggest a rigorous and systematic approach can support this comprehension, and also provide a useful guide to action, indicating potential routes for reaching sustainability. According to these authors, a good sustainability quality, defined by the long-term maintenance of the equity, well-being and environmental quality functions, depends on four internal and external properties of systems:

- *Durability* under internal pressures;
- *Robustness* under external pressures;
- *Stability* against internal shocks; and
- *Resilience* against external shocks (Scoones et al, 2007)

One of the stages for such rigorous and systematic approach as suggested by Scoones et al (2007) consists in *identifying how the systems respond to internal and external changes,* what is rather similar to the *consequential* LCA approach. For this identification, a previous stage is to establish a *general framework of the dynamism and socially built complexity*. This general framework can be characterized by a variety of contexts of system-environment (Figure 47). This means that the complex reality is represented by different contexts of interactions of the system within its environment, according to different perspectives. These perspectives must reflect aspects such as: expected results; impacts of changes; impacts of shocks and tensions; and the trade-offs between internal and external properties of systems (Scoones et al, 2007). Such representation of the complex reality of systems according to different perspectives is one of the main features of PSM. Scoones et al (2007) recommend a last stage of *negotiating sustainability*, which consists in opening debates in governance systems, for a scientific analysis of contexts, systems and their properties. Once again, this is a decision-making process that can be facilitated by PSM, especially SODA individual and merged maps.

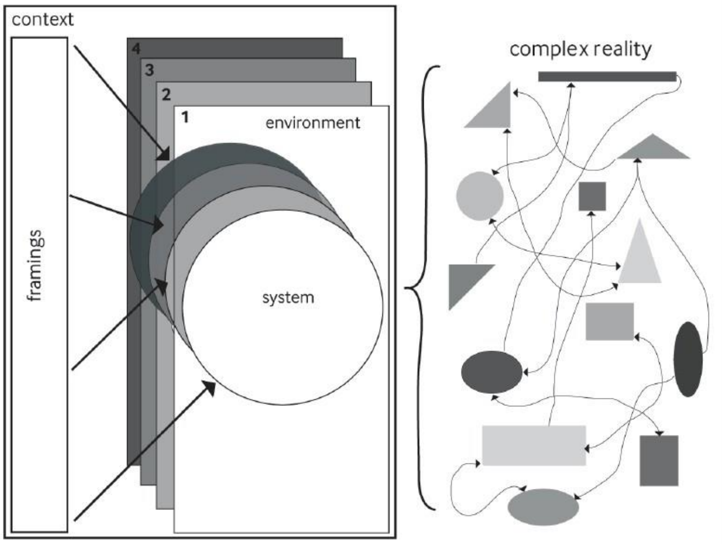


Figure 47. Representation of the complex reality in different contexts of the system within its environment
Source: Scoones et al (2007)

Similarly to OR, Scoones et al (2007) argue that, as a response to the challenges of dealing with complexity, there is in researches a transition of perceptions, from the approximation of "equilibrium" (similar to Hard OR models) to the "complex systems of non-equilibrium" (basis for Soft OR). The authors argue that these visions are mutually excluding but complementary and interactive. They introduce a posterior change called "reflexive turn", where a constructivist approach is adopted to comprehend the systems and their structures, properties and functions, focused in political and normative perceptions of sustainability. Table 13 presents a comparison of these three approaches.

Table 13. Schema of approaches to understanding sustainability

	A **'Equilibrium' approaches**	**B** **'Non-equilibrium', 'complex systems' approaches**	**C** **The reflexive turn: pathways to sustainability**
Key features	Linearity, predictability, homogeneity, simplification	Non-linearity, complexity, heterogeneity, uncertainty, ambiguity, ignorance, surprise	Multiple possible framings/constructions of the 'system'
System organisation	Single level, social dimensions separable – closed, 'hard' systems	Multiple scales, hierarchy, interaction, integration	Multiple framings of system and contexts
Models and methods	Equilibrium models, normal distribution based statistics, controlled experimentation, valuation/audit/CBA	Open experimentation, interactive modelling, adaptive learning, trialand-error, non-standard distributions and statistics, open-ended appraisal	Scenarios, multicriteria mapping, pathways analysis

Fonte: Scoones et al (2007)

2.3.7. Some OR applications in sustainability-related problems

Some OR studies have been development in the environmental area. Merrick (2010) describes a study aimed at maximizing the water quality of a certain watershed. They consulted specialists, and in a subjective analysis potential strategic objectives were identified and structured in a hierarchy. These objectives were defined as decision criteria, and an MCDA model was used to approach the problem.

Mingers and Rosenhead (2004) applied Strategic Choice Approach (SCA) combined with Robustness Analysis to support planning decisions of the Venezuela Government, after the occurrence of catastrophic flooding and landslides in the state of Vargas. The authors also mention the use of multimethodology to manage natural resources (SSM + non-equilibrium ecology); management of a lake (SSM + DSS); and rationalization of energy (SSM + QQT).

Specifically regarding waste management, Souza et al (2011) applied concept maps and DEA to compare waste collection services of Brazilian cities. Souza et al (2013) and Souza et al (2014) applied SODA and SSM combined with LCSA to the case of Brazilian WEEE reverse logistics.

2.4. WEEE reverse logistics and the Brazilian National Solid Waste Policy

Waste Electric and Electronic Equipment (WEEE) reverse logistics is established as mandatory by the Brazilian National Solid Waste Policy (PNRS) from 2010. In PNRS (2010), reverse logistics is defined as an "instrument for social and economic development characterized by a set of actions, procedures and means focused on enabling the collection and delivery of solid waste to the business sector, for recycling, in theirs or other production cycles, or for environmentally sound final disposal". PNRS determines that responsibility for planning and implementing such systems is shared by manufacturers, importers, distributors and retailers. Representatives of these stakeholders groups are required to submit proposed models for the WEEE reverse logistics systems, to be approved by the Ministry of Environment and selected by a Commission. After approval, those stakeholders and the Federal Government must sign a *Sectoral Agreement*, a contract that specifies procedures and roles for Brazilian WEEE management. More restrictive sectoral agreements can be signed at the regional level, led by Brazilian states governements.

PNRS also adopts the principles of polluter-pays and shared responsibility for the product life cycle. This makes other actors such as consumers, waste pickers and their cooperatives, private companies and municipalities legally responsible for their specific roles within WEEE systems. Their organised representatives can also take part in decision-making about the sectoral agreement.

This complexity of actors necessarily implies a complexity of interests, expectations and concerns, which in turn will be reflected in a variety of expected goals and impacts (and possibly conflicting interests). WEEE reverse logistics, then, can expect to face a range of accommodations between social, economic and environmental criteria.

2.4.1. A preliminary model for Brazilian WEEE reverse logistics

Before issuing a public call for sectoral agreements, the Brazilian Government established a Thematic Task Group (GTT), with the aim of assessing the technical and economic feasibility of WEEE reverse logistics systems in Brazil. The GTT members were the same representatives required for sectoral agreements. In order to achieve their goal, the GTT had several meetings where they discussed their different perspectives on the problem, some critical issues and the interpretation of some benchmarking cases. In the end, the GTT hired a consultancy company to develop a preliminary model for feasibility assessment.

Although the methodology adopted by the consultants involved a series of interviews of stakeholders, it was unclear how they structured and analysed those interviews to generate inputs for the system modeling. However they emerged with a set of nine decision variables, each with corresponding alternatives (**Table 14**). After discussing and categorizing benchmarks according to the variables, the consultants proposed a final model, represented by the selected alternatives from the options in **Table 14**.

Based on our previous theoretical discussion, we can sketch some critiques of this suggested model, and the methodological steps through which it was derived. Firstly, although carrying out a series of interviews, the decision-making both for the modeling method and for the model itself was centered on the consultancy company. Stakeholders behaved more as clients hiring for a ready solution, rather than as participants in a decision-making process, and secondarily as sources of data rather than as sources of knowledge on the problem situation.

Secondly, this is not a valid system model. The selected alternatives do not describe specific processes needed to obtain each desired outcome. There is no specification on "how" the system should be configured in order to accomplish its tasks. Some activity models (SSM's CMs) can, for example, specify the activities needed to adequately accomplish "defining recycling targets", the chosen alternative for variable C in **Table 14**.

Finally, there is no clear description of the transformations carried out by the suggested model. What are the inputs and outputs for the system? What is being transformed, and how? In general, the model does not make clear what are the main products or services delivered by the system. The report mentions "targets", but how are those targets intended to be developed, without having clarity on what is being processed (WEEE, workforce, information, financial resources…)? SSM could be an appropriate approach to generating understanding of those resources flows, and to developing indicators for performance assessment (see Mingers et al, 2009).

Table 14. Decision variables and alternatives considered in the study hired by the WEEE GTT

Variables	Alternatives (* = Selected)
A. Sources of funding	1. Taxes; 2. Manufacturer/importer; 3*. Shared costs
B. Responsibility for "orphan" WEEE	1*. Public administration; 2. Manufacturer/importer
C. Targets for recovery and recycling	1. No targets; 2*. Recycling targets; 3. Recovery and recycling targets
D. Level of responsibility of the public administration	1. Legislator, regulator and supervisory; 2*. Active; 3. Operator
E. WEEE classification	1. Commodity; 2*. Non-hazardous waste; 3. Hazardous waste
F. Reuse within the system	1. Not stimulated; 2. Estimulated via campaigns; 3*. Enabled by the system
G. WEEE segregation according to brands	1. With segregation per brands; 2*. Monitoring and sampling; 3. Without segregation per brands
H. Proportional responsibility for WEEE	1. Individualized; 2*. Proportional
I. Competition model	1. Monopoly; 2*. Competitive (diverse management entities)

Source: ABDI (2013)

The official reverse logistics model to be implemented in Brazil is to be announced by the Ministry of Environment by August 2014. In November 2013 the public call for WEEE sectoral agreement received four proposals, which are to be evaluated by the Ministry of Environment in order to define the final model.

2.4.2. WEEE targets in the Brazilian National Plan for Solid Waste

In 2011, the Ministry of Environment issued a preliminary version of the Brazilian National Plan for Solid Waste, mandatory in PNRS, for public consultation. It does not define specific targets for WEEE reverse logistics, as in that time this depended on on-going studies. Such targets are to be defined by the Sectoral Agreement.

2.4.3. WEEE reverse logistics in the Rio de Janeiro State Plan for Solid Waste

By stimulus of the National Policy, the Rio de Janeiro State developed its Solid Waste Management Plan, elaborated by a consultancy company. This plan determines that WEEE delivery stations are to be made available by municipalities. Their mandatory selective collection systems can also be adopted for WEEE delivery. WEEE delivered in these channels has to be sorted by cooperatives at Sorting Stations, in order to gain scale and get transformed into secondary raw material for further commercialization or adequate treatment (**Figure 48**). The Plan also defines the creation of regional-scale Sorting Stations, which will receive WEEE from the municipal ones gaining more scale. They must be implemented under the responsibility of Public Consortiums joining municipalities within same regions in the RJ State. The Plan also determines that choice of implementing recycling plants as an alternative for WEEE transportation to other states must be defined based on environmental assessment and environmental accounting. In terms of governance, the Plan determines the involvement of consumers (information and transparency about products' environmental performances and correct procedures for WEEE disposal), NGOs (identification of problems and solutions), manufacturers, importers, distributors and retailers (recycling strategies and innovation). There is no clear definition on the role of the State within this chain, and an excessive transfer of responsibilities to municipalities, what is always a questionable strategy in Brazil due to their lack of resources and inability to manage complex systems. As for the system described in 2.4.1, it is not explained how the suggested model was defined, what are its performance criteria and how to implement it in practical terms. The plan determined a target for 2013/2014 when all municipalities must have an implemented program for WEEE reverse logistics. The target for WEEE collected by the system in the same period is 40% of the total produced, planned to reach 100% in the medium-term period (2019-2024) and further.

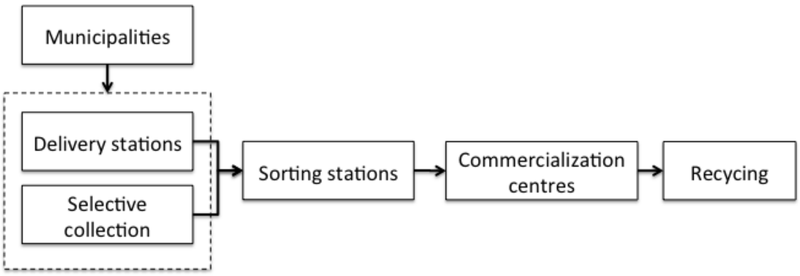


Figure 48. Generic reverse logistics model defined in the RJ Solid Waste Plan
Source: Based on Cobucci et al. (2013a)

The RJ Plan also defines indicators to monitor the WEEE targets. These are presented in **Table 15**. As seen, this is a very poor set of indicators, which does not translate all complex aspects regarding sustainability of WEEE systems. The authors of this Plan have certainly not analysed deeply the involved sustainability aspects, rather focusing on political concerns of WEEE reverse logistics implementation in all RJ municipalities.

Table 15. Targets and indicators for WEEE reverse logistics in the RJ Plan

Target	Indicator
Implemented reverse logistics systems	No. of municipalities with implemented reverse logistics systems
WEEE takeback to responsibles	No. of municipalities covered by reverse logistics
Implementation of a program for WEEE collection	No. of municipalities with implemented WEEE program

Source: Cobucci et al. (2013b)

3. METHODOLOGY

The methodology for this research is illustrated in **Figure 49** and explained in sequence. It consists of five phases: A. gathering of background knowledge; B. (part of) SODA; C. (part of) SSM; D. (part of) LCSA; and a fifth and constant phase of E. interpretation and discussion. These phases describe a qualitative approach for analysing stakeholder perspectives; whilst this is a systemic approach, it still requires a certain level of subjectivity, what is minimized by iterative validation steps with stakeholders.

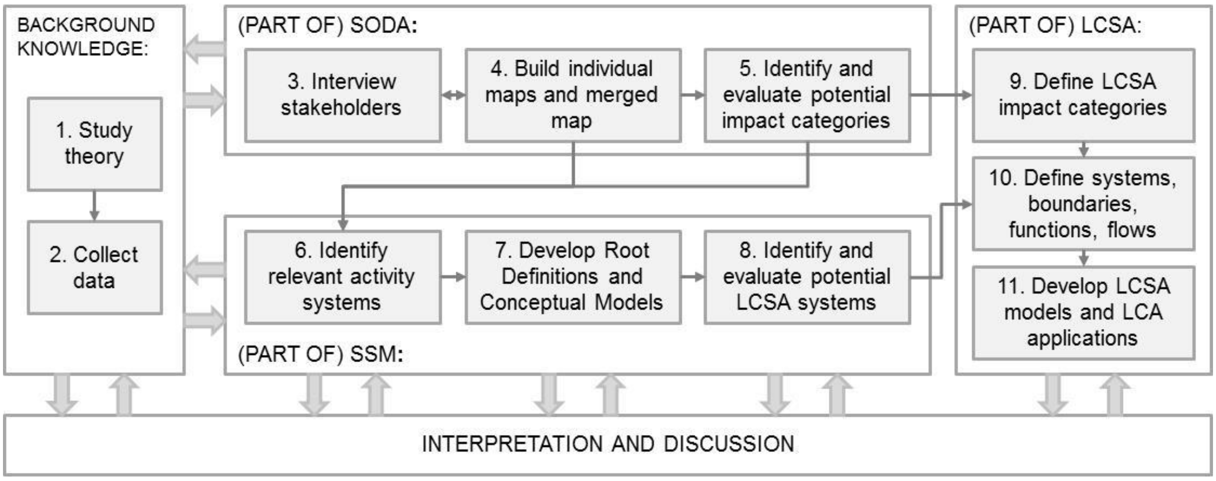


Figure 49. Research methodology

Gathering *background knowledge* consisted in: 1. the study of theory; and 2. the collection of data for the methodology application in a case study. Study of the theory covered reference literature, laws, standards and courses regarding the main scientific topics of this research: Brazilian WEEE reverse logistics; LCSA, LCA, LCC and SLCA; Decision Science and PSMs. We also collected data in visits to WEEE reverse logistics units and consultation to specialists in Rio de Janeiro, Sao Paulo and in Europe.

The case study for the application of the methodology is the development of WEEE reverse logistics systems to be implemented in Brazil, with focus to the Metropolitan Region of Rio de Janeiro (RMRJ). We searched for an overview of the current chains for WEEE generated in the RMRJ. Data collection of the case study covered: specific regulation; relevant actors; current flows and processes; available alternatives to be implemented. Additional data was collected from databases such as EcoInvent for LCA parameters and scientific literature for impact categories and models of WEEE management. In order to track the current WEEE chain in Rio de Janeiro, we also investigated all identified environmental licences of companies in the State that declared their main activities to be related to waste management (collection, treatment, transport, recycling, commercialization), or that received WEEE from big companies, as declared to the State Secretary of Environment in their Waste Inventories. We also made several visits to Government departments and WEEE facilities in the RMRJ and in Europe, registered in pictures and many times with guidance of specialized staff. The researcher has also worked for a week as a WEEE dismantler in an Austrian social enterprise for WEEE dismantling called *Demontage und Recycling Zentrum* (DRZ) in order to map processes, make interviews and collect data. The WEEE facilities in the RMRJ were two units of a State government project called *Fabrica Verde*, in which young people from favelas are selected and offered a 3-months training in computers refurbishment. Another WEEE facility was the unit of a waste pickers' cooperatives called COOPAMA, who acts in WEEE collection, dismantling and commercialization in the RMRJ. They often receive WEEE other than reusable computer components from Fabrica Verde, who has been facing huge demand from large WEEE producers to collect and give destination to all kinds of WEEE. COOPAMA has also received part of the WEEE collected by a State campaign called *Christmas of the Eletrorecycling.*

We identified and interviewed (task 3), either personally, by email or Skype, representatives of stakeholder groups directly related to the case study, and also specialist in related themes. The choice of interviewees was based on the previous theoretical review, and complemented with personal indications by stakeholders and specialists. The group of interviewees should preferably comprehend representatives of all pressure groups identified in the case study. All personal and Skype interviews were taped and typed, in order to allow for further detailed analysis. Email consults were recorded as digital files. Questions to stakeholders should be formulated preferably using "why?" to identify effects, and "how?" to identify causes of determined issues of concern (Keeney 1996). This facilitates the construction and iterative analysis of cognitive maps. In this research, interviews usually started with the questions: "what are key issues in planning Brazilian WEEE systems?"; and "what would describe a sustainable Brazilian WEEE system?". These allowed interviewees to explain broadly a range of different aspects that regards to the object of study. Key issues presented in responses for these questions were then explored by questioning: “why is this issue important?”. This induces following answers to focus in naming and explaining relevant “top” strategic issues, what are important for the purposes of this study. We then asked “how does issue ‘A’ relate do issue ‘B’?”, in search to get detailed explanations on potential cause-effect chains between each pair of relevant identified issues. Roadmaps for some of the interviews carried out in this research are presented in Appendix 1.

Second stage of the methodology is an application of a *part of SODA*, consisting on analysing the series of interviews with stakeholders and specialists for the development of individual cognitive maps (task 4, only for stakeholders) and the final merged map (task 5). This last combines the top (hierarchy level) issues of concern identified in stakeholders’ maps, as well as their identified connections with further explanations by stakeholders and specialists. All maps were built by using the software Compendium, which was developed by NASA. By analysing the cause-effect hierarchy of these maps it is possible to execute task 6 - identify potential strategic objectives (on the top, receiving arrows), which can be reinterpreted as potential LCSA impact categories. In this sense we assume the hypothesis that the most complete is the group of interviewed stakeholders and respective maps and the most complex is the problem, the more likely is the merged map to express major concerns in all three sustainability areas. The potential impact categories are analysed and redefined in a round consultation to stakeholders individually, in order to obtain a final set of LCSA impact categories that fits best to the following properties:

- Essential: consider all essential objectives in the decision;
- *Understandable*: clear meaning for all the members of the decision group;
- *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: the smallest number of objectives required for the analysis;
- *Preferentially independent*: performance measurement of decision alternatives on one objective disregarding all other objectives, allowing for the use of an aggregation function (Franco and Montibeller 2009).

SODA maps are also used in substitution to the rich picturing stage of SSM. In our methodology we applied a *part of SSM* consisting of the identification of potential relevant activities from SODA maps (task 6), which were further described as Root Definitions and modelled by systems thinking (task 7). These systems are analysed in order to identify potential LCSA product systems (task 8), their possible scope, functions, flows, functional units and reference flows.

Both the potential impact categories identified by the use of SODA and the product systems modelled with the support of SSM were analysed and redefined with stakeholders in order to structure an initial LCSA model for the case study. This model, comprehending the final impact categories (task 9) and potential alternative systems for comparison (tas 10), is interpreted and discussed, based on literature references and other similar studies in the area. The LCSA model was also structured as an MCDA performance table (task 11, Table 16), followed by a discussion on the main features and rules for the application of multicriteria methods in this LCSA study.

Table 16. Structure of a generic MCDA performance table applied to LCSA studies

Alternative systems	Impact Categories		
	Social	Economic	Environmental
Current system	Performances of each system in each qualitative/quantitative indicator		
Alternative system 1			
Alternative system 2			
…			
Alternative system n			

The main expected products of this research are: a methodology to combine PSMs and LCSA; LCSA impact categories and alternative system models for the case study, and an MCDA model to support decision-making on defining the WEEE reverse logistics system to be implemented in Brazil.

4. RESULTS AND DISCUSSION

4.1. Background knowledge: current WEEE chains in Rio de Janeiro Metropolitan Region

In this Section we describe briefly the results from our investigation of current WEEE flows in the RMRJ. It is based on the interpretation of data collected from technical reports, visits in site, interviews and environmental licenses.

4.1.1. Estimates of WEEE generation in Brazilian regions and in the RMRJ

There is no formal data quantifying WEEE generation in Brazil and its regions. In order to calculate estimates for WEEE generation and have a better notion on the necessary dimension of WEEE systems, we adopted the method based on the correlation of WEEE generation and GDP per capita discussed in Section 2.1. We also adopted the same regression equation calculated by Huissman et al (2005), based on the analysis of European countries (**Figure 1** in Section 2.1). In **Figure 50**, we present results for these estimates, comparing municipalities from the RMRJ and the largest cities of each Brazilian region: Sao Paulo (Southeast); Brasilia (Center-West); Curitiba (South); Manaus (North) and Salvador (Northeast). According to these estimates, only Sao Paulo generates more WEEE in Brazil than the RMRJ. We can see that the city of Rio de Janeiro has significant contribution to the total WEEE generated in RMRJ, while the second city in terms of relevance for this region is Duque de Caxias. When it comes to WEEE generation per capita (**Figure 51**), we can see that Brasilia and Sao Paulo account for the highest rates with Rio de Janeiro and Curitiba in third place, what is a reflection of GDP per capita in these cities (the Federal District and the two biggest cities in the country). In **Table 17** we present all data used for this calculation. In order to get GDP values in US$ as applicable to the regression equation, we obtained GDP figures in Brazilian Reais (R$) and adopted the average of official conversion rates to US$ in all years of 2011 (same year as for GDP data). We consider these estimates reasonable, for two reasons: first, that the overall WEEE generation estimated for Brazil (1.4 million tonnes in 2011) is not far from the value calculated by STEP (2013) based on the Purchasing Power Parity of countries (1.36 million tonnes in 2012). Second, that this overall estimate for Brazil adopts a method with lower uncertainty than the Market

Supply method (Section 2.1), because it is based on a direct correlation of two variables of which one is known. We consider better results would arise from the correlation of WEEE with PPP (no data for Brazilian cities) rather than GDP.

These estimates can serve as a reference for modelling WEEE systems for the RMRJ, as well as providing a notion to support modelling of WEEE systems in a wider scale in Brazil. Such information is crucial in determining the capacity of formal WEEE chains to be implemented, and also grasping current flows along different available chains in the RMRJ.

4.1.2. Current WEEE chains identified in the RMRJ

In our data collection, we identified a range of alternative courses that have been adopted to absorb WEEE generated in Rio de Janeiro. They are summarized in Figure 52.

As discussed in Section 2.1.3, a considerable share of WEEE generated in the Rio de Janeiro Metropolitan Region (RMRJ) is being sent mixed to household waste, what ends up in the metropolitan landfill, or being deviated by workers at waste transfer stations and inserted within the informal sector. Figure 53 represents a Sankey diagram of this household waste system managed by COMLURB (Municipal Company for Urban Sanitation). Most mixed waste goes through transfer stations (ETR) to a sanitary landfill (AS) in Seropedica, while waste collected in AP 5 goes to a controlled landfill (AC) and a very small volume of compost in produced in ETR Caju for reforesting. An LCA model of this chain is shown in Appendix 2.

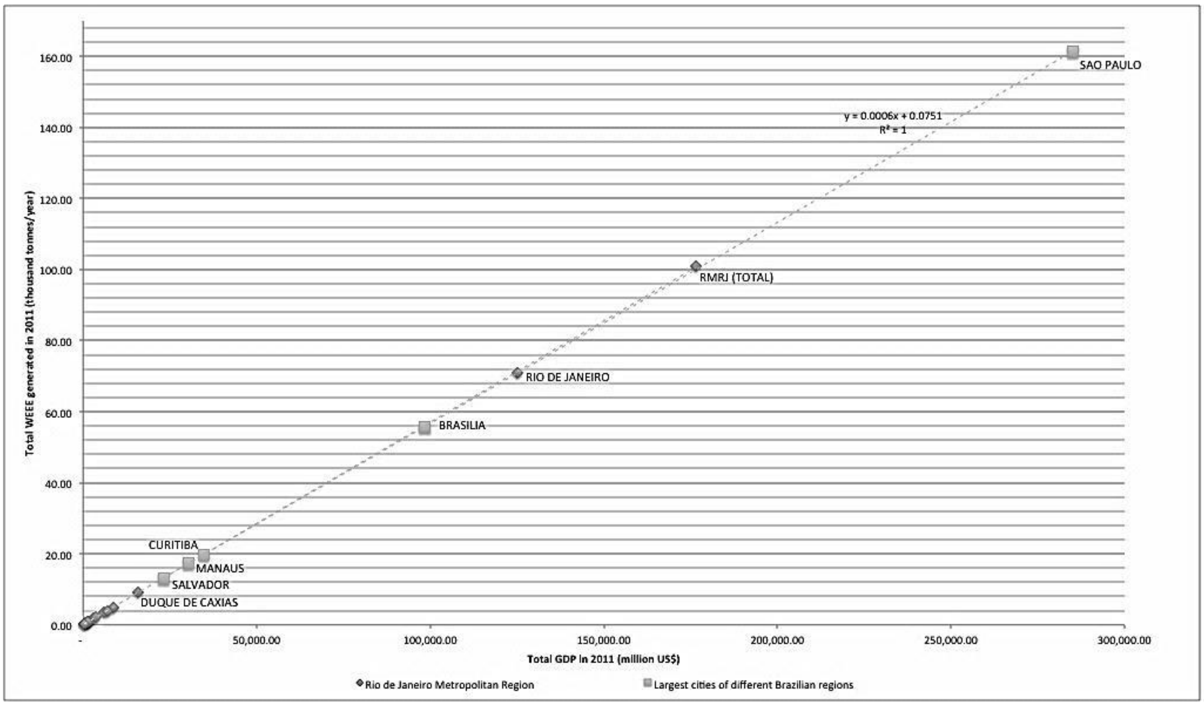


Figure 50. Estimates of WEEE generation in the RMRJ and biggest Brazilian cities in 2011

Source: Authors based in IBGE (2014) and The World Bank (2014)

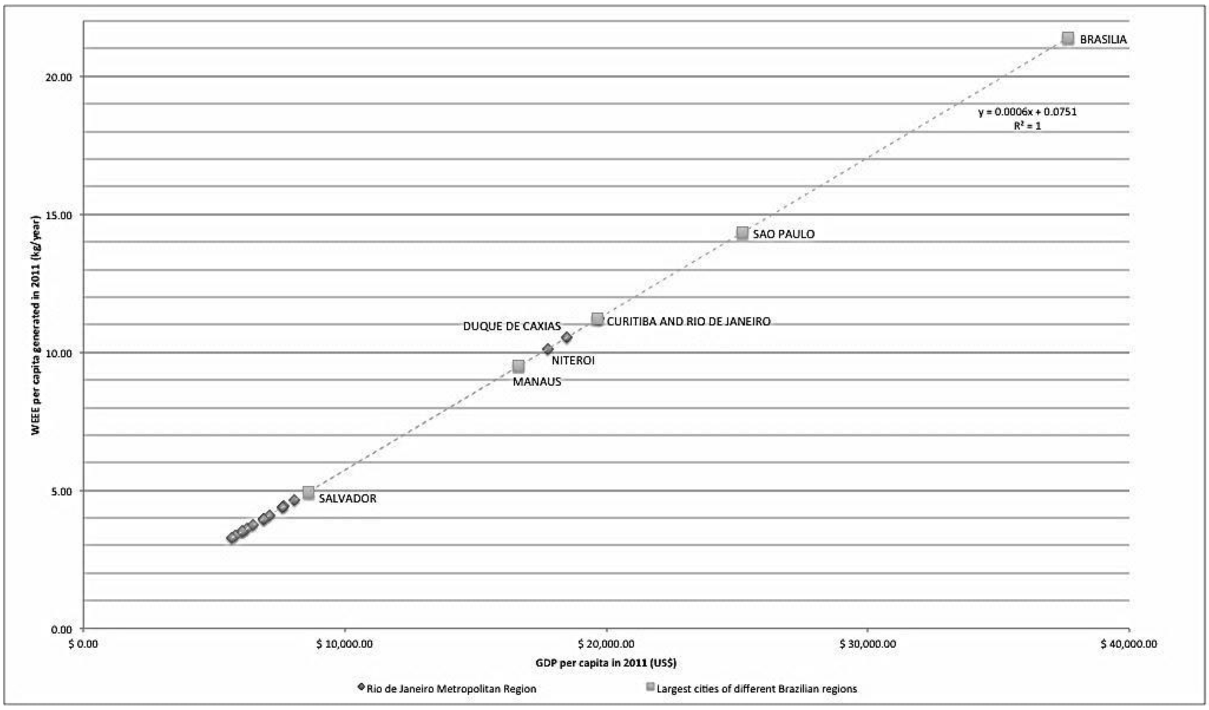


Figure 51. Estimates of WEEE generation per capita in RMRJ and Brazilian cities in 2011

Source: Authors based in IBGE (2014) and The World Bank (2014)

Table 17. Estimates of WEEE generation in Brazil, RMRJ and biggest cities in each Brazilian region based on GDP in 2011

City/Metropolitan Area (Brazilian Region)	GDP per capita (R$)	Total GDP (million R$)	GDP per capita (US$)	Total GDP (million US$)	WEEE per capita (kg/year)	Total WEEE (thousand tonnes/year)	% WEEE Brazil
RMRJ (SE)	-	295,225.97	-	176,483.08	-	91.36	**6.52%**
Belford Roxo	10,434.44	4,925.14	6,237.60	2,944.20	3.26	1.580	0.11%
Duque de Caxias	30,921.86	26,628.61	18,484.77	15,918.31	9.53	8.214	0.59%
Guapimirim	9,749.12	512.04	5,827.92	306.09	3.06	0.232	0.02%
Itaborai	11,884.86	2,618.85	7,104.65	1,565.52	3.71	0.876	0.06%
Japeri	10,144.26	978.21	6,064.14	584.76	3.18	0.374	0.03%
Mage	10,184.64	2,332.00	6,088.27	1,394.04	3.19	0.788	0.06%
Mesquita	9,484.83	1,602.62	5,669.93	958.03	2.97	0.565	0.04%
Nilopolis	11,498.86	1,813.49	6,873.90	1,084.08	3.59	0.629	0.04%
Niteroi	29,738.21	14,563.40	17,777.20	8,705.85	9.16	4.526	0.32%
Nova Iguacu	12,822.61	10,245,87	7,665.23	6,124.88	3.99	3.207	0.23%
Queimados	13,509.37	1,880.34	8,075.76	1,124.05	4.20	0.650	0.05%
Rio de Janeiro	32,940.23	209,366.43	19,691.33	125,157.12	10.14	64.066	4.57%
Sao Goncalo	11,488.34	11,581.00	6,867.61	6,923.00	3.59	3.615	0.26%
Sao Joao de Meriti	12,713.18	5,840.17	7,599.81	3,491.19	3.96	1.860	0.13%
Tangua	10,865.72	337.83	6,495.42	201.95	3.40	0.178	0.01%
Biggest cities of Brazilian regions (Region)							
Sao Paulo (SE)	42,152.76	477,005.60	25,198.49	285,149.09	12.96	145.867	10.41%
Brasilia (CE)	63,020.02	164,482.13	37,672.73	98,325.74	19.34	50.347	3.59%
Curitiba (S)	32,916.44	58,082.42	19,677.11	34,721.08	10.14	17.827	1.27%
Salvador (NE)	14,411.73	38,819.52	8,615.19	23,205.91	4.48	11.940	0.85%
Manaus (N)	27,845.71	51,025.15	16,645.88	30,502.31	8.59	15.670	1.12%
Brazil	21,252.00	4,143,013.00	12,704.23	2,476,651.00	6.92	1,401.860	100.00%

NOTES:

(1) RMRJ: Metropolitan Region of Rio de Janeiro.

(2) Figures in US$ calculated based on the average exchange rate of 0.5978 US$/R$ in 2011 (The World Bank 2014).

Sources: Based on IBGE (2014); The World Bank (2014); Huisman et al. (2008)

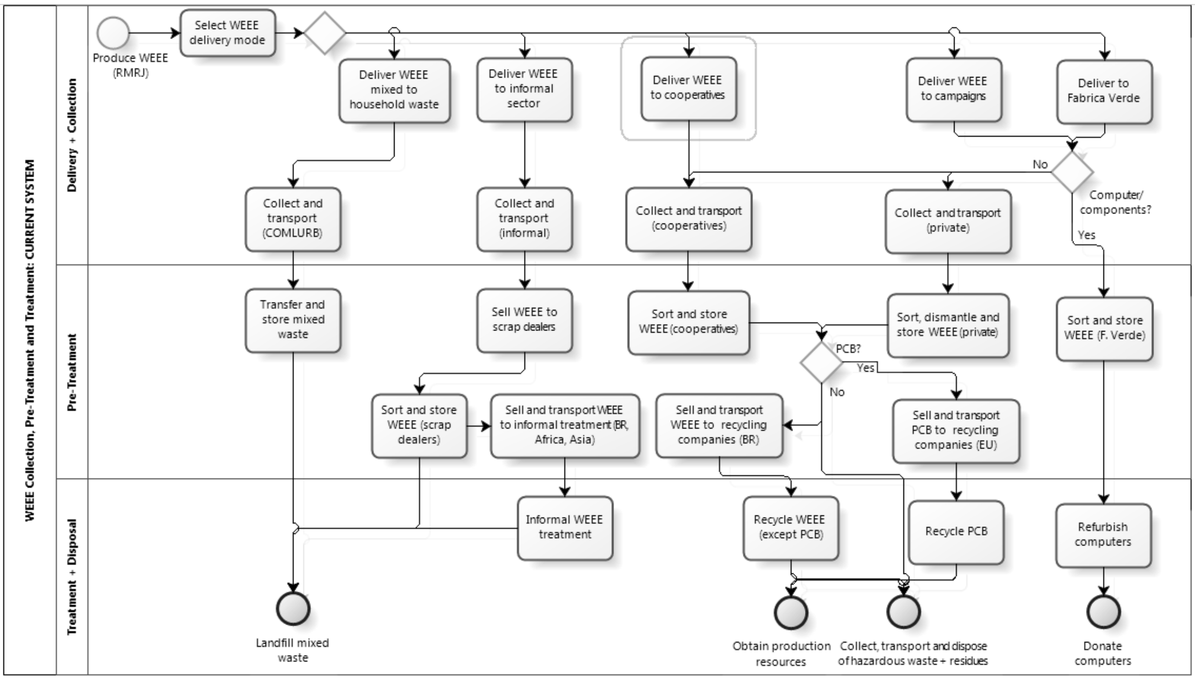


Figure 52. Identified WEEE flows in the RMRJ

Source: Authors

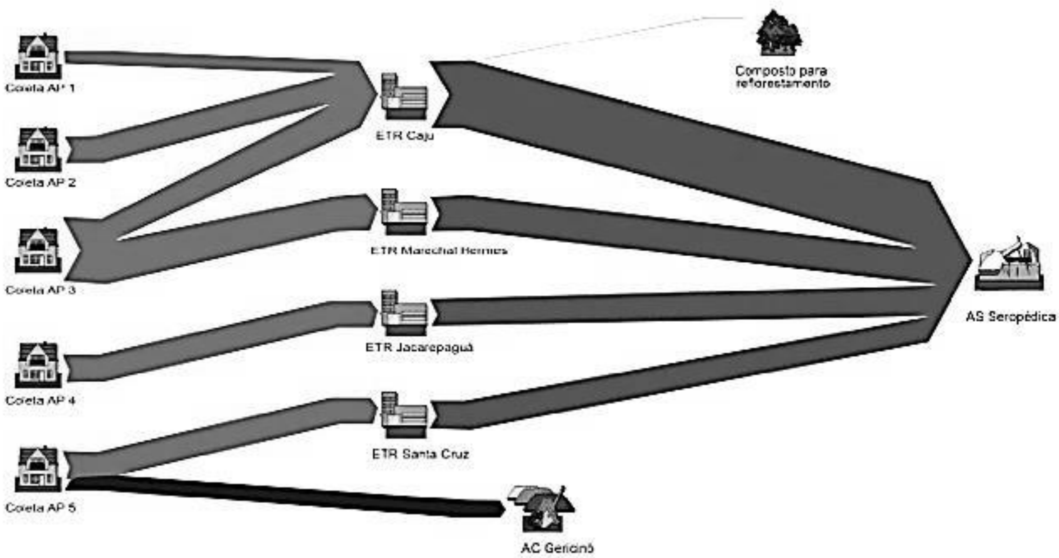


Figure 53. Sankey diagram of the mixed household waste flow in the city of Rio de Janeiro

Source: Angelo (2014)

In 2012 the average household waste generation was 833 g/day.person, so we can estimate 3.66 thousand tonnes of WEEE were delivered mixed to household waste in

2012 (COMLURB, 2013a). Figure 54 presents the composition of household waste collected in the city of Rio de Janeiro in the last years, showing a slight decrease in organic waste and slight increase in recyclables and WEEE. Figure 55 presents the variation in household waste composition in terms of each Planning Areas (AP) of the city of Rio de Janeiro. This variation has clear correlation with the purchasing power of population from the poorest to the richest areas in the city. For example, AP 2.1 corresponds to the residential area of highest living costs, comprising 19 districts including the ones with highest values in the real estate market (Leblon, Ipanema, Lagoa). This AP presents lower volumes of organic waste and higher volumes of recyclables and WEEE. The opposite occurs to AP 5.2, a suburban area of low-income households (including the district of Campo Grande and surroundings). The highest concentration of WEEE mixed to household waste (0.61%) comes from AP 3.2, an average to low-income area comprising district like Penha and Ilha do Governador. In this AP are located the Rio de Janeiro International Airport and the large campus of the Federal University of Rio de Janeiro, as well as an intensive commercial zone, what can explain this highest average WEEE rate. Curiously, the WEEE average from AP 5.2 (0.41%) is higher than the value found for AP 2.1, the richest area (0.34%). A possible reason is that WEEE are usually donated as second-hand goods to poorest classes, and that informal WEEE collectors are more likely to be living in these poorest areas.

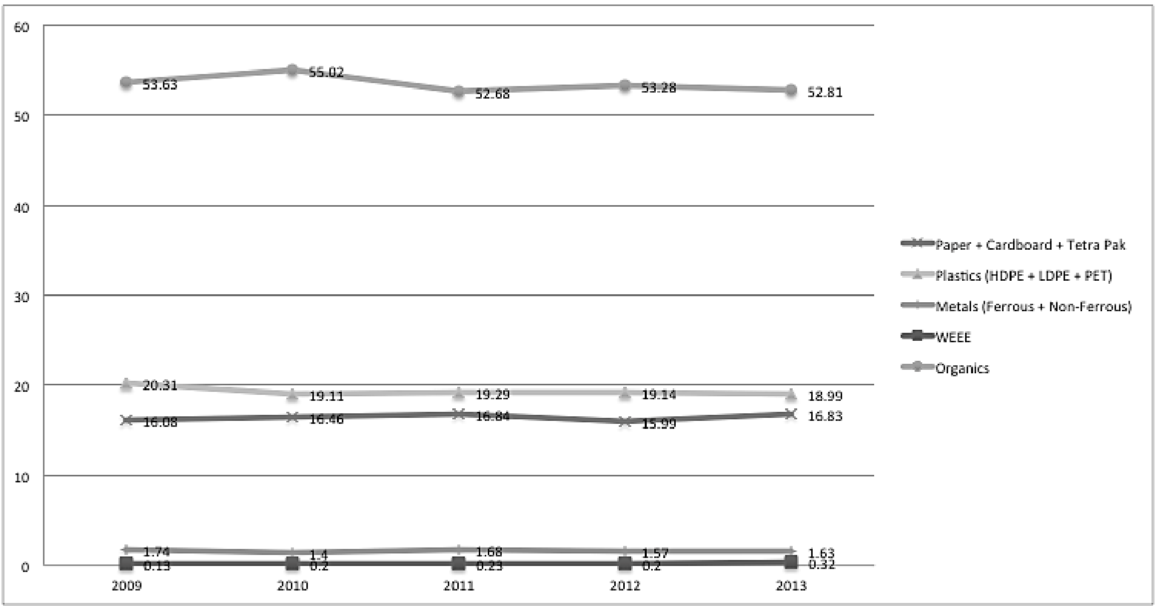


Figure 54. Composition of mixed household waste collected in Rio de Janeiro in the last years
Source: COMLURB (2013a)

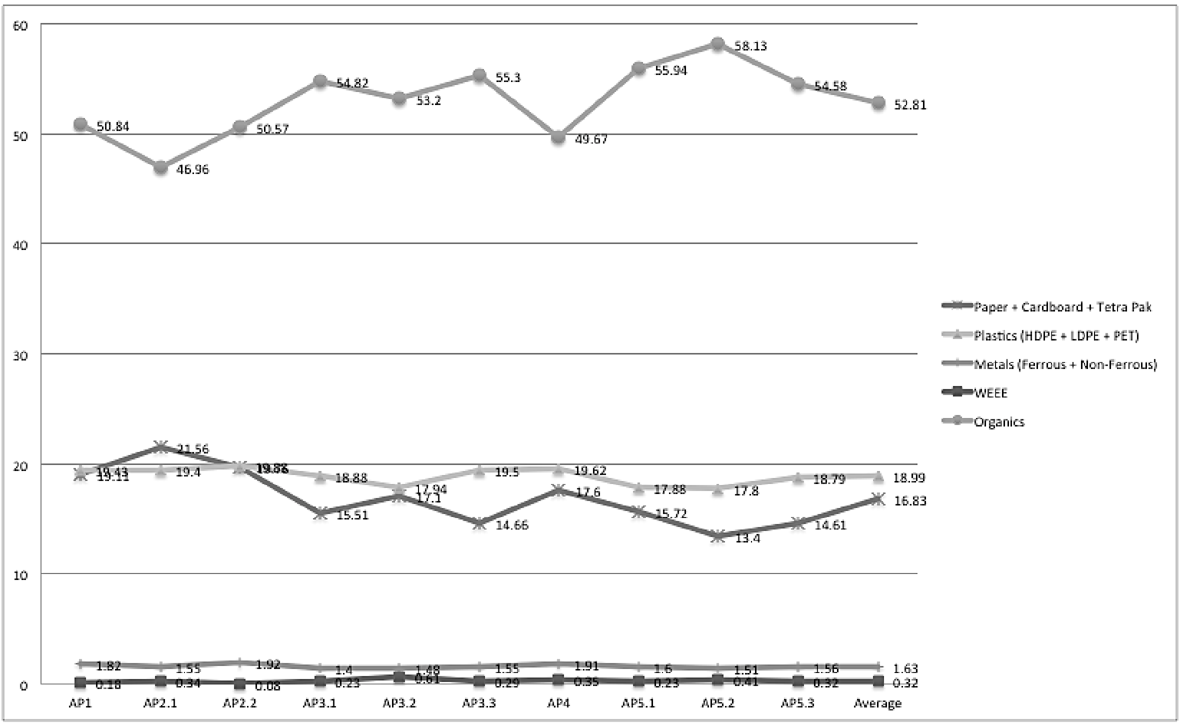


Figure 55. Composition of household waste collected from each AP of Rio de Janeiro in 2013
Source: COMLURB (2013a)

Little is known about the informal sector in Brazilian WEEE systems, but making a parallel with recyclables collection, we can assume they have huge importance in absorbing WEEE generated in Brazil. Individual informal waste pickers in Brazil usually work by collecting valuable material either from the streets or on dumpsites, and selling them to scrap dealers who in turn negotiate this material with recycling companies. When waste pickers are organized in cooperatives, they can collect recyclables either from streets via donation and by selective collection programs that may or not include the organized cooperatives (Figure 56). In our study we adopt this scheme to describe the WEEE chains based on waste pickers' cooperatives and on informality as indicated in Figure 52.

A study carried out by Silva et al. (2013a), which defined *informality* by the lack of formalized contractual job relation, found that most of Brazilian workers in waste collection are informal (Figure 57), out of a total of 387,910 workers in the country. These workers are in average 39 years-old, 69% men, 66% black or brown, 93% living in urban areas, monthly income of R$ 571.56 (US$ 265.38 or 84% of the Brazilian

Minimum Salary in 2013), 20% illiterate, 50% without access to basic sanitation, and 18% who own computers.

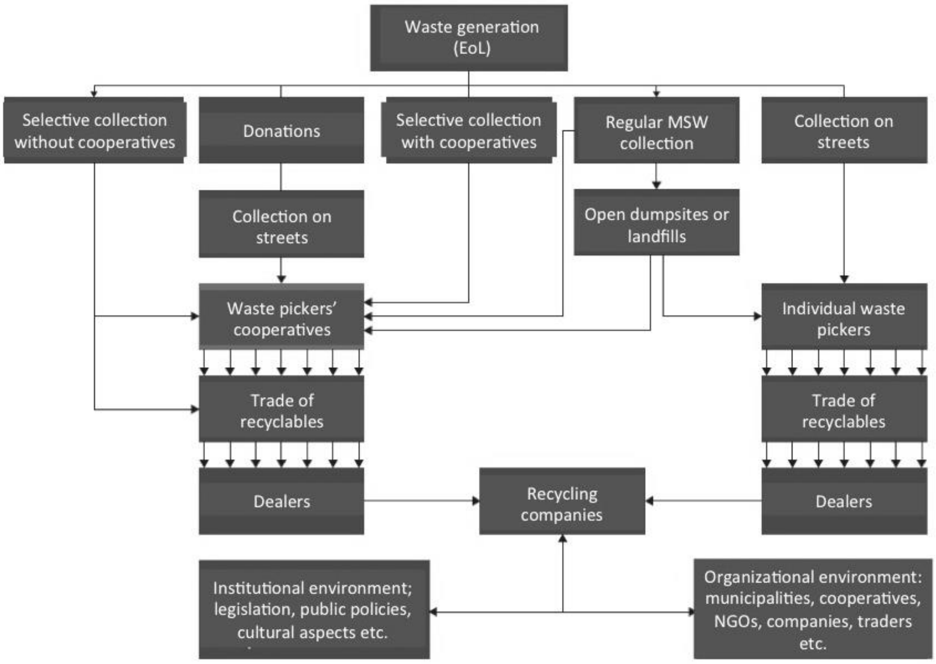


Figure 56. The recycling chain in Brazil

Source: Silva et al. (2013a)

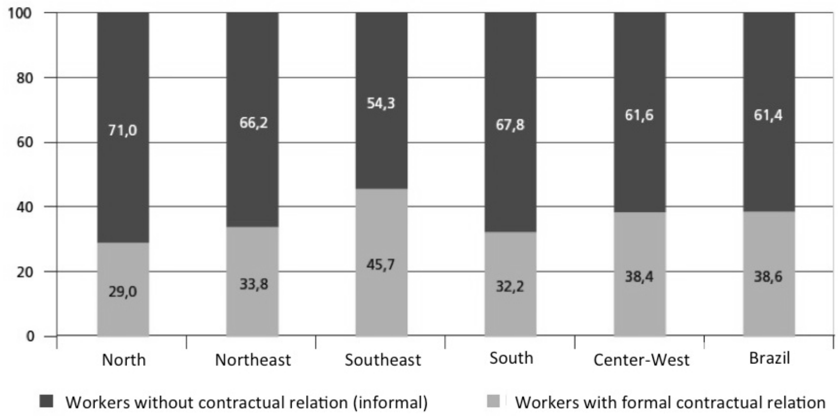


Figure 57. Formal and informal workers in Brazilian waste collection

Source: Silva et al (2013a)

The southeast region of Brazil concentrates 116,417 of these workers (41.6% of total), of which 36,238 live in the State of Rio de Janeiro. In Rio de Janeiro, 72.7% of waste collection workers are black or brown, 96.4% live in the urban area, earning R$ 653.15 (US$ 303.26) with income inequality (Gini) index of 0.37 (highest inequality = 1), 10% are illiterate. In this State there are 130,316 people living with waste pickers, and of these households, 42.7% have dependent children, 2.2% live in extreme poverty, 68.5% have no access to basic sanitation and 30.6% have computers (Silva et al. 2013b). This is the closest profile of WEEE informal pickers we could get in this research.

We also consider that most informal waste pickers who collect recyclables for leaving are also collecting WEEE and selling it to scrap dealers. We had access to documentation of all environmental licences of companies which main declared activity relates to waste management (collection, treatment, commercialization) in the State of Rio de Janeiro. We found cases where environmental inspectors detected scrap dealers not licenced to manage WEEE who were storing such material inadequately. In one case a scrap dealer was treating WEEE with acid leachate to recover valuable metals (as described in Section 2.1).

Another regular WEEE chain in the city of Rio de Janeiro is a yearly campaign of the Rio de Janeiro State Government called “Natal da Eletrorreciclagem” (Christmas of Electrorecycling), when they place special bins for WEEE collection in underground stations. According to the responsible manager at the State Secretary of Environment, the total amount of WEEE collected by this campaign in 2010, when they had two delivery stations, was of 1.5 ton, increased to 12.23 ton in 2011 when they placed five delivery stations. WEEE collected in these campaigns where forwarded to formal WEEE collection companies and to a WEEE dismantling cooperative in RMRJ. The total amount collected by this campaign in 2011 is far less (0.3%) than the total WEEE found mixed with household waste, but considering the campaign lasted for just 10 days a year, this value could be more expressive if WEEE delivery stations were fixed all along the years. Another factor that could raise this amount would be an increase on the number of delivery stations, expanding to all underground stations (total of 34) for example. A possible analysis is to infer WEEE generation in the different regions of the city reached by the underground system and estimate WEEE generation per capita/region based on data measured by Natal da Eletrorreciclagem for each station, and by COMLURB for each AP (**Figure 55**). Such estimates can support dimensioning of demands for WEEE delivery station if installed in all or most underground stations in a regular basis. Statistical analysis can be enriched by crossing this information with data regarding GDP per capita or PPP in each RMRJ region, but this requires access to and analysis of microdata of Brazilian Census 2010, what can increase statistical variations in the results of the inference. This is an interesting topic for further research. Another intended step is to dismantle samples of WEEE collected in these projects in order to analyse their compositions and feed LCA databases with regionalised inventory data from Brazil.

Fabrica Verde ("Green Factory") is a project from the State Secretary of Environment focused in capacity building for young people from favela to work in assembly and refurbishment of computers. There are currently five units, each in a different favela: Alemao, Rocinha, Chacrinha, Manguinhos and Jacarezinho. Each training cycle lasts 3 months, 12 hours/week, of each 2 months are for training and 1 for practice, with a target of 2 assembled computers by each student. In each cycle there are usually 7 instructors and 120 students, of whom 6 are selected to act as instructors for further training cycles. Each instructor receives R$ 600 (about US$ 270) and each student receives R$ 120 stipend per month. Computers refurbished in Fabrica Verde are donated to communities and NGOs, after an evaluation of available space, demand and access to internet, mainly for the implementation of telecenters – 11 of them where raised in favelas after donations from the project. In January 2014 there was a demand of 110 computers for 16 community associations. Used computers are mainly donated by large companies, such as PETROBRAS, who also acts as a partner and source of funding, and governmental agencies. The quality of computers received varies depending on the source: efficiency in producing usable computers out of used computers from PETROBRAS is estimated in 80%, while when inputs are from a governmental body this efficiency decreases to 10%. This is explained by the level of obsolescence and lack of components of computers donated by partners. The process of Fabrica Verde consists mainly of the processes illustrated in Figure 58. A growing problem in Fabrica Verde is the growing demand from partners for giving their WEEE (not just computers) a destination. Fabrica Verde has increasingly received all sorts of WEEE from large companies, stored and donated them to cooperatives or companies who manage this waste. This is a very inefficient process that should be remodelled for that the system can work with feasibility.

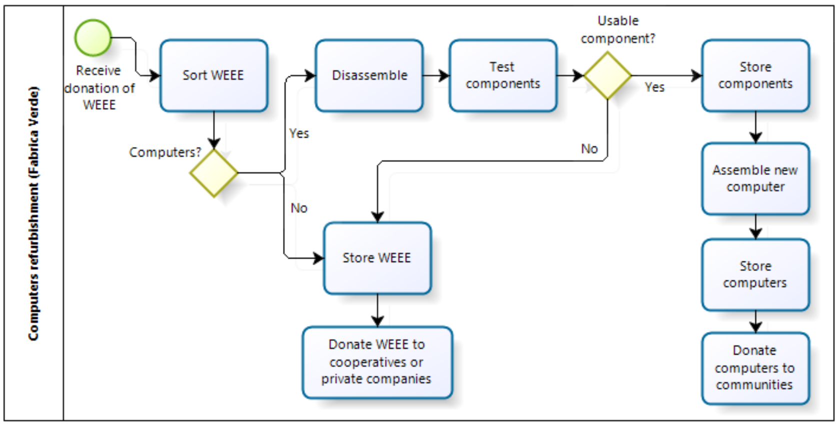


Figure 58. The process of Fabrica Verde

Formal WEEE reverse logistics companies, who usually collect and process WEEE obtained with scrap dealers, campaigns, cooperatives and Fabrica Verde, are usually placed in the Southeast and South regions of Brazil, as seen in **Figure 59**. As informed by the Executive Manager of ABREE in interview, Brazil has technology to recycle every WEEE rather than the process of extracting valuable metal from PCBs, for which WEEE is exported. However, most of the 92 companies represented in **Figure 59** are just logistics companies, who buy, collect, sort, store and negotiate WEEE to the adequately called recyclers – those companies who process WEEE in order to extract valuable material and dispose of refuse and hazardous waste. These, according to our interviewee, are mainly placed in the axis of the States of Minas Gerais (MG), Sao Paulo (SP) and Parana (PR), which can be clearly seen with a higher density of "recycling" companies in **Figure 59**. This fact was confirmed in our search to environmental licenses, where we observed that all recyclers receiving WEEE where from these regions, and those who are based in Rio de Janeiro (RJ) are actually logistical units of these companies or just dealers. Iin this axis there are also logistical units from international companies like UMICORE, where WEEE is dismantled and sorted in order to be exported to the main units in Europe. This is what happens to many of PCBs sorted along the previous processes. Other formal chains are reverse logistics programs implemented by EEE producers to collect and process WEEE from their own products. This is the case of Phillips and HP for example. Still according to the ABREE manager, restrictions in implementing a PCB recycling plant in Brazil do not relate to initial costs, but to the capacity of feeding the plant with a feasible input of PCBs. This issue can certainly be overcome when efficient reverse logistics chains are implemented in Brazil, with high economic and environmental benefit.

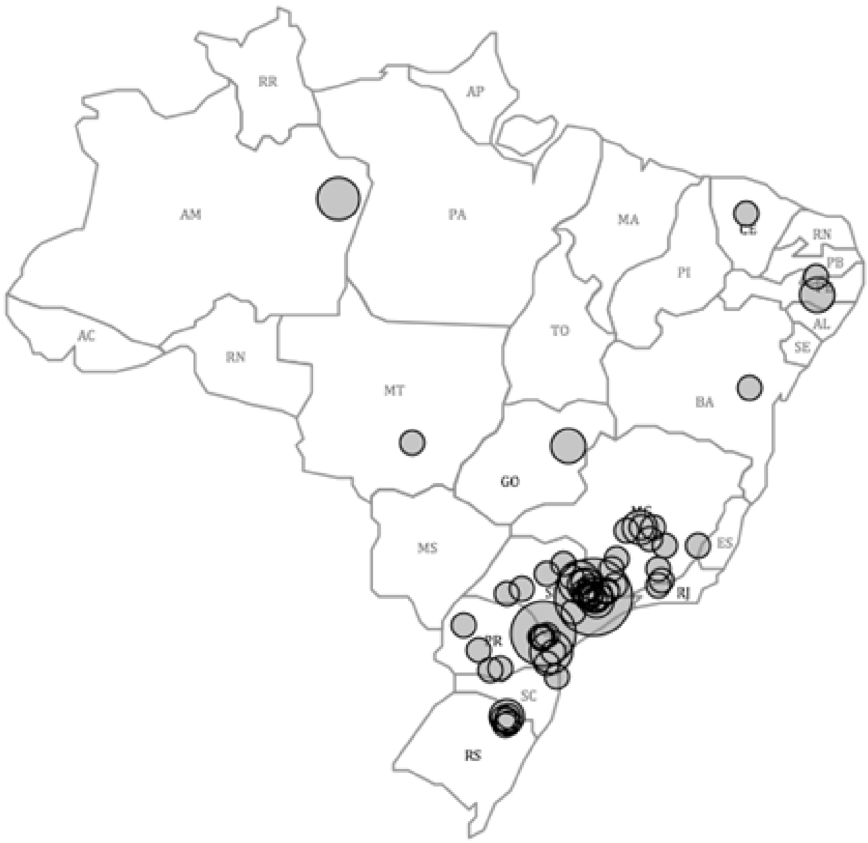


Figure 59. Map of Brazilian WEEE logistics and recycling companies
Source: ABDI (2013)

Regarding waste management companies in the State of Rio de Janeiro, we searched the database of INEA, the State Institute responsible for environmental licensing, for all registered companies whose main declared activity was related to waste management. In 2012 we have identified 117 companies that fit this profile, whose main activities are distributed as seen in **Figure 60**. We consulted each process for their environmental licensing, in order to track WEEE flows and management processes applied within the State. We can see that most companies act mainly in the collection of non-hazardous waste and in wholesale of scrap, while few ones are mainly concerned with waste treatment or recycling. We observed that environmental licenses in Rio de Janeiro are not a good source to track WEEE flows, as companies do not specify in details the types of waste they process, but just an overall classification into hazardous/non-hazardous or metals/plastics/others. Based in the proposals and inspections for licencing and monitoring, we could just find some clues of companies processing specific types of WEEE like batteries and lamps, and very few declaring to process electric or electronic "scrap". All these identified WEEE companies were dealers. Exception is for lamps and batteries, which some companies in the State are able to recycle by industrial processes. There where cases of companies who were prohibited to process batteries (it was located in an Environmental Protection Area – APA), or who were notified by inspectors because WEEE storage was inadequate (exposure to weather, no floor sealing).

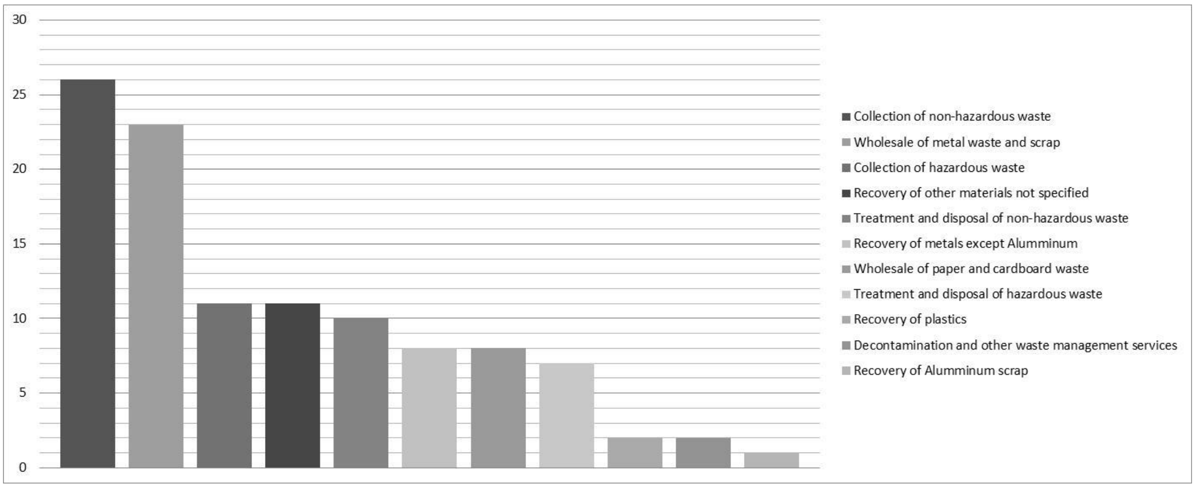


Figure 60. Waste management companies licensed in RJ by their declared main activity

We have also searched INEA´s database for Waste Inventories, a mandatory declaration of large waste producers. In this database there is not a specific class for WEEE; we then searched for "lamps", "batteries" and "waste with corrosives". For lamps, there were 15 identified companies, of which 11 are placed in Rio de Janeiro. From these last, three declared their main activity to be "treatment of hazardous waste", what means they are recyclers of such WEEE. For batteries there were 7 companies, 6 in Rio de Janeiro, of which 2 are registered for "treatment of hazardous waste" as well. All waste management companies registered in INEA must declare a Waste Manifest, where they inform the amounts of waste processed, their origins and destinations. Once again, it was not possible to track a WEEE class, but we could identify the main destinations for lamps. One difficulty in measuring this flow is that companies declare amounts of waste in different units: tonnes, kg or m3. For those who declared amounts of lamps in tonnes and kg we could draw a profile of their applied treatments (based on predefined categories of the database), as shown in Figure 61.

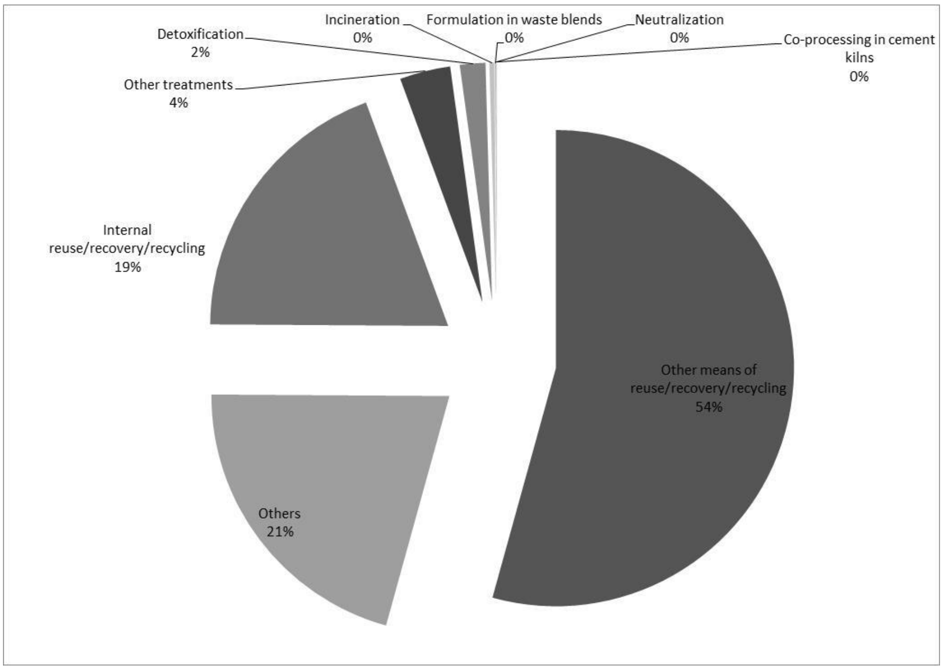


Figure 61. Destinations of waste lamps in the State of Rio de Janeiro according to Waste Manifests

In general, we conclude that WEEE processing by waste management companies in Rio de Janeiro consists of collection, sorting, storage and commercialization to recycling companies in other states, with exceptions in the case of lamps and batteries recycling, what can occur within the State. However, in the Brazilian legislation (PNRS 2010) reverse logistics systems must be developed for lamps, batteries and WEEE independently, while in Europe the first two are classes of WEEE. This way, lamps and batteries escape the scope of this study for LCSA modelling and assessment.

4.1.3. Identified actors related to current WEEE chains in the RMRJ

By analysing the WEEE chains mapped in RJ, it was possible to identify some relevant actors for the case study (Table 18).

4.2. LCSA modelling (SODA, SSM and LCSA elements)

In this Section we present the results for all SODA and SSM stages in the case study, leading to the definition of LCSA impact categories and alternative systems for potential implementation in Brazilian WEEE reverse logistics.

Table 18. Relevant actors identified in the case study

WEEE chain	Actors (roles)
WEEE informal collection	Informal waste pickers; cooperatives; scrap dealers
WEEE mixed to household waste	COMLURB (MSW collection company) and workers
WEEE to cooperatives	FEBRACON; COOPAMA; WEEE producers; SEA; recycling companies (BR)
WEEE to Fabrica Verde	SEA; communities of favelas; Instructors; WEEE producers; NGOs
WEEE to formal companies	Collection/Treatment/Commercialization companies; INEA; WEEE producers; recycling companies (BR and EU)

4.2.1. Interviews and individual cognitive maps

Based on the study of legislation and of the current situation of WEEE systems in Brazil, focusing the state of Rio de Janeiro, we selected and contacted a range of stakeholders directly or indirectly involved in the problem and especially in the WEEE Sectoral Agreement. We also consulted specialists in topics directly related to this problem. Some of them allowed for one or more interviews with an average duration of 1.5 hour each, both in the states of Rio de Janeiro and Sao Paulo, as well as international specialists from Austria and UK. Others preferred to answer to a questionnaire sent by email, while some stakeholders kindly answered to questions via phone or Skype calls. Appendix 3 presents all consulted stakeholders and specialists, detailing their relevance to the problem and their contribution to this research. In summary, we have consulted representatives of:

- Stakeholder groups: EEE manufacturers; EEE commerce; SEA; university business incubators of waste pickers‘ cooperatives; waste pickers‘ cooperatives for WEEE dismantling and commercialisation; Fabrica Verde; environmental regulation agency;
- Specialists: on environmental legislation; on waste management; on WEEE; on reverse logistics; on environmental journalism.

We only developed individual cognitive maps from stakeholders’ discourses, as theirs are the relevant perspectives to be elicited in order to support decision-making in the case system. In **Figure 62** we can see a (mid-bottom) part of the cognitive map from a representative of EEE manufacturers. We can see that his greatest concerns regard economic aspects like extended costs to producers and feasibility of WEEE reverse logistics implementation. He had also several complaints on the pressures from Federal Government to accelerate systems implementation (opposite pole to “rational implementation…”). Social and environmental aspects were also mentioned, as the representative is aware of such issues related to WEEE systems. In Appendix 4 we present individual maps of other stakeholders.

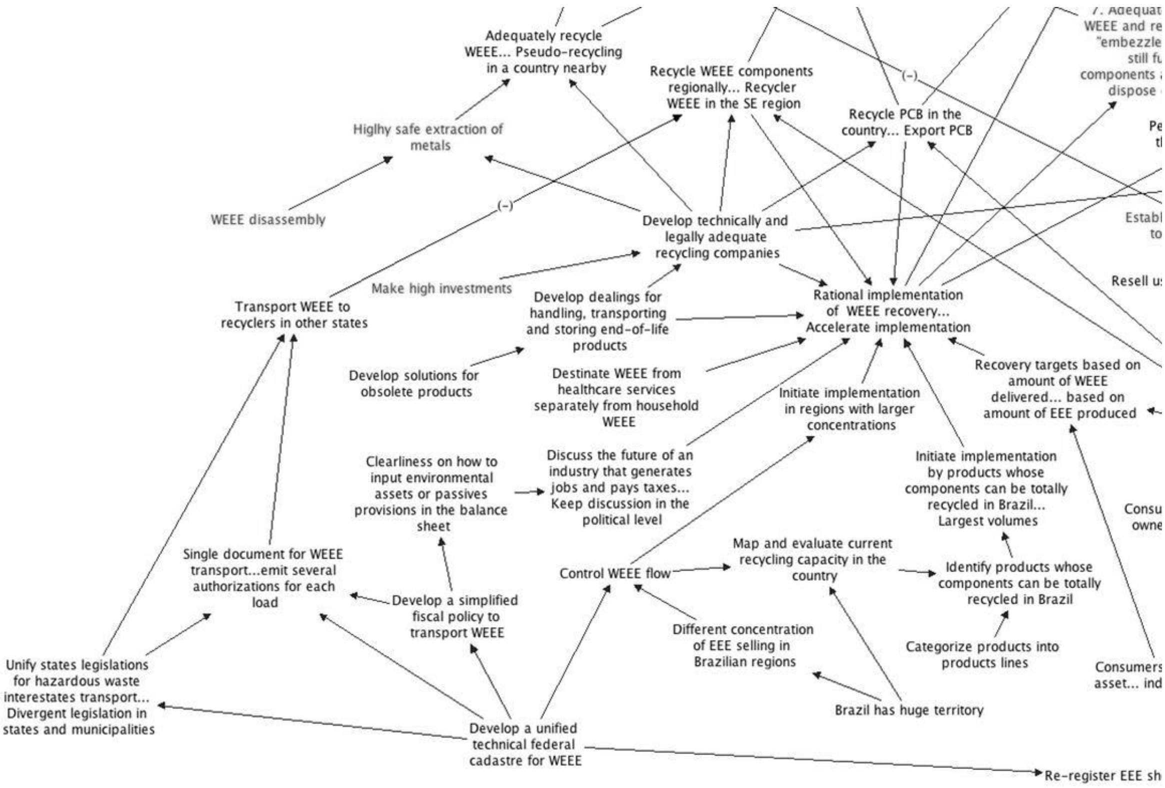


Figure 62. Part of the cognitive map of an EEE manufacturers' representative

We usually started interviewing stakeholders asking them what are the main issues regarding WEEE reverse logistics in Brazil. We noticed that most of their concerns related to aspects in the mid-bottom areas of the maps, meaning they are more concerning with strategic directions and decision options than with overall goals of the system. These bottom-area issues of the map are relevant for the identification of potential SSM Root Definitions. However, for the first analysis of our methodology (SODA to LCSA impact categories) we searched to their implicit objectives related to the mentioned issues. This is done by questions like “why is X important?”, and also “how does Y relate to Z?”. By this iterative process we developed both the individual maps and the merged map.

By observing the cognitive map representing the manufacturers’ representative, we notice that a critical issue in his opinion regards the pressure for an accelerated implementation of reverse logistics, what is the opposite of a rational implementation which should involve the development of recycling companies, dealings, analysis of current capacity and WEEE generation, and definition of feasible targets. Consequences of such accelerated implementation can be that people are not prepared to use the Law, the concentration of WEEE recycling in the SE region with large export of PCBs, and the stimulus of informal flows that may lead to a “pseudo-recycling” in nearby countries (illegal reassembly of appliances extending producer responsibility). Their top issues of concern are: to reduce currently high costs to industry and not to harm them with illegal extended responsibility for products, and the maintenance and efficiency of the new reverse chain to be implemented.

The discourse of the EEE retailers’ representative is also very focused in minimizing their costs, by avoiding burdens from inadequate WEEE delivery procedures, cascade WEEE taxation, dedication of extra space and workforce by shops due to the allocation of WEEE delivery stations, environmental licensing and penalization of retailers and producers. Their main goal is to add value in WEEE recycling, enhancing quality and sustainability value of products, and the maintenance of the systems’ financial balance, avoiding the necessity of external input from industry.

The main operational concern of the State Government representative was to define their role within WEEE reverse logistics and Sectoral Agreements. This may involve the articulation of partnerships, environmental licensing, exemption of taxes, creation of public consortiums, and the institutional support to Sectoral Agreements. Main operational goals regard: the definition of targets and implementation of reverse logistics with opportunity to technology, job and income opportunities in all Brazilian regions; the creation of recycling plants and the adequate collection, recycling and final disposal; system feasibility by costs minimization and value recovery from WEEE; stimulus to the Brazilian EEE chain. His main fundamental goals are the minimization of environmental impacts, and Brazilian Social and economy developments.

The perspective of the business incubator of cooperatives concentrates on the formal inclusion of cooperatives within the system, providing them with adequate working conditions and increasing their incomes. Operational goals are social inclusion and enhancement of waste pickers' self-esteem. Main goals are the enhancement of human development and to dignify human life.

4.2.2. Merged map

The merged map (see Appendix 4) in our case study represents mid-top hierarchical issues of individual maps, with further additions from new rounds of interviews and specific explanations from specialists around some issues. In merging top areas of individual maps into a single one, we could analyse issues and their causal connections in search to identify the overall goals for WEEE reverse logistics in Brazil.

It was possible to check that all sustainability dimensions where comprehended in the map, as expected (**Figure 63**). This means that there are overall and specific objectives regarding each dimension, and critical decisions that may impact more than one dimension. Fundamental objectives identified for each dimension were interpreted as LCSA Areas or Protection; their closest objectives downstream were interpreted as endpoint categories and the remaining operational objectives as midpoint LCSA impact categories.

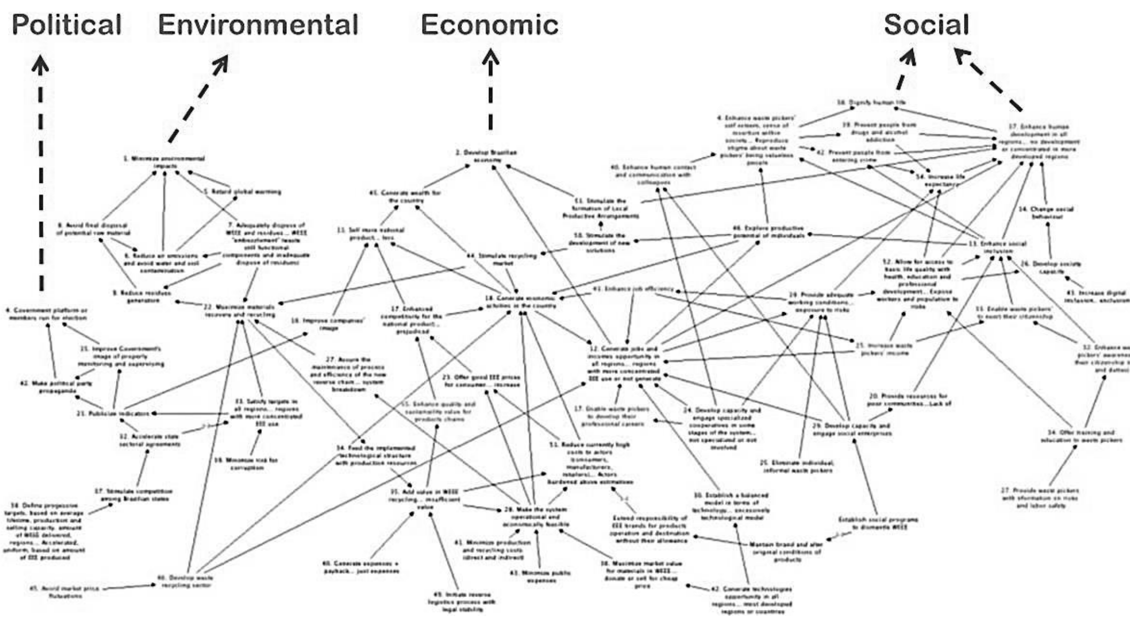


Figure 63. Sustainability dimensions + political represented in the merged map

Figure 64 presents a part of the merged map representing issues related to the overall economic goal (AoP) "develop Brazilian economy". This dimension is densely connected to the social issues (**Figure 65**), of which the ultimate goals (AoPs) are to "dignify human life" and to "enhance human development in all regions".

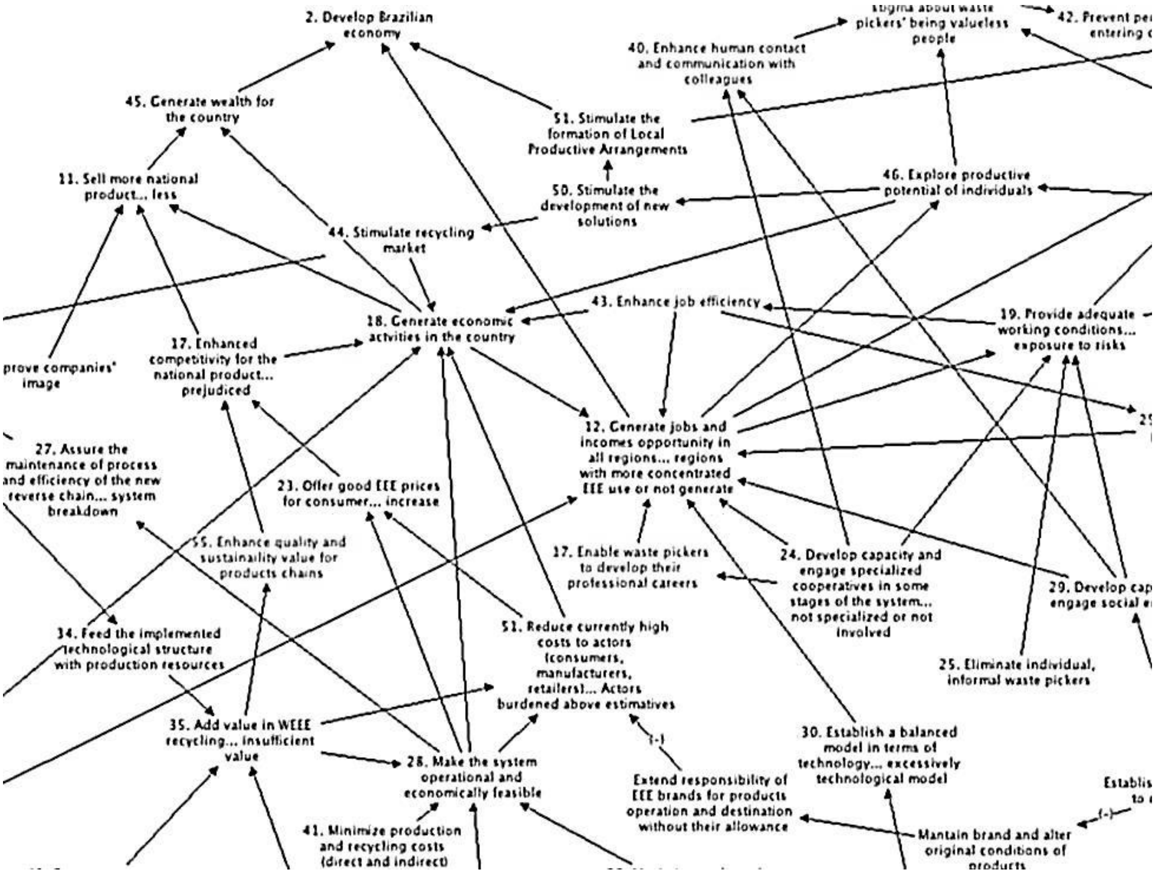


Figure 64. Part of the merged map representing economic issues of concern

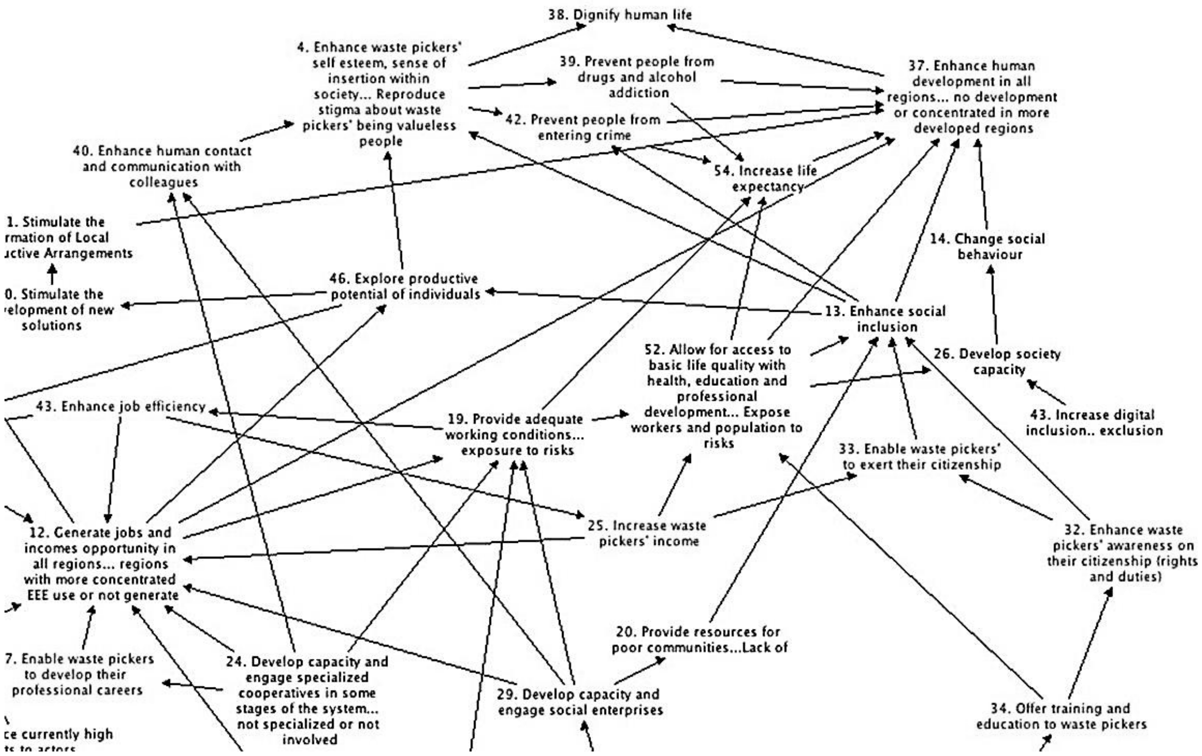


Figure 65. Part of the merged map representing social issues of concern

Regarding the environmental issues of concern, It is possible to see in **Figure 66** that the highest concern is to “minimize environmental impacts”, and this is accomplished by goals such as: “retard global warming”; “reduce air emissions and soil contamination” and “avoid final disposal of raw material”. These issues are not as specific and technical as required for LCA impact categories, but LCA categories commonly used to assess WEEE systems are directly related to them and to some social issues identified (health, working conditions). This shows that our group of stakeholders has a good perspective about environmental problems related to WEEE, and that our methodology can provide a cross-check of stakeholders’ awareness on the problem situation from the environmental perspective.

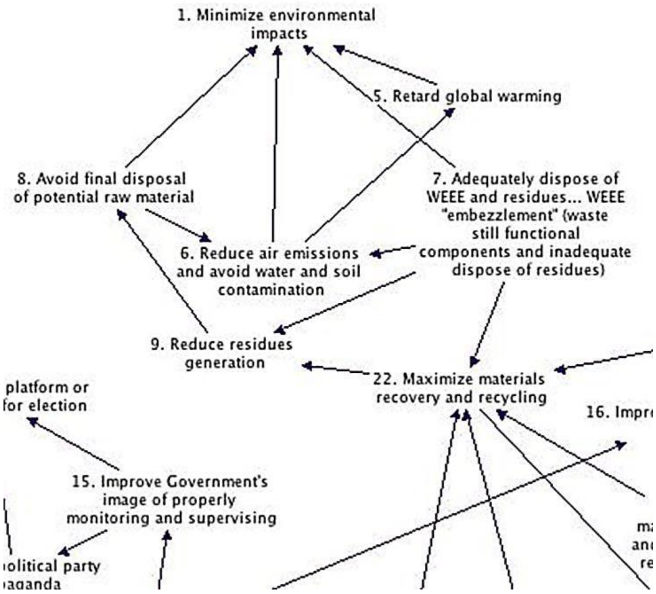


Figure 66. Environmental issues of concern arising from the merged map

We could also notice another dimension arising from the merged map: the political (**Figure 63**), whose fundamental objective was to "re-elect governmental platform or members". Social, environmental and economic objectives could be translated into impact categories because it was possible to interpret if reaching such objectives would have a positive or negative impact in AoPs. In the case of political goals identified, it was not clear if their impacts would be positive or negative, or if there were impacts at all. In our interviews we could not elicit from stakeholders what are the connections between political aspects and the other dimensions on the top-hierarchy level. For this reason we decided to eliminate such issues from LCSA.

Analysing causal connections within the merged map it is possible to identify the critical issues, i.e. those with largest flows of incoming and outgoing arrows. These include: maximization of waste recovery and recycling; generation of economic activities in the country; generation of jobs and incomes; working conditions; and social inclusion. These issues represent the hierarchical region of operational objectives. As such, they are considered as potential midpoint impact categories for our case study.

On the top level of the map, it is possible to identify the fundamental objectives, which describe potential Areas of Protection and endpoint categories: to minimize environmental impacts; to develop Brazilian economy; and to dignify human life. These are the issues that give reason for the environmental, economic and social dimensions respectively, as represented in **Figure 63**. They are the final destination of causal arrows, flowing from the bottom to the top, including all interconnected midpoint issues that are intermediate goals for achieving those fundamental objectives on the top.

4.2.3. Definition of SLCA and LCC impact categories

By analysing connections and hierarchy of the issues of concern expressed in the merged map, it was possible to identify potential endpoint and midpoint impact categories. We assumed that fundamental objectives in the map described the Areas of Protection: environment, Brazilian economy, dignity of human life and human development. Right below these AoPs in the maps are the endpoint categories, and below them the potential midpoint categories. An interpretation of such hierarchy of AoPs, endpoint and midpoint categories for SLCA and LCC impact pathways of the case study are presented respectively in Figure 67 and Figure 68. In this study we decided to consider AoPs at a different level than endpoint categories, but in most LCA studies these are coincident, the last being the measurable version of the first. Here we considered endpoints as components to reach the "protection" of AoPs. Possible modifications in Figure 67 and Figure 68 could refer to the definition of thresholds between AoPs, endpoints, midpoints and the rest of the merged map. For example, in Figure 67 another interpretation would be to consider "human development" as an endpoint, because in the merged map this is still a cause or means for "dignity of human life". Issues of concern in the merged map found below the indicated midpoint categories could also be considered as such. For example, "feed the implemented technology with production resources", which is a mean to "add value…" (Figure 68), could be interpreted as a midpoint category concerned with the relation inputs/capacity. In this sense, we consider that many issues of concern acting more like "causes" than like "ends", what includes some midpoints in Figure 67 and Figure 68, can also be interpreted as performance indicators for upper-level categories to which these issues are direct causes or means. This approach is adopted in the definition of the final set of categories, as discussed further in this Section.

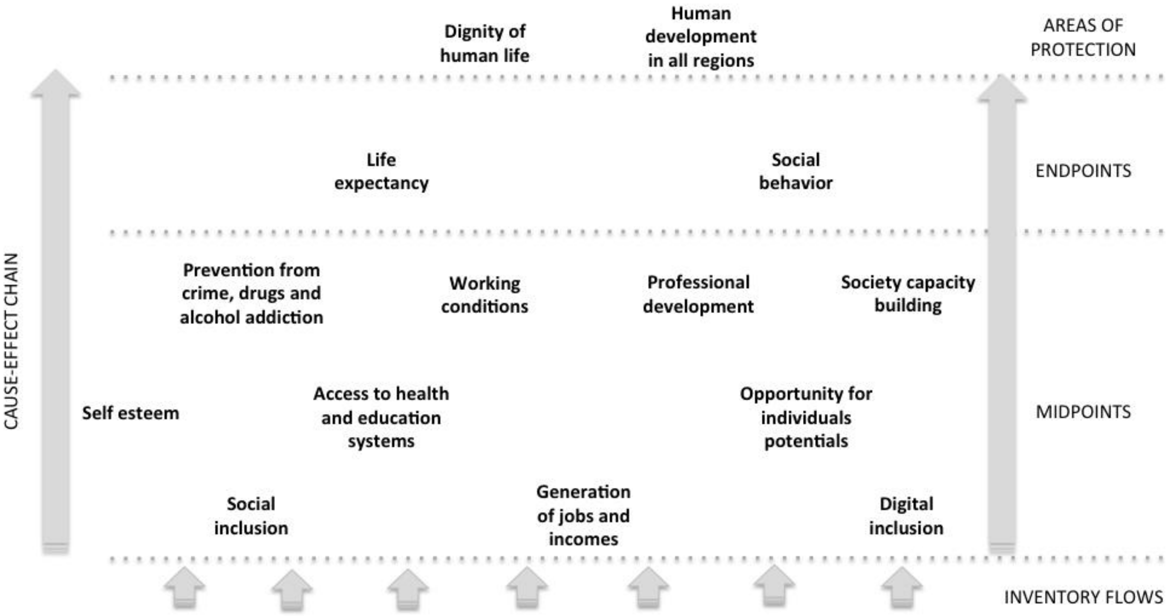


Figure 67. Potential SLCA impact categories for the case study

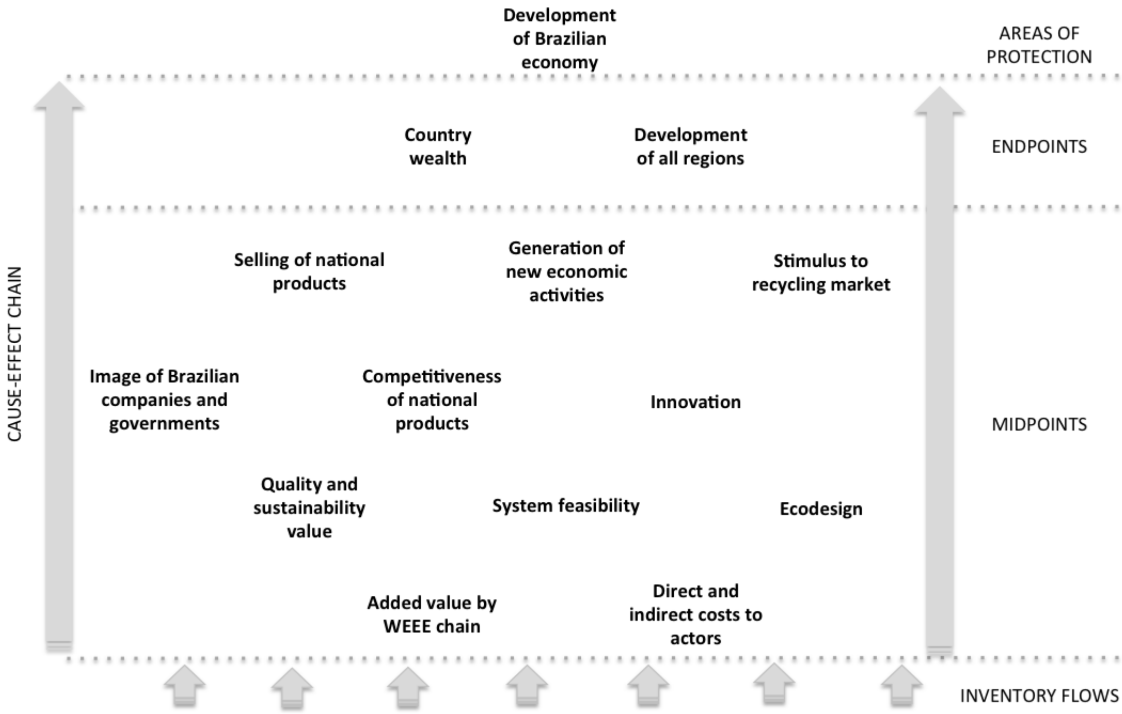


Figure 68. Potential LCC impact categories for the case study

The next step is to evaluate and refine the potential set of social and economic midpoint impact categories towards a final set, which can be considered adequate when, according to the judgement of stakeholders, it satisfies the expected properties presented **Table 11** and Section 3. There are two levels, one for the endpoint categories and the other for all midpoint issues. It is the latter which are the focus of our research, for reasons explained in Section 2.2.4. Redefinition of impact categories included merging some potential categories into a single one, and assuming lower-level categories as indicators for directly related upper-level ones.

The analysts undertook a first analysis of the initial midpoint set, by identifying and eliminating dependent, redundant or non-operational impact categories. For example, we considered that product "competitiveness" and "selling" are strongly causally related, so that they are not preferentially independent. We also considered that both "ecodesign" and "quality and sustainability value" could be regarded as embraced within "innovation", so this group of categories are redundant. "Self-esteem" can be considered to be a non-operational category. In this way the analysts developed a modified set of impact categories which overcame the identified inconsistencies.

The modified set suggested by analysts needs to be iteratively redefined by stakeholders until they agree that it satisfies all properties in **Table 11**. This should preferably be achieved through discussion in a facilitated workshop format, but in this research practical considerations dictated that we carry out sequential individual interviews with a subset of the stakeholders. This subset included a representative of the State Government; of the EEE manufacturers; and of a WEEE dismantling waste pickers' cooperative. After all reviews, the final set of LCSA impact categories that satisfied all desired properties, as defined with stakeholders, is shown in Table 19 and Table 20. Regarding LCA impact categories, we consider those midpoints presented in Section 2.2.5. as an adequate set that satisfies the desired properties and do not depend on stakeholder perspectives.

4.2.4. Comparison with categories found in literature

Some of the potential impact categories identified are in line with reference frameworks for LCC and SLCA. This is the case of "working conditions" and "generation of jobs and incomes" (Figure 67), mentioned in some SLCA approaches (Benoit & Mazijn 2009; Aparcana and Salhofer 2013). The same holds for "direct and indirect costs" in Figure 68, which can be considered the core for LCC assessment in other established frameworks (Swarr et al. 2011).

Table 19. Final set of SLCA impact categories for the case study

Social impact categories	Suggested indicators
Social inclusion (socialising and social assistance for WEEE workers and their families)	- Number of WEEE workers and relatives provided with social and psychological assistance - Number of new WEEE workers that come from such groups: women; informality; prison; slums; alcoholism; drugs addiction; crime; physical and mental disabilities [a]
(Formal and informal) employment and generation of income with opportunity to professional development	- Number of WEEE workers (formal and informal) per occupation; - Average income of WEEE workers (formal and informal) per occupation; - Number of workers that undertook professional training and refresher courses [b]
Risks and working conditions	- Number of WEEE workers (formal and informal) working in adequate conditions (equipment, protection, training); - Occurrence of job accidents and diseases directly related to risks of the WEEE chain
Access to healthcare, education, environmental education and digital inclusion	- Number of WEEE workers and their relatives provided with health insurance; - Number of WEEE workers and their relatives per level of education; - Number of individuals (workers and relatives, community) benefited by the WEEE chain with digital inclusion and environmental education

Notes:

[a] This indicator was modified to merge two potential impact categories that had inter-dependency.

[b] This indicator was included by stakeholders.

Source: Souza et al. (2014)

Table 20. Final set of LCC impact categories for the case study

Economic impact categories	Suggested indicators
System feasibility and efficiency	- Direct and indirect costs per actor and stage of the system (US$); - Profit and avoided costs per actor and stage of the system (US$); - WEEE per destination/Total WEEE collected; - Demand/capacity of the WEEE system
Awareness and adhesion to WEEE reverse logistics [a]	Number of citizens and companies delivering WEEE to formal collection points
Innovation and generation of new economic activities	- Number of recently created companies within the EEE and WEEE chain; - Number of companies within the EEE and WEEE chains with innovation recognized by the Brazilian Ministry of Science and Technology
Competitiveness of the formal EEE and WEEE products [b]	- Increase rate of prices of formal products due to increased costs by reverse logistics; - Amount of informal products collected by the WEEE system; - Evolution of the EEE and WEEE informal market

Notes:

[a] This impact category and respective indicator were included in substitution to the former category "Image of Brazilian companies and governments", suggested by the analysts in the first redefined set.

[b] This category with respective indicators was included by stakeholders in substitution to "Selling of national products", suggested by the analysts in the first redefined set.

Source: Souza et al. (2014)

On the other hand, interesting new issues emerged in our case study from the interpretation of stakeholders' perspectives with the support of causal maps. One illustrative example is "digital inclusion" (Figure 67), which can be a positive effect of good WEEE systems on the social Areas of Protection, especially "human development in all Brazilian regions". In the Brazilian context, according to stakeholders' maps, digital inclusion can be facilitated both via the donation of refurbished or used computers to NGOs and communities, and by the capacity development of waste pickers' cooperatives, providing them with a powerful resource for managing their business. Other innovative categories were: "self-esteem" (social) and competitiveness of products (economic). Without the systematic mapping of all aspects mentioned by the various stakeholders, such innovative issues might be neglected.

The present methodology also revealed innovative impact categories in the economic dimension (Figure 68), for example the "competitiveness of national products". This issue, expressed by representatives of manufacturing and commerce, concerns the unavoidable price increase of national products as a result of the increased costs provoked by their financial responsibility for WEEE reverse logistics. Facing higher prices, consumers would be tempted to choose cheaper imported products rather than purchasing national ones, even if they have entered the country illegally.

Another consequence of this enhanced perspective is that issues that are usually regarded as endpoints in literature references can now be viewed alternatively as midpoints for broader concerns. For example: rather than *working conditions* being seen as an SLCA endpoint category (UNEP-SETAC 2009), we can now see it, in a wider context, as a means for achieving improved *life expectancy* and *human development in Brazilian regions*. Similarly, in the economic dimension, *direct and indirect costs* can be viewed as bottom-level midpoints that affect other midpoints such as *system feasibility*, with consequences for the endpoints *country wealth* and *development of all regions*.

4.2.5. Identification of potential relevant systems to be modelled

Based on individual maps and the merged map, there can be an extensive list of potential relevant systems to be modelled in Brazilian WEEE reverse logistics. For example, by analysing the map from the State Government representative, we could identify potential systems like ("A system that…"):

- Defines progressive targets to Brazilian WEEE reverse logistics in all regions;
- Structures regionalized WEEE management systems;
- Obtains resources for financing public and private WEEE systems;
- Provides environmental licensing to WEEE systems;
- Feeds the implanted technology with production resources;
- Collects, dismantles and refurbishes WEEE;
- Controls WEEE flows.

Other identified potential systems to be modelled are ("a system that…"):

- Charges taxes and tributes from the WEEE actors;
- Provides fiscal incentives and financial support;
- Manages WEEE chain contracts and delivery stations;
- Defines classification of WEEE as hazardous or non-hazardous waste;
- Develops a fiscal police for WEEE transportation;
- Generates a cadaster to control EEE and WEEE flows;
- Informs and educates citizens on WEEE management;
- Develop dealings for handling, transporting and storing end-of-life products;
- Disciplines technical assistances;
- Defines regional technologies and scales for WEEE recycling.

In Appendix 5 there is an extensive list of identified potential systems to be modelled. Modelling all these systems would be a laborious task for the purposes of this study. There can even be many other potential systems either in the maps or in the perspectives of actors still to be elicited. In this study we selected some of these potential systems to be analysed in search to define few but robust Root Definitions with potential to be modelled and implemented in Brazil or Rio de Janeiro.

4.2.6. Root Definitions, Conceptual Models, Multilevel Analysis

Based on the identified potential relevant systems, the next step was to analyse some of them and to define some suggested Root Definitions. Appendix 5 presents a full set of Root Definitions defined in this study. The first step in defining Root Definitions is to describe “what” each system does and from this what is the transformation (entity as input → same entity transformed as output). Another basic analysis for defining RDs is to look to its upper and lower levels (multilevel analysis), what is synthesized by the PQR analysis.

One of the most relevant RDs defined in this study is RD ENV.01, described in Table 21. It is based on a potential relevant system identified in the merged map and individual maps. This system corresponds to the operational part of reverse logistics itself. It considers the same processes as those usually modelled within the boundaries of a WEEE LCA study. For this reason we considered this RD belongs mostly to the environmental (ENV) dimension. PQR elements were entirely based on the hierarchy of causal maps. Another essential part of a RD is the CATWOE/BATWOVE analysis. For RD ENV.01, this analysis is presented in Table 22. There can coexist different definitions for T in this RD, because they also describe the by-products produced along the process: air and water emissions, waste generation, jobs generation, etc. These coexisting Ts for a same RD can be a reference for structuring LCSA inventory flows. They are also relevant because they put light in interesting reference flows for analysis in LCSA.

In Table 22 it is possible to notice that the Clients, Beneficiaries or Victims of the system described in RD ENV.01 are the same described as Areas of Protection in LCA (environmental). The Transformation T describes a flow and transformation of materials (WEEE), what explains that its impacts are on human health or the environment, this being the World-view (Table 22) and the R in PQR (Table 21). In Table 21, second column (Q in PQR) it is possible to have an idea of the activities or sub-systems involved in producing the transformation T: WEEE collection, WEEE dismantling, WEEE recycling, WEEE disposal. These are the core processes modelled in the Conceptual Model for RD ENV.01. In Figure 69 there is a proposal a CM for such T, based on the assumption that WEEE is to be delivered by consumers at delivery stations (shops and/or public policies). This CM also describes surrounding processes (sub-systems) necessary for the proper execution of the core systems (those within traditional WEEE LCA boundaries). However, as explained in the theory review, this CM is just an alternative or scenario describing a stakeholder or specialist perspective. There can be other alternative system configuration with their different sets of processes that, working together, can produce the same transformation described in T. For example, an alternative system would include both WEEE delivery at stations and WEEE collection at doors by the municipal system (COMLURB) and selective collection (COMLURB and cooperatives). This also provokes a variation of actors involved in all processes, what may be relevant to consider in LCSA studies. These possible variations regarding the process of “transport” in Figure 69 are illustrated in Figure 71. SSM is able support the identification of variations that can describe alternative LCSA models. Multilevel analysis is an approach in SSM which can support the systematic analysis of RDs to identify alternative system configurations for a same T. By looking to each sub-system describing the process in Figure 69 and zooming the system thinking analysis to their levels, each process in the CM of RD ENV.01 can be modelled as a RD itself, with their own sets of sub-processes. An example of multilevel analysis for the process “transport” in ENV.01’s CM is presented in Figure 70.

In Appendix 6 we present the CATWOE/BATWOVE analysis for three potential LCSA alternative scenarios for the process of WEEE transport. These are: the *baseline* or the current system; a WEEE collection chain based on WEEE delivery at *EEE shops*; and a *hybrid* system that involves door-to-door collection by COMLURB, cooperatives or private companies, WEEE delivery at EEE shops, Fabrica Verde units and metro stations. These three scenarios are based on the real situation and the perspectives of stakeholders with support of the maps. There can even be variations within each of these alternative systems, by analysing their subsystems with support of SSM.

So far we have discussed RD ENV.01 by analysing its subsystem or its lower level of processes (Q in PQR). But it is also important to analyse the upper levels of a RD (R in PQR) in order to comprehend the broader context within which each RD is just a subsystem in a network of processes. In SSM this is usually defined as the level of the Owner (O in CATWOE). For example, we have defined that RD ENV.01 is owned mainly by the Sectoral Agreements, because there are the agents who can make the system exist or not. Therefore the upper level of RD ENV.01 would be a system that describes all processes carried out by the Sectoral Agreements, who are responsible for planning and implementing WEEE reverse logistics in Brazil. This way, an upper-level RD containing RD ENV.01 would be “a system that plans and implements reverse logistics in Brazil”. This would be an interesting system to be modelled as RD with

PQR, CATWOE and multilevel analysis. Other of its subsystems can be found amongst the RDs defined in Appendix 5.

Table 21. Root Definition ENV.01

A SYSTEM THAT…			TRANSFORMATION
DOES… (P)	BY… (Q)	IN ORDER TO… (R)	
Minimizes water contamination, air emissions and raw material depletion	Adequately collecting, dismantling and recycling WEEE and disposing of residues	Minimize environmental impacts	WEEE generated → WEEE recycled or adequately disposed of

Table 22. CATWOE/BATWOVE analysis for Root Definition ENV.01

Clients/ Beneficiaries/ Victims	Population; Ecosystems
Actors	Waste management companies; cooperatives; informal workers; EEE commerce and industry; municipalities
Transformation	WEEE generated → WEEE recycled/adequately disposed of Environmental burdens from current chains → Environmental burdens reduced and controlled
World-view	WEEE can produce several negative impacts to human health and the environment if not treated properly
Owner	Sectoral Agreement
Environment	Legislation; environmental and public policies; natural and urban environment; society needs and expectations

An interesting example is RD SOC.01: "<u>a system that</u> creates jobs and income opportunities with adequate working conditions, <u>by</u> organizing, capacitating and engaging cooperatives and young workforce in some stages of the system, generating more economic activities and establishing a balanced model in terms of technology, <u>in order to</u> enhance social inclusion. This RD is characterized by the transformation: unemployed or informal worker → formal worker within the WEEE chain. This way, RD SOC.01 is directly connected to RD ENV.01 because it provides the WEEE chain with workers, who are key actors in ENV.01's CATWOE, especially these: waste pickers' cooperatives, young workforce from favelas (Fabrica Verde) and formal workers at WEEE companies. Regarding the formation of WEEE cooperatives, a CM is suggested in Appendix 7. This CM is based on the methodology applied by our interviewed representative of business incubators for cooperatives. There can be significant variations in this model, depending on the approaches adopted to select, organize, formalize and capacitate cooperatives to work within the WEEE chain.

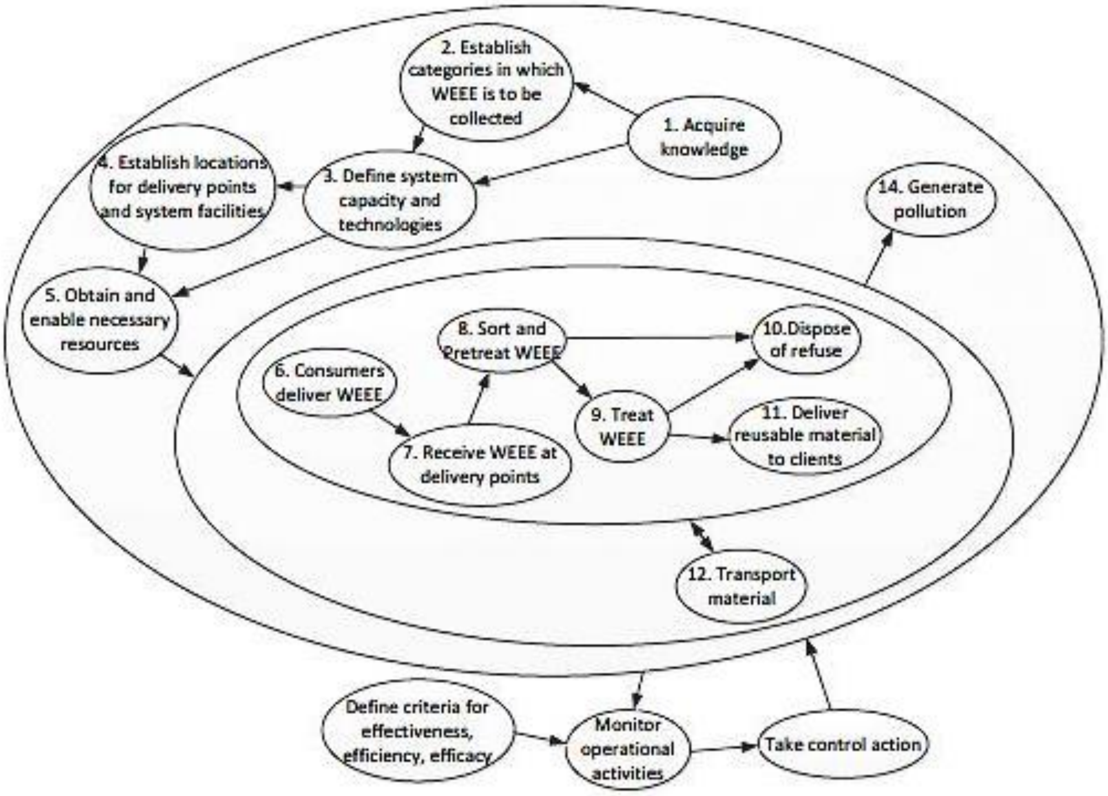


Figure 69. CM for Root Definition ENV.01

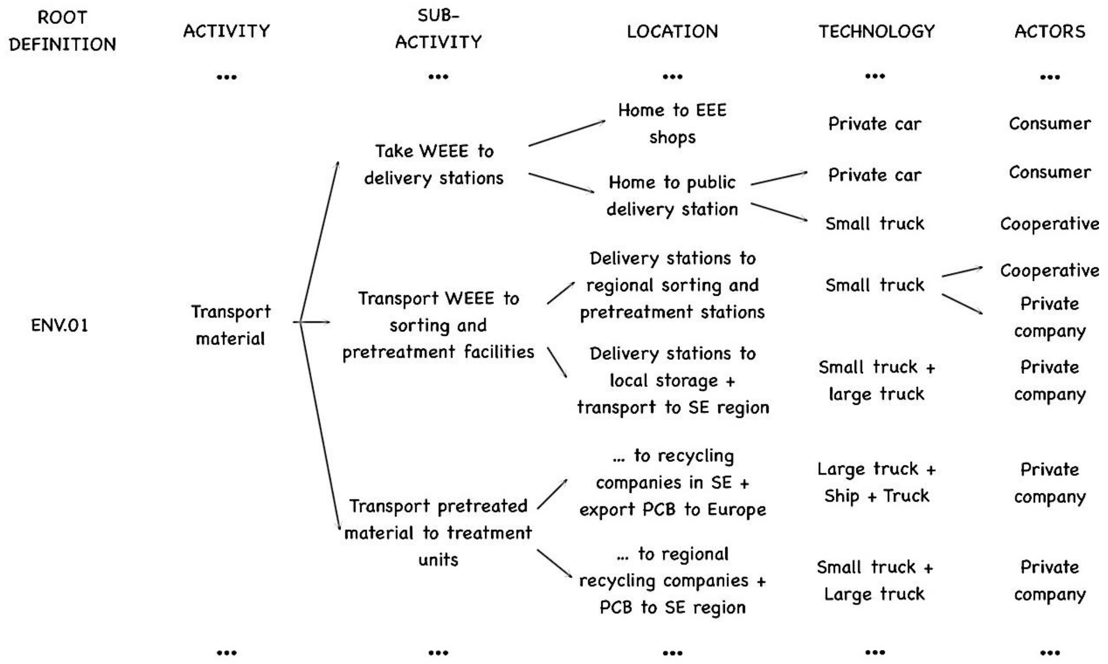


Figure 71. Alternative systems for WEEE transport considering three variables

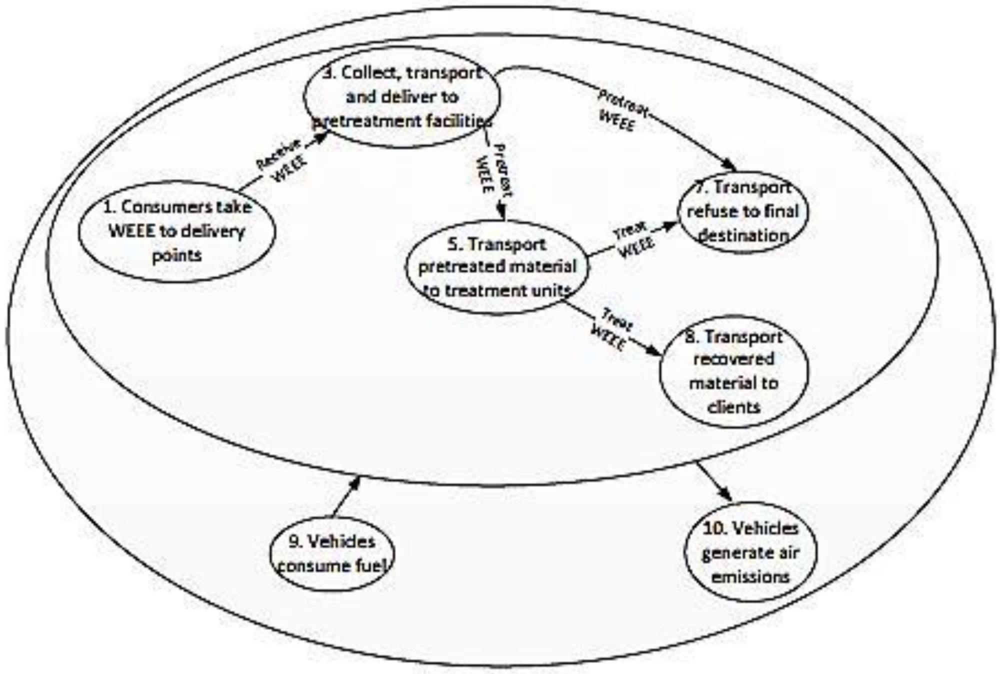


Figure 70. CM for the subsystem "WEEE transport"

A reference system model both for WEEE dismantling (a subsystem in RD ENV.01) and for enabling specialized workforce in WEEE dismantling (an alternative for RD SOC.01) is an Austrian social enterprise called Demontage und Recycling Zentrum (DRZ). It receives approximately 25% of all WEEE produced in Vienna, while 75% is processed by private companies. Unemployed or socially excluded people, like exprisoners, receive a training, a fixed salary and social assistance for a working period of 6 months. During this time they work in WEEE collection, dismantling, refurbishment, and development of new products from WEEE. Products from dismantling are commercialized to WEEE recyclers (e.g. UMICORE) while new products and refurbished appliances can be bought by the population. Figure 72 presents an overview of the processes carried out by DRZ and Appendix 8 illustrated the components separated in their WEEE dismantling of specific appliances. It is important to highlight that WEEE dismantling in DRZ is more specific than the process currently carried out by WEEE dismantling cooperatives in RMRJ. Some components are separated similarly by both systems, like PCB which is separated into three quality (Q) categories – Q1, Q2 and Q3. On the other hand, some components like motors found in printers are not separated by the RMRJ cooperative as they are at DRZ, what provokes waste of resources, as these can be sold separately but are currently being sold as mixed scrap in RMRJ. Table 23 presents market prices for main WEEE fractions and costs for disposal as due for DRZ in 2013.

In comparison to the full SSM steps, the part of SSM suggested in our methodology does not comprehend the rich mapping phase (substituted by SODA) and the comparison of systems with reality to determine desirable and feasible changes. We also did not detail the 3 E's for all RDs, what would be an important further analysis to define performance measures for selected systems for implementation.

4.2.7. Definition of LCSA systems and boundaries for the case study

After analysing the most relevant Root Definitions for the case study, the next step is to analyse what are potential alternative models to be assessed and compared in LCSA. As discussed previously, RD ENV.01 can be interpreted as a description of WEEE systems as traditionally modelled in LCA. There are complementary systems that can be relevant to LCSA, because they process inputs and outputs with direct influence to social and economic impacts. Examples of these systems are RDs SOC.01 and ECN.01. These complementary systems are connected to RD ENV.01 by the flows of resources other than materials, like workforce, information and money. These systems are normally considered as part of the homogeneous LCA background system, while in LCSA they can be included within the expanded foreground boundary. These interconnected systems can present alternative models with different potential impacts to society and the economy.

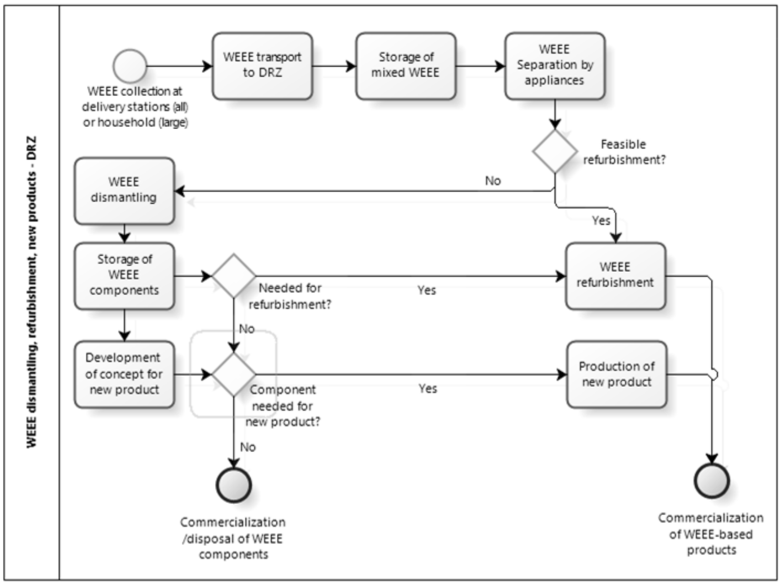


Figure 72. Resumed DRZ system model

In this work we have identified and described several potential systems to be modelled (Appendix 5), and most of them will be interconnected within a complex chain of processes which goes far beyond traditional LCA models. Selecting the most relevant of them for modelling would require additional workshop sessions with stakeholders. For the purpose of demonstrating the methodology, we selected some of them to describe a broader LCSA system boundary (Figure 73). From these, we present in **Table 24**, **Table 25** and **Table 26** some potential subsystems (activities) with alternative possible configurations, which can be considered independently or combined. These alternatives vary from the currently existing systems to the possibilities discussed by stakeholders. As each RD subsystem has its own inputs-outputs flows, by which they are connected to other subsystems, there can be alternative ways to transform same inputs into same outputs (with more or less efficiency/efficacy/effectiveness). Combining alternatives for each subsystem with an overall WEEE system can produce a range of potential LCSA scenarios for the case study, when it comes to the overall chain presented in Figure 73. This emphasizes the need of decision-support tools like MCDA or DEA to compare several alternatives against the sustainability criteria (LCSA impact categories). Only considering alternatives in **Table 24** it is possible to define several alternative models for ENV.01. In this work we illustrate and discuss just some of them: the baseline model (current system) already presented in **Figure 52**; a system based in WEEE delivery at EEE shops (**Figure 74**); and a hybrid system considering the partnership with the underground transport system and the MSW company COMLURB (Figure 75).

Table 23. Market prices and costs of disposal of main WEEE fractions as for DRZ in 2013

WEEE fractions as separated at DRZ	Price/ton (+) or cost/ton (-) in EUR
Processors	45,000
PWB, Q1	6,000
Mobile phones without batteries	6,000
Bronze/brass	5,000
Copper	4,500
Neodym magnet	4,000
PWB, Q2	2,000
Cable without plugs	1,900
Cable with plugs	1,700
HDD with PWB	1,300
Printer cartridges	1,000
Aluminium	900
HDD without PWB	900
Motors/inductors/transformers	700
Stainless steel	500
PWB, Q3	500
Batteries	500
Drives	450
Power supply	300
Mixed scrap	150
Iron/steel	120
Plastics	0
Wood	0
Glass	0
CRT glass	-150
Residual waste	-200
Capacitators	-500
LCD displays	-500
Deflection coil	N/A
Getterpil-electrogun	N/A
Fluorescent tubes	N/A

Table 24. Considered alternatives for subsystems of RD ENV.01

Transformation: WEEE produced → WEEE adequately collected, processed, disposed of					
RD subsystems	Activities	Actors	Locations	Technologies	Costs
…**01**. WEEE delivery and collection	…**01**. Take WEEE to delivery place	…**01**. Consumers	…**01**. Home to EEE shops	Private car + public transport	Fuel; transport fee
			…**02**. Home to street bin	Walk	Collection fee
			…**03**. Home to tube stations	Walk + Public transport	Transport fee
	…**02**. Collect WEEE	…**01**. EEE shops	Shops	WEEE bins; computer with internet	Workers; Lost space; Maintenance; taxes; licensing
		…**02**. Cooperatives …**03**. Private companies …**04**. MSW company	…**01**. Street bins	WEEE bins; Trucks	Fuel; Workers; Fleet + Maintenance; taxes; licensing
			…**02**. Tube stations	WEEE bins; Trucks; PPE	
		…**05**. Informal worker	Streets	Human-powered cart	Food; cart
…**02**. WEEE pre-treatment	...**01**. Sort WEEE by appliances + Store	…**01**. Cooperatives	…**01**. Cooperatives units	Large bags; PPE	Workers; fuel; energy; water; taxes; licensing
			…**02**. Dismantling unit	Large pallets; forklifts; PPE	
		…**02**. Private companies	…**01**. Regional unit		
			…**02**. Sao Paulo		
		…**03**. MSW company	ETRs		
		…**04**. Scrap dealers	RMRJ	Scrap yard; large bags	

(Cont.)

…**02**. WEEE pre-treatment (cont.)	…**02**. Dismantle WEEE + Store components	…**01**. Cooperatives	…**01**. Cooperatives units (current)	Workbench; simple toolkit; PPE	Workers; energy; water; taxes; licensing
			…**02**. Dismantling unit (DRZ model)	Workbench; advanced toolkit; PPE	
		…**02**. Private companies	…**01**. Regional unit		
			…**02**. Sao Paulo		
	…**03**. Test appliances + components	…**01**. Fabrica Verde	Fabrica Verde units	Workbench; IT + electronics + electrical toolkit	Workers; training; energy; water; taxes
		…**02**. IT + electronics companies	…**01**. Brazilian units (SP)		
			…**02**. USA + Europe + China + Japan		
…**03**. WEEE refurbishment	…**01**. WEEE refurbish + resell	…**01**. Specialized associations (former F. Verde students)	RMRJ		
		…**02**. Cooperatives			
		…**03**. Informal technicians	South America		Workers; energy; water
…**04**. WEEE processing	…**02**. Remanufacture EEE	EEE industry	…**01**. Brazil (SP)	EEE Industrial plants	Workers; training; energy; water; production resources; equipment; taxes; licensing risks; obligations; penalties
			…**02**. USA + Europe + China + Japan		
	…**03**. Recover rare earth metals (REM) from WEEE	WEEE industry	…**01**. Brazil (RMRJ)	UMICORE-based technology	
			…**02**. Europe + Japan		
		Informal actors	…**03**. RMRJ + China + India (informal)	Acid leaching; burning; melting	Workers; training; energy; water; chemical substances; equipment

(Cont.)

…**04**. WEEE processing (cont.)	…**04**. Recycle Large Household Appliances (freezers, refrigerators; air conditioners)	WEEE industry	Brazil (SP)	Industrial technology	Workers; training; energy; water; equipment; taxes; licensing risks; disposal of residues; obligations; penalties
	…**05**. Decontaminate hazardous waste	Waste management companies	Brazil (RJ + SP)		
	…**06**. Develop new products from WEEE	Product designers; trained workforce; DRZ	RMRJ communities	Computer with graphical software; workstation; workbench; advanced toolkit; welder; glass printer; metals shaper	Workers; training; energy; water; taxes; equipment
…**06**. Disposal of residues	Landfill residues	Waste management companies	Brazil (RJ + SP)	Industrial landfill	Workers; training; energy; water; equipment; taxes; licensing risks; obligations; penalties
…**07**. Deliver products to clients	…**01**. Donate refurbished computers	Fabrica Verde	RMRJ	Workstation; computer with internet; mobile phone; trucks + private cars	Fuel; energy; water; taxes and fees
	…**02**. Commercialize WEEE + components	…**01**. Cooperatives			
		…**02**. Private companies			
		…**03**. Scrap dealers			
…**08**. Transport	(see **Figure 71** and **Figure 70**)				

Table 25. Considered alternatives for RD SOC.01

Transformation: Unemployed or informal worker → Formal worker within the WEEE chain					
RD subsystems	Activities	Actors	Locations	Technologies	Costs
…**01**. Organize, capacitate and engage cooperative within the system	…**01**. Engage and mobilise marginalized population	Business incubators	RMRJ	Private car + Public transport	Transport fees; fuel
	…**02**. Organize and network cooperatives and associations			Computers with internet; audio-visual; cameras; software; telephones; workstations; meeting rooms; training rooms	Workers; training; energy; water; taxes; equipment
	…**03**. Provide training and develop participatory capacity				
	…**04**. Manage resources	Cooperatives members			
	…**05**. Diversify products and raise scale				
	…**06**. Negotiate with recycling industry				
…**02**. Organize, capacitate and engage young workforce from poor communities within the system	…**01**. Recruit young trainees	Fabrica Verde + young workforce		Computers with internet; audio-visual; workstations; toolkits + PPE; meeting rooms; training rooms	
	…**02**. Offer training				
	…**03**. Practice PC refurbishment				
	…**04**. Test trainees				
	…**05**. Select new trainers				
…**03**. Organize, capacitate and engage workforce within the system	…**01**. Recruit workers	Private companies	RJ; SP		
	…**02**. Offer training	…01. Private companies …02. Technical schools			
	…**03**. Practice				
	…**04**. Monitor performance				

Table 26. Considered alternatives for RD ECN.01

Transformation: Unfeasible EEE and WEEE chain → Feasible EEE and WEEE chain					
RD subsystems	Activities	Actors	Locations	Technologies	Costs
…**01**. Feed the EEE and WEEE systems with production resources	…**01**. RD ENV.01's	WEEE and EEE chain (RD ENV.01)	Brasília (Federal District); RMRJ; SP	Offices; Computers with internet; telephones; seminary rooms; governmental facilities; laboratory for chemical analyses; monitoring equipment; banks and financial institutions	Workers; training; energy; water; taxes; equipment
…**02**. Add value in WEEE recycling	…**01**. Maximize market value for WEEE materials				
	…**02**. Control fluctuations on market prices	Brazilian Government			
	…**03**. Provide financial support and fiscal benefits	Governments (BR; RJ)			
…**03**. Minimize costs	…**01**. Minimize public expenses with MSW management	Municipalities + WEEE chain (RD ENV.01)			
	…**02**. Optimize waste collection and transport, and distribution of WEEE delivery stations	WEEE management entity; Sectoral Agreements; partners			
	…**03**. Prevent additional costs to EEE shops and industry	Sectoral Agreements			
	…**04**. License and monitor WEEE facilities	RJ Government (INEA)			
	…**05**. Avoid cascade taxation	Governments (BR; RJ)			
…**04**. Establish a balanced technological system	…**01**. Analyse workforce availability and demands in all BR regions	Sectoral Agreements; RJ Government; universities and research institutes			
	…**02**. Analyse opportunities for new companies and job generation				
	…**03**. Stimulate technological opportunities to all BR regions				

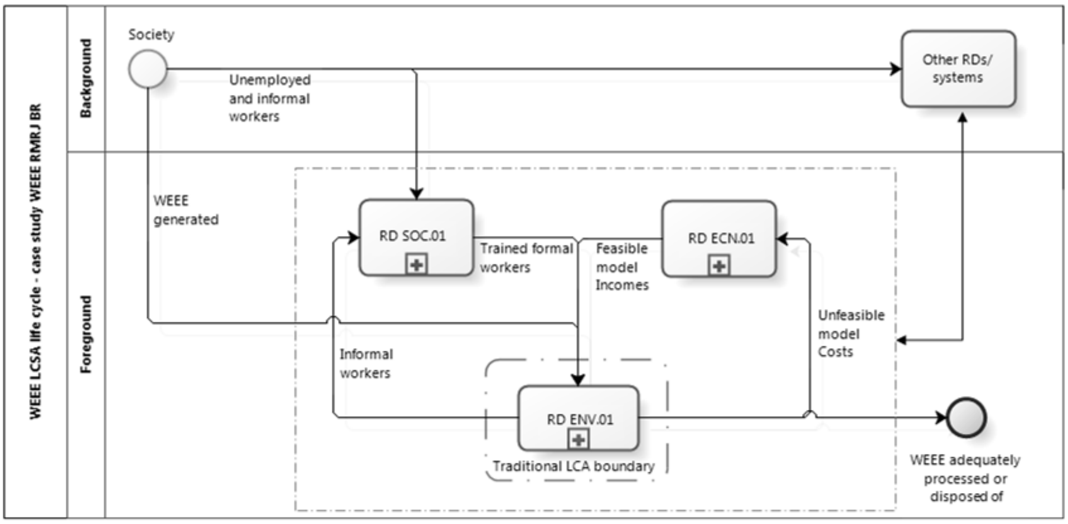


Figure 73. LCSA foreground and background systems for the case study

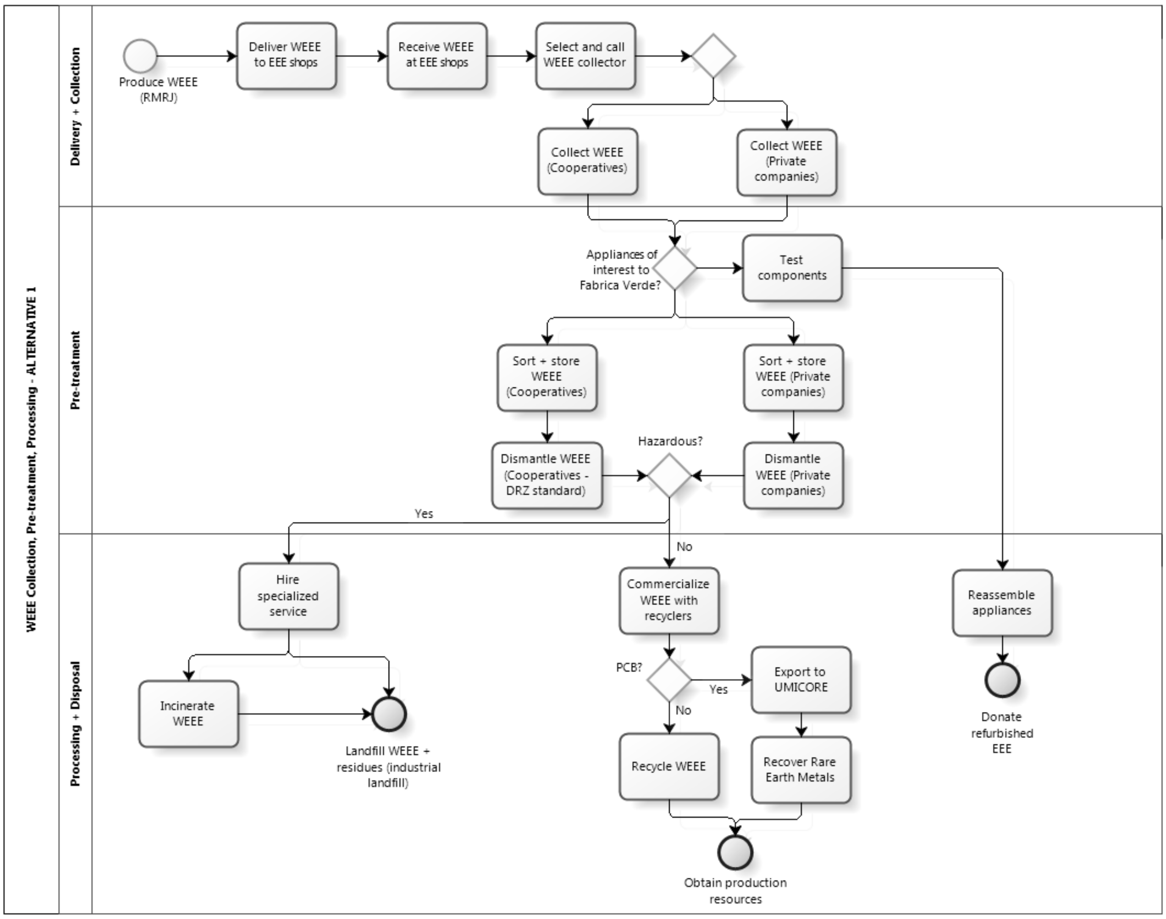


Figure 74. Alternative system for ENV.01 based on WEEE delivery at EEE shops

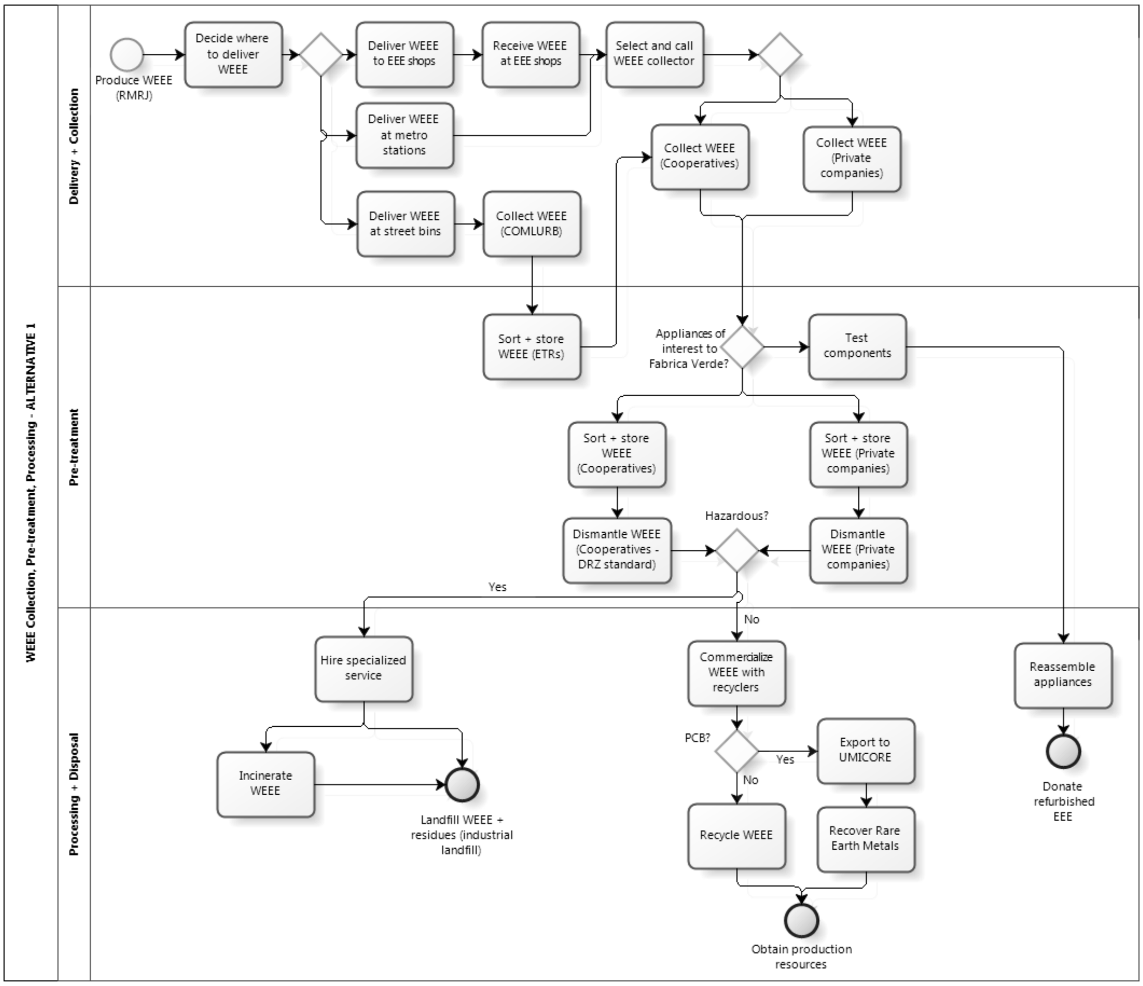


Figure 75. Alternative system for ENV.01 with hybrid WEEE delivery and collection

4.2.8. Functions, Inventory flows, Reference flows, Functional Unit

The broader WEEE life cycle combining different RD may also define different functions, flows, reference flows and functional units for the system, depending on the assessed impact category, rather than adopting LCA standards. For example, assessment of social impact categories like “social inclusion” may be based on the function of RD SOC.01: to formalize workers. This RD has also its own inventory flows which are not just material but mainly of persons and information. This way, a possible reference flow for this category would be in the output arrow of SOC.01: workers inserted in the WEEE chain. Consequently the functional unit would be “worker in the chain”.

4.2.9. Structuring of MCDA performance table

An MCDA performance table for the case study is structured in **Table 27**.

Table 27. Structure of an MCDA performance table for assessment and interpretation of the RMRJ WEEE LCSA study

	LCSA impact categories and indicators for the Brazilian WEEE reverse logistics																									
	Environmental (LCA)					Social (SLCA)											Economic (LCC+)									
						Social inclusion		Employment and generation of income			Risks and working conditions		Access to healthcare, education, environ. education and digital inclusion				Feasibility and efficiency				AW	Innovation/ New econ. Activities		Competitiveness		
LCSA scenarios	GW	A	HT	RD	E	EG	SA	NW	AI	TR	AC	AD	HI	LE	EE	DI	CO	PA	DE	DC	CD	EC	CI	RP	IP	IM
Current system																										
Alternative System 1																										
Alternative System 2																										
Alternative System 3																										
… (Other relevant combinations of RDs/subsystems)																										
Alternative System (n-1)																										
Alternative System N																										

Note:

Environmental categories: GW: Global Warming; A: Acidification; HT: Human toxicity; RD: Resource depletion; E: Eutrophication;

Social indicators: EG: entering workers per group; SA: Social assistance (workers + family); NW: Number of Workers (formal/informal); AI: Average Income (formal/informal); TR: Number of workers that received professional trainings; RW: Risks and working conditions; AC: Number of workers with adequate working conditions; AD: Occurrence of accidents and diseases; HED: Access to healthcare, education and social inclusion; HI: No. workers with health insurance; No. workers/level of education; EE: No. people benefited by environmental education; DI: No. people benefited with digital inclusion.

Economic indicators: CO: Costs/actor and stage of chain; PA: Profits and avoided impacts; DE: WEEE processed (per destination)/WEEE collected; DC: Demand/capacity; AW: Awareness and adhesion (category); CD: No. citizens and companies delivering WEEE to system; EC: No. entering WEEE companies; CI: No. companies with innovation; RT: Increase rate in price; IP: Collected informal products; IM: Growth of informal market.

N: Number of total relevant alternative systems considered for implementation based on SSM/system thinking analyses.

4.3. Discussion

4.3.1. Discussion on the results of the study

The main results of this study have already been discussed in Sections 4.2 and 4.3. In summary, the key topics of discussion regarding these results are:

- Based on our estimates of WEEE generation, Rio de Janeiro is the second city in terms of total WEEE produced, and third in WEEE generation per capita. However, most of this WEEE is believed to enter the informal chains and a large amount is disposed of mixed to household waste. This highlights the urgency of a WEEE management plan in the city of its metropolitan region (RMRJ);
- Existing chains like Fabrica Verde, cooperatives and governmental campaigns could be expanded and enabled to receive larger amounts of WEEE in the city;
- Interviewed stakeholders in this study are representative of relevant stakeholder groups, but some other important groups (consumers, importers) were not covered. This could enrich the content of individual maps and the merged map, thus influencing on their cause-effect hierarchy and the identified social and economic impact pathways. We consider the more complete is the group of interviewed stakeholders, the lower is the intensity of modifications in the merged map. In this sense, we believe the interviews carried out in this study are enough to get a highly enriched map and results;
- Identified potential SLCA and LCC impact categories comprehend some well-established ones, like costs or job generation, but also some unforeseen categories like self-esteem or digital inclusion. Without the elicitation of stakeholder perspectives such categories would hardly be unveiled;
- Root Definitions ENV.01, SOC.01 and ECN.01 may constitute the core integrated systems to be considered within the boundary of an LCSA study in this case. Other RDs and potential relevant systems can also be considered within this boundary. Some of these systems are lower-level processes (subsystems) of others, what is natural in SSM's multilevel analysis. It is possible that all identified potential systems are connected by their inputs and outputs flows.

4.3.2. Advantages and limitations of the methodology

Based on the research results we can make some comments regarding the operation of the methodology in practice. First, in this application it was simply infeasible to hold workshop meetings with the stakeholders. However there is no doubt that a more thorough exploration and discussion with them would have been advantageous. This issue was overcome by the iterative interviews with individual stakeholders as the methodology progressed, which enabled missing information to be incorporated in the map. The workshop facilitator must be sensitive to the need to make progress, especially when determining when it is time to stop eliciting stakeholders' perspectives during the causal map steps.

Second, no work of this kind can be entirely free of subjectivity. So although analysts can suggest redefinitions of impact categories, it is important that during stakeholders consultation they must bring into discussion both the suggested redefined set and also the impact pathway or the merged map containing all the original potential categories identified. In this case some potential categories that were excluded by the analysts in the first analysis were brought back by stakeholders at the next step. This possibility of iterative redefinition confers a degree of robustness on our methodology.

Finally, we would like to highlight that the suggested process did not require any radical intervention by the analysts. As a result, feedback from stakeholders was highly positive: they felt identified and satisfied with the completeness of the defined set of impact categories. Such a sense of ownership of the results by the stakeholders is a significant benefit of Problem Structuring Methods which extended also to the other steps of our methodology.

- While offering significant support to LCSA studies, especially in facilitating stakeholders consultation, our methodology still presents some practical issues that need to be addressed if it is to deliver its full potential contribution to sustainability assessment:
- *Consulting all relevant stakeholders*: Identification and consultation of all relevant stakeholders is fundamental to many steps of our methodology. There is a risk of missing important stakeholders in the consultation. The best way to

overcome this issue is by analysing carefully the statements of consulted stakeholders' in order to identify new stakeholders. Another approach is to ask interviewed stakeholders who they think are respected people in the field and need to be consulted;

- *Determining the hierarchic level of concepts within the cause-effect chain*: the richer the merged map is, the more complex are its elements and causal connections. The task of determining the hierarchical level of issues (inventory, midpoints or endpoints) is a demanding one for analysts and decision-makers. If necessary tangles at this stage (step 4) can be refined during steps 5 and 6 of the methodology;
- *Determining when it is time to stop*: the interactive process of interviewing stakeholders is time intensive. As more stakeholders are interviewed new ideas and issues emerge and the process of preparing and analysing maps becomes more complex. There is a need to decide when to stop this process. One pragmatic resolution of the dilemma is to observe closely when new inputs start predominantly to repeat issues and connections already raised, albeit in slightly different formulations;
- *Evaluating potential sets of impact categories qualitatively*: the evaluation of potential impact categories (step 6) is irreducibly subjective, and relative values for categories can vary depending on the interviewed stakeholder. Workshop discussion processes should be used to facilitate consensus;
- *Appling the methodology comparatively*: while the methodology is in principle context-free, the data it elicits from stakeholders is not. Therefore this will not provide a standard LCC and SLCA impact pathway or set of impact categories for WEEE management, as is possible in LCA.

Regarding SSM, although there is potentially good applicability 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.

5. CONCLUSIONS AND RECOMMENDATIONS

This worked has developed and applied a methodology that combines PSMs and LCSA for system modelling and sustainability assessment of waste management systems, focusing the case of Brazilian WEEE reverse logistics and specifically in the RMRJ. So far we concluded that:

- The methodology described in this research has large potential for facilitating stakeholder consultation in LCSA modelling. Results showed to be rich while concise. Feedback from stakeholders was positive, as they identified with and felt ownership of the results obtained;
- Causal maps can make a useful contribution to structuring impact pathways and to the selection of social and economic impact categories based on real stakeholders' perspectives;
- In our case study causal mapping and the involvement of stakeholders has revealed potential impact categories that have already been established in other SLCA and LCC methodologies, but also other quite innovative and unique ones;
- Endpoint impact categories reflect best the essential sustainability concerns for systems studied in LCSA, but their measurement is problematic. Midpoint impact categories, in contrast, are more operational, but they need to be assembled with care, and refined to ensure that their properties render them logically and practically coherent. Analysis of causal dependency among issues is a good starting point for such refinement;
- Impact categories derived from SODA maps are theoretically more useful to assess real cases than generic ones, especially those concerned with social and economic aspects;
- The quality of impact categories selected 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, what can be supported by the use of SODA;
- SSM provides a holistic perception of a complexity of systems that can constitute a product's life cycle (broader level of processes). It 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;

- Some remaining methodological tangles remain regarding the identification and involvement of all relevant stakeholders, the definition of endpoint and midpoint levels, and the qualitative evaluation of potential sets of impact categories. Progress here will be most effectively achieved through learning from practical applications of the approach. There is good potential for contribution from SODA (supported by value-focused thinking) and SSM to LCSA studies;
- The application of SSM to LCSA needs to be further investigated, in order to tackle methodological issues regarding impacts allocation, scenarios selection and data collection.

For future work it could be instructive to compare both the selected impact categories and the results of LCSA studies on two or more cases involving similar decision situations but in different cultural contexts (for example, WEEE reverse logistics modelling in Brazil, India, China and other developing countries). Another suggestion is to apply this methodology in other types of complex sustainability issues (multiple stakeholders, perspectives, interests) rather than waste management. We also suggest making estimates for WEEE generation in different regions and micro-regions of Brazil or other countries based on their respective PPP, in order to support planning reverse logistics systems in the regional scale and/or to provide inventory data for LCA studies.

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APPENDIX 1. Roadmaps of some interviews carried out in the research

Interview with the EEE industry representative – September 6th, 2011

1. What are key issues in Brazilian WEEE management?
2. What would describe a good social performance of WEEE systems?
3. What are key environmental performance aspects?
4. What products have adequate implemented takeback systems and what are still lacking such systems?
5. What are key drivers to provoke variations in WEEE systems costs?
6. What are potential solutions to WEEE takeback implementation in Brazil?
7. What are the negative consequences if an adequate system is not implemented?
8. What are successful cases in WEEE takeback and why?
9. What would be your sustainability performance measures for WEEE systems? How to collect data?

2nd Interview with the EEE industry representative – August 8th, 2013

1. Why is WEEE takeback important to add value in recycling? What are negative consequences of not adding such value? What is necessary to such value-adding? What are critical obstacles? What describes a good or bad value adding in WEEE takeback?
2. What are the consequences of "pseudo-recycling"? How does it relate to value-adding?
3. How can social inclusion contribute to Brazilian development? How can WEEE takeback contribute to social inclusion? What aspects describe good or bad social inclusion?
4. How can WEEE takeback influence societal behaviour? Why is change in behaviour relevant?

* * *

Interview with the EEE commerce representative – December 13th, 2011

1. What is the role of the RJ Commerce Federation in developing WEEE management in the State?
2. How are commerce companies to get involved in WEEE systems?
3. What are main difficulties in implementing WEEE systems?

4. How should technologies and procedures be defined?
5. What aspects describe good social, environmental and economic performances?
6. What solutions for the system are already known? What are their advantages and disadvantages?

2nd Interview with the EEE commerce representative – April 10th, 2013

1. What is the relevance of WEEE systems value adding to: a) Brazilian economic development? b) social inclusion?
2. What are risks and opportunities of WEEE systems to EEE commerce?
3. What describes a good or bad social inclusion in WEEE systems?
4. How can political marketing harm WEEE systems?
5. What is the importance of Local Productive Arrangements for Brazilian social and economic development?

* * *

Interview with the RJ Government representative – October 26th, 2012

1. What is the role of the State Government in WEEE systems development?
2. What should be the Government's role in WEEE systems implementation?
3. What are critical decisions to be taken in WEEE systems development?
4. What should be social, economic and environmental criteria to assess performances of such decisions?
5. What are existing WEEE chains in the State? What are their pros and cons?

2nd Interview with the RJ Government representative – April 22th, 2013

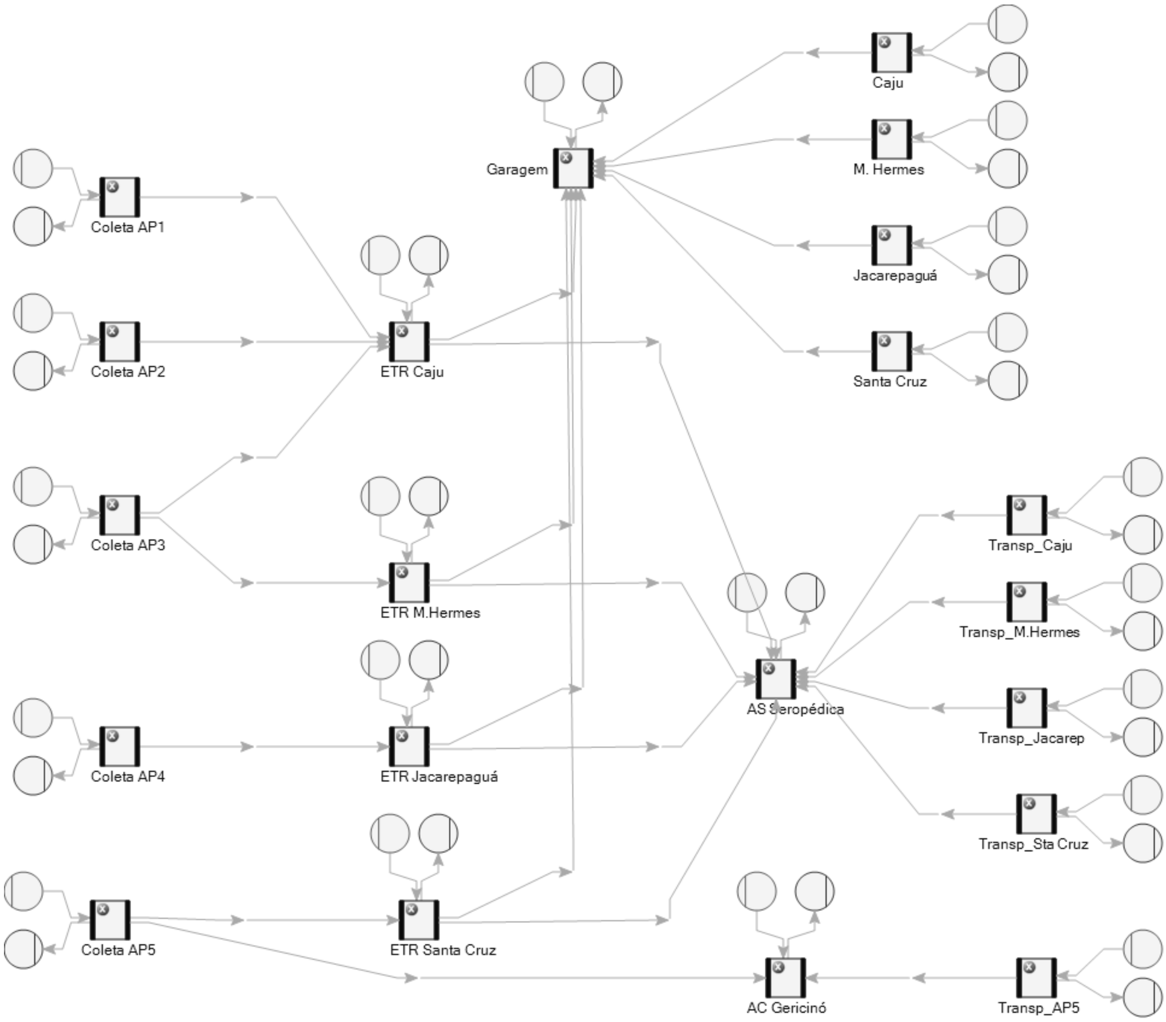
1. What is the relevance of WEEE systems to Brazilian development? How can a bad system harm such development?
2. How is digital inclusion related to social inclusion?
3. How can WEEE systems produce good social inclusion? How can a bad system harm such inclusion?
4. Why is it important to make WEEE systems feasible? How can they be made feasible?
5. How can corruption influence WEEE systems? What are consequences?
6. Why is it important to satisfy WEEE defined targets? What are consequences if not satisfied?
7. What are key political interests in WEEE systems? What is their importance for social and economic development and environmental quality?

* * *

Interview with WEEE specialists – March 14th, 2013

1. What are the most important aspects Brazil should consider in its model for WEEE reverse logistics? Why are they important?
2. What can be the environmental, social and economic consequences of a bad WEEE management system? What current practices can lead to these consequences? Why are they still being practiced? Where?
3. What are the main achievements that would define a sustainable WEEE system? What has to be implemented in Brazil, in order to enable for these achievements?
4. What are the available technologies for WEEE recycling and treatment? Where have them been operated? Could you briefly describe their processes? What are their pros and cons?
5. What defines decent work conditions in WEEE systems? How can the Brazilian WEEE system generate more jobs with decent work conditions?
6. What levels of tolerance can be admitted for environmental and social impacts, in order to assure economic and operational sustainability for the WEEE systems? (trade-offs)

APPENDIX 2. LCA model for the mixed household waste system in the city of Rio de Janeiro



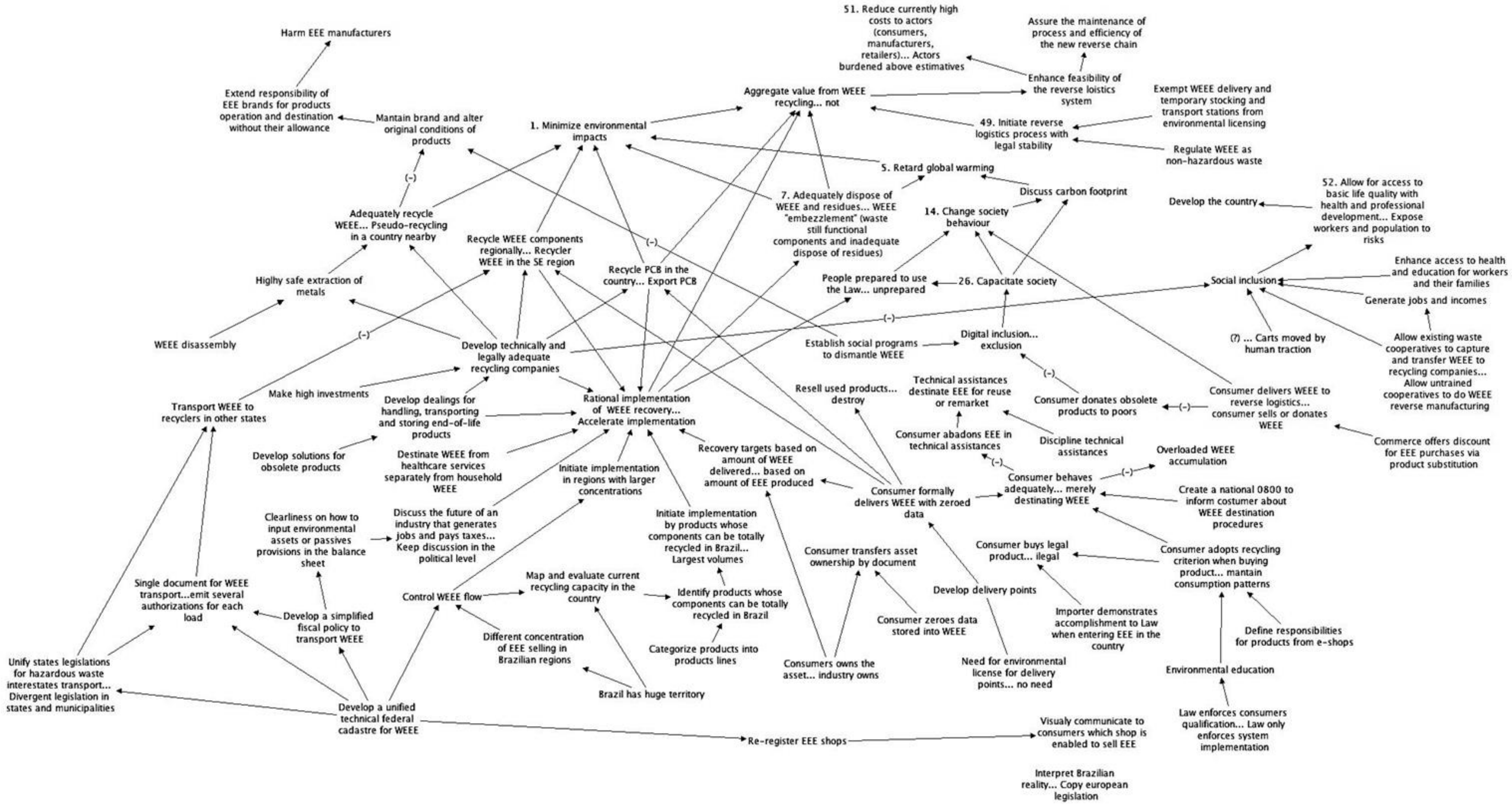
APPENDIX 3. Consulted stakeholders and specialists for the case study

Name (initials)	Institution	Role/ relevance to the problem situation (WEEE RMRJ)	Mode of consultation	Built indiv.map? (Y/N)
<u>Stakeholders:</u>				
A.S. A.B. E.M.	ABINEE	- ABINEE is the association of Brazilian EEE industries; - ABINEE is a member of the WEEE GTT and in one of the proposals for Sectoral Agreement; - A.S. was referendary of the WEEE GTT and A.B. is their current representative in Sectoral Agreement. E.M. is its Coordinator of Logistics.	Interview; e-mail	Y N N
H.M.	ABREE	- ABREE is the association of WEEE recyclers and a member of Sectoral Agreement; - H.M. is ABREE's president.	e-mail	N
C.S.	FEBRACON -RJ	- FEBRACON is the Brazilian association of commerce companies; - C.S. is its representative in Sectoral Agreement.	Interview	Y
V.Z.	SEA	- V.Z. is SEA's Superintendent of Sanitation Policies, and responsible for waste management policies of the RJ Governement.	Interview; e-mail	Y
D.G. R.R.	Fabrica Verde	- They are respectively the former and the current Coordinator of the Fabrica Verde program.	Interview; e-mail	Y N
J.G.	UVIC	- She is a professor at the University of Victoria and works at a Business Incubator for Waste Pickers' Cooperatives in the state of Sao Paulo, Brazil.	Interview; e-mail	Y
P.P.	AGENERSA -RJ	- AGENERSA is the governmental agency for regulation of public sanitation services, and P.P. is responsible for waste management.	Interview	N
I.R.	ABILUX	- ABILUX is the Brazilian association of lightning industry; Mr. Roizenblatt is its president and representative in Sectoral Agreement.	Interview	Y

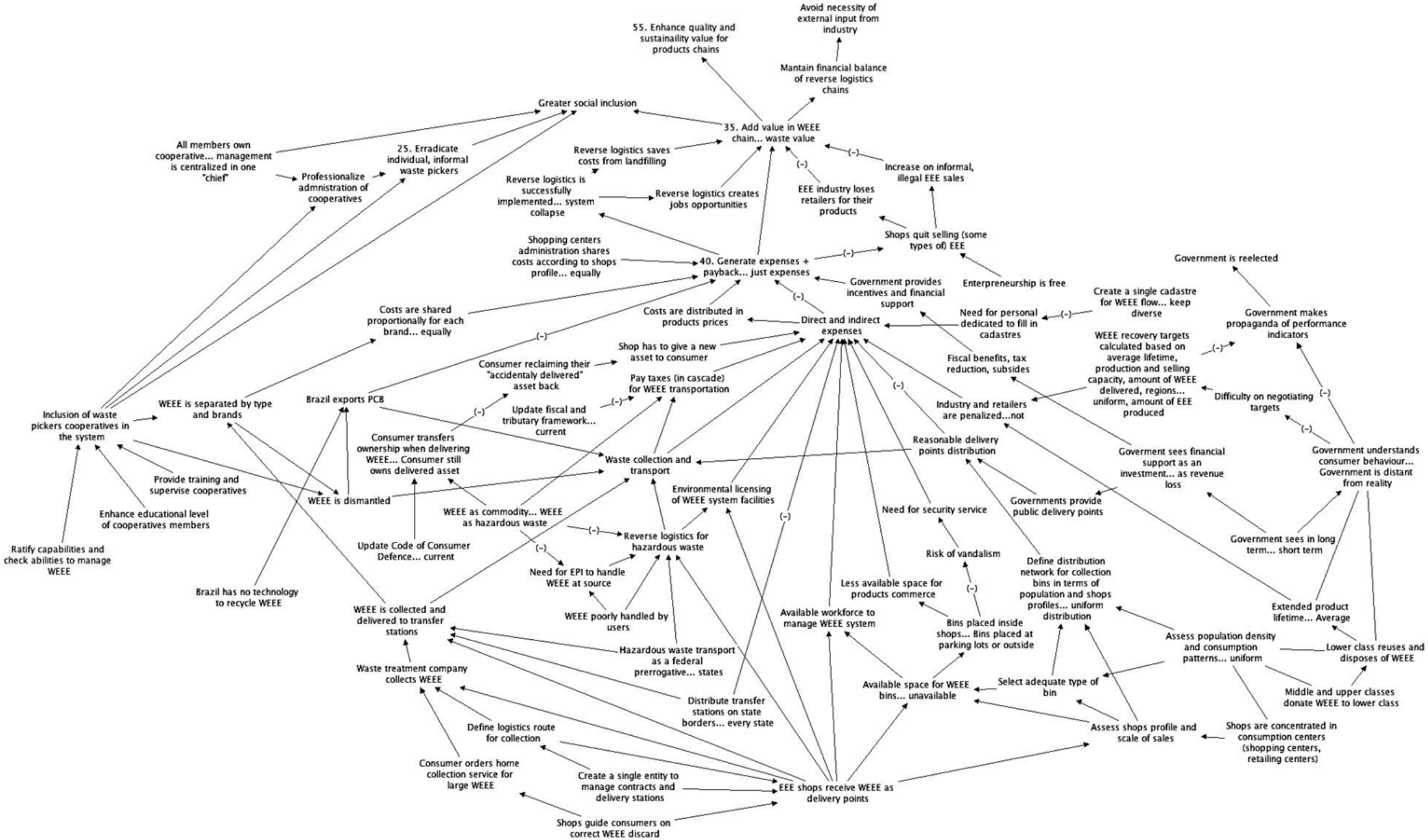
Specialists:				
C.S.F.	ABRELPE	- ABRELPE is the Brazilian association of public sanitation and waste management companies; C.S.F. is its director.	Interview	Y
M.P.M.A.	-	- He is a specialist and consultant in Brazilian environmental law	Interview	Y
P.R.L.	CLRB/ Mackenzie	- He is a professor, consultant and specialist in reverse logistics.	Interview	Y
I.W. F.O.	University of Southampton	- They are respectively a professor and a post-doc fellow; specialists in WEEE management and LCA applied to waste management.	Interview	N
M.S.	DRZ	- DRZ is an Austrian reference company in WEEE dismantling and refurbishment; M.S. is its chief engineer.	Interview	N
A.T.	PUC-Rio/ GloboNews	- He is a professor and journalist in the field of environmental journalism, and runs a TV programme focused in sustainable development.	Interview	Y
R.G.	FIESP	- FIESP is the federation of Sao Paulo industries, and R.G. is its representative in the sectoral agreement for reverse logistics of lubricating oil and their packages. - This reverse logistics chain is well established in Brazil and is considered a reference model for other sectoral agreements.	E-mail	N
L.P.	Phillips Brazil	- Phillips runs a reverse logistics program for their products in Brazil.	Interview; e-mail	N

APPENDIX 4. Cognitive maps of some stakeholders and final merged map

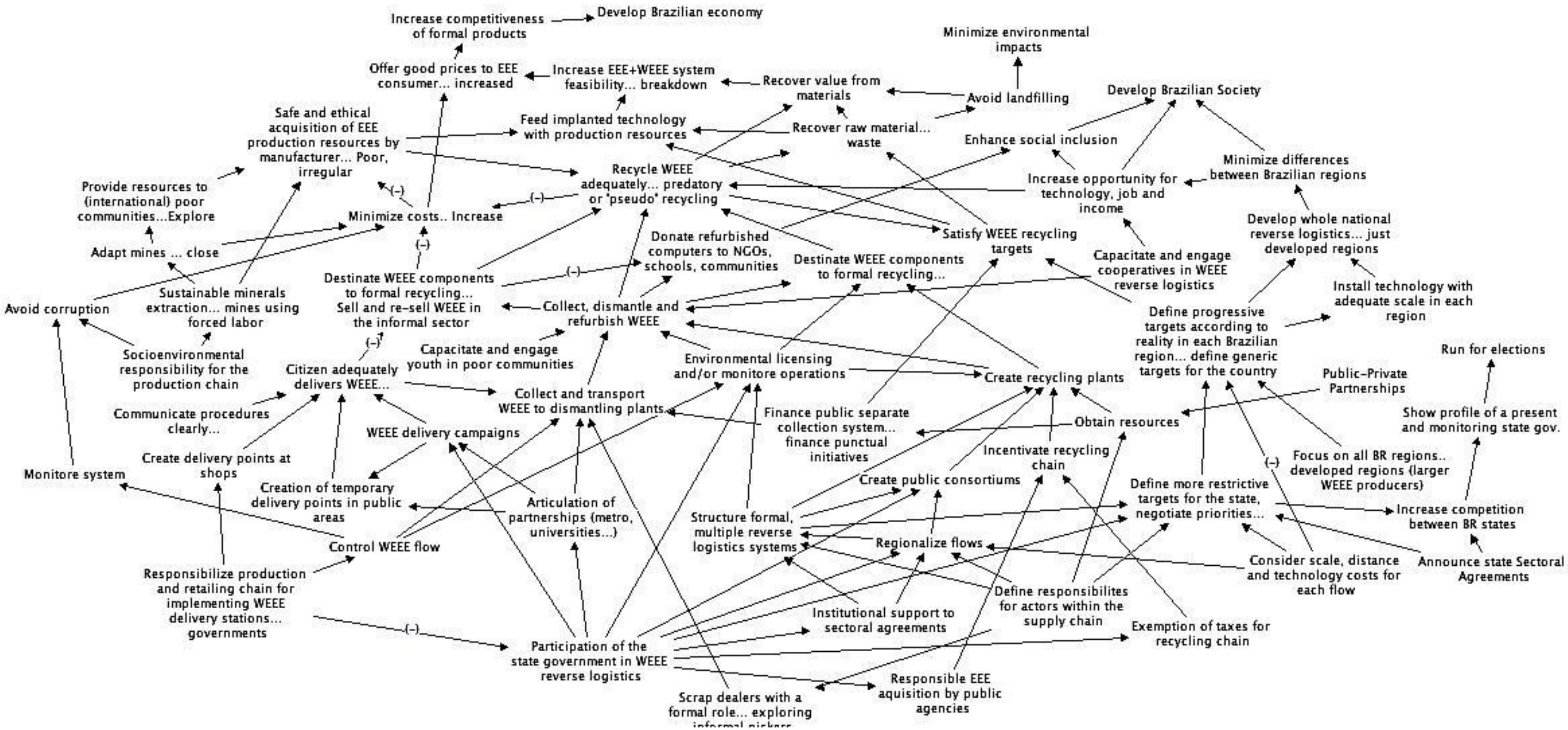
- EEE manufacturer:



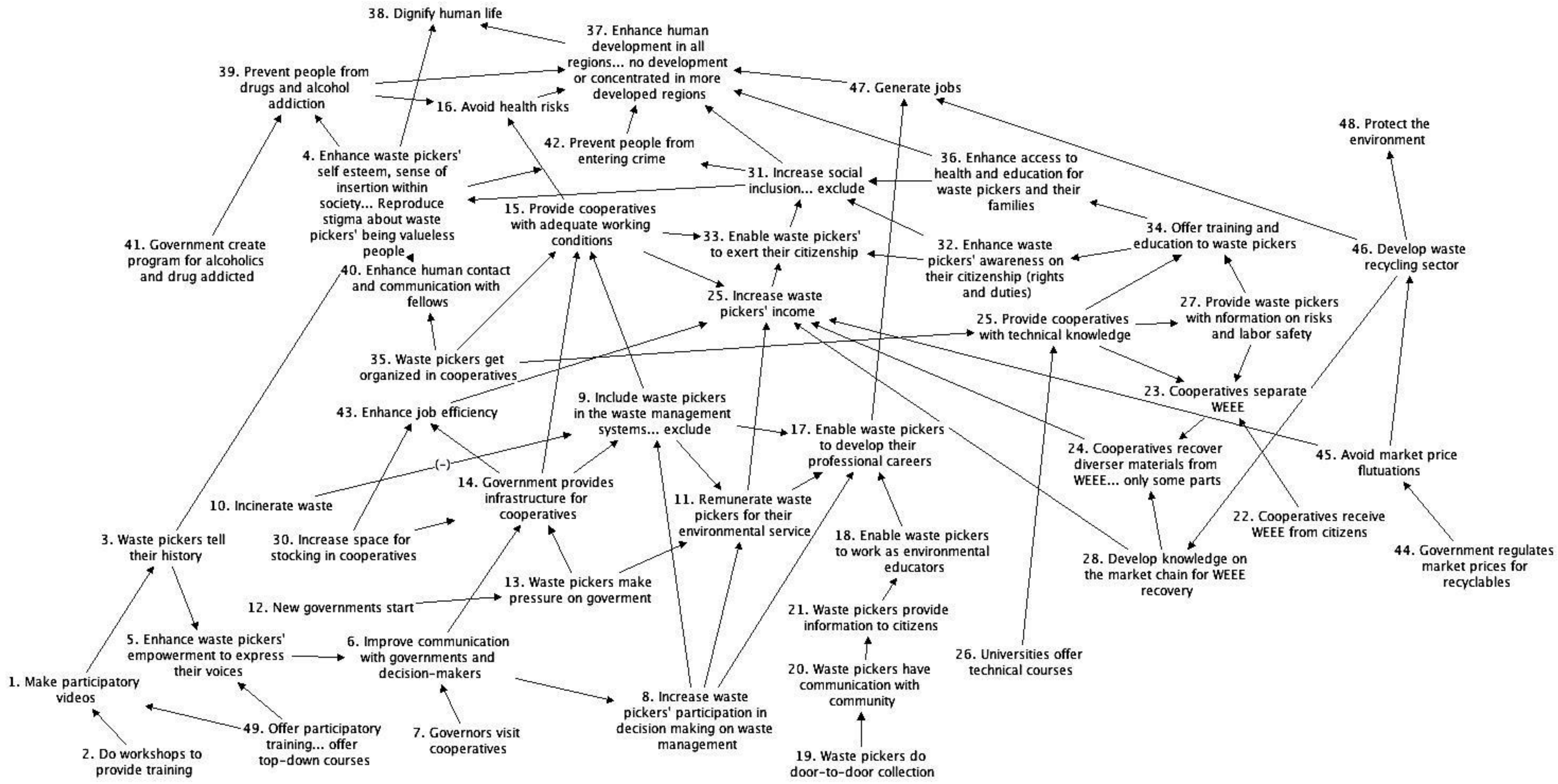
- EEE commerce:



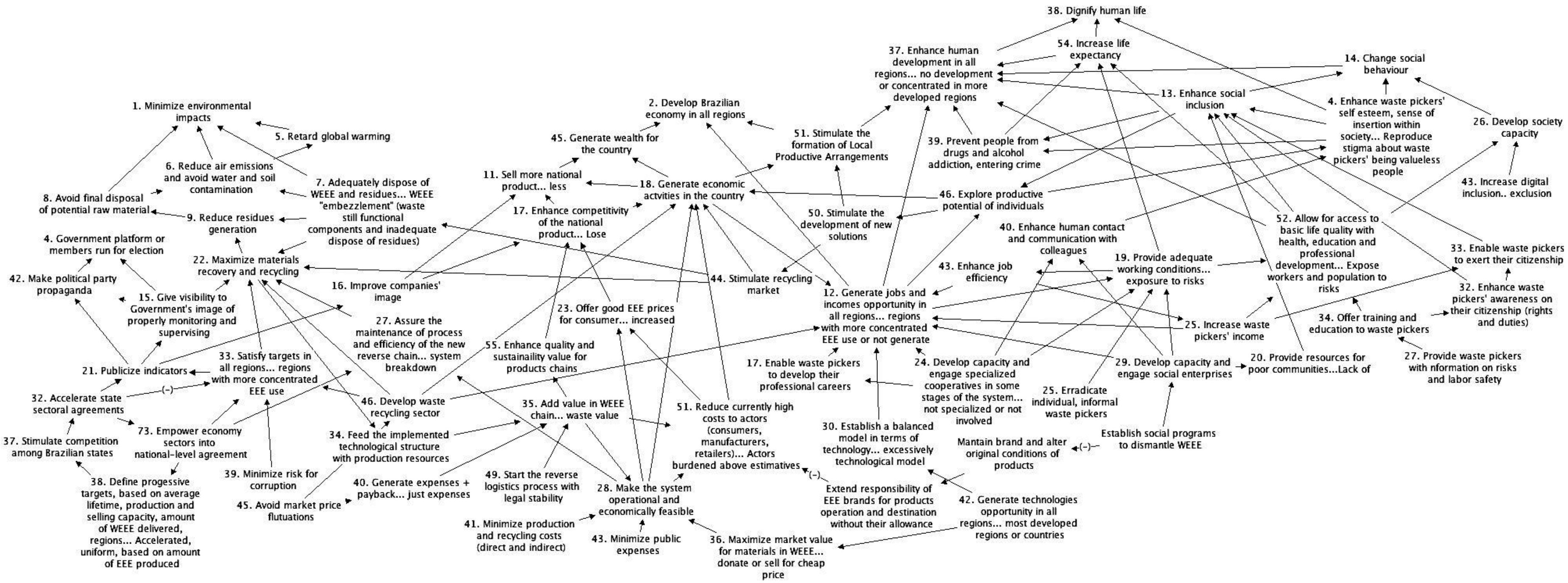
- State Secretary of Environment (Superintendent of Public Sanitation Policies):



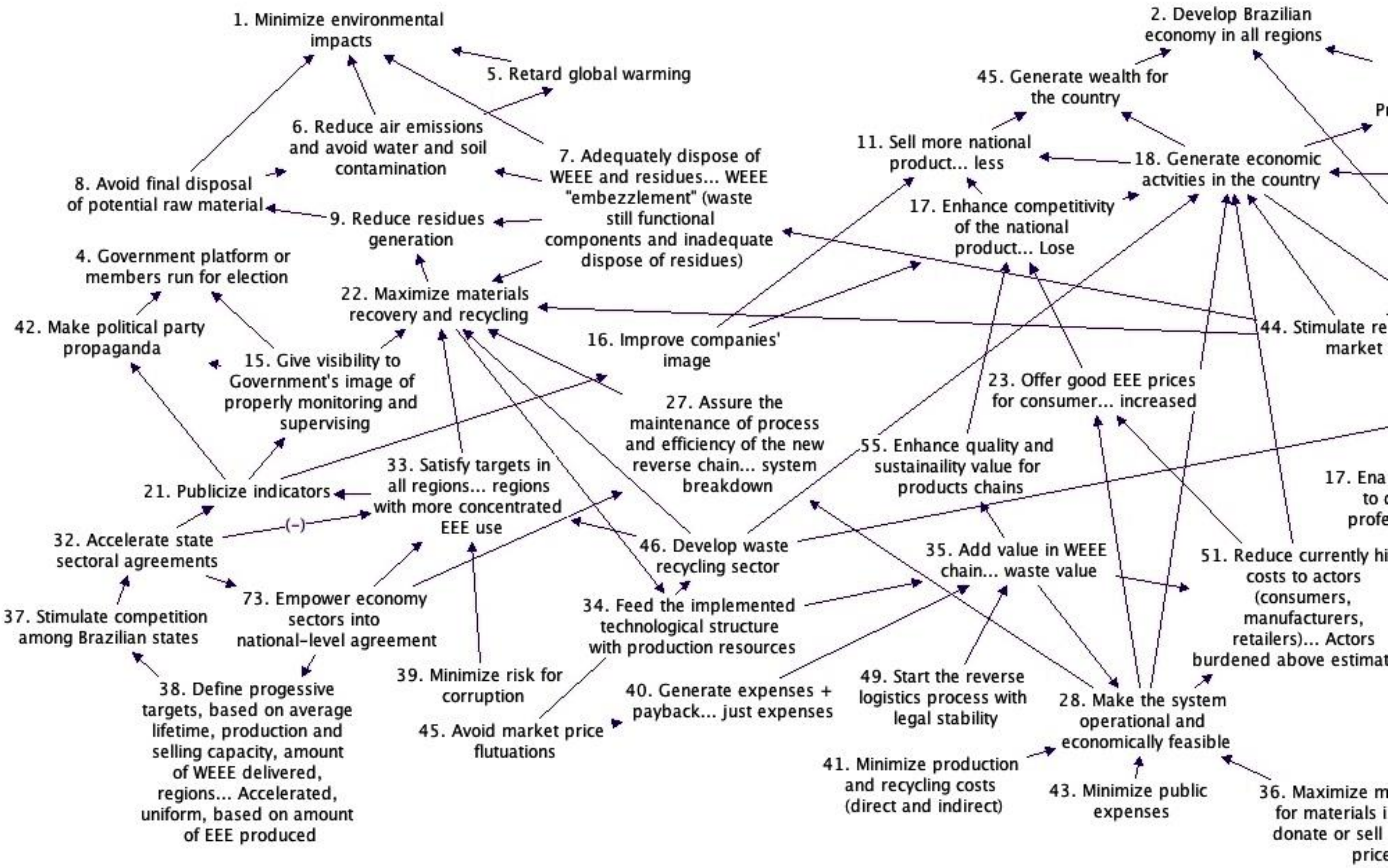
- Incubator for waste pickers' cooperatives



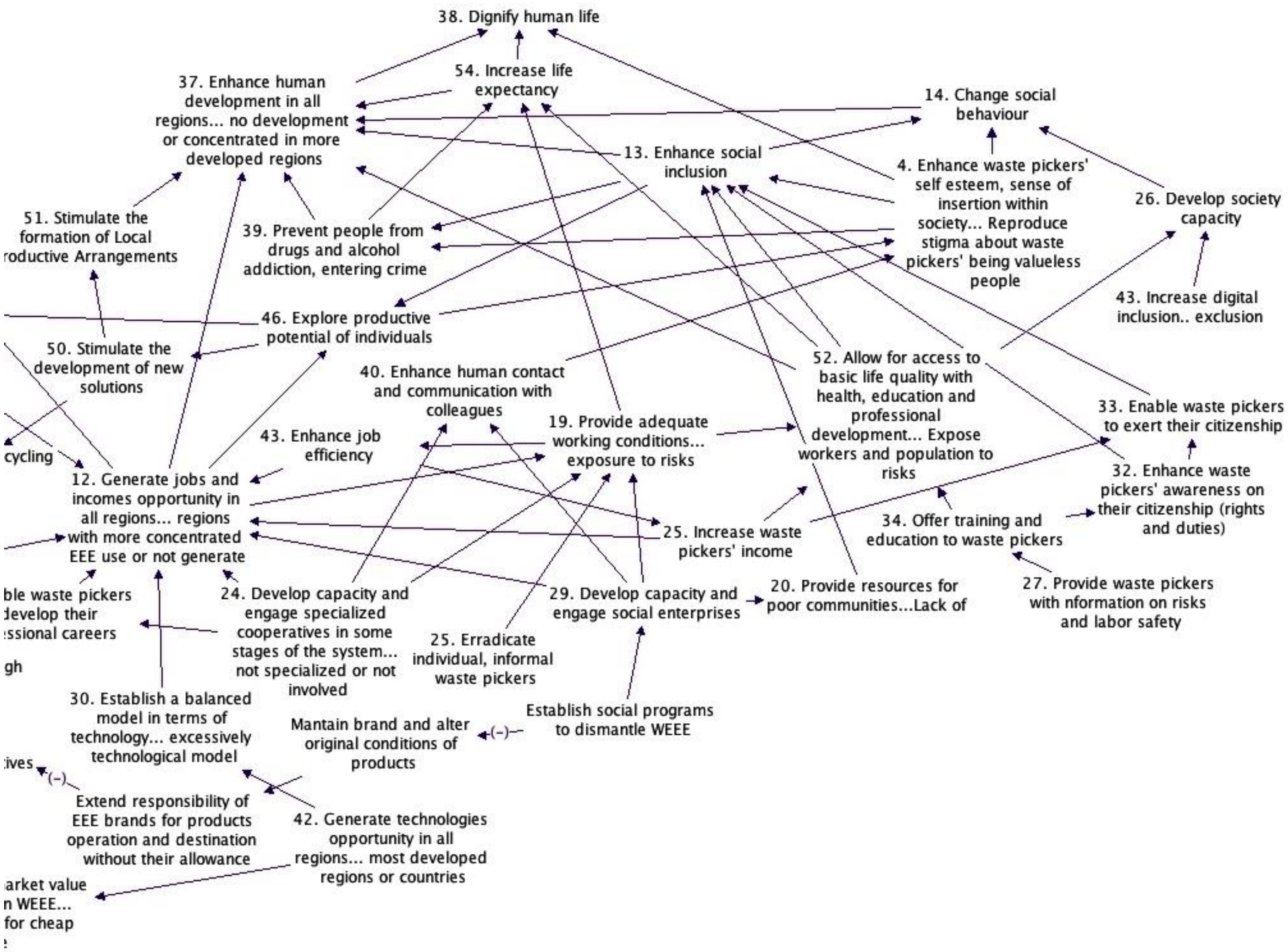
- Merged map (full view):



- Merged map (left half):



- Merged map (right half):



APPENDIX 5. Potential Root Definitions for the case study

RD No.	A SYSTEM THAT… DOES… (P)	BY… (Q)	IN ORDER TO… (R)	TRANSFORMATION
ENV.01	Minimizes water contamination, air emissions and raw material depletion	Adequately collecting, dismantling and recycling WEEE and disposing of residues	Minimize environmental impacts	WEEE generated → WEEE recycled
SOC.01	Creates jobs and income opportunities with adequate working conditions	Organizing, capacitating and engaging cooperatives and young workforce 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 within the WEEE chain
ECN.01	Makes the EEE and WEEE chain operational and economically feasible	Feeding the system with production resources, adding value from recycling, minimizing costs, recovering value from material, establishing a balanced technological 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 → Good price
ECN.03	Improves Brazilian EEE companies' image	Meeting WEEE takeback system targets in all regions	Sell more national product	Companies' image → Improved image
ECN.04	Adds 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
POL.02	Meets WEEE system 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 bad and not-satisfied targets → System with well defined and met targets
OPR.01	Controls EEE and WEEE flows in the country	Regulating the market, preventing informal chains, creating a cadastre for WEEE actors and flows, licensing WEEE reverse logistics systems	Recycle WEEE adequately	Uncontrolled EEE and WEEE flows → Controlled

Other potential systems to be modelled (in different levels):

A system that disassembles WEEE in each Brazilian region, recycles plastics, metals and glasses in Brazil, and exports printed circuits to be recycled in other countries
A system that disassembles WEEE and recycles plastics and glasses in each Brazilian region, and exports printed circuits to be recycled in other countries
A system that disassembles WEEE in each Brazilian region, recycles plastics and glasses from WEEE in the S and SE regions, and recycles printed circuits in the SE region
A system that disassembles WEEE and recycles plastics and glasses in each Brazilian region, and recycles printed circuits in the SE region
A system that separates and provides special treatment to WEEE of hospitals use
A system that separates and provides special treatment to obsolete WEEE
A system that separates and provides special treatment to WEEE of large volume
A system that separates and provides special treatment to WEEE of medium volume
A system that separates and provides special treatment to WEEE of particular technologies
A system for transferring the formal ownership of a product from the consumer to the delivery station of WEEE collection company
A system to zero all data stored in the WEEE after it is delivered
A system to zero all data stored in the WEEE before it is delivered
A system that disposes WEEE rejects in landfills, together with other urban wastes
A system that disposes WEEE rejects in landfills, separate from other urban wastes
A system that recycles 100% of WEEE, without disposing of rejects
A system that provides incentives for citizens who adequately deliver their WEEE
A system that provides environmental education to all citizens
A system that provides environmental education to high class citizens
A system to provide citizens with communication and awareness
A system with an established framework to do evaluate direct and indirect costs of WEEE reverse logistics
A system with an established framework to do evaluate only direct costs of WEEE reverse logistics
A Union-owned predefined system to elaborate financial statements
A fiscal and taxing framework for assets transportation
A system that charges taxes in a cascade effect
A system with human traction to collect WEEE
A system to eradicate the work of individual waste pickers
A system to professionalize the management of waste collectors cooperatives
A system where all cooperative members behave like owners
A system where the cooperative has one member behaving as owner
A system to improve the educational level of waste collectors
A system where cooperatives do all the WEEE disassemble at transfer stations, supervised
A system where cooperatives do the disassemble of low-risks WEEE at transfer stations, supervised
A system by that importers prove to accomplish law requirements before allowing products in the country
A system by that 98% of all electric and electronic products consumed in Brazil are imported in RJ and SP and distrusted through the country
A system to stimulate national production of electric and electronic products
A system for collection and treatment or commercialization of equipment abandoned in technical assistance shops for more than 90 days

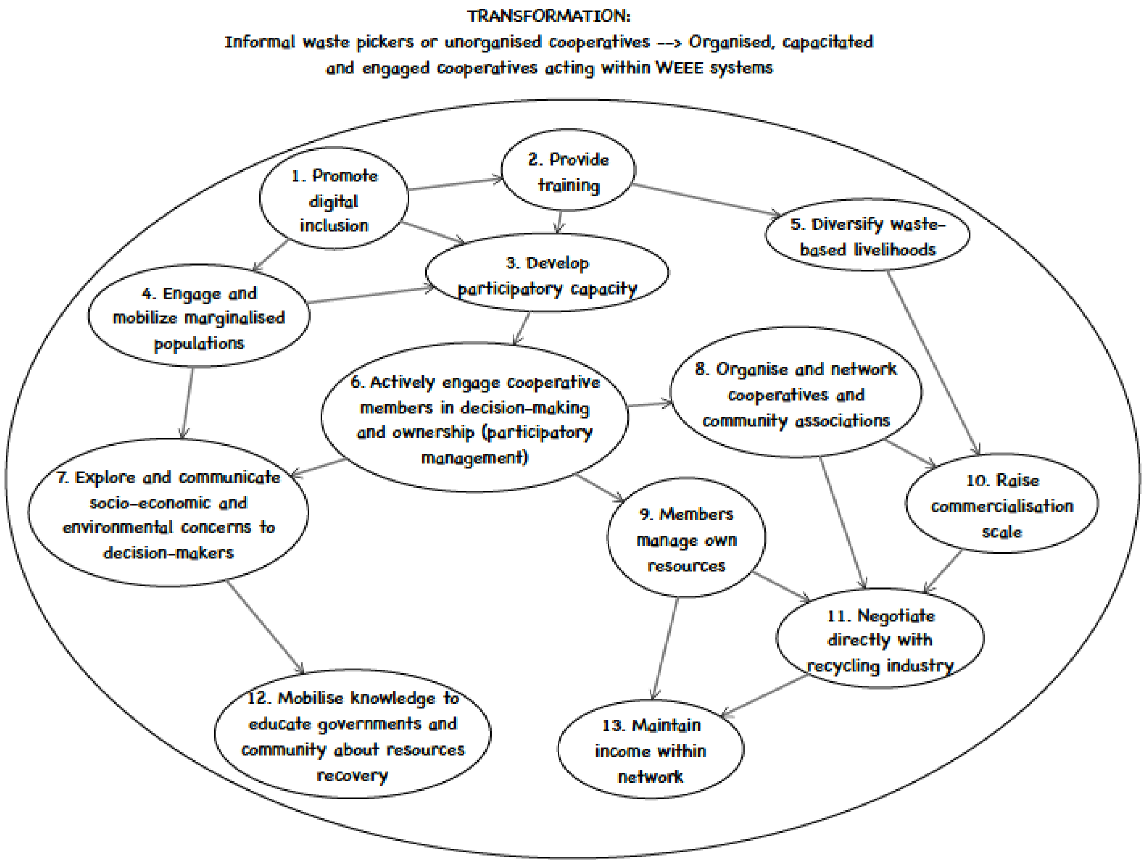
A system to store equipment in technical assistance shops regardless of the time it takes
A system that provides different costing, storage, collection and treatment procedures for WEEE generated by citizens or by corporations
A system that charges online purchases consumers
A system that charges online purchases shops
A system that charges online purchases logistic companies
A system that charges the Brazilian industry for online purchases
A system that regulates WEEE reverse logistics systems
A system that separates and provides special treatment to hazardous WEEE
A system to prevent workers from contamination by hazardous WEEE
A system with delivery stations inside all electric and electronic products shops, for all WEEE delivery
A system with delivery stations inside shops, based on their physical capacity, profile of products sold and ease of access to consumer, for WEEE delivery
A system with delivery stations in shopping centers parking, for WEEE delivery
A system with delivery stations outside the shops, with security, for WEEE delivery
A system with delivery stations outside the shops, without security, for WEEE delivery
A system with delivery stations on public areas, under public security, for WEEE delivery
A system with delivery stations distributed uniformly along the cities, for WEEE delivery
A system with delivery stations distributed in accordance to population economic status and electronics regional selling, for WEEE delivery
A system for the transfer of WEEE
A system that charges consumers for WEEE reverse logistics systems
A system that charges industries for WEEE reverse logistics systems
A system that charges commerce for WEEE reverse logistics systems
A system that charges distributors for WEEE reverse logistics systems
A system that charges importers for WEEE reverse logistics systems
A unified system to manage contracts and delivery stations
A system to monitor products flows in and out distributors
A system to monitor products flows in and out WEEE transfer stations
A system to monitor products flows in and out WEEE delivery stations
A system to monitor products flows in and out WEEE collection services
A National information system to manage all information regarding products and WEEE flows

APPENDIX 6. CATWOE/BATWOVE analysis for the subsystem “WEEE transport” in RD ENV.01

CATWOE/ BATWOVE	Baseline (current)	Delivery at shops	Hybrid
Clients/ Beneficiaries/ Victims	Population; environment	Population; environment	Population; environment
Actors	COMLURB; informal actors; Fabrica Verde; cooperatives; public administration; waste management companies; recycling companies	Population; EEE commerce; waste management companies; recycling companies; cooperatives; public administration; Fabrica Verde	Population; EEE commerce and industry; waste management companies; COMLURB; cooperatives; Fabrica Verde; metro stations; public administration
Transformation	WEEE produced → WEEE collected, processed in the informal chain, landfilled, dismantled, refurbished and recycled	WEEE produced → WEEE collected, dismantled, refurbished, recycled or adequately treated	WEEE produced → WEEE collected, dismantled, refurbished, recycled or adequately treated
World-view	A large amount of WEEE from RMRJ is landfilled or processed by informal chains. There is no control on the flows and impacts these may be causing to human health and environment	PNRS enforces EEE shops to host WEEE delivery stations, proportionally to the amount of EEE they insert in the market. PNRS also enforces population to deliver WEEE adequately.	There are positive things happening in RMRJ regarding WEEE management, but they are managed independently by actors. A regional Sectoral Agreement should explore and develop installed capacity and control all WEEE flows. This is aligned to the PNRS principle of shared responsibility.
Owner	Formal and informal actors	Federal Government; Sectoral Agreements	Federal Government; Sectoral Agreements
Environment	PNRS recently established; risks to human health and environment; demands from society; technology and market opportunities	PNRS recently established; risks to human health and environment; demands from society; technology and market opportunities	PNRS recently established; risks to human health and environment; demands from society; technology and market opportunities

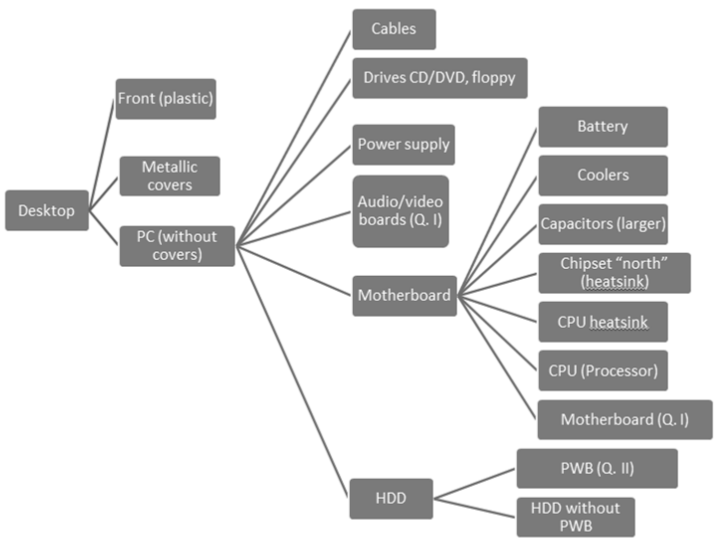
APPENDIX 7. Conceptual models for two sub-systems of RD SOC.01

- Subsystem "enable and capacitate waste pickers' cooperatives to work formally within the WEEE chain"

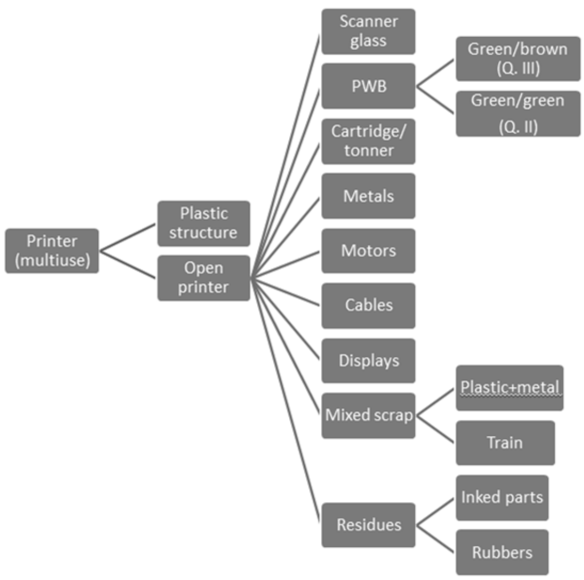


APPENDIX 8. WEEE components from appliances as separated at DRZ

- Desktop computers:



- Printers:



ANNEX 1. Models and results of LCA studies in Switzerland (2004 and 2009)

- LCA models and main results in 2004 (Hischier et al. 2005)

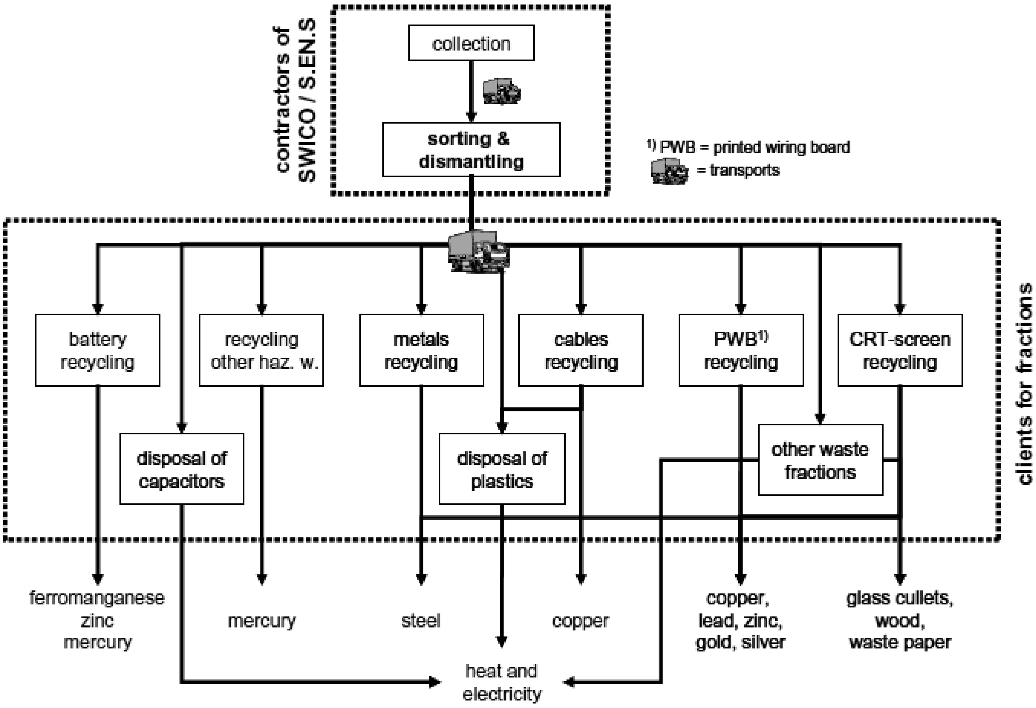


Fig. 1. System boundaries of the modeled WEEE take-back and recycling systems, including processing steps up to the production of secondary raw materials.

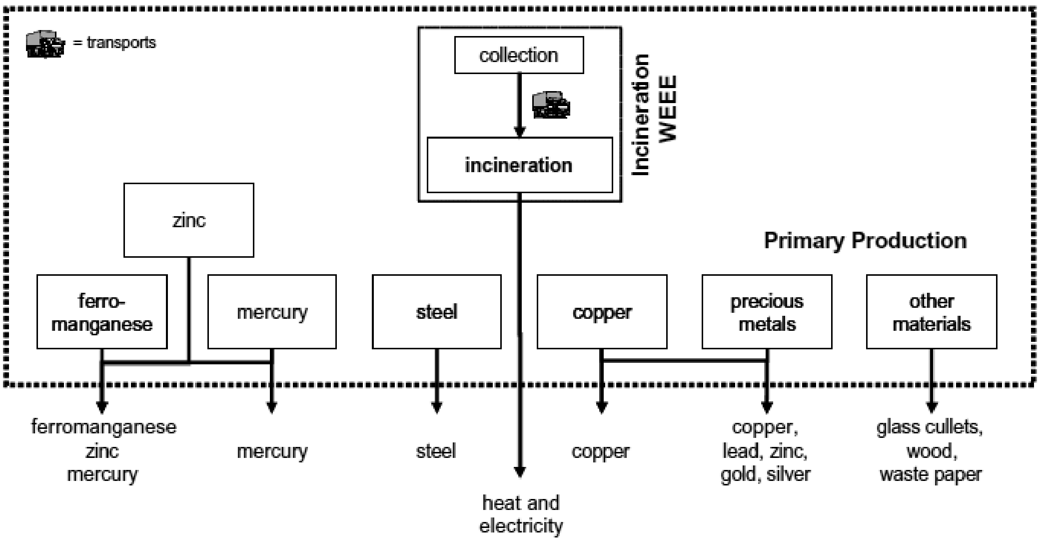


Fig. 2. System boundaries of the baseline system, including incineration of the complete WEEE and primary production of raw materials generated from WEEE take-back and recycling.

Table 4
Characterization factors used within this study (according to the CML methodology)

Category	Abbrev	Unit	Remarks
Baseline impact categories			
Depletion of abiotic resources	ADP	kg antimony eq.	–
Climate change	GWP	kg CO_2 eq.	Factors for GWP 100a
Stratospheric ozone depletion	ODP	kg CFC-11 eq.	Factors for ODP steady state
Human toxicity	HTP	kg 1,4-DCB eq.	Factors for HTP infinite
Ecotoxicity			
Freshwater aquatic ecotoxicity	FAETP	kg 1,4-DCB eq.	Factors for FAETP infinite
Marine aquatic ecotoxicity	MAETP	kg 1,4-DCB eq.	Factors for MAETP infinite
Terrestrial ecotoxicity	TETP	kg 1,4-DCB eq.	Factors for TETP infinite
Photo-oxidant formation	POCP	kg ethylene eq.	Factors for high NO_X values
Acidification	AP	kg SO_2 eq.	Factors for average Europe
Eutrophication	EP	kg PO_4^{3-} eq.	Generic factors
Study-specific impact categories			
Ecotoxicity			
Freshwater sediment ecotoxicity	FSETP	kg 1,4-DCB eq.	Factors for FSETP infinite
Marine sediment ecotoxicity	MSETP	kg 1,4-DCB eq.	Factors for MSETP infinite

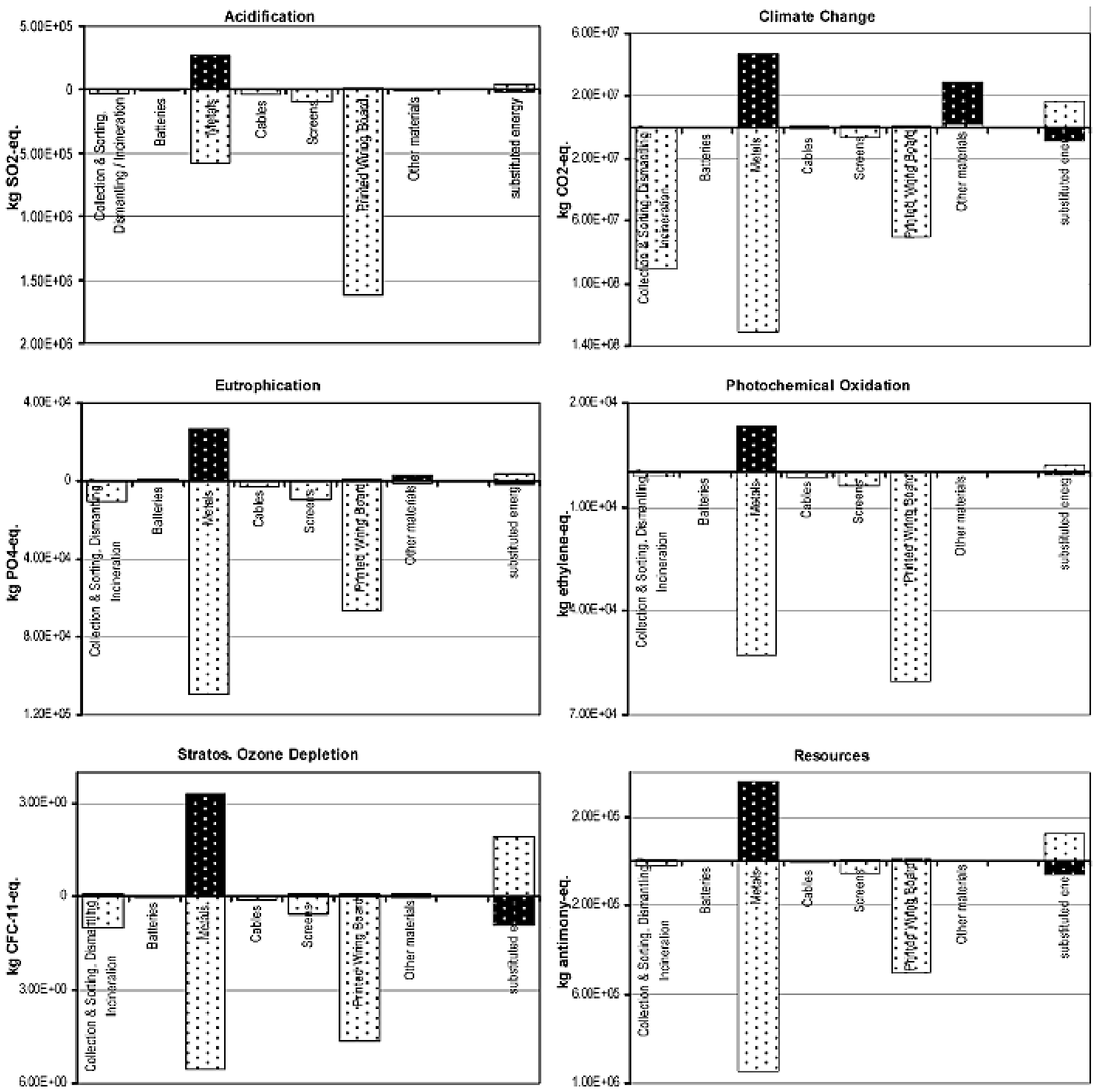


Fig. 6. Environmental impacts of the WEEE recycling system, i.e. collection, sorting and further treatment (dark bars), compared with the avoided environmental impacts of the WEEE incineration and the primary production of the raw materials (bright bars).

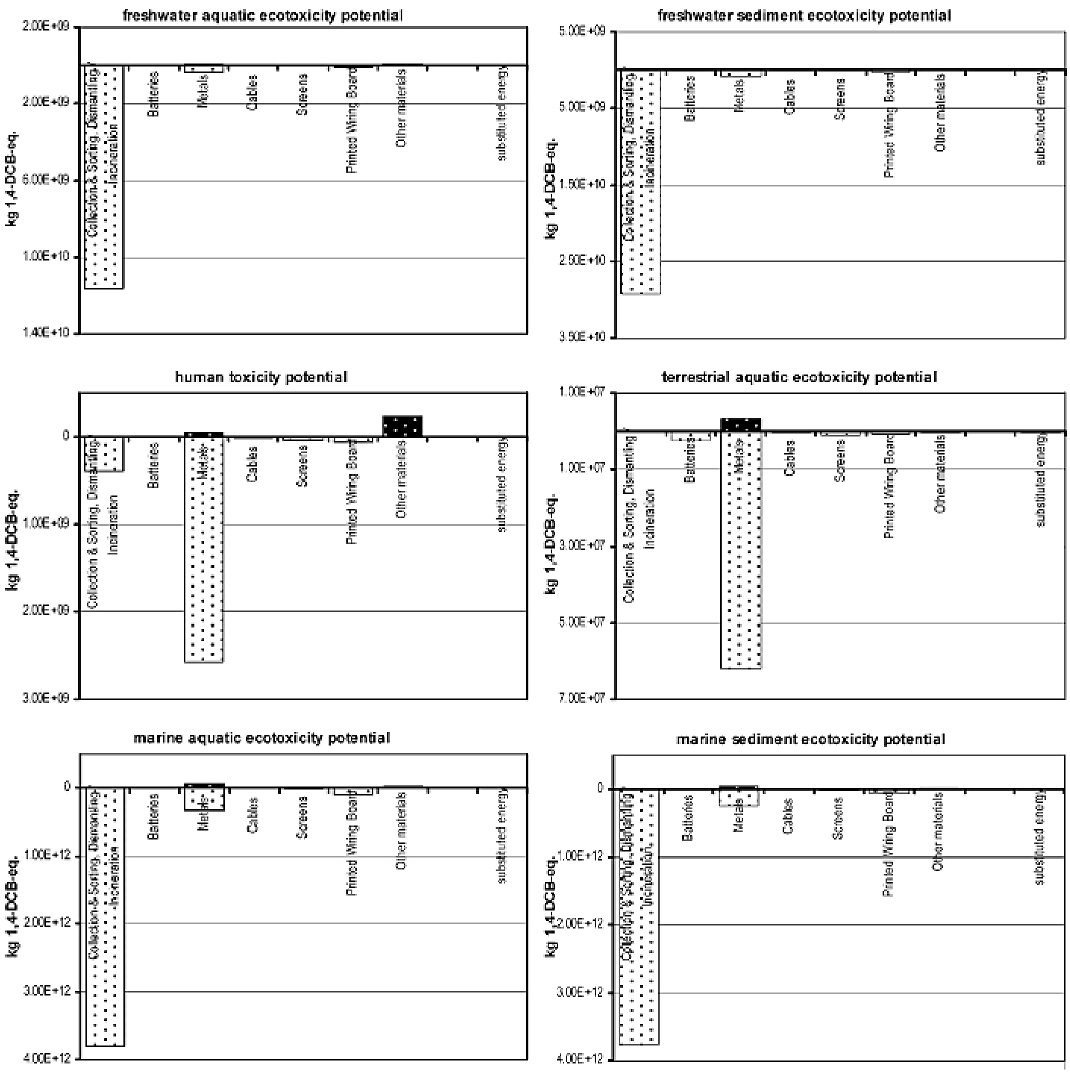


Fig. 7. Toxicity potentials of the secondary production, i.e. collection, sorting and further treatment (dark bars), compared with the avoided environmental impacts of the WEEE incineration and the primary production of the raw materials (bright bars).

- LCA models and main results in 2009 (Wager et al. 2011)

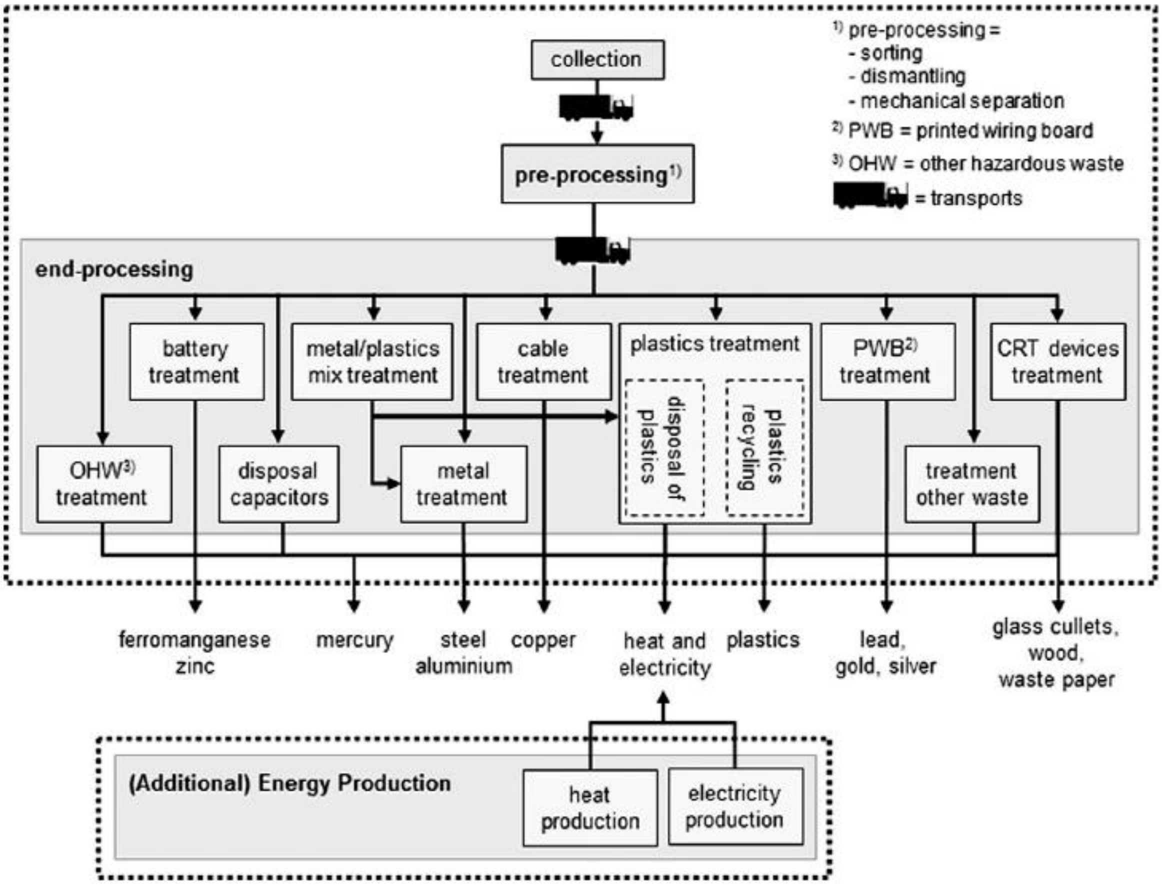


Fig. 1. System boundaries (dotted lines) for the Swiss WEEE recovery scenario.

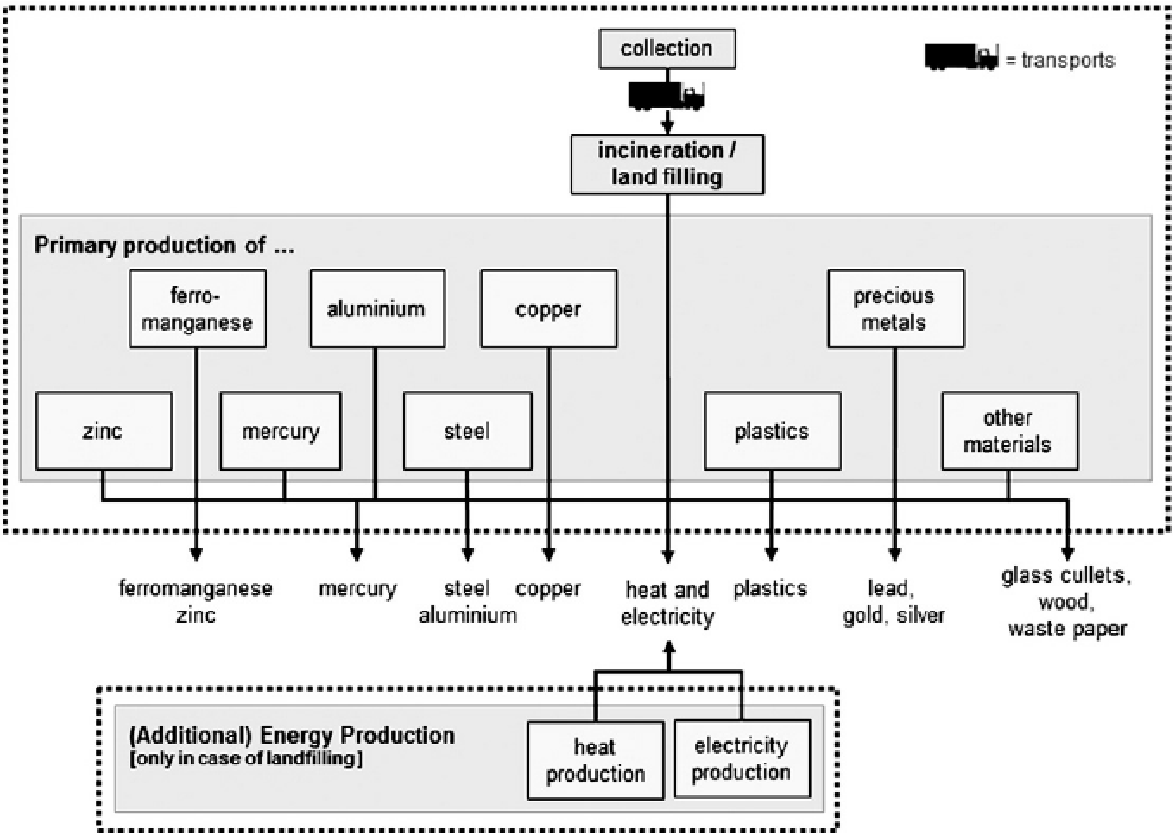


Fig. 2. System boundaries (dotted lines) for the baseline scenarios 'Incineration in an MSWI plant' and 'Landfilling'.

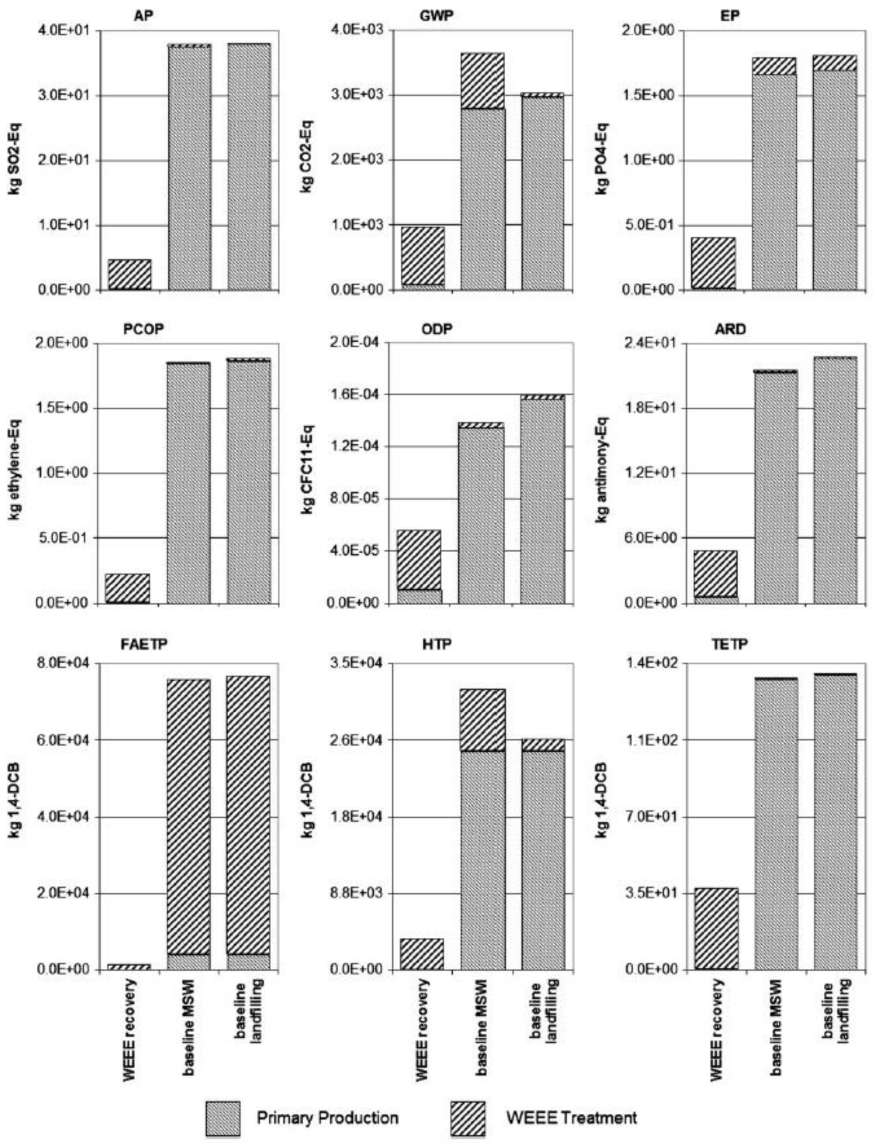


Fig. 4. Environmental impacts of the Swiss WEEE recovery scenario 2009 compared to the environmental impacts of the baseline scenarios 'Incineration in an MSWI plant' and 'Landfilling' according to the CML method, without normalization. Legend: AP = Acidification Potential, GWP = Global Warming Potential, EP = Eutrophication Potential, PCOP = Photochemical Oxidation Potential, ODP = (Stratospheric) Ozone Depletion Potential, ARD = Abiotic Resource Depletion, FAETP = Freshwater Aquatic Ecotoxicity Potential, HTP = Human Toxicity Potential, TETP = Terrestrial Ecotoxicity Potential.

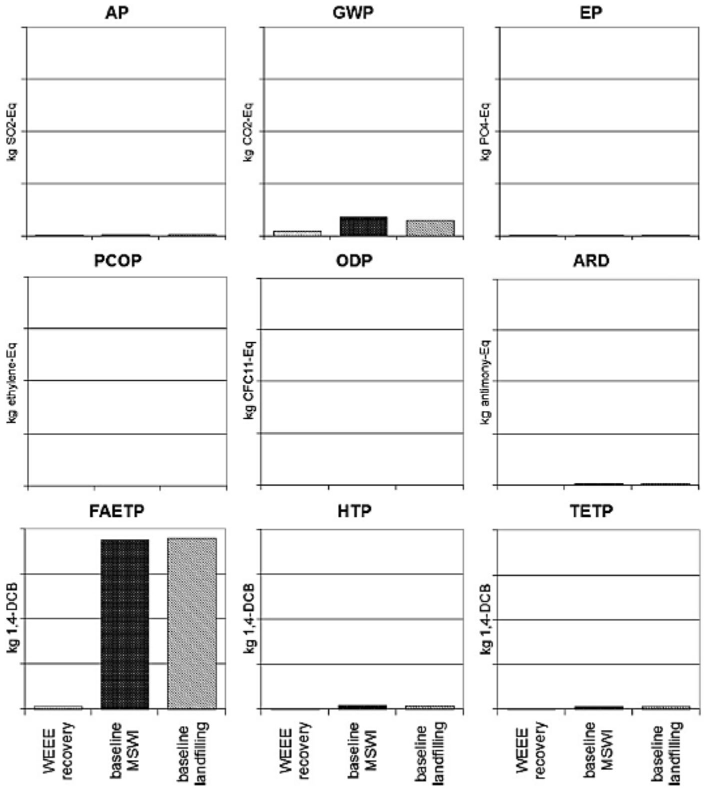


Fig. 5. Environmental impacts of the Swiss WEEE recovery scenario 2009 compared to the environmental impacts of the baseline scenarios 'Incineration in an MSWI plant' and 'Landfilling' according to the CML method, with normalization for Europe (Legend: see Fig. 4).

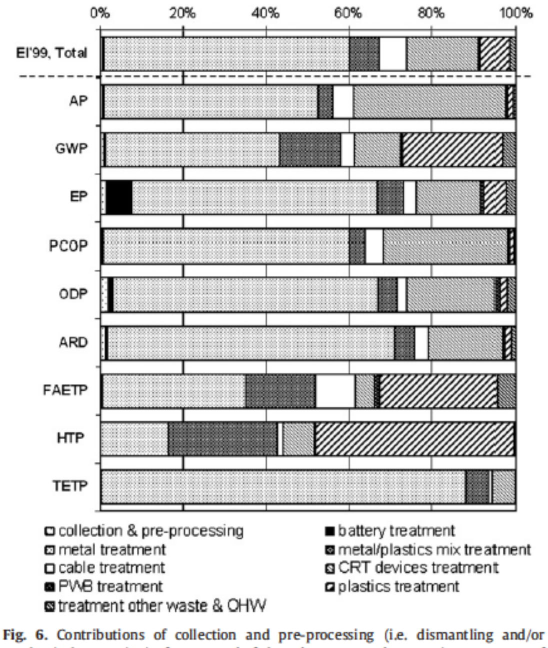


Fig. 6. Contributions of collection and pre-processing (i.e. dismantling and/or mechanical separation) of WEEE and of the subsequent end-processing treatment of the various resulting fractions to the total environmental impacts for the Swiss recovery scenario 2009 (Legend: EI '99 = Eco-Indicator '99/other abbreviations: see Fig. 4).

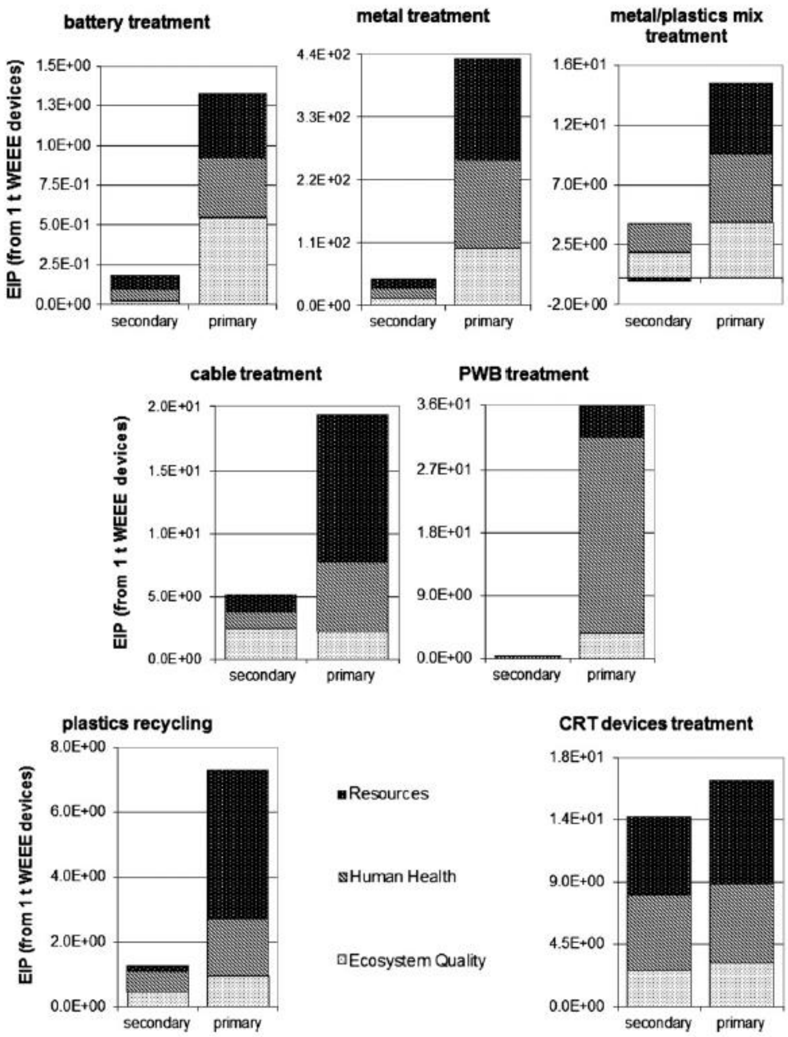


Fig. 7. Environmental impacts of selected fractions associated with secondary production (including a bonus for energy recovery from MSWI treatment for some of the fractions) in the Swiss WEEE recovery scenario 2009 vs. environmental impacts associated with substituted primary production in the baseline scenario 'Incineration in an MSWI plant' according to the Eco-Indicator '99 (H/A) method (in Eco-Indicator points per t of WEEE).

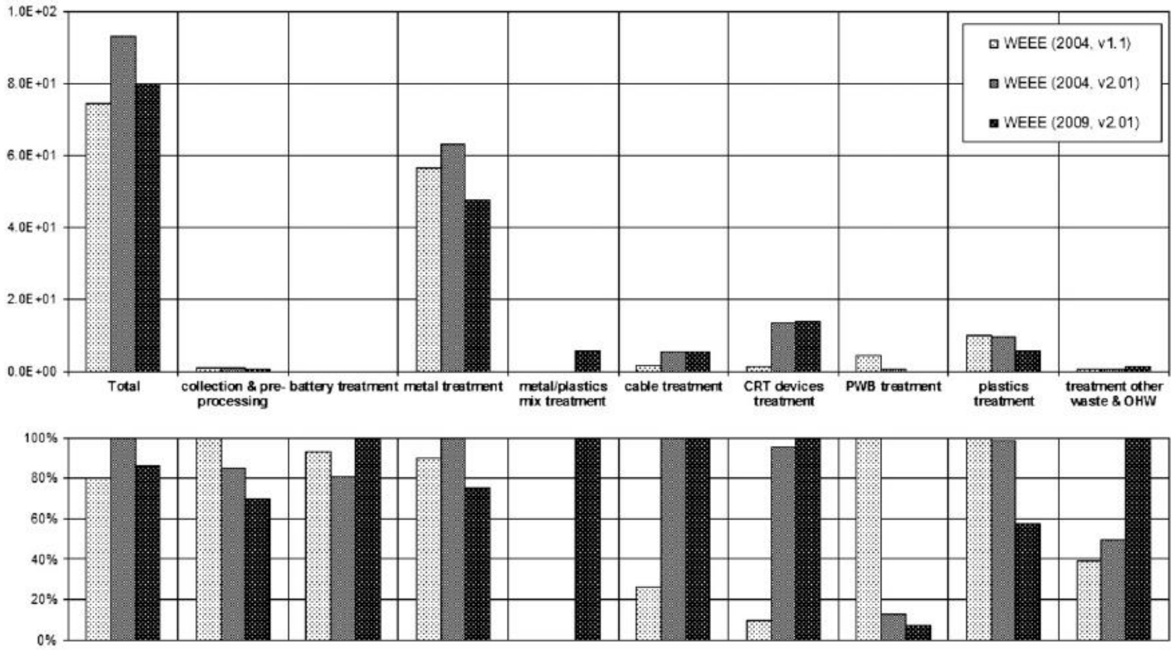


Fig. 8. Environmental impacts of the Swiss WEEE recovery scenario 2009 vs. environmental impacts of the Swiss WEEE recovery scenario 2004, according to the Eco-Indicator '99 (H/A) method. All results are per t of collected WEEE.

ANNEX 2. Some SLCA Impact Categories, Indicators and Data Sources

(Source: Norris, 2013)

STAKEHOLDER: Local Community

- Community Engagement:

Aim and approach of indicator assessment:

This subcategory assesses whether an organization includes community stakeholders in relevant decision-making processes. It also considers the extent to which the organization engages with the community, in general.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Available
Freedom of Peaceful Assembly and Association	Qualitative	U.S. Dept. of State Human Rights Country Reports
Transparency of Government Policymaking	Semi-Quantitative	World Economic Forum rankings, by country
Public Trust of Politicians	Semi-Quantitative	World Economic Forum rankings, by country

Specific Analysis

Inventory Indicator	Unit of Measurement	Data Methodology
Strength of written policies on community engagement at organization level	Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with community members, employees, management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits
Diversity of community stakeholder groups that engage with the organization	Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with community members, employees, management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits
Number and quality of meetings with community stakeholders	Quantitative/Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with community members, employees, management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits
Organizational support (volunteer-hours or financial) for community initiatives	Quantitative	▪ Site visit or site-specific audit ▪ Interviews with management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits

STAKEHOLDER: Local Community

<u>- Local Employment:</u>

Aim and approach of indicator assessment:

This subcategory assesses the role of an organization in directly or indirectly affecting local employment.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Available
Unemployment Statistics by Country	Quantitative	ILO data on unemployment
Poverty and Working Poverty by Country	Quantitative	ILO data on unemployment
Presence of Local Supply Networks	Semi-Quantitative	World Economic Forum rankings of supplier quantity, by country

Specific Analysis

Inventory Indicator	Unit of Measurement	Data Methodology
Percentage of workforce hired locally	Quantitative	▪ Site visit or site-specific audit ▪ Interviews with management ▪ Review of organization-specific reports, such as GRI or COP reports
Strength of policies on local hiring preferences	Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with community members, employees, governmental agencies, management and NGOs ▪ Review of organization-specific reports, such as GRI or COP reports
Percentage of spending on locally-based suppliers	Quantitative	▪ Site visit or site-specific audit ▪ Interviews with management ▪ Review of organization-specific reports, such as GRI or COP reports

STAKEHOLDER: Local Community

<u>- Safe and Healthy Living Conditions:</u>

Aim and approach of indicator assessment:

This subcategory assesses how organizations impact community safety and health. This includes the general safety conditions of operations and their public health impacts.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Available
Burden of Disease by Country	Quantitative	WHO disability adjusted life year statistics, by country
Pollution Levels by Country	Quantitative	World Bank data on particulate matter concentrations, by country
Presence/Strength of Laws on Construction Safety Regulations by Country	Qualitative/Semi-Quantitative	World Bank and IFC descriptions of license and permit requirements, by country

Specific Analysis

Inventory Indicator	Unit of Measurement	Data Methodology
Management oversight of structural integrity	Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with management, community members, employees, governmental agencies and NGOs ▪ Review of organization-specific reports, such as GRI or COP reports
Organization efforts to strengthen community health (e.g. through shared community access to organization health resources)	Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with management, community members, employees, governmental agencies and NGOs ▪ Review of organization-specific reports, such as GRI or COP reports and social impact assessments
Management effort to minimize use of hazardous substances	Qualitative/Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with management, community members, employees, governmental agencies and NGOs ▪ Review of organization-specific reports, such as GRI or COP reports

STAKEHOLDER: Value Chain Actors

- Fair Competition:

Aim and approach of indicator assessment:

This subcategory assesses if the organization's competitive activities are conducted in a fair way and in compliance with legislations preventing anti-competitive behavior, anti-trust, or monopoly practices.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
National law and regulation	qualitative/semi-quantitative	▪ National legislation ▪ OECD
Sectoral regulation	qualitative/semi-quantitative	▪ Sectoral reports e.g. from OECD
Sectoral agreement	qualitative/semi-quantitative	▪ Sectoral reports
Sector is present in consumer unions	qualitative/semi-quantitative	▪ Consumers International ▪ Consumers Union

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Legal actions pending or completed during the reporting period regarding anti-competitive behavior and violations of anti-trust and monopoly legislation in which the reporting organization has been identified as a participant. (GRI SO7)	qualitative/semi-quantitative/ quantitative	▪ Interviews with community members, employees, governmental agencies, union branch, management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits
Membership in alliances that behave in an anti-competitive way	qualitative/semi-quantitative	▪ Interviews with community members, employees, governmental agencies, union branch, OECD contact points, management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits
Documented statement or procedures (policy, strategy etc.) to prevent engaging in or being complicit in anti-competitive behavior	qualitative/semi-quantitative	▪ Interviews with community members, employees, governmental agencies, union branch, OECD contact points,management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits
Employee awareness of the importance of compliance with competition legislation and fair competition.	qualitative/semi-quantitative	Global Compact

STAKEHOLDER: Value Chain Actors

<u>- Supplier Relationships:</u>

Aim and approach of indicator assessment:

Procurement practices have strong effect in the supply chains, driving behaviors. An organization should consider the potential impacts or unintended consequences of its procurement and purchasing decisions on other organizations, and take due care to avoid or minimize any negative impact (ISO 26000).

Generic analysis (Hotspots)

None identified.

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Absence of coercive communication with suppliers	qualitative/semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers
Sufficient lead time	qualitative/semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers
Reasonable volume fluctuations	qualitative/semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers
Payments on time to suppliers	semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers

STAKEHOLDER: Value Chain Actors

<u>- Promoting Social Responsibility:</u>

Aim and approach of indicator assessment:

This subcategory seeks to assess whether the enterprise promotes social responsibility among its suppliers and through its own actions. This measure considers whether the enterprise manages its suppliers in a socially responsible way, including monitoring, auditing and training efforts. This subcategory also examines whether enterprises take corrective action towards suppliers when warranted.

As a starting point, an enterprise should consider human rights records when selecting suppliers. With existing suppliers, an enterprise may develop a supplier code of conduct or a contractual agreement that covers social and environmental responsibilities. Other actions towards suppliers, such as tight purchasing deadlines and low pricing policies, may discourage opportunities for social responsibility.

Enterprises also can promote social responsibility by encouraging suppliers to join foundations and initiatives with a related focus. Promoting the use of social responsibility certifications and/or product labels is another positive indicator.

STAKEHOLDER: Value Chain Actors

<u>- Promoting Social Responsibility (cont.):</u>

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Industry code of conduct in the sector	semi-quantitative	▪ Industry associations

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Presence of explicit code of conduct that protect human rights of workers among suppliers	semi-quantitative	▪ Interviews with management ▪ Review of organization-specific reports, such as GRI reports or COP reports
Percentage of suppliers the enterprise has audited with regard to social responsibility in the last year	quantitative	▪ Interviews with management ▪ Review of organization-specific reports, such as GRI reports or COP reports
Membership in an initiative that promotes social responsibility along the supply chain	semi-quantitative	▪ Interviews with management ▪ Review of organization-specific reports, such as GRI reports or COP reports
Integration of ethical, social, environmental and regarding gender equality criterions in purchasing policy, distribution policy and contract signatures	qualitative	▪ Interviews with management ▪ Review of organization-specific reports
Support to suppliers in terms of consciousness-raising and counselling concerning the social responsibility issues	qualitative	▪ Interviews with management ▪ Interviews with suppliers

STAKEHOLDER: Consumer

<u>- Promoting Social Responsibility:</u>

Aim and approach of indicator assessment:

This subcategory helps to identify the existence and scope of systematic efforts to address consumer health and safety across the organizations involved in the life cycle of a product and/or service.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Quality of or number of information/signs on product health and safety	Quantitative, Semi-Quantitative	U.S: Department of Health and Human Services – Household Products Database, Health & Safety information on Household Product
Presence of consumer complaints (at national, sectorial, organizational level)	Quantitative, Semi-Quantitative	U.S. Consumer Product Safety Commission
GRI PR2 Total number of incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services and type of outcomes	Quantitative, Semi-Quantitative, Qualitative	GRI Sustainability Reports

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Number of consumer complaints	Quantitative/ Semi-quantitative	▪ Interviews or questionnaire filled by management, retailers and NGOs ▪ Review of enterprise-specific reports, such as GRI reports or audits ▪ Consumer organizations
Presence of Management measures to assess consumer health and safety	Qualitative	▪ Interviews or questionnaire filled by management, retailers and NGOs ▪ Review of enterprise-specific reports ▪ Consumers organizations
Quality of labels of health and safety requirements	Qualitative/Semi-Quantitative	▪ Labels on the product

STAKEHOLDER: Consumer

- Transparency:

Aim and approach of indicator assessment:

This subcategory assess if the organization communicates on all issues regarding its product and social responsibility in a transparent way.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Presence of a law or norm regarding transparency (by country and/or sector)	Semi-Quantitative/Qualitative	Government websites
Sector transparency rating; number of organizations by sector which published a sustainability report	Quantitative/Semi-Quantitative/ Qualitative	Global Reporting Initiative

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Non-compliance with regulations regarding transparency	Semi-Quantitative/ Qualitative	▪ Interviews with consumer protection agencies, governmental agencies, management and NGOs
Consumer complaints regarding transparency	Semi-Quantitative/ Qualitative	▪ Interviews with consumers, employees, consumer protection agencies, governmental agencies, management and NGOs ▪ Review of enterprise-specific reports, such as GRI reports or audits
Publication of a sustainability report	Semi-Quantitative/ Qualitative	▪ Organization's Website
Quality and comprehensiveness of the information available in the sustainability report or other documents regarding to the social and environmental performance of the organization	Qualitative	▪ Review of organization-specific reports ▪ Interview with management
Communication of the results of social and environmental life cycle impact assessment	Semi-Quantitative/ Qualitative	▪ Interview with management ▪ Review of enterprise-specific reports, such as GRI reports or audits
Certification/label the organization obtained for the product/site	Semi-Quantitative/ Qualitative	▪ Review of organization-specific reports ▪ Interview with management
Company rating in sustainability indices (Dow Jones Sustainability Index, FTSE4Good, ESI, HSBC, Corporate Sustainability Index, etc.)	Semi-Quantitative/ Qualitative	▪ Dow Jones Sustainability Index ▪ FTSE

STAKEHOLDER: Consumer

<u>- End-of-Life Responsibility:</u>

Aim and approach of indicator assessment:

This subcategory examines management efforts to address the social impacts of product or service end-of-life. Organizations should provide accurate, complete and clear information to consumers regarding appropriate end-of-life options. In some cases, producers should buy back and recycle or safely dispose of waste.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Strength of national legislation covering product disposal and recycling	Semi-Quantitative	ECOLEX search for legislation by country

Specific analysis

Inventory Indicator	Unit of Measurement	Data Methodology
Do internal management systems ensure that clear information is provided to consumers on end-of-life options (if applicable)?	Semi-Quantitative	▪ Site visit or site-specific audit ▪ Interviews with consumers, governmental agencies, management and NGOs ▪ Review of organization-specific reports and audits, such as GRI reports
Annual incidents of non-compliance with regulatory labelling requirements	Quantitative	▪ Site visit or site-specific audit ▪ Interviews with governmental agencies and management ▪ Review of organization-specific reports and audits, such as GRI reports

STAKEHOLDER: Worker

<u>- Fair Salary:</u>

Aim and approach of indicator assessment:

This subcategory aims to assess whether practices concerning wages are in compliance with established standards and if the wage provided is meeting legal requirements, whether it is above, meeting or below industry average and whether it can be considered as a living wage.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Living Wages in the US by state, county, community (*)	quantitative	Living wage calculator
Minimum wage by country	quantitative	Comprehensive resource
Non poverty wage by country	quantitative	Non poverty wages

* Comparing average sector wage with living wage, minimum wage and non-poverty wage

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Lowest paid worker, compared to the minimum wage	Quantitative/Semi -quantitativ	▪ Country minimum wage ▪ Interview with directors or Human resources officer ▪ Verification of organization documents: e.g. wage records ▪ Review of organization-specific reports, such as GRI reports or audits
The lowest paid workers are considering their wages meets their needs.	qualitative/semi-quantitative	▪ Interviews with workers ▪ Interview with local NGO's
Presence of suspicious deductions on wages	Qualitative/Semi-Quantitative	▪ Interviews with employees, management and human resources ▪ Review of organization-specific reports, such as GRI reports or audits agreement or contracts between organizations and employees ▪ Review of wage records
Regular and documented payment of workers (weekly, bi-weekly)	Qualitative / Semi-Quantitative	▪ Interviews with employees, governmental agencies, management and NGOs ▪ Review of organization-specific reports, such as GRI reports or audits ▪ Review of wage records

STAKEHOLDER: Worker

<u>- Health and safety:</u>

Aim and approach of indicator assessment:

This subcategory aims to assess both the rate of incidents and the status of prevention measure and management practices. An incident is defined as a work-related event(s) in which a injury or ill health (regardless of severity) or fatality occurred or could have occurred.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Occupational accident rate by country	Quantitative	OSHA European Union

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Number/ percentage of injuries or fatal accidents in the organization by job qualification inside the company	Quantitative	▪ Interviews or questionnaire filled by management and Human resources ▪ Review of enterprise-specific reports ▪ Interview with workers and union
Hours of injuries per level of employees.	Quantitative	▪ Interviews or questionnaire filled by management and Human resources ▪ Review of enterprise-specific reports ▪ Interview with workers and union
Presence of a formal policy concerning health and safety	Semi-quantitative	▪ Interviews and or questionnaire filled by management and human resources ▪ Review of organization-specific web site and reports
Adequate general occupational safety measures are taken	Qualitative/semi-quantitative	▪ Interviews and or questionnaire filled by management, workers, governmental agencies and NGOs ▪ Review of organization-specific reports, such as audits
Preventive measures and emergency protocols exist regarding accidents & injuries	Qualitative/semi-quantitative	▪ Interviews and or questionnaire filled by management, workers, governmental agencies and NGOs ▪ Review of organization-specific reports, such as audits

STAKEHOLDER: Worker

<u>- Health and safety (cont.):</u>

Preventive measures and emergency protocols exist regarding pesticide & chemical exposure	Qualitative/semi-quantitative	▪ Interviews and or questionnaire filled by management, workers, governmental agencies and NGOs ▪ Review of organization-specific reports, such as audits
Appropriate protective gear required in all applicable situations	Qualitative/semi-quantitative	▪ Interviews and or questionnaire filled by management, workers, governmental agencies and NGOs ▪ Review of organization-specific reports, such as audits
Number of (serious/non-serious) Occupational Safety and Health Administration (OSHA) violations reported within the past 3 years and status of violations	Quantitative /semi-quantitative	▪ Questionnaire filled by management, government violation records, news articles
GRI LA8 Education, training, counselling, prevention and risk control programs in place to assist workforce members, their families, or community members regarding serious diseases	Qualitative/semi-quantitative	▪ GRI Sustainability reports ▪ Interviews and or questionnaire filled by management, workers, governmental agencies, local communities and NGOs ▪ Review of organization-specific reports

STAKEHOLDER: Worker

- Social Benefit/Social Security:

Aim and approach of indicator assessment:

This subcategory assesses whether an organization provides for social benefits and social security of workers and to what extent.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Social security expenditure by country and branches of social security (eg. Healthcare, sickness, maternity)	Quantitative /semi-quantitative	ILO Social Security Expenditure Database
GRI LA3 Benefits provided to full-time employees that are not provided to temporary or part-time employees, by major operations	Quantitative	GRI Sustainability report

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
List and provide short description of social benefits provided to the workers (eg. Health insurance, pension fund, child care, education, accommodation etc.)	Qualitative	▪ Interviews or questionnaire filled by management and Human resources ▪ Review of enterprise-specific reports, ▪ Review of audits ▪ Interview with workers/union (s)
Evidence of violations of obligations to workers under labour or social security laws and employment regulations.	Quantitative/ semi-quantitative/ qualitative	▪ Interviews or questionnaire filled by management and Human resources ▪ Review of enterprise-specific reports ▪ Review of government reports/ violation documentation ▪ Review of audits ▪ Interview with workers/unions
Percentage of permanent workers receiving paid time-off	Quantitative/ semi-quantitative	▪ Interviews or questionnaire filled by management and Human resources ▪ Interview with workers/union (s)

STAKEHOLDER: Society

- Public Commitment to Sustainability Issues:

Aim and approach of indicator assessment:

This subcategory assess to what extent an organization is engaged in reducing its sustainability impacts. Public promises entail a higher binding character than mere internal goals.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Existence of (legal) obligation on public sustainability reporting	semi-quantitative	▪ Government
Engagement of the sector regarding sustainability	qualitative/semi-quantitative	▪ Sector reports

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Presence of publicly available documents as promises or agreements on sustainability issues	qualitative/semi-quantitative	▪ Interviews with community members, employees, governmental agencies, union branch, management and NGOs ▪ Review of enterprise-specific reports, such as GRI reports or audits
Complaints issued related to the non fulfilment of promises or agreements by the organization by the local community or other stakeholders at OECD contact points or Global Reporting Initiative.	qualitative/semi-quantitative	▪ Interviews with community members, employees, governmental agencies, union branch, OECD contact points, management and NGOs ▪ Review of enterprise-specific reports, such as GRI reports or audits
Presence of mechanisms to follow-up the realisation of promises	quantitative/ semi-quantitative	▪ Interviews with community members, employees, governmental agencies, union branch, OECD contact points,management and NGOs ▪ Review of enterprise-specific reports, such as GRI reports or audits
The organization has pledged to comply with the Global Compact principles and has engaged itself to present yearly Communication On Progress	semi-quantitative	▪ Global Compact
Implementation/signing of Principles or other codes of conduct (Sullivan Principles, Caux Round Table, UN principles, etc.)		▪ Sullivan Principles ▪ Caux Round Table ▪ United Nations ▪ Global Compact

STAKEHOLDER: Society

<u>- Contribution to Economic Development:</u>

Aim and approach of indicator assessment:

This subcategory assesses to what extent the organization/product or service contributes to the economic development of the country.

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Economic situation of the country/region (GDP, economic growth, unemployment, wage level, etc.)	qualitative/quantitative	Statistics about economic development (eg. from World Bank, OECD, CIA or NGOs)
Relevance of the considered sector for the (local) economy (share of GDP, number of employees in relation to size of working population, wage level, etc.)	qualitative/quantitative	National economic statistics

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R+D costs in relation to revenue, etc.)	qualitative/quantitative	▪ Interviews with community members, governmental agencies, management and NGOs ▪ Review of enterprise-specific reports, such as GRI reports or audits

STAKEHOLDER: Society

<u>- Technology Development:</u>

Aim and approach of indicator assessment:

This subcategory assesses whether the organization participates in joint research and development for efficient and environmental sound technologies.

Technology transfer between more advanced economies and developing economies is key for the improvement of social conditions and to prevent further environmental damage related to old technology use and it is formally part of many international instruments (eg. UNFCCC, Agenda 21).

Generic analysis (Hotspots)

Inventory Indicator	Unit of Measurement	Data Sources
Sector efforts in technology development	qualitative	▪ Sector reports ▪ Reports on technology exchange
Research and development costs for the sector	qualitative	▪ Sector reports

Specific analysis

Inventory Indicator	Unit of Measurement	Data Sources
Involvement in technology transfer program or projects	qualitative/semi-quantitative	▪ Interviews with management ▪ Reports on technology development of the organization ▪ Project reports
Partnerships in research and development	qualitative/semi-quantitative	▪ Interviews with management ▪ Reports on technology development of the organization ▪ Reports of collaborating organizations on the technology development of the organization
investments in technology development/ technology transfer	quantitative	▪ Interviews with management ▪ Reports on technology development of the organization ▪ Reports of collaborating organizations on the technology development of the organization

ANNEX 3. Social impact categories, subcategories and indicators for recycling systems in low-income countries

Impact category	Impact subcategory	Indicator
Human rights	Child labour	No child labour
	Discrimination	Formal policy against discrimination
		No income differences between women and men
	Freedom of association and collective bargaining	Presence of collective bargaining
Working conditions	Working hours	Fulfilment of overtime agreed in working contracts
	Minimum income, fair income	Average income according to legal framework
		Absence of non-agreed income deductions
		Regular payment for the workers
		Minimum income according to legal framework
	Recognised employment relationships and fulfilment of legal social benefits	Existence of legal working contracts for all workers
		Access to legal social benefits
		Access to further social support programmes for workers
	Physical working conditions (health, security, working equipment)	Absence of work accidents
		Formal policy about occupational health and safety
		Vaccination for workers
		Training programmes for workers regarding occupational health and safety
		Access to preventive health care programme for workers
		Presence of medical equipment at the working place for the workers' use
		Absence of diseases related to waste handling
		Appropriate working equipment
	Psychological working conditions	Willingness to continue working in the same company or sector
		Work satisfaction
		Willingness to be trained regarding the work activities
Socio-economic repercussions	Education	Educational level of children from families of recyclers
		No school absence of children from families of recyclers
		Existence of educational programmes for self-development

Source: Aparcana and Salhofer (2013)