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Waste Management and Sustainability: Indicators under Ecological Economy Perspective

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Abstract

For indicators to assess a society's sustainability it is necessary that the understanding of what type of sustainability one wishes to measure is clear. The hypothesis tested in the present study is that solid waste management indicators, used in city sustainability assessments, do not represent the concept of strong sustainability. To test the hypothesis, the article initially identifies the perspectives of solid waste management from the strong sustainability's point of view, under Ecological Economy perspective. The hypothesis was tested in thirteen sustainability assessment tools, covering approximately 400 cities. Two, out of five perspectives identified, had indicators selected represent them. Only one system presented three perspectives, and eight presented two. To represent the theme's complexity, all perspectives should be considered, so the hypothesis formulated was accepted.

Keywords: strong sustainability, ecological economics, sustainability assessment, solid waste, sustainability indicators

1. Introduction

Sustainability indicators are tools used to support decision-making, by providing information, and contribute to sustainable development policies planning, implementation and evaluation (Bossel, 1999; Dahl, 1997). The United Nations Conference on Sustainable Development (United Nations Conference on Sustainable Development [UNCED], 1992) highlighted its key role for management processes, since then, several sustainability-based assessment instruments have emerged to tackle society's sustainable development. This paper focuses on indicators to support cities sustainability assessments (Bohringer & Jochem, 2007; Moreno-Pires & Fidelis, 2012; Ness, Urbel-Piirsalu, Anderberg, & Olsson, 2007; Rametsteiner, Pülzl, Alkan-Olsson, & Frederiksen, 2011; Tanguay, Rajaonson, Lefebvre, & Lanoie, 2010).

Although sustainability indicators are major tools for a given system evaluation, they present weaknesses in selection processes, therefore, leading to a system with problems (Gibson, Hassan, Holtz, Tansey, & Whitelaw, 2005). Thus, Meadows (1998) states that for a set of indicators to be valid alternatives to describe society's sustainability, the first step is to identify how that society understands sustainability and then to tackle how indicators can represent that understanding.

City sustainability assessment methodologies have incorporated solid waste management indicators, as presented by Atkisson (1996), Huang, Wong, & Chen (1998), Diamantini & Zanon (2000), Portney (2001), Dijl & Mingshun (2005), Nader, Salloum, & Karam (2008), Li et al. (2009), Scipioni, Mazzi, Mason, & Manzardo (2009), Tanguay et al. (2010), Shen, Ochoa, Shah, & Zhang (2010), Moussiopoulos, Achilllas, Vlachokostas, Spyridi, & Nikolaou (2010), Rosales (2011), and Lucena, Cavalcante, & Cândido (2011). Nevertheless, heterogeneity in indicators used to represent this sustainability aspect, leads to questions about the real scope and purpose of these indicators. Specifically regard understanding how these indicators represent sustainability.

Considering this context, this work's hypothesis is: solid waste management indicators, used in city sustainability assessment, are not being selected to represent a strong sustainability from ecological economy's perspective.

In order to do so, the paper was divided in four sections, where the first section presents sustainability through ecological economy perspective, the second section presents solid waste management through ecological economy perspective, the third section tests the hypothesis in thirteen cities' sustainability assessments by using perspectives previously identified, and the last section discusses the final considerations.

2. Sustainability under Ecological Economy Perspective

Ecological Economy is a scientific school linked to sustainability, one of its possible classifications is "Science and Sustainability Management" (Constanza, 1991) and one of its purposes is to say to what extent the use of nature can be done sustainably (Cavalcanti, 2010). The point of departure of this science is linked to the term strong sustainability, under the focus of the irreplaceability of natural capital (Constanza & Daily, 1992; Daily, 1991).

In this understanding, sustainability translates into physical stocks of natural capital maintenance and not their monetary values, that is, natural capital and constructed capital cannot be exchanged by each other (Pelec & Ballet, 2015).

It is also intrinsic to this understanding the intergenerational aspect regarding future generations' justice and equality of opportunity in natural resources access (Klassen & Opschoor, 1991; Kates, Parris, & Leiserowitz, 2005).

In general, Ecological Economy concepts regarding sustainability are associated with the material and energetic aspects of economic activities (Constanza, 1991; Daly & Farley, 2004) using the second law of thermodynamics (Law of entropy), in addition to concepts of energy flow, mass conservation and supportability. Unlike reductionism of "circular diagram of economics" underpinned by conventional economics, the ecological economy sees the economic system as an open system, in constant interaction with the environment. This means that capital flows are linked to energy flows that have environmental impacts (Odum, 1973). Thus, entropy inputs and energy are used by economic systems to produce goods, services, and waste, degraded matter and high entropy dissipated energy (Georgescu-Roegen, 1971).

Therefore, Ecological Economy sustainable development respects the Earth's finite capacity to provide energy and material resources as input to economic systems and to absorb residues (Odum, 1973; Daly, 1992).

3. Identifying Ecological Economy Perspectives Regarding Solid Waste Management

Ecological economy perspectives were identified through systematic literature review structured in three steps. The first step consisted of searching relevant articles in Science Direct, Web of Science and Scopus scientific databases. In total, 205 results were found in the database Science Direct, 199 on Scopus and 28 on Web of Science. From 432 results, 35 were repeated reaching a total of 397 relevant articles. In the second stage, exclusion criteria were used to select most relevant publications. Thirty-one results from Science Direct, 23 from Scopus and 8 from the Web of Science, with 325 remaining papers. In the last step these articles were analyzed in relation to the following question: What are the perspectives presented by ecological economy regarding solid waste management? Among 325 papers analyzed, 66 presented perspectives on solid waste management, presented below.

A first ecological economy perspective regarding solid waste management was identified in 25 articles and concerns society, economy, and environment input-output relationship, in which energy and materials are withdrawn from environment (low entropy) and return in different forms of waste (high entropy). This view is based on the Law of Entropy (Second Law of Thermodynamics) and relates to flow of matter and energy concepts, ecological economy founding bases discussed by Georgescu-Roegen (1971), Odum (1973), Daly e Farley (2004).

The second ecological economy perspective, identified in 18 articles, relates the solid waste issue to mass conservation throughout society's production and consumption processes. Resources are removed from the environment to be used by economic systems and return to the environment as waste, but mass amount does not change in time, changing only its shape. In this case, materials can be disposed in the environment as tailings from production processes or can be reinserted into economic systems through recycling.

Ecosystems physical limit in providing resources and assimilating residues from economic systems, the supportability principle of Ecological Economy, motivated the base perspective, adding a total of 26 works. These articles presented a point of view that demonstrates concern with the relationship between final disposition of residues and ecosystem's assimilation capacity. Discussions regarding this relationship consider economic system aspects, level of consumption, and scale of intervention in the environment and sustainability of society.

Another perspective was that waste can interact with other ecological components and affect ecological supplies for economic sector. Nine papers addressed solid waste pollution issues from irreversibility point of view. These works understand that solid waste pollutants have potential to transform usable resources into non-usable resources, therefore, related to the Entropy of Ecological Economics.

Finally, eight papers tackled the waste issue from social inequalities perspective, between cities' core and peripheral communities. From this point of view regards to issues, for instance, disposal of hazardous waste at poor countries, disposal of hazardous waste in cities' poor areas and other forms of disrespect to those less favored by the social system.

Ecological economy perspectives, the work in which they were identified, and the principles of sustainability to which they relate are presented in Table 1.

Table 1. Ecological economy perspectives on solid waste management, sources and related principles of sustainability

Sources	Perspectives regarding solid waste management	Principle of sustainability
Ingebrigtsen & Jakobsen (2012), Nadeau (2015), Weaver (2013), Røpke (2004), Martinez-Alier (1997), Rammelt & Boes (2013), Pelletier (2010), Røpke (2009), Klaassen & Opschoor (1991), Darwin, Tsigas, Lewandrowski, & Raneses (1996), Binswanger (1993), Nihoul (1998), Sousa & Domingos (2006), Stahel (2005), Farley & Costanza (2010), Pearce (1987), Ockwell (2008), Chee (2004), Buenstorf (2000), Christensen (1989), O'Connor (1991), Burkett & Foster (2006), Lawn (2001), Özkaynak, Adaman, & Devine (2012) e Hodas (2013).	Waste as a component that increases the system's entropy.	Law of entropy / flow of matter and energy.
Victor (2015), Shi (2002), Røpke (2004), Martinez-Alier (1997), Stem (1997), Kiaassen & Opschoor (1991), Ferraro & Reid (2013), Common (2007), McMahon (1997), Noël, O'Connor, & Sang (2000), Schandl & Schulz (2002), Røpke (2016), Crane & Swilling (2008), Korhonen & Niutanen (2003), Macrae, Henning, & Hill (1993), Lintott (1998), Lawn (2001) e Farley & Costanza (2010).	Conservation of matter between resource and waste relations, and vice-versa.	Mass conservation.
Pelletier (2010), Pelletier, Maas, Goralczyk, & Wolf (2014), Giampietro & Saltelli (2014), Friend & Rapport (1991), Weaver (2013), Klitgaard & Krall (2012), Forstater (2004), Andrade & Garcia (2015), Rammelt & Boes (2013), Pelletier (2010), Farley et al. (2007), Common & Perrings (1992), Ferng (2007), Erb et al. (2009), Curtis (2003), Farley & Costanza (2010), Pearce (1987), Common (2007), Ulh¢i (1995), Duxbury and Dickinson (2007), Bojković, IAnić, & Pejčić-Tarle (2010), Farley & Costanza (2010), Guzmán, Molina, & Alonso (2011), Meppem & Gill (1998), Schandl & Schulz (2002), Jenkins (1996), Nobre, Musango, Wit, & Ferreira (2009), Summers et al. (2012), Røpke (2016) e Lawn (2001).	Ecosystem's finite capacity to assimilate waste.	Supportability.
Røpke (2004), Common & Perrings (1992), Martinez-Alier (2001), Huber (2009), Friend & Rapport (1991), Lawn (2001), Faber et al. (2005), Ulh¢i (1995) e Warlenius, Pierce, & Ramasar (2015).	Pollution by solid waste increases system's entropy.	Law of entropy / flow of matter and energy.
O'Hara (2009), Warlenius, Pierce, & Ramasar (2015), Martinez-Alier (2001), Roberts (2011), Berrens & Polasky (1995), Schneider, Kallis, & Martinez-Alier (2010), Martinez-Alier (1997) e Rammelt & Boes (2013).	Social asymmetries and waste disposal.	Environmental justice.

4. Indicators of Solid Waste Management from the Perspective of the Ecological Economy

In this section, sustainability perspectives raised in the previous section were used as subsidy to perform an analysis regarding solid waste management indicators, used in thirteen sustainability assessment exercises executed in almost 400 cities. Among these tools, nine were applied in only one city, Trento, Padua, Jining, Taipei, Seattle, Iserlohn, Thessaloniki, Mexico City and João Pessoa and four assess sustainability of more than one city, see Table 2.

Table 2. Cities were indicators for sustainability assessment of ecological economy perspective regarding solid waste management were carried out

Cities	Source	Indicators used	Perspectives
Trento (Italy)	Diamantini & Zanon (2000)	Final disposal of waste	Waste as a component that increases system's entropy
44 cities in Lebanon	Nader, Salloum, & Karam (2008)	Household waste disposal Solid waste generation at city Composition of municipal waste Healthcare waste generation Problems in solid waste disposal Number of households without collection	Conservation of matter between resource and waste relations and vice-versa. Pollution due to waste increasing system's entropy. Waste as a component that increases system's entropy
Pádua (Italy)	Scipioni at al. (2009)	Waste generation Recycling	Conservation of matter between resource and waste relations and vice-versa. Waste as a component that increases system's entropy
More than 300 cities in developed western countries	Tanguay et al. (2010)*	Quantity of waste generated Amount of recycled waste	Waste as a component that increases system's entropy Conservation of matter between resource and waste relations and vice-versa.
Jining (China)	Li et al. (2009)	Urban waste proportion treated according to national standards Industrial waste proportion treated according to national standards	Conservation of matter between resource and waste relations and vice-versa. Pollution due to waste increasing system's entropy
Taipei (China)	Huang et al. (1998)	Waste generation per capita Percentage of recycled waste	Waste as a component that increases system's entropy Conservation of matter between resource and waste relations and vice-versa.
Seattle (US)	Atkisson (1996)	Generation per capita waste Percentage of recycled waste	Waste as a component that increases system's entropy Conservation of matter between resource and waste relations and vice-versa.
24 US cities	Portney (2001)	Recycling of household waste Recycling of industrial waste Recycling of hazardous waste	Conservation of matter between resource and waste relations and vice-versa.
4 cities in China	Dijl & Mingshun (2005)	Percentage of recycled waste	Conservation of matter between resource and waste relations and vice-versa.
9 cities in China	Shen et al. (2011)	Percentage of population with regular collection Percentage of final destination Generation per capita waste Generation of hazardous waste Treatment and final disposal Management of radioactive waste	Waste as a component that increases system's entropy Pollution due to waste increases the entropy of the system.
Thessaloniki (Greece)	Moussiopoulos et al. (2010)	Generation per capita waste Waste characterization Recycling Production and treatment	Waste as a component that increases system's entropy Conservation of matter between resource and waste relations and vice-versa.
Mexico CIty (Mexico)	Rosales (2011)	Generation per capita waste Generation of construction waste Screening	Waste as a component that increases system's entropy Conservation of matter between resource and waste relations and vice-versa.
João Pessoa (Brazil)	Lucena & Cavalcante e Cândido (2011)	Expenditure on municipal solid waste Recycling rate in relation to the amount of household waste and public waste Recovered mass from selective collection	Conservation of matter between resource and waste relations and vice-versa.

Note. * In this paper are presented only indicators that were used in six or more cities.

Analysis results are presented discussing the whole set of indicators. As can be seen in the fourth column of Table 2, from thirteen city sustainability assessment indicators, only one presents three Ecological Economics perspectives for solid waste management, eight present two perspectives, and four present only one perspective. This means that indicators that were designed were not based or constructed to represent strong sustainability concepts, analyzing through Ecological Economy perspective.

These results regarding 400 cities studied are of major importance. The fact that from five Ecological Economics perspectives identified on solid waste management, only three were contemplated ("Waste as a component that increases the entropy of the system", "Conservation of matter between resource and waste relations" and "Pollution due to waste increasing system's entropy") and for ("Ecosystem's finite capacity to assimilate waste" and "social asymmetries and waste disposal"), no system has devised indicators to represent them. These findings reinforce results importance.

Most of analyzed works present indicators regarding amount of waste that society generates and recyclable percentage that returns to economic systems. These indicators, respectively, can be used to represent system's entropy increase level, by generation of non-usable resources and mass conservation by usable inputs from "theoretically" unusable resources.

Although the principle of mass conservation is represented by recycling indicators, it is important to consider that recycling is not always environmentally and economically feasible, since recycled materials gradually lose their functional characteristics (Kronenberg, 2007) and recycling process generates dissipation of high entropy energy that cannot be reused (Klaassen & Opschoor, 1991). And these aspects, based on Ecological Economy perspectives of Law of entropy and matter and energy flow, should also be represented by sustainability indicators.

Other indicators studied, include, to a lesser extent, questions of final disposal and treatment of waste, especially those with large pollution risk. From Ecological Economy perspective, these indicators can be used to prevent loss of public health due to wastes' pollution potential, when disposed in natural areas present risk to natural resources.

However, final disposal of waste in landfills disrespects intergenerational equity, under premise of Ecological Economy. The area used for waste disposal restricts its use, which affects negatively equal opportunity of future generations to access that specific area's resources. In addition, there is a risk of unplanned pollution impacts occurred from depleted landfill sites.

One of Ecological Economy's main foundations is ecosystem's physical capacity to provide resources to, and assimilate residues of, economic systems. However, none of sustainability assessment systems analyzed contemplated the supportability principle. The generation of municipal waste allows to foretaste the degree of natural resources exploitation (Pelletier, 2010), but does not provide any representation for assimilation of waste capacity.

Although ecosystem's ability to support is an essential Ecological Economics perspective in solid waste management, establishing ecosystem support capacity is not an easy task, especially when different ecosystems are considered to have different rates of waste assimilation.

In this sense, in the absence of a specified value for waste amounts of that could be generated without exceeding ecosystems potential to assimilate them, an alternative way to represent this principle, using waste assimilation indicators, would be to consider the area used by the city. Despite weaknesses, for instance, the fact that all ecosystems are considered to have the same rate of waste assimilation and if they do not continue to work with a scientific physical limit, the use of this indicator alongside with an evaluation standard would allow a prediction regarding the intervention intensity in the environment. Thus, it is key to use the "area" variable, which would result in waste generation / area of the city, into the waste generation indicator, which is already widely disseminated and used by sustainability assessment tools.

It was found that social aspects of solid waste management were also not considered in discussions of analyzed works as a system's limitation. In this sense, it is questioned whether the absence of these aspects in solid waste problem is due to lack of information by local city responsible, since most of assessment tools use available information, not always reliable or existing, or if a trans disciplinary approach, major key for sustainability initiatives, is being considered or whether there is a prevalence of environmental dimension.

5. Final Considerations

Considering sustainability assessment tools and their indicators main objective is to support for decision-making tackling a more sustainable society (Ness et al., 2007), it is essential that the understanding regarding sustainability is well defined so systems are able to accomplish a purposeful pursuit.

A starting point to discuss sustainability assessment tools is the use of indicators to express reality complexity. And this limitation causes even greater problems when it is not clear what one wants to measure.

In this paper, it was proposed that solid waste management indicators used in sustainability assessments should be analyzed in relation to their capacity to actually represent sustainability aspects.

The main results of this paper are: an analysis structure for solid waste indicators used in sustainability assessment tools and an application in 13 works that presented sustainability assessment tools in approximately 400 cities.

The structure is composed of five perspectives of strong sustainability according to ecological economy: "Waste as a component that increases the entropy of the system", Conservation of matter between resource and waste relations and vice-versa, "Finite capacity of the ecosystem to assimilate waste", "Pollution due to waste increasing system's entropy" and "Social asymmetries and waste disposal". This structure can be applied both to indicators development and to perform assessments at different spatial scales.

Cases studied were deployed at cities scale and results showed that indicators used to evaluate the solid waste management aspect were not selected and used based on the ecological economy's strong sustainability. Therefore, the hypothesis formulated was accepted.

Two explanations are possible regarding to this and are hypotheses to be studied in future works: 1) Current tools used to assess cities sustainability do not accomplish ecological economy's strong sustainability purpose; 2) Indicators selection is not carried out in a judicious way to represent the reality of the place studied.

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