Identification of the Elements and Systematisation of the Pillars of Solid Waste Management

DOI: 10.12776/QIP.V26I2.1717

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Received: 2022-07-07 Accepted: 2022-07-25 Published: 2022-07-31

ABSTRACT

Purpose: This study identifies elements and systematises them into pillars based on relevant scientific publications on the subject, highlighting actions that contribute to the public authorities and private organisations for developing Solid Waste Management (SWM), contributing to environmental, social, and economic sustainability.

Methodology/Approach: This research used the content analysis method with the aim of identifying the main elements of SWM. To this end, the inductive approach was used to classify in a logical and organised manner the elements identified in the literature and then systematise them into pillars.

Findings: The pillars identified in SWM were: Public Management, Public Policies, Environmental Solutions and Triple Bottom Line.

Research Limitation/Implication: The main limitation of the study is the use of articles between the periods 2014 and 2018.

Originality/Value of paper: The main scientific contribution was to expand and deepen the literature on the subject, articulating concepts in pillars that can be developed and improved according to the characteristics of different regions or localities, improving the use of SWM resources. As to the applied contribution, it was possible to analyse the fields of direct and indirect action of public and private sectors that can be implemented in SWM, improving the understanding of the limits that each stakeholder can contribute to the effectiveness of SWM.

Category: Literature review

Keywords: solid waste management; sustainability; stakeholder engagement; content analysis

1 INTRODUCTION

An estimated one million people die every year in the world because of contamination from solid waste disposed of inappropriately in the environment (Espuny et al., 2021a). With the increase in the rate of urban and population growth, it is estimated that the amount of waste produced on the planet is increasing significantly and is expected to reach 3.4 billion tons by 2050 (World Bank, 2022). Solid waste comes from the generation, consumption and disposal of food, plastics, paper, cardboard, polyethylene terephthalate (PET), glass, textiles, metals, wood, leather, nappies, and ash, among others, in residential, commercial and institutional areas (Tan et al., 2015a; Tozlu, Özahi and Abuşoğlu, 2016). It must be well managed considering its specificity and processed in a complex chain of steps called Solid Waste Management (SWM), so that its environmental, social and economic impacts are mitigated (Anuardo et al., 2022).

The most commonly used solid waste control procedures in SWM are biological treatment, thermal treatment, and landfills, which protect the environment and provide a correct destination for the waste (Tan et al., 2015a). In addition to composting, methods such as incineration are used to eliminate waste, recover energy and reduce the volume of waste generated (Wu et al., 2014). In SWM, collection and transportation can be considered critical factors because their processes are more expensive due to labour intensity and the massive use of vehicles (Das and Bhattacharyya, 2015). To alleviate the waste burden on landfills, recycling has been widely accepted as a sustainable method of SWM (Moh and Abd Manaf, 2014).

Thus, researchers have developed studies of solid waste impacts based on technology and management tools, seeking to identify procedures that treat solid waste efficiently. Ding et al. (2021) identified technologies aimed at SWM from eight eastern coastal regions of China, comparing them with developed cities. Abdallah et al. (2020) compiled 85 studies published between 2004 and 2019, analysing the application of artificial intelligence in SWM, to map software platform that can be implemented in municipalities. Nanda and Berruti (2021) identified the impact of state-of-the-art landfill conditions, discussing volume reduction, resource recovery, and waste valorisation, among others. Vinti et al. (2021) identified 29 studies to assess the impacts of landfills, incinerators, and dumpsites on the health of nearby residents.

However, still scientific gaps that need to be filled to make SWM more efficient through the interaction between public authorities, academia, the private sector, society and other stakeholders (Anuardo et al., 2022). In this sense, approaches that enhance and integrate social, economic, political, technical and environmental aspects of SWM should be elaborated and proposed (Das et al., 2019; Ramos et al., 2022; Bravi et al., 2020; Carvalho et al., 2020; Costa et al., 2019). Thus, this paper has the following research question: what are the main pillars of SWM, and how should the public and private initiatives articulate to

boost it? To address this, this study identifies elements and systematises them into pillars based on relevant scientific publications on the subject, highlighting actions that contribute to the public authorities and private organisations to develop SWM.

2 THEORETICAL REFERENTIAL

The main groups of solid waste commonly identified are: municipal, commercial, industrial (in detriment of civil construction), agricultural, and institutional, among others. These wastes are produced in human activities, both at homes and in organisations, and are subject to storage, collection, handling and disposal processes. These processes impact the environment and population, leaving them vulnerable to potential toxicities caused by the lack of adequate management of these wastes (Gupta, Yadav and Kumar, 2015; Araujo et al., 2021).

Social, cultural and economic aspects interfere in the generation of solid waste, which may hinder the return of discarded items in the form of raw materials and increase the complexity of its management (Miezah et al., 2015). The variety and quantity of discarded solid waste have grown significantly over the years as the purchasing power and standard of living increase, the quality of life improves, etc. With this, municipalities are encountering increasingly complex challenges in managing their solid waste properly and effectively (Nabavi-Pelesaraei et al., 2017; Nijkamp and Kourtit, 2017).

SWM is comprehensive and involves steps beyond the collection, such as transportation, separation and final disposal of waste (Beliën, De Boeck and Van Ackere, 2012). One of the first procedures to be fulfilled in SWM is the identification of the most appropriate places for disposal. With this, it is possible to direct the collected waste to separate and final disposal units (Liu et al., 2014). Local collection services absorb approximately 70% of the waste production (Johari et al., 2014).

Effective SWM is essential for the population to have a dignified and healthy life and minimise environmental effects (Gouveia, 2012). It is worth remembering that the articulation of the governors with their citizens is one of the main strategies to reduce the impacts caused by the inefficiency of SWM, improving the quality of life in society (Kaza et al., 2018). However, SWM has faced difficulties due to the characterisation and heterogeneity of the composition of organic and inorganic waste that can negatively impact its separation step and make the recycling process unviable (Miezah et al., 2015; Al-Salem et al., 2017). Solid waste recycling aims to reintroduce the discarded material either in product form or as an input or raw material (Bing et al., 2016). Organic waste can be recycled through composting, which is decomposition by microorganisms in a moisture environment with aerobic and anaerobic characteristics (Gupta, Yadav and Kumar, 2015).

With the intention of promoting effective SWM, the former European Economic Community presented a waste hierarchy and established the priorities in public policies through Council Directive 75/442/EEC (Cucchiella, D'Adamo and Gastaldi, 2014). With this, several nations have instituted similar legislation to regulate and standard waste management processes, with predictions about the practices adopted to be implemented and the protective definitions that States should cherish (Rajaeifar et al., 2015).

In this law process developed by the public sector, companies had more responsibility for SWM in their production process. Despite this accountability, they had several market opportunities, both established and emerging companies (Lima et al., 2014). Opportunities have emerged for recycling cooperatives, energy exploration through biogas or waste burning, consulting services for SWM, urban mining, etc. (Ghisellini and Ulgiati, 2020; Espuny et al., 2021a). The technological development of the last decades (Zgodavova, Lengyel and Golemanov, 2008) has also enabled a significant advance in waste management, as in the case of scrap, making the monitoring and trading of these materials more sophisticated and automated by organisations. Thus, scrap can be reused in production, reducing the demand for virgin raw materials (Mastos et al., 2020).

Companies have also created solutions to implement sensors and software to monitor the complete production cycle, extending the useful life of resources and decreasing waste generation, namely, with lean and green tools (Silva et al., 2020) and 3D printing (Zgodavova et al., 2021). Another sophisticated strategy developed by companies with circular economy contribution is the industrial symbiosis, characterised by the use of waste discarded by a particular company, which can be used as raw material by a different company (da Rocha et al., 2022). Also worth noting is the development by companies of applications to facilitate the marketing of recyclable materials in the B-2-B format in countries such as China and the United States of America. Reliable data mining, being a sensitive point in SWM, has been prioritised for business development to improve waste diagnostics, improving the quality of decisions by public managers (Anuardo et al., 2022).

3 METHODOLOGY

This research can be classified as applied and exploratory, with the approach qualitative. The technical procedures adopted, respectively, were bibliographic research and content analysis (Kothari and Garg, 2019). This research was carried out according to the flow presented in Figure 1, and its stages are described below.

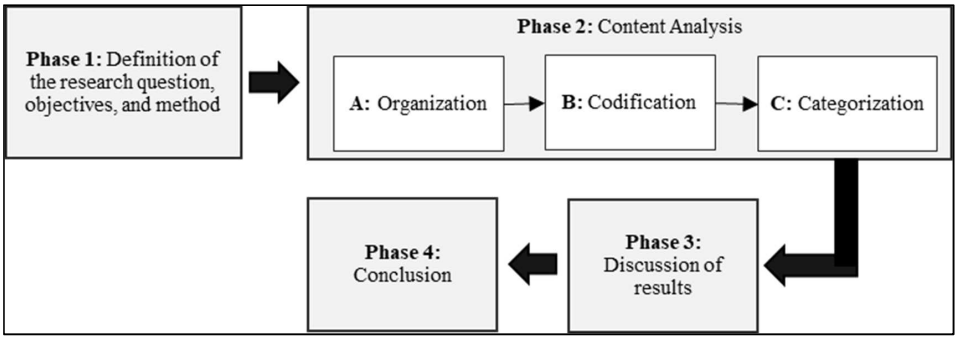

Figure 1 – Methodological Flow

In Phase 1, the research question, objectives, and method were defined. This research used the content analysis method to identify the main elements in SWM (Alvarenga et al., 2021; Costa, Santos and Oliveira, 2021; Espuny et al., 2021a). The articles chosen were from the Scopus database, which encompasses the main ones in the environmental management area (Oliveira et al., 2019). In Phase 2, inductive content analysis was performed with the aim of classifying in a logical and organised way the elements identified in the literature on SWM from the selected articles (Vnoučková, 2018; Kothari and Garg, 2019; Belkind, 2021). This phase followed three stages: Organization, Coding and Categorization. In Organization (Stage A) was performed the search for articles and scientific reviews in the Scopus database, which contained in their titles, keywords and abstract the term "solid waste management". Thus, the 30 most cited scientific documents between the years 2014 and 2018 were selected.

In Coding (Stage B), the elements (words) related to SWM were defined as units of record. Then, the frequency of each element identified in the most cited articles was marked (Appendix, Table A1). Thus, the elements with a low contribution to the topic were discarded. In Categorisation (Stage C), the identified elements were grouped according to their similarities in pillars. In Phase 3, the elaborated pillars were discussed in the light of the most recent scientific literature. In Phase 4, the conclusion was conducted, evidencing the answer to the research question, the objectives attained, the contributions, limitations and suggestions for future works.

4 RESULTS

Based on the 30 articles selected, 15 elements were identified and quantified by their frequency in the articles (Figure 2), then systematised into pillars.

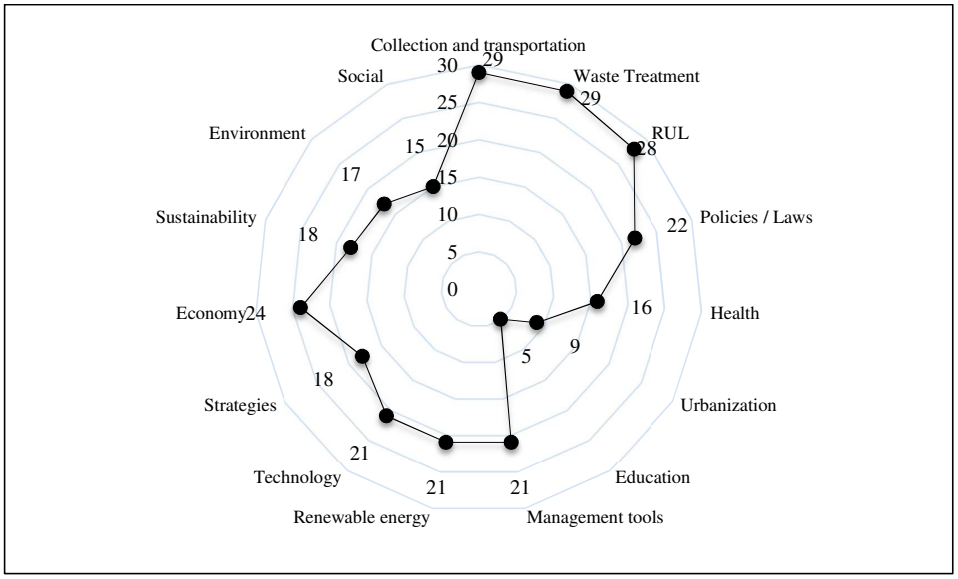

Figure 2 – Elements of SWM

According to Appendix (Table A1), the waste management elements identified were systematised into: Public Management, encompassing the elements collection and transportation, waste treatment and recycling, use and landfill (RUL); Public Policies, which covers policies/laws, health, urbanisation, and education; Environmental Solutions, grouping management tools, renewable energy and technology; and Triple Botton Line (TBL), which brings together economy, sustainability, environment and social. All pillars seek to boost SWM, contributing to the reduction of environmental and social damages.

The pillar of Public Management has preponderant participation of municipal governments and should be managed mainly by the Secretariats of Public Service and the Environment. Some municipalities determine this competence to municipal autarchies, mixed capital companies, or even public-private partnerships (Pan et al., 2018). It is essential that the municipalities participate in this process because SWM is one of the most costly services for the municipal treasury. Rulers must be aware of the financial capacity of the municipality in which they operate because this sector involves campaign promises that often may not be fulfilled. Many times the non-compliance does not occur due to the lack of operational competence of its agents but because the budgets of the municipalities are increasingly immobilised with mandatory expenses, which involve the payroll, education and health, which end up not providing a margin for investments in improvements needed for managing of municipalities. Given these considerations, it should be mentioned that successful waste management is only possible through responsible work on the part of municipal managers (Kaza et al., 2018).

The Public Policies pillar involves the management of the municipal executive authorities in consonance with the legislative authorities, as here are considered the legal factors that can speed up important procedures and projects (Tozlu, Özahi and Abuşoğlu, 2016). It is also considered the co-participation of the Health and Education Secretariats to make the population aware of the importance of changing the attitude of the residents. Also, posture should be changed in practically the entire national territory, both in relation to the attention in recycling their own domestic waste, as well as taking care of the waste of the environment in which it is located, to inhibit the transmission of diseases (Keeble, 1987). Another important issue that must be listed is the alignment that institutions must have in municipal urban planning so that SWM can always be prioritised (Panepinto, Blengini and Genon, 2015). Such negligence allows for the formation of clandestine dumps whose omission by the State may culminate in the contamination of important environmental areas and aquifers (Abd El-Salam and Abu-Zuid, 2015).

The Environmental Solutions pillar aggregates the intelligence differentials that a municipality can use, whether the municipality is the provider of waste solutions or a partner, or even when hiring differentiated services from the private sector (Wilson et al., 2015a). The public authority is not always up to date with the main good practices that the world has developed in the area because the solutions often require high financial investment (Qambrani et al., 2017). Often, it only takes the goodwill of the public employees themselves, such as articulation, to gain the support of the citizens. Developing countries have a significant percentage of organic waste; in this context, it is essential to develop alternative methods to obtain energy from the methane gas generated in landfills (Malinauskaite et al., 2017).

The TBL pillar aggregates the issues of the environment, society, economy, and issues that involve two or three of these aspects is called sustainability. After exploring economic activity with little concern about environmental impacts, as in the 1990s, the analysis of environmental impacts and liabilities arising from human activities began (Elkington, 1994). Within this context, it was possible to analyse the consequences that the lack of criteria in waste management had in the public and private lives of the populations of the planet. Many people still live in the surroundings of dumpsites, collecting part of the materials that exist there to trade it at derisory values (Kaza et al., 2018). Furthermore, people are living next to currently inoperative dumps with foul smells and the presence of animals that are poisonous to the population. For SWM to reach satisfactory rates, it is essential that the population, entrepreneurs from various segments and non-governmental organisations participate together with the government to build an integrated agenda (Nunhes et al., 2021).

When organising the above four pillars, it was found that “Public Management” and “Public Policies” depend solely and exclusively on actions provided by the public sector.

The "Environmental Solutions" and "TBL" pillars depend on public and private initiatives to implement actions that seek to solve environmental problems impacted by SWM (Figure 3).

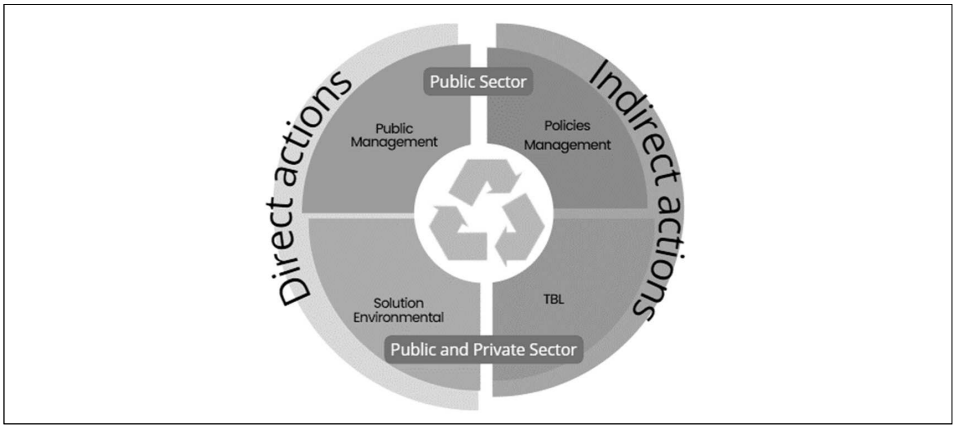

Figure 3 – Stakeholder Interaction for SWM Development

Direct Actions refer to the contributions that intervention by both the "Public Initiative" and the "Public-Private Initiative" can provide to efficient SWM. In the first case, it would be instrumented by Public Management, and in the second case, with Environmental Solutions. Indirect Actions are performed by involuntary aspects but are of great importance in action against "Critical Factors". These actions are conducted by means of Public Policies, whereby the State is exclusively responsible for mediation, and by the TBL, which might either be promoted by the State or induced by the private sector.

5 DISCUSSION

Public management in municipalities of several developing countries, such as Brazil, China, and India, have sought to improve collection and transportation techniques, treatment, recycling, reuse, and landfills to mitigate the increase in waste generation in municipalities (Fan et al., 2020). Collection and transportation are stages that should complement each other since, in many scenarios, citizens separate organic waste from inorganic waste. However, when the material goes to the truck, the entire content is mixed, reducing the effectiveness of sustainable waste management (Jerin et al., 2022). Additionally, public managers seek alternatives to address by reducing route length, optimising time, waste content and decreasing costs (Hannan et al., 2020). Among waste treatments, technologies focused on thermal conversion (incineration, pyrolysis and gasification) and biological (anaerobic digestion) have been accepted as interesting options for reducing the volume of waste and producing energy at an affordable cost for municipalities (Chen et al., 2019).

Recycling and reuse have become increasingly important for the conservation of virgin material sources, as in the case of metals, plastics and papers, become an essential environmental management strategy, especially for construction and industries (Barbosa et al., 2020; Tang et al., 2020; Silva et al., 2021). Landfills remain the most common method used by municipalities to dispose of their solid waste, but large metropolitan regions have increasingly less space to support this structure. Thus, it becomes necessary to periodically remove waste with the potential for reuse and land reclamation from operating landfills, thereby extending their useful life (Nanda and Berruti, 2021).

Public policies have been developed based on the environmental and economic performance indicators of municipalities so that SWM can be better structured (Paes et al., 2020). The main objectives of the elaboration of these policies are the preservation of citizens' health; reduction of the impact of waste management on the environment; reduction of the expenses of transportation services, collection, treatment and disposal of waste; and energy use of waste (Pujara et al., 2019). Thus, municipalities are always revising their laws and developing actions for public health, urban planning and education (Anuardo et al., 2021). Regarding laws, the major challenge for countries is to attune national laws with local ones, minimise overlapping responsibilities, and drive stakeholder engagement in SWM (Abu Hajar et al., 2020).

The issue that significantly impacts urban planning is the difficulty municipalities have in providing sites for waste treatment and disposal. This ends up impacting the low efficiency of collection and disposal that escapes environmental protocols (Barklign and Gashu, 2021). In the case of education, it is essential that public authorities raise the awareness of society at all age groups and education levels so that citizens dispose of waste at the appropriate sites and properly handle food waste and recyclables (Lee, 2020).

Environmental Solution is a resource that seeks to reconcile the improvement of SWM with the resolution of other problems such as the scarcity of material and energy resources (Espuny et al., 2021b). To improve SWM, public authorities and organisations have developed management methods and strategic planning to meet the needs of each location in a more customised way, considering the purchasing power, consumption habits, behaviour and culture (Lalitha and Fernando, 2019). Additionally, public and private authorities have been dedicated to developing technologies that preserve natural resources, mitigate pollution effects, and recover energy from waste (Azam et al., 2020; Bui et al., 2020).

TBL is a premise that all stakeholders engaged in SWM should incorporate (Nunhes et al., 2022). In addition to the need to preserve the environment and society, SWM's efforts must be directed toward sustainable development so that economic results will emerge in the long term (Bui et al., 2020). Spaces for metropolis landfills are increasingly reduced, and the regions with irregular occupation, especially in developing countries, hinder the optimisation of the

routing and waste disposal processes (Azevedo, Scavarda and Caiado, 2019). The workers involved in collection and recycling are in a deplorable situation, and many of them have an income of less than the minimum wage. Thus, these people who are the primary human resources for the operationalisation of SWM cannot maintain their livelihood and remain with no prospect of improved quality of life (Azevedo et al., 2021).

6 CONCLUSION

This article aimed at the proposition of pillars through the most relevant scientific literature on the subject between the period 2014 and 2018. The proposed analysis made it possible to identify the most important and recurrent terms, organising them into 15 elements. Thus, identified elements were systematised into four pillars: Public Management, Public Policies, Environmental Solutions and TBL, seeking to mitigate vulnerabilities arising from the negative impacts of solid waste. In this work, the main scientific contribution was to expand and deepen the literature on the theme, articulating concepts in pillars that can be developed according to the characteristics of different regions or localities, improving the use of human, material and financial resources of SWM. However, the main contribution of this article was to analyse the fields of Direct and Indirect Action of Public and Private authorities that can be implemented in SWM to improve the understanding of the limits that each stakeholder can contribute to the effectiveness of SWM. The main limitation of this work was the selection of only articles and reviews from 2014 to 2018, although the findings were discussed based on the most recent literature. Finally, as a suggestion for future studies, we encourage a more detailed analysis of each proposed pillar, adding information from studies applied in industries and municipalities.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

APPENDIX

Table A1 – List of Top 30 Articles

Pillars	Public Management				Public Policies			Environmental Solutions				Triple Bottom Line				Total
Elements	Collection and transportation	Waste Treatment	RUL	Policies / Laws	Health	Urbanisation	Education	Management tools	Renewable energy	Technology	Strategies	Economy	Sustainability	Environment	Social	
Laurent et al. (2014a)	x	x	x	x	x	x		x	x	x	x	x	x	x	x	14
Laurent et al. (2014b)	x	x	x	x	x			x	x	x	x	x	x	x	x	13
Lim, Lee and Wu (2015)	x	x	x		x	x		x	x	x	x	x		x	x	12
Chen et al. (2014)	x	x	x		x				x	x		x		x		8
Soltani et al. (2015)	x	x	x	x	x			x	x	x	x	x	x	x	x	13
Edjabou et al. (2015)	x	x	x	x				x		x						6
Tan et al. (2015b)	x	x	x	x				x	x	x	x	x		x		10
Ghiani et al. (2014)	x	x	x		x	x		x	x	x	x	x	x	x	x	13
Erses Yay (2015)		x	x		x				x	x	x	x	x	x		9
Agyeman and Tao (2014)	x	x	x	x	x		x	x	x	x	x	x	x	x		13
Allesch and Brunner (2014)	x	x	x	x	x		x	x		x	x	x	x			11
Moh and Abd Manaf (2014)	x	x	x	x		x	x			x	x	x	x		x	11
Al-Salem et al. (2017)	x	x	x	x	x			x	x	x	x	x	x	x		12
Torretta et al. (2015)	x	x	x						x			x				5
Alibardi and Cossu (2015)	x	x	x	x		x	x	x								7
Tan et al. (2014)	x	x	x	x		x		x	x	x	x	x	x		x	12
Abd El-Salam and Abu-Zuid (2015)	x	x		x					x	x		x	x		x	8

Pillars	Public Management				Public Policies			Environmental Solutions				Triple Bottom Line				Total
Elements	Collection and transportation	Waste Treatment	RUL	Policies / Laws	Health	Urbanisation	Education	Management tools	Renewable energy	Technology	Strategies	Economy	Sustainability	Environment	Social	
Miezah et al. (2015)	x	x	x	x	x	x			x	x		x	x	x	x	12
Gupta, Yadav and Kumar (2015)	x	x	x		x				x		x					6
Ariunbaatar et al. (2014)	x	x	x	x	x			x	x	x		x		x	x	11
Nabavi-Pelesaraei et al. (2017)	x	x	x		x	x		x			x		x	x	x	10
Naveen et al. (2017)	x	x		x					x				x			5
Das and Bhattacharyya (2015)	x	x	x	x				x			x	x			x	8
Aghajani Mir et al. (2016)	x	x	x	x	x		x	x	x	x	x	x	x	x	x	14
Wilson et al. (2015b)	x	x	x	x				x	x	x		x	x	x		10
Liu et al. (2014)	x	x	x	x				x				x				6
Wu et al. (2014)	x	x	x	x	x			x	x		x	x	x	x	x	12
Rada and Ragazzi (2014)	x	x	x			x		x		x	x		x	x	x	10
Basso et al. (2015)	x	x	x	x					x	x		x				7
Fernández-Nava et al. (2014)	x		x	x				x				x				5
Total	29	29	28	22	16	9	5	21	21	21	18	24	18	17	15	