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Critical analysis of waste management systems utilizing a performance assessment and optimization model

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ABSTRACT

The management of solid waste has been recognized as the cornerstone for sustainable development and closed loop circular economy models. Moreover, solid waste management is at the forefront of initiatives seeking to cut greenhouse gas emissions. This research stems from the limited success that solid waste management programs have had in the context of developing countries and the need to overcome the obstacles and impediments hampering the implementation of a sustainable solid waste management framework. It aims to facilitate the optimization process of the applied technical, operational, and managerial schemes, streamline sustainable practices and close the circularity gap that currently exists in waste management taking Lebanon as a case example. Accordingly, a performance assessment and optimization tool was developed to evaluate the administrative, environmental, and operational performance of 27 unions of municipalities and large municipalities encompassing more than 90 villages/cities. The model compares different technologies based on a set of user defined constraints and groups municipalities and operational facilities into four classes: (A) Superior, (B) Satisfactory, (C) Poor, and (D) No service. The excessive amounts of disposal rates, failure in the adoption of a comprehensive solid waste management framework, the absence of a contingency plan, and the consistent reliance on ad hoc strategies for handling solid waste characterized the sector in Lebanon. A thorough analysis of the various waste management systems revealed that none could be classified as “superior”, with the ratings of most schemes compounded in the lower end of the spectrum.

1. Introduction

At the core of the Sustainable Development Goals (SDGs) are targets that delve into environmental issues with climate change being at the forefront. Waste hierarchy which prioritizes reduction, recycling, and reuse of waste over treatment and disposal was brought in the SDGs of the 2030 Agenda for Sustainable Development under ‘Responsible consumption and production’. The solid waste sector has far-reaching impacts, as solid waste management (SWM), primarily municipal solid waste, operations engender significant risks on the environment and public health. The sector is one of the leading anthropogenic sources of greenhouse gas (GHG) emissions, ranking the third largest human-induced source of GHGs, with roughly 11% of the world’s methane being emitted due to mismanagement

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within the sector (Singh et al., 2018; Pujara et al., 2019). Accordingly, SWM often takes center stage in initiatives seeking to cut GHG emissions (Hajar et al., 2020). Rodić and Wilson (2017) reported that SWM has the potential to directly impact 12 of the 17 SDGs due to its social, economic, and environmental implications. Moreover, Phonphoton and Pharino (2019) concluded that the sustainability of a city can be determined merely by examining the efficiency of its solid waste system. The management of solid waste is recognized as one of the cornerstones for sustainability and closed loop circular economy models, which view waste management as a form of resource management and aim to minimize resource consumption and perpetuate the use of the extracted resources. Circular economy models are perceived as an alternative approach to materials management than traditional disposal-oriented linear economic systems. The primary purpose of circular models is to mitigate the environmental stresses generated by resource depleting anthropogenic activities by prolonging the lifecycle of generated products and extracted resources to the fullest while maximizing production efficiency. The prime output of circular economy models' centers around improving the circularity of resources to decouple economic growth from environmental deterioration (Lieder and Rashid, 2016; Tisserant et al., 2017; Zacho et al., 2018; Parchomenko et al., 2019).

The prospect of developing a sustainable and dynamic SWM structure is subject to the ability of the system to contextualize regional circumstances and conditions, account for potential environmental variabilities, internalize external costs, diminish uncertainties, and achieve economic viability. Environmental strategies in developing countries by and large fail to recognize the association and the interconnectedness between the social, environmental, political, and economic dimensions of environmental regulatory programs and neglect the fact that the repercussions associated with environmental degradation impact all aspects of society. The adverse environmental, social, economic, and managerial aspects that manifest in the SWM structures that are applied in developing countries are summarized in Fig. 1. Wilson et al. (2012) stated that the sustainability of integrated solid waste management (ISWM) policies and strategies is contingent on the implementation of a set of interdependent measures that include the formation of a coherent regulatory structure, the establishment of a financially sustainable system, and the inclusion of miscellaneous stakeholders in the structural and operational scheme. According to Periathamby et al., 2009, the environmental constituent of SWM has only recently emerged as a public concern in developing nations, whose SWM systems had previously been, and continue to be, primarily driven by economic considerations due to the insufficient availability of financial and technical capita. This prompted the adoption of policies that focus on economic feasibility and efficient service delivery, with little emphasis on sustainability; leading to the proliferation of environmental malpractices.

Several studies considered developing certain indicators that aim at evaluating a SWM system such as indicators for waste prevention, reduce, reuse and recycle (3Rs), and resource recovery (Wilts, 2012; Hotta, 2014) in addition to a more comprehensive set of indicators for ISWM that was developed and verified in many cities (Wilson et al., 2012). Solid waste management systems and technologies were first assessed based on several criteria, including diversion rates, methods of disposal and treatment, public engagement and operational performance of the facility. Key performance indicators (KPIs) associated with product quality (i.e. compost quality), percentage of material recovery, the availability of qualified personnel, cost recovery, the presence of precautionary and preventative measures, and operational costs were then proposed. Emphasis was also placed on the aspects involved in the governance of the solid waste management system, public engagement and participation, the 3Rs implementation, available systems for facilities assessment, as well as the environmental considerations that were taken into account before and during the construction and operation of these facilities and their impacts on the sustainability dimensions.

In Lebanon, municipal solid waste management has been a chronic problem, particularly in areas with high population density, high production of refuse, and low availability of land adequate for landfills. The 2015 waste crisis exemplified the incompetent state of the SWM sector and emphasized the need to transition away from linear disposal-oriented strategies, in favor of a more sustainable

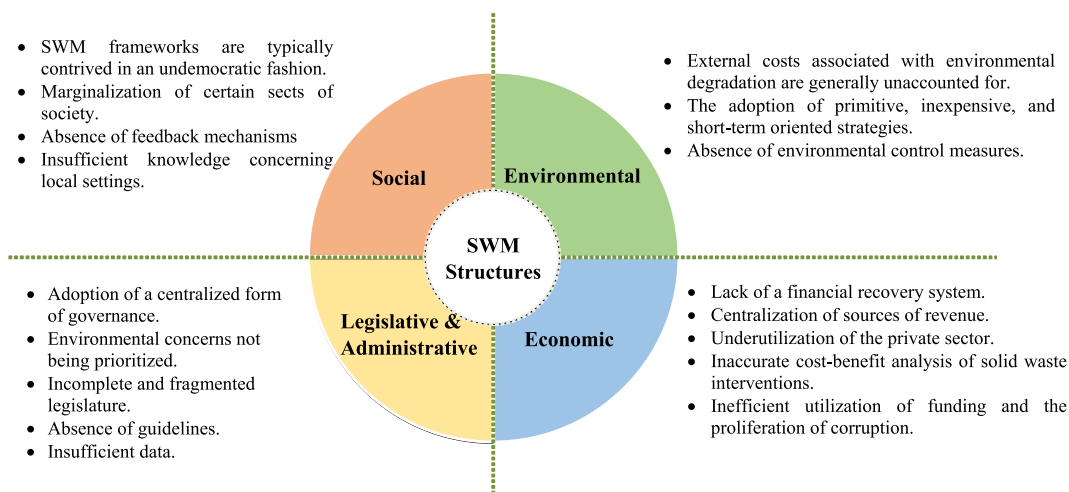


Fig. 1. Aspects of solid waste management frameworks in developing countries (Guerrero et al., 2013; Marshall and Farahbakhsh, 2013; Mmerekki et al., 2016).

and cyclical approach. The negative disposition that developing countries, such as Lebanon, find themselves in with regard to SWM stems from the negligence of decision- and policy-makers to integrate the social, economic, and environmental dimensions into the developed intervention mechanisms. In recognition of the need to decentralize service delivery in the sector, an optimized multi-criterion municipal solid waste decision support model was developed. The model was created to respond to the absence of national guidelines and standards and act as a monitoring and evaluation tool that allows governmental officials to conduct self-evaluation audits that assesses the operational performance and the environmental and financial sustainability of existing systems. The devised model was then tested and validated by evaluating the administrative, environmental, and operational performance of several municipalities throughout Lebanon. The significance of this research stems from the limited success that waste programs have had in the context of developing countries, with established facilities and strategies falling short of meeting their targets and objectives.

2. Research methodology

2.1. Model development

In an effort to expand on the technical skills available at the municipal level and facilitate the process of decentralizing the solid waste sector, a computerized optimization model was developed using an interactive and user-friendly software C# which is a remarkable versatile programming language that is easy to maintain, scalable, and largely utilized for developing Windows desktop applications. It aims to help sub-national authorities in diverting away from “end of the pipe” solutions, such as landfilling and open dumping; in favor of more sustainable options that abide by the waste hierarchy and conform with the environmental management principles of precaution and uncertainty, which stress on the need to adopt preventative approaches to governance. The model facilitates the decisions that municipal authorities have to take to efficiently manage their solid waste stream. It compares different technologies based on a set of user defined constraints (e.g. quantities generated, waste minimization targets, capital and operational investments, time constraints and technical knowhow). The model will form a knowledge-based system that can assist communities in solid waste management across Lebanon. It is built around the concept of sustainable ISWM and assesses the economic as well as environmental sustainability. The first part of the model assesses the performance of the municipality itself. This is followed by solid waste collection and transport that is either filled by the municipality or a private company responsible for collecting the wastes. Depending on the technology present, a specific questionnaire is assigned to each facility type taking into consideration control measures and technological components (Material Recovery Facility - MRF, aerobic and anaerobic digestion facilities, thermal destruction facilities and disposal facilities) as well as economic sustainability. Interviews were conducted with Environmental Managers, Quality, Health, Safety and Environment (QHSE) Managers and/or operational managers. The model develops a unified national score sheet that can be used to evaluate the sustainability of existing individual waste management systems and to highlight areas that are in need of improvement. The decision support system (DSS) served to categorically stratify municipalities and operational solid waste facilities into different classifications based on a set of scoring criteria.

2.2. Performance assessment criteria

The model divided the assessment criteria into five different categories, (1) governance, legislative and administrative aspect, (2) solid waste characteristics and data, (3) public participation and 3Rs implementation, (4) solid waste collection and transport, and (5)

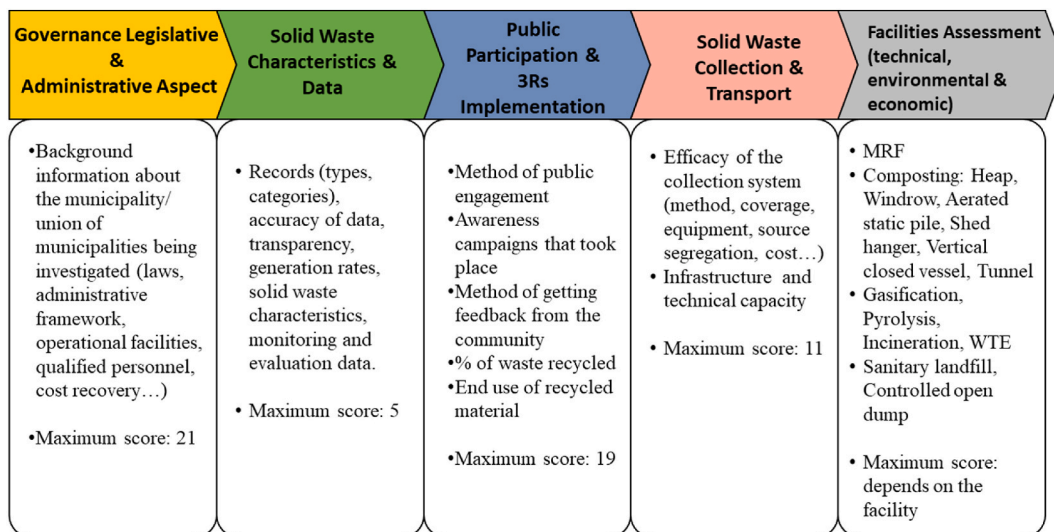


Fig. 2. Main aspects assessed in the study.

facilities assessment. Each of these categories was assigned a weight so that an overall index score can be developed. Fig. 2 depicts the main aspects assessed by the model. The scoring criteria for each solid waste facility differed depending on the services provided by that facility and the technology it employed (Table 1). Municipalities and operational facilities were then grouped into four classes: (A) Superior, (B) Satisfactory, (C) Poor, and (D) No service. Generally, a system to be classified as “superior” the operating conditions under which services are provided, by the municipality or facility, need to be strictly regulated, whereby environmental considerations are inducted into operational frameworks, and the system as a whole needs to be in peak performance and financially sustainable. Should the facility or municipal operational system be functioning at sub-optimal conditions but have all the mandatory prerequisites demanded by international standards in place, the services provided would be considered “satisfactory”. The term “poor” is applied if structural deficiencies that threaten the financial and environmental sustainability of operational schemes manifest themselves in the audited systems or facilities. While the classification of “no service” would apply to cases where service delivery is bordering non-existence and is primitive and inefficient. Fig. 3 shows an example of scoring criteria for a sanitary landfill. A landfill must typically score between 58 and 77 to be considered superior.

The numerical integers that would be displayed at the end of the process would serve to quantify the efficiency, sustainability, and eco-friendliness of the municipality’s or operator’s administrative, regulatory, and legislative practices. The scores would exhibit the domains that are in need of improvement, alongside the aspects that are practiced in an adequate manner and abide by national and international standards. Fig. 4 depicts sample forms of the various categories assessed with the maximum score possible.

2.3. Study sites and data collection

The devised model was used to evaluate the administrative, environmental, and operational performance of 27 unions of municipalities and large municipalities encompassing more than 90 villages/cities. The municipalities selected for evaluation were located in urban and rural areas throughout the country and included major cities. Moreover, they had an independent functional and context-specific waste management system, with most having established solid waste facilities within their jurisdictions. A GIS map of selected study sites is depicted in Fig. 5. The data for the performance assessment indicators were collected through interviews with municipalities’ representatives and were complimented with site observation and self-assessment checklist.

3. Results and discussions

3.1. Governance, legislative and administrative aspect

The private sector in Lebanon is highly involved in SWM, with approximately 48% of the municipalities reporting that private contractors are responsible for managing at least one operation. However, in most cases it was an “all or none” situation where one entity assumed all SWM operations. In the cases where responsibilities within a town were distributed, the private sector would mostly be involved in downstream operations such as treatment and disposal, likely because these operations require a relatively high level of technical capacity, with public entities being responsible for collecting and transferring the wastes. Integrating the private sector into operational schemes has been shown to reduce some of the costs associated with SWM, improve on service delivery, expand on the technical skills available, and curb political interference (Ahmed and Ali, 2004; Tilaye and Van Dijk, 2014; Ma and Hipel, 2016). Several studies (Arbulú et al., 2016; Saadeh et al., 2019; Berrone et al., 2019) reported that involving the private sector in the operational schemes and establishing public private partnerships (PPPs) improved the sustainability and efficacy of solid waste related services by resolving some of the technical, financial, and infrastructural deficiencies afflicting SWM structures in developing countries. Such deficiencies have impeded the ability of public authorities to capitalize on available resources and infrastructure.

In terms of decentralization, municipalities currently do not possess the capacity to independently operate sustainable waste management systems. Decentralization is achieved by means of addressing three dimensions, namely political, financial, and administrative independence. Subnational authorities need to have the political independence and power to self-govern and determine their own pathways and strategies, the financial autonomy to fund and implement devised frameworks without heavily relying on external sources of revenue, and a need to have the legal (i.e. administrative) authority to carry out the duties they intend to undertake (Zotos et al., 2009; Ahmad and Talib, 2015). In Lebanon, local authorities only have the administrative authority to perform

Table 1
The scoring criteria for each solid waste facility grouped into four classes.

Aspect	Maximum score			
	D	C	B	A
Governance, legislative, and administrative aspects	3	8	14	21
Public participation and 3 Rs implementation	2	9	12	19
Solid waste characteristics and data	1	2	3	5
Solid waste collection and transport	2	5	8	11
Material recovery facility	13	32	64	91
Composting facility	12	31	43	65
Anaerobic digester	12	25	42	60
Thermal destruction facility	14	34	56	75
Sanitary landfill	13	36	58	77

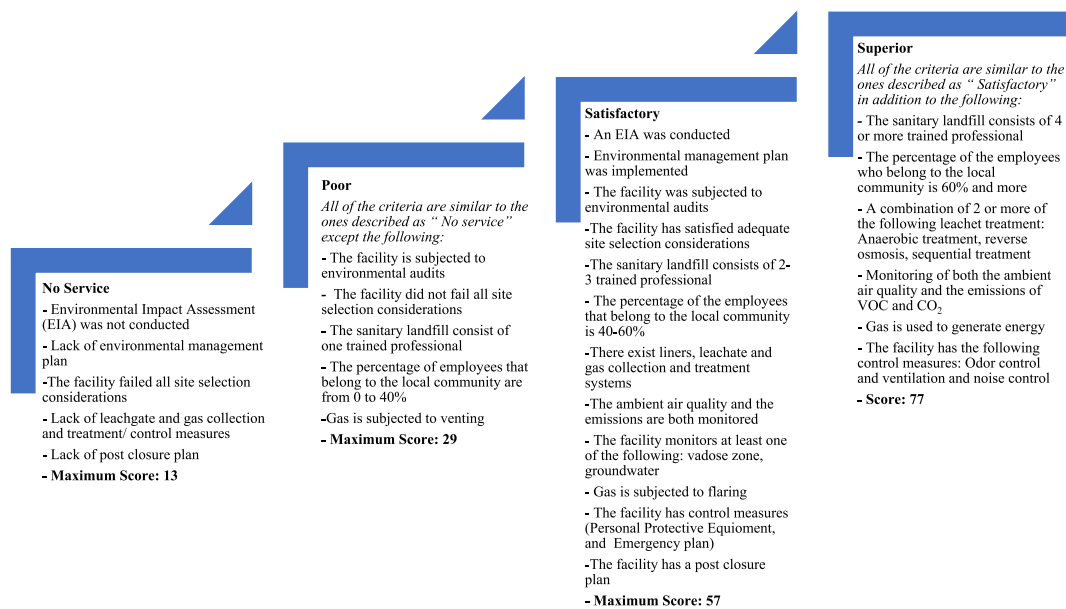


Fig. 3. Example of scoring criteria for a sanitary landfill.

waste-related operations. Yet, they do not possess the financial or the political capacity to carry them out. Almost all municipalities attained a 'poor' classification on the governance, legislative and administrative aspects. Despite the Lebanese government announcing its intentions to shift towards a decentralized model for SWM, by means of transferring the responsibility for solid waste operations towards local authorities, the means and preliminary measures that permit accomplishing this outcome have yet to be established. Moreover, a legislative framework that defines the institutional groundwork for SWM in Lebanon remains unavailable.

3.2. Solid waste characteristics and data

The study revealed that exact figures that accurately detail a municipality's expenditure on SWM were not available, as physical or digital records tend to be absent in most instances. Most municipalities lack accurate records concerning waste generation rates, waste composition, and operational costs. Lacking data and inadequate inventory management systems were more evident in small-sized and medium-sized municipalities. Some municipalities refused to reveal their budgets or how much they spent on waste management, which clearly highlights the absence of any effective financial monitoring and evaluation system. The absence of monitoring and evaluation systems at the sub-national level is often by design as it allows for the misappropriation of public funds. In relation to this aspect, it should be noted that the waste sector has been identified as one of the most prone to corruption and lack of transparency globally (Abrate et al., 2013). Idris et al. (2004) and Guerrero et al. (2013) cited that the lack of up-to-date and reliable data were major liabilities hindering the advancement of SWM systems in developing countries.

3.3. Public participation and 3Rs implementations

Barely 20% of the studied municipalities scored satisfactory on public participation and 3Rs implementation, thus signifying that public engagement and community participation in SWM projects are still weak in Lebanon. Previous attempts for public awareness campaigns have largely been not sufficient and ineffective. The few attempts to implement sorting at source in some municipalities were found to be below par. The weakest aspect identified by the model was the implementation of the 3Rs although the vast majority of the surveyed municipalities conducted at least one awareness campaign. Results allude to the fact that the different approaches that the awareness campaigns delivered failed to change prevailing attitudes, behaviors, and practices. While several studies (Birhanu and Berisa, 2015; Amasuomo et al., 2015; Xiao et al., 2017) agree that public participation is key for the successful implementation of a SWM system, the adopted approach should also be participatory and inclusive of all social and ethnic groups to prompt greater involvement and compliance. According to Shukor et al. (2011), including local communities in the decision-making process is vital because it opens a "two-way" communication channel where information, ideas, and opinions can be readily shared and provides residents with a sense of responsibility towards implemented efforts. Based on this study, we found that municipalities only engaged residents intermittently and responded to local concerns in a reactive, rather than proactive, manner, awaiting for complaints to be submitted before any corrective actions were taken in the absence of organized communication channels. Almost all municipalities did not involve residents in the decision-making process or solicit their opinions and concerns regarding current practices in any way. Numerous studies (Sujauddin et al., 2008; Shukor et al., 2011; Dhokhikah et al., 2015) reported that the success and failure of solid waste interventions highly depended on the responsiveness of local residents and thus encouraged decision-makers to elicit public

Material Recovery Facility (MRF)

» What type of waste segregation does the facility include and keep records of?

<p>Organic material</p> <p><input checked="" type="radio"/> Yes <input type="radio"/> No</p> <p>What is the percent recycled/reused from received</p> <p><input type="radio"/> Less than 10% (of total waste by weight) <input type="radio"/> 10 – 20% (of total waste by weight) <input type="radio"/> 20 – 30% (of total waste by weight) <input type="radio"/> 30 – 40% (of total waste by weight) <input type="radio"/> More than 40% (of total waste by weight)</p> <p>Paper/cardboard</p> <p><input checked="" type="radio"/> Yes <input type="radio"/> No</p> <p>What is the percent recycled/reused from received</p> <p><input type="radio"/> Less than 10% (of total waste by weight) <input type="radio"/> 10 – 20% (of total waste by weight) <input type="radio"/> 20 – 30% (of total waste by weight) <input type="radio"/> 30 – 40% (of total waste by weight) <input type="radio"/> More than 40% (of total waste by weight)</p>	<p>Plastics</p> <p><input checked="" type="radio"/> Yes <input type="radio"/> No</p> <p>What is the percent recycled/reused from received</p> <p><input type="radio"/> Less than 2.5% (of total waste by weight) <input type="radio"/> 2.5 – 5% (of total waste by weight) <input type="radio"/> 5 – 8% (of total waste by weight) <input type="radio"/> 8 – 10% (of total waste by weight) <input type="radio"/> More than 10% (of total waste by weight)</p> <p>Glass</p> <p><input checked="" type="radio"/> Yes <input type="radio"/> No</p> <p>What is the percent recycled/reused from received</p> <p><input type="radio"/> Less than 2.5% (of total waste by weight) <input type="radio"/> 2.5 – 5% (of total waste by weight) <input type="radio"/> 5 – 8% (of total waste by weight) <input type="radio"/> 8 – 10% (of total waste by weight) <input type="radio"/> More than 10% (of total waste by weight)</p>	<p>Metals</p> <p><input checked="" type="radio"/> Yes <input type="radio"/> No</p> <p>What is the percent recycled/reused from received</p> <p><input type="radio"/> Less than 2.5% (of total waste by weight) <input type="radio"/> 2.5 – 5% (of total waste by weight) <input type="radio"/> 5 – 8% (of total waste by weight) <input type="radio"/> 8 – 10% (of total waste by weight) <input type="radio"/> More than 10% (of total waste by weight)</p> <p>Residues</p> <p><input checked="" type="radio"/> Yes <input type="radio"/> No</p> <p>What is the percent recycled/reused from received</p> <p><input type="radio"/> Less than 10% (of total waste by weight) <input type="radio"/> 10 – 20% (of total waste by weight) <input type="radio"/> 20 – 30% (of total waste by weight) <input type="radio"/> 30 – 40% (of total waste by weight) <input type="radio"/> More than 40% (of total waste by weight)</p>
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Maximum score: 91

Sanitary Landfill Facility

» Does the facility conduct regular monitoring for the following gases

<p>VOCs A</p> <p>1. <input type="radio"/> Yes 2. <input type="radio"/> No</p> <p>1. Where are the locations monitored</p> <p>a. <input type="checkbox"/> Air quality on site b. <input type="checkbox"/> Off gas from treatment facility c. <input type="checkbox"/> Offsite monitoring</p>	<p>Methane A</p> <p>1. <input type="radio"/> Yes 2. <input type="radio"/> No</p> <p>1. Where are the locations monitored</p> <p>a. <input type="checkbox"/> Air quality on site b. <input type="checkbox"/> Off gas from treatment facility c. <input type="checkbox"/> Offsite monitoring</p>	<p>CO₂ A</p> <p>1. <input type="radio"/> Yes 2. <input type="radio"/> No</p> <p>1. Where are the locations monitored</p> <p>a. <input type="checkbox"/> Air quality on site b. <input type="checkbox"/> Off gas from treatment facility c. <input type="checkbox"/> Offsite monitoring</p>
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Maximum score: 77

Fig. 4. Sample forms of the various categories assessed with the maximum score possible.

opinions and induct the recommendations of local communities into the devised strategies. Therefore, municipal authorities must find an equivalence point that crosscuts the typically diverging social and economic responsibilities that are imparted to them. Lebanese public officials have yet to recognize the pivotal role that residents assume in any waste management scheme.

3.4. Solid waste collection and transport

Waste collection stood at approximately 90% across all study areas. Yet, the main dilemma was with what occurred after the wastes were collected, as a mere fraction of the wastes underwent treatment. The inefficient operation of the treatment facilities resulted in over 80% of the generated wastes ending up in a landfill. As such, the fundamentals of the waste hierarchy are violated by both the government and Lebanese citizens as overall and per capita waste generation rates continue to increase, which highlights the need for greater public awareness (SWEEP-Net, 2014). Fig. 6 shows the variations among the 27 studied unions of municipalities/large municipalities encompassing more than 90 villages/cities concerning governance, legislative and administrative aspect, solid waste

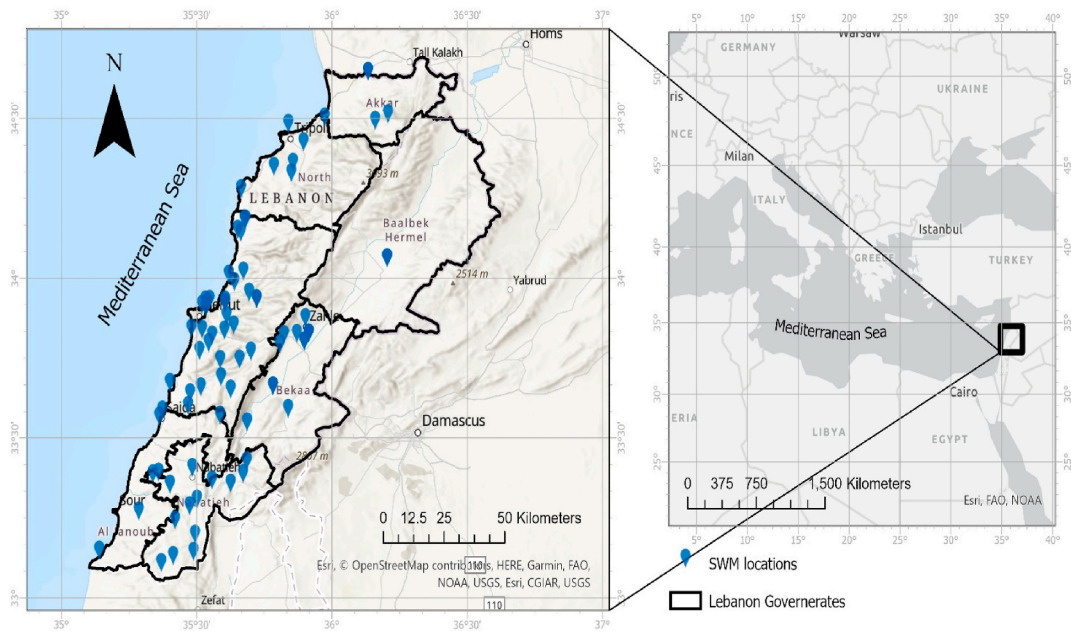


Fig. 5. A GIS map of the study sites.

characteristics and data, public participation and 3Rs implementations as well as solid waste collection and transport.

3.5. Infrastructure and technical capacity

A significant proportion of SWM facilities were non-operational. It was noted that in 46% of the cases where private sector involvement was not reported, municipalities had non-functioning SWM facilities. Many of the existing facilities were in collaboration with non-governments organizations (NGOs), who are highly active in Lebanon and often lead localized initiatives. Basic sorting and composting are what the majority of the facilities are. There is also one landfill, one thermal treatment facility, and one anaerobic digestion plant. The majority of the facilities were constructed without an EIA being conducted. Moreover, they lacked pollution abatement measures, which negatively affected the environmental sustainability of their practices. The absence of an EIA allowed for

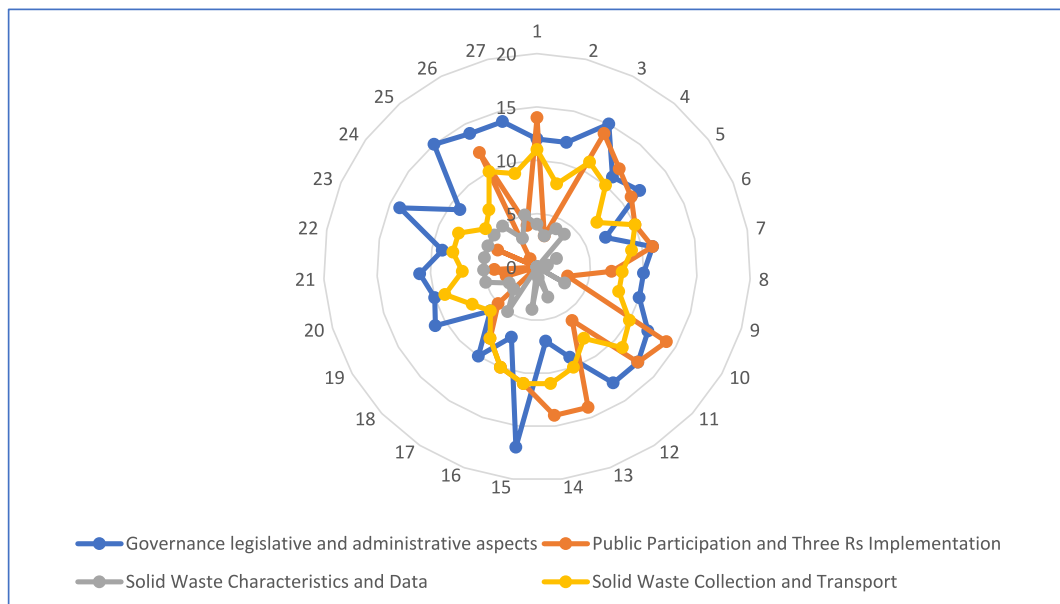


Fig. 6. Variations among the 27 studied unions of municipalities/large municipalities.

unforeseen risks to materialize, forwent the opportunity to identify better possible alternatives, and may have lead to the absence of proper mitigation measures. None of the reviewed systems and facilities were classified as “superior” with the ratings of most schemes being compounded in the lower end of the spectrum. Overall, the study showed that municipalities, where the private sector was involved in service delivery, generally, had better access to technologically advanced treatment, disposal, and material recovery facilities. In fact, private firms were responsible for operating the SWM facilities found in most of the municipalities (66.7%) that reported having operational facilities within their jurisdictions. Furthermore, the practice of disposing wastes in sanitary landfills was only found within municipalities that have contracted with private operators, with the disposal of wastes arbitrarily in open dumpsites continuing to be the most widely used method for the elimination of generated refuse.

Generally, the waste management systems in the assessed areas were characterized by rudimentary approaches with the exception of main cities and selected villages/unions of Municipalities, where private contractors were responsible for the operations. Table 2 summarizes the classifications of the various facilities. None of the reviewed facilities were classified as “advanced” with the ratings of most schemes being compounded in lower end of the spectrum. In some cities, sorting plants, rehabilitated dumps and an anaerobic digester have been put in place to treat the municipal waste. It is to be noted that most sorting and composting plants that have been executed in the surveyed villages had been implemented through international financing. The most commonly available facilities were MRFs. The MRFs operated by private firms were, generally, more technologically advanced and effective than those handled by municipal entities. In addition, the most commonly operational treatment facilities were compost plants, which were typically located in close proximity to established MRFs. This outcome was expected since organic materials such as food waste tend to represent more than 50% of the generated municipal waste stream in Lebanon, especially in rural areas (MOE/UNDP/ECODIT, 2011). Windrow composting, a relatively simple form of biological treatment, was the only treatment methodology employed by public entities, with technologies involving thermal disintegration and anaerobic digestion being exclusively operated by private firms. Nonetheless, all of the functional facilities that were examined were operating at sub-optimal conditions, with numerous operational and environmental parameters, benchmarks, and requirements falling short of internationally established standards. The composting process suffered from significant odor emission problems and poor-quality compost product. Odor emissions can be attributed to waste composition (low C/N ratio), poor temperature control, excessive moisture, low oxygen content, and poor mixing. In the absence of effective sorting at source programs most of the organic wastes were landfilled even after composting, as Grade ‘A’ compost is difficult to obtain under such conditions. The absence of sorting at the source is a major obstacle for the production of good quality compost and hence its marketability. Moreover, composting, in all its possible methods, requires special systematic maintenance and monitoring skills,

Table 2
Classifications of the various facilities.

Municipality	Facility	Classification
1	Open dumping	D
2	Open dumping	D
3	Open dumping	D
4	Open dumping	D
5	Open dumping	D
6	MRF	C
	Compost Plant	C
7	MRF	C
	Anaerobic digestion	C
8	Open dumping	D
9	MRF	B
	Compost plant	C
10	Open dumping	D
11	Thermal destruction	C
12	MRF	C
	Landfill	C
13	Open dumping	D
14	MRF	B
	Compost plant	C
15	MRF	C
	Compost plant	C
16	Open dumping	D
17	MRF	C
18	Open dumping	D
19	Open dumping	D
20	MRF	C
	Compost plant	C
21	Open dumping	D
22	Open dumping	D
23	Open dumping	D
24	Open dumping	D
25	Open dumping	D
26	Open dumping	D
27	MRF	C

analytical characterization technology, and a market for the end product. While technical skills and technology are becoming more available in Lebanon, a market for the end product of composting has not been clearly defined.

3.6. Financial sustainability

Noticeably, there is inadequate investments in local infrastructural capacity, an issue that is amplified by the lack of financial autonomy granted to local governments who possess limited sources of revenue and are heavily reliant on the intergovernmental transfers relayed by the central authority, despite constitutionally being endowed with the right to be financially and politically independent. Funding for the construction and operation of SWM facilities were found to come from a diverse set of sources including private entities, governmental institutions, and international and local non-governmental organizations. The independent municipal fund (IMF) is a source of revenue for municipalities. However, payments are subject to several-year delays as the IMF is withholding a large proportion of generated revenue. As the case with other developing countries, user fees tended to be absent or minimal with most of the revenue generated from waste-related activities being from the direct sale of recovered material, which heavily affects the sustainability and longevity of the applied SWM scheme (Aleluia and Ferrão 2017). Efforts in decentralizing Lebanon's SWM structure remain insufficient as they predominantly focus on the administrative dimension of governance, all while ignoring the political and fiscal aspects.

Despite the rudimentary approach by which the wastes are being collected and transferred, the costs associated with the operations of these systems were relatively high, reaching up to 80 USD per ton. This, in turn, is draining the already limited financial capital of municipalities and is driving them to switch to open dumping. The limited financial and infrastructural capacity hinder municipalities from shifting away from unsustainable practices in favor of more environmentally and socially acceptable options. Most local officials claimed that the intergovernmental transfers provided by the national government, which are typically transferred following years of delay (MOE/UNDP/ECODIT, 2011), are insufficient to cover all of the administrative and operational costs borne by municipalities. Similar issues were identified by local officials in other developing countries who often report the lack of horizontal cooperation between stakeholders, the absence of adequate support from the national government, and the high fees associated with waste transport as major liabilities (Pokhrel and Viraraghavan, 2005; Henry et al., 2006; Guerrero et al., 2013).

4. Conclusions and recommendations

The implementation of the 3Rs is among the enabling mechanisms of circular economy approach to the management of solid waste. In Lebanon, despite more than 80% of the generated municipal solid waste being recoverable, the vast majority of it is disposed of, as recycling remains minimal and compounded in personal efforts and the efforts of the informal sector. An analysis of the present situation of waste management and the status of 3R initiatives in the studied municipalities clearly indicated that reduction strategies barely exist and recycling was predominantly practiced in the informal sector through waste pickers and thus relied on rudimentary technologies. Very few initiatives for promoting 3R-based solutions existed. The results also showed a general disregard to the precautionary principle, whereby there was a heavy reliance on national policies that emphasized "end of the pipe" solutions, such as landfilling or thermal treatment, despite being the least preferable alternatives in the waste hierarchy. Furthermore, a thorough examination of the various waste management systems in Lebanon utilizing information on local waste streams and treatment facilities demonstrates system inefficiency in terms of both technical indicators and metrics. The majority of evaluated facilities lacked EIAs, control and mitigation measures, and preventative strategies. In addition, the open dumping of wastes is highly prevalent with the majority of all generated wastes being indiscriminately disposed of in an unsanitary manner.

The lack of appropriate facilities, inadequate management structures and the lack of technical skills represent the main obstacles for the development of effective and efficient municipal waste management systems. Negligence in the implementation of a coherent and overarching framework for SWM prompted the national authority to instate an ad hoc managerial system for governing the sector; relying on emergency planning for service delivery. Integrated and sustainable waste management strategies that aim to rectify the intrinsic dysfunctions of contemporary structures should be developed from the bottom-up and ought to adopt a precautionary approach to management, while utilizing economic measures to finance operational costs. These economic measures could include pay-as-you-throw (PAYT) schemes that would be utilized to enhance the financial autonomy of sub-national authorities, by recovering some of the costs of solid waste operations, and reduce resource consumption and waste disposal rates, by discouraging waste production and holding polluters accountable.

One of the major challenges and focus will be to influence and change citizens' and stakeholders' attitudes, behaviors, and practices towards sustainable waste management. Thus, changing the role of citizens from passive consumers to evolved stakeholders who actively prevent and sort waste. Priority should be given to upstream interventions that aim to reduce the dimension of the problem by the quantity of waste. Sorting at source aims to remove organic material from the waste stream and reduce the contamination of the other waste streams, which will reduce the cost and increase the efficacy of downstream activities. The second aspect is a continuation of the waste value chain and is concerned with recycling and composting activities. These are economically attractive as they promote the reuse of segregated materials back into the production cycle with high environmental and economic benefits such as reducing energy costs, increasing agriculture productivity (through compost), creating 'Green' jobs/skills, and diversifying the local economy. The enablers for a sustainable and circular economy approach include.

- Administrative and constitutional reforms that clearly define the roles and responsibilities of public agencies and transfer judicial authority from the national government towards subnational agencies.

- Financial autonomy of municipalities through the introduction of user fees based on the “polluters pay” principle to finance waste operations.
- Financial incentives and disincentives that would curb waste disposal rates and incentivize increasing waste treatment.
- Municipal cooperation models that aggregate efforts and capabilities and offset the difficulties municipalities face on an individual level.

Authors statement

Conceptualization: May Massoud and Ibrahim Alameddine; Methodology: May Massoud and Ibrahim Alameddine; Software: May Massoud and Ibrahim Alameddine; Data Curation: May Massoud, Michel Mokbel, and Ibrahim Alameddine; Writing original draft: May Massoud and Michel Mokbel; Writing - review and editing: May Massoud and Ibrahim Alameddine; Funding acquisition: May Massoud.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: May Massoud reports financial support was provided by Lebanese National Council for Scientific Research.

Data availability

Data will be made available on request.

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