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ORIGINAL ARTICLE

Reframing environmental problems: lessons from the solid waste crisis in Lebanon

May A. Massoud[1] · Michel Mokbel[1] · Suheir Alawieh[2]

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Abstract
This research seeks to examine the fundamental environmental management principles that have been violated and how their adoption may remediate solid waste management practices in Lebanon. The study will enrich the more traditional approaches to assessing environmental problems by identifying the factors facilitating and impeding improvement in some contexts but not others. The root cause analysis methodologies were utilized to systematically disclose the underlying components that contribute to the impairment of contemporary solid waste structures. The principles of subsidiarity, precautionary, and cost internalization are in direct correlation with the identified root causes and are capable of propagating the beneficial outcomes associated with integrating environmental management perspective into the strategic planning process. Integrated and sustainable waste management strategies that aim to rectify the intrinsic dysfunctionalities 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.

Keywords Environmental management principles · Strategic planning · Solid waste · Sustainability

Introduction

Developing countries have thus far stagnated and struggled to control locally generated refuse in an environmentally and socially responsible manner. The negative disposition that developing countries find themselves in, with regard to solid waste management (SWM), stems from the negligence of decision- and policy-makers to integrate environmental management perspective in developed intervention mechanisms. The adverse environmental, social, economic, and managerial traits that manifest in the SWM structures that are applied in developing countries are summarized in Table 1. Research studies [1–4] have shown that the application of the environmental management principles leads to the implementation of systematic managerial structures that extract environmental, social, and economic dividends. These postulates serve not only to assist in the decision-making process, but also help in ensuring that the various stakeholders comply with the policies, targets, and objectives integrated into a developed framework [5].

A variety of principles govern environmental management that assist in implementing a dynamic and versatile environmental regulatory structure that is incessantly subjected to changes and revision, generating an administrative construct capable of tackling environmental issues in a systematic and sustainable manner [10]. The principle of uncertainty advocates for the installation of pre-emptive control measures that account for the presence of unforeseeable risks when implementing an environmental management program. The precautionary principle is developed to counteract the risks associated with implementing environmental initiatives that are based on scientifically unproven assumptions, to prevent the transpiration of critical or irreparable environmental damage. It is generally practiced in situations where a cost–benefit analysis cannot be properly performed due to the absence of sufficient data and decision-makers are incapable of fully determining how the various elements of an ecological system will reciprocate in response to a certain change. Moreover, this principle incentivizes conducting studies that assess the risks of a certain project, such as environmental impact assessments (EIAs), and the installation

✉ May A. Massoud
may.massoud@aub.edu.lb

[1] Department of Environmental Health, Faculty of Health Sciences, American University of Beirut, P.O. Box 11-0236, Riad el Solh 1107, 2020 Beirut, Lebanon

[2] Lebanese University, Beirut, Lebanon

Table 1 Fallacies plaguing solid waste management frameworks in developing nations [6–9]

Social aspect
Solid management frameworks are typically contrived in an undemocratic fashion
The influence of local stakeholders on the decision-making process tends to be limited
The impact that a solid waste intervention will have on the informal sector is typically unaccounted for
Marginalization of certain sects of society
Solid waste services are likely to be impaired and deficient in impoverished regions
Absence of feedback mechanisms
Lack of public engagement activities
Lack of monitoring and reporting procedures
Insufficient knowledge concerning local settings
The contrived SWM plans typically fail to accommodate the cultural and social aspects of local communities
Environmental aspect
External costs associated with environmental degradation are generally unaccounted for
The health and social costs sustained by the public, tend to be omitted
Issues such as land and resource shortages are not properly accounted for
The adoption of primitive, inexpensive, and short-term oriented strategies
The open dumping and burning of wastes are perceived as being low-cost treatment and disposal methods
Disregard to the principles of prevention and uncertainty
Absence of environmental control measures
Economic aspect
Lack of a financial recovery system
The polluter-pays principle is unimplemented
Resource recovery remains minimal
Centralization of sources of revenue
Inadequate infrastructure at the municipal level
Municipalities are typically underfunded and suffer from financial limitations
Underutilization of the private sector
Restricted amount of public–private partnerships
Inaccurate cost–benefit analysis of solid waste interventions
The exclusion of external costs
Inefficient utilization of funding and the proliferation of corruption
Legislative and administrative aspect
Adoption of a centralized form of governance
Restriction of decision-making authority
Insufficient technical and financial capacity at the local level
Environmental concerns not being prioritized
Incomplete and fragmented legislature
The roles and responsibilities of regulatory bodies are not accurately defined
Incoherent organizational planning
Solid waste operations are not performed in a consistent manner
Absence of guidelines for proper SWM practices
Insufficient data regarding resource consumption and waste generation patterns
Absence of monitoring and auditing programs

of control measures in the form of emergency plans, control measures, and preventative actions, that permit governing bodies to appropriately counteract unforeseeable events [11].

Incorporating the environmental and social costs and liabilities in the form of economic losses, with the intention of performing an accurate cost–benefit analysis prior to the implementation of an environmental intervention is the prime objective of the internationalization of costs principle. Despite the existence of several cost–benefits analysis models, ascertaining a financial statement that accurately translates the economic and communal damage incurred upon implementing an environmental strategy remains implausible. As a response to the failure of economic methods to incorporate the environmental damage that products or services have caused, the polluter-pays principle is frequently applied [12]. The objective of this principle is to use economic instruments to discourage pollution, establish accountability, and compensate victims of environmental degradation. This financial model would hold polluters responsible for their actions and would permit the formation of a sustainable financial recovery system that ensures the financial continuity of an SWM structure [13].

The notions of intragenerational and intergenerational equity are integral for the conceptualization of a sustainable environmental management framework that does not incite internal conflicts and reduces negative public sentiments. Inter-generational equity promotes the preservation of natural resources and the environment, so that the ability

of future generations to develop and prosper is not compromised. While the principle of intra-generational equity underlines the need to avoid any form of discriminatory behavior against a particular group, especially those who are vulnerable, such as low-income communities, by ensuring that the environmental, economic, and social burdens and benefits of developed strategies are distributed in an equitable manner [14]. The conservation of social diversity hinges on the proper implementation of the principle of intra-generational equity, where the different sects of society are treated in an equitable manner, have equal rights and access to natural and economic resources, are inducted into the decision-making process, and are provided with the adequate financial means to thrive in their local communities [15, 16].

Multisectoral integration, also known as the cross-sectorial approach, is a participatory form of governance that promotes the inclusion of stakeholders from the various sectors and denominations of society in the decision-making process [17]. The principle of subsidiarity complements the principles of multisectoral integration, social diversity, and intragenerational equity, since it promotes the implementation of a participatory form of governance where citizens exercise greater control over decisions that directly influence their lives. The prime objective of the subsidiarity principle is to endow local communities with the means that would permit local governments to regulate themselves. A preventative approach to management represents a long-term oriented strategy that seeks to inhibit the propagation of the negative effects of pollution by preventing the formation of environmental threats, such as wastes. Minimizing the possible health risks or threats posed by an intervention is typically achieved through the application of preventative, precautionary, disciplinary, and uncertainty measures that protect the current and future social wellbeing of populations [13].

Research methodology

Study design

The root cause analysis (RCA) method was employed in this study. It allows to cohesively restructure the data put forth regarding a negative incident that had previously occurred, in order to identify the most prominent underlying factors that have influenced the generation of the undesirable outcome [18]. The prime analytical mechanism that was applied is the Six Sigma technique, which is also known as the DMAIC (define–measure–analyze–improve–control) method. The DMAIC approach to management was selected because it is not limited to a single standardized configuration, can be administered in accordance to a different set of parameters and definitions, is capable of incorporating several RCA organizational tools simultaneously, and facilitates the installation of a systematic and sustainable regulatory framework that is founded on the principle of continuous improvement [19]. The DMAIC methodology typically measures the performance of a system or function in a quantifiable manner, through the use of numerical or statistical figures. In this research, the environmental management principles served as the parameters that benchmark the viability of the Lebanese SWM structure, substituting the need for quantitative data.

Firstly, an account of the SWM framework in Lebanon was provided, coupled with a description of the organizational structures that govern SWM within the nation. While in the measurement and analytical phases, the events and factors that influenced the 2015 waste crisis were illustrated in a casual tree that serves to highlight the underlying causal agents for the crisis. To systematize the reformatory ventures needed to address current insufficiencies, the environmental management principles were categorically stratified based on their perceived equivalence and parallelism. Corrective measures, in the form of input factors, were introduced to address the principal factors and conditions directly associated with the categorized variables.

Description of the case study

Up until today, Lebanon's SWM structure has been in a perpetual state of emergency even though significant capital being invested into the field. Despite the unsustainability of Lebanon's SWM structure becoming more publicly apparent during the crisis, practices such as open dumping and burning have always been common in the country, especially in rural areas. Although a financially burdensome governmental emergency plan had prevented the adoption of these practices in most of Beirut and Mount Lebanon, which is a relatively wealthy region, through the construction of two sanitary landfills; a measure that was readopted in the newly formed emergency plan [20]. Notions that highlight the inequity in service delivery and ascertain the need for a holistic SWM scheme directed towards addressing the sector on a nationwide basis.

Lebanon's SWM construct suffers from conditions exhibited in other developing countries, which include but are not limited to infrastructural and financial deficits and political intrusion. However, these problems are exacerbated by Lebanon's relatively high population density and ever-increasing waste generation rates, with estimates indicating that an excess of 2 million tons of solid waste were produced in 2013, excluding the amounts generated by Syrian refugees. The figure is expected to continuously inflate, reaching roughly 2.9 million annually by 2035, as reports project a 1.65% yearly growth in waste generation rates [20]. The

pressure placed on Lebanon's SWM infrastructure was further inflated by the Syrian crisis, which caused the influx of approximately 1.5 million refugees, resulting in a 15% increase in waste volume, half of which were reportedly being openly dumped or burnt [24, 26].

Generally, the problem does not lie with service delivery considering that an upwards of around 90% of generated wastes are collected. The issue lies in what occurs after the wastes had been gathered, with about 77% of generated wastes being landfilled or openly dumped [20]. This comes despite the implementation of a relatively advanced and costly emergency waste management strategy for Lebanon's most populous region, Beirut and Mount Lebanon, which produces more than half of the nation's wastes. The strategy called for the collection, sorting, treatment, and landfilling of generated wastes and had a unit cost of approximately 143 USD/ton, a figure that reportedly surpasses those recorded in some high-income nations. This caused the waste sector to rank amongst the highest environmental-related sectors being expended on by the central government, with the emergency plan alone costing 130 million USD annually [20, 22]. These figures highlight the low rates of productivity and cost efficacy of the current system, despite the private sector playing a pivotal role in service delivery most notably in urban areas where all solid waste-related activities are provided by private firms.

The accumulation of all of these factors, the unavailability of a contingency plan, and the inability of municipalities, who are the legal entities responsible for the provision of solid waste services, to handle generated wastes, produced an 8-month waste crisis. The crisis was initiated upon the closure of the nation's largest landfill, which used to serve Beirut and Mount Lebanon, after it had accumulated several times over its initially designated capacity following a series of operational extensions. The operational life expectancy of the landfill, which opened in 1998 and was initially designed to have a 5-year service period, was constantly extended in conjunction with its continuous expansion, in the absence of any alternatives. A site that would serve as a substitute to the nation's primary disposal facility had not been identified prior to its closure in the summer of 2015, resulting in what has been described as the worst environmental crisis that Lebanon had ever witnessed in recent times [23]. Wastes were haphazardly dumped and burnt in public and open areas, causing the number of open dumpsites within the country to increase from 670 in 2010 to 904 at present [24, 25]. The government's inability to procure new disposal sites or implement a new solid waste strategy was primarily attributed to factors such as the opposition of local populations to the construction of solid waste facilities within their region, the lack of political consensus, limited land availability, and the high costs associated with draft strategies [20, 22, 23]. Additionally, the lack of financial incentives for the municipalities that host solid waste facilities could also be cited as a contributing factor, since their willingness to accommodate centralized installations would in turn be diminished [25].

The government's response to this disaster was an interim plan that involved the establishment of two new landfills that would serve the Beirut and Mount Lebanon region for the upcoming years until a long-term strategy involving the decentralization of solid waste services can be implemented. Unfortunately, the ecological footprint of the sector continues to dilate due to the allocation of the two new landfills in environmentally sensitive locations, with both dumpsites being located along the coastline and one being adjacent to an airport and an estuary, spawning numerous concerns regarding civil aviation safety and marine pollution. Concerns that are further magnified by the absence of a comprehensive environmental impact assessments (EIAs) for both facilities. Furthermore, the operational continuity of the landfills is threatened by the high disposal and low waste diversion rates, problems that the current emergency plan failed to adequately address.

Some of the observed impacts correlated with the improper disposal of wastes include the pollution of surface and ground water, soil contamination, elevation in greenhouse gas emissions, attraction of pests, spread of pollutants and disease-causing agents, and the devaluation of land [21]. Lebanon's ecological system was subjected to these adverse implications which proliferated throughout the nation during the 2015 crisis and continue to threaten the health and safety of the population and the environment until today. However, these threats are not evenly distributed due to the disproportionality in the quality of service delivery, as a result of the Lebanese government concentrating its efforts in certain geographical locations, namely Beirut and Mount Lebanon. For instance, the strategy adopted following the crisis failed to supplement the solid waste management systems of towns located outside the aforementioned region and urban areas, as rural and low-income regions continue to rely on the open dumping and burning of wastes as their primary means for the treatment and disposal of hazardous and non-hazardous wastes, resulting in elevated burden of disease and in the contamination of natural resources. These practices have also impacted the livelihoods of residents who rely on the agricultural sector for income, due to the diminished availability of fertile land and fresh water, which will likely exacerbate urban–rural migration [21, 25, 26]. This comes 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, an outcome that remains implausible considering the absence of cost recovery mechanisms, the inequitable distribution of funds and services, and the

limited financial and administrative capacity of local public entities.

Additionally, a coherent national legislative framework that defines the institutional groundwork for SWM in Lebanon has yet to be established in Lebanon; with policies and laws tackling the solid waste sector being characterized as incomplete or outdated. This has allowed for certain laws and regulations to be transgressed, caused the development of a fragmented regulatory structure where the responsibilities and jurisdictions of various stakeholders overlap, and hindered the ability of stakeholders to collaborate and communicate amongst each other [20]. The overlap in judicial authority between national and subnational agencies has also enabled the national government to enact solid waste strategies, such as the one adopted after the crisis, in a top-down format. This effectively negates the need for any form of horizontal cooperation between nation and subnational entities. The accumulation of the aforementioned factors has decreased the productivity and efficiency of public bodies, diminished transparency, and contributed to the squandering and misappropriation of funds. The applicability of a context-driven decentralized form of governance for the sector remains contingent on resolving the underlying technical, regulatory, operational, and legislative conditions that have impaired the ability of municipalities to deliver solid waste-related service during the onset of the crisis, conditions which continue to prevail until today.

Results and discussion

Root cause analysis

The principal causes for the 2015 waste crisis are primarily compounded into three factors, which are the government's inability to implement an integrated and sustainable nationwide SWM framework, the closure of the country's largest landfill, and the inability of municipalities to independently deliver solid waste services. A summary of the prominent negative conditions that manifests itself in Lebanon's SWM structure in relation to the environmental management principles is presented in Table 2. The underlying circumstances that have led to the direct causes of the crisis to transpire and how violations to the principles of environmental management have caused these factors to materialize are depicted in Fig. 1.

Violation of environmental management principles

The prime outcome that a SWM system tries to achieve is the protection of the health of population and the environment. In the case of Lebanon, public mistrust has on several occasions led to the abandonment of drafted SWM strategies [20, 25, 27]. The principles of environmental management are correlated in a manner where the application or contravention of one principle influences several others. This result coincides with the findings of Wilson et al. [27], who stated that the sustainability of 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; concepts that are integrated into several environmental management principles. A number of the principles are realized only following the application of features that characterize other principles, most notable of which being the principle that advocates the protection and promotion of health and safety which requires the installation of a diverse set of preliminary measures. However, achieving this principle has thus far been difficult for developing countries. The environmental constituent of SWM has only recently emerged as a public concern in

Table 2 The environmental management principles in relation to the negative conditions in Lebanon's SWM structure

Environmental management principle	Negative outcome
Uncertainty	Absence of mitigation measures
Precautionary	Absence of an integrated long-term SWM strategy
Internalization of costs	Inaccurate representation of costs for SWM strategies
Polluter-pays	Lack of financial deterrence
Intra- and Inter-generational equity	Unequal access and distribution of resources and services
Conservation of social diversity	Continued rural–urban migration
Multisectoral integration	Biased decision-making
Subsidiarity	Centralization of decision-making authority
Prevention	Minimal waste recovery and continuous increase in waste generation rates
The protection and promotion of the health and safety of populations	Potential exposure of residents to health hazards and deterioration of the environmental health
Development of guidelines and standards	Unavailability of manuals and guidelines for local operators

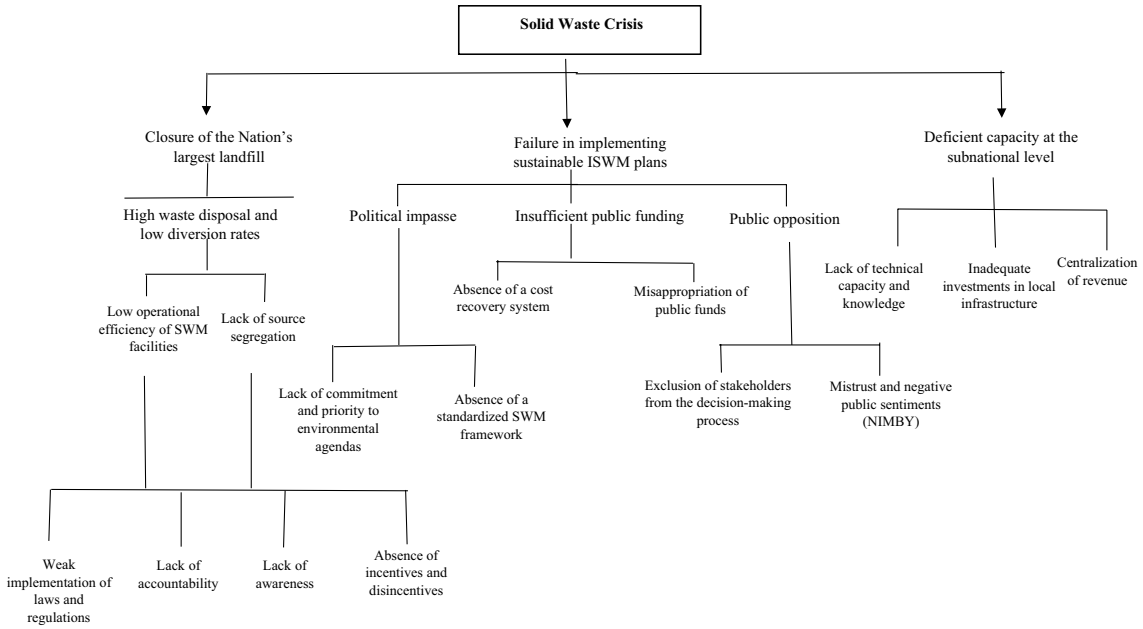

Fig. 1 Causal tree analysis diagram

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 capacity. 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, as in the case of Lebanon. This implies that Lebanese decision-makers have thus far treated the environmental dimension of waste management as an element isolated from the domain of public health safety, which explains why service delivery stood at a very high level, yet the waste diversion rates were relatively vastly low.

This research identifies three central environmental management principles that are in direct correlation with the previously identified root causes and are capable of propagating the beneficial outcomes associated with an environmental management system, in the context of Lebanon. In accordance with Fig. 2, this paper will prioritize the need to advance decentralization efforts, account for the long-term social, economic, and environmental costs of a strategy or practice, and highlight the role of the precautionary principle in driving preventative practices which alleviate social and environmental burdens.

The principle of subsidiarity

As mentioned earlier, despite the concept of decentralization being regarded as one of the major tenets of the adopted interim SWM plan, the means and preliminary measures that permit accomplishing this outcome are lacking. Adequate investments in local infrastructural capacity have yet to be made, 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. Municipalities receive their allowances through an intergovernmental grant system known as the independent municipal fund (IMF). The financial vulnerability of municipal authorities stems from irregularity at which funding is distributed since proceedings are typically transferred after years of delay and are disseminated in an inequitable manner, which further inflates regional disparity and prevents subnational bodies from having a reliable source of income [25]. Additionally, the government has consistently utilized the funds allocated in the IMF to finance centralized SWM strategies it had developed, which is likely to be a factor contributing to the delays involved in fund allocation. Giannozzi [28] added that municipalities in Lebanon are also politically constrained by the established bureaucratic hierarchy that renders communication between various stakeholders difficult and limits the decision-making authority of local governments. The accumulation of the previously mentioned factors has limited the political representation of local authorities in drafted SWM strategies and has allowed the national government to continuously influence local policies.

Therefore, efforts in decentralizing Lebanon's SWM structure remain insufficient as they predominantly focus

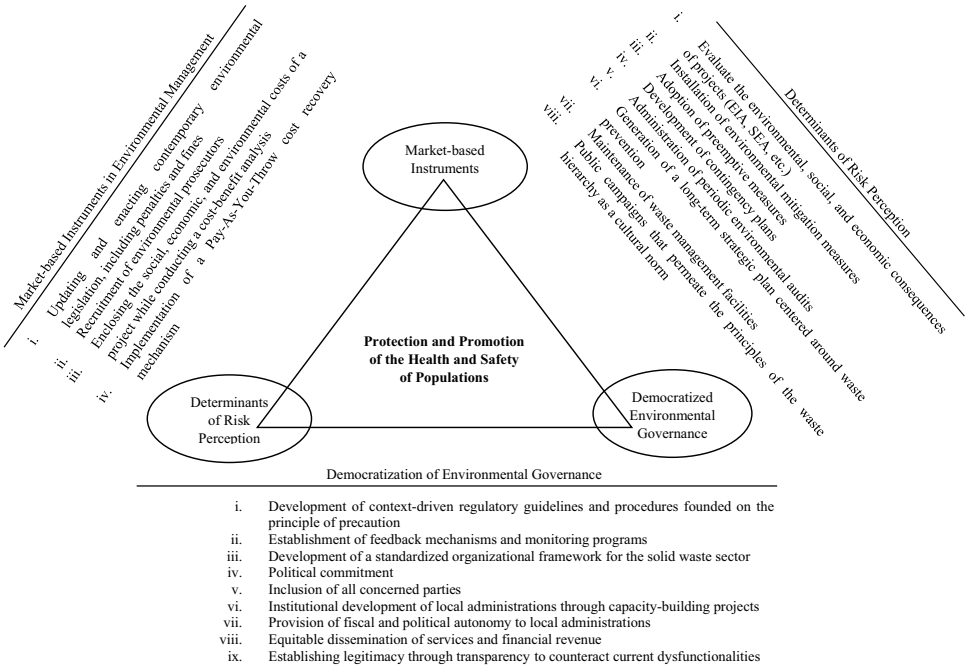

Fig. 2 Measures that should be adopted in relation to environmental management principles

on the administrative dimension of governance, all while ignoring the political and fiscal aspects. Accordingly, the principle of subsidiarity which complements the principles of multisectoral integration, social diversity, and intragenerational equity has been violated. There is a lack of a participatory form of governance where the targets and objectives of SWM systems are determined by the needs and priorities of local citizens, who exercise greater control over decisions that directly impact their lives. Decentralization efforts need to be accompanied by constitutional provisions that grant local authorities fiscal and political sovereignty, investments that develop local infrastructural capacity, and the construction of a uniform organizational hierarchy that facilities the coordination of efforts between various stakeholders [29]. A successful decentralization policy necessitates elevating local authorities from a subordinate position, granting municipalities the sufficient financial and infrastructural provisions that would enable them to administer solid waste operations. Otherwise, decentralization strategies will yield contradictory effects which will further aggravate the efficiency of solid waste systems [30]. Decentralizing Lebanon's solid waste structure would also improve the resilience of localized operational systems, allowing municipalities to withstand and diffuse abrupt external disturbances, such as those brought about by the Syrian refugee crisis. Furthermore, decentralized structures of governance exhibit faster emergency response rates. Hence, in the case of an outbreak of another refugee crisis, subnational bodies would be capable of counteracting incremented pressures.

The financial autonomy of municipalities, however, can be enhanced through the application of mechanisms relating to the polluter-pays principle, such as the pay-as-you-throw (PAYT) scheme, which have the potential to increase the financial fortitude of local administrations 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 [31, 32]. Despite the polluter-pays-principle being incorporated into Lebanese environmental legislation, its application has been hindered by the absenteeism of monitoring and feedback mechanisms and poor law enforcement. The urgency of its application is magnified by the unavailability of an adequate cost recovery scheme, since material and resource recovery are scarce, leading to the sector to be described as vulnerable, inefficient, and unsustainable. The difficulty in applying this principle, however, is elevated by the unwillingness of the public to pay, which in Lebanon and other developing nations is amplified by public dissatisfaction and mistrust.

The precautionary principle and the internalization of costs principle

Similar to other developing nations, Lebanon's contemporary operational schemes for SWM, especially those in rural and low-income regions, are primarily directed towards service delivery and cost efficacy, as they fail to accommodate for the adverse socio-economic and environmental implications associated with enacted strategies. Disregard to the precautionary principle is also exhibited at the national level, evident in the constant reliance on national policies that continuously emphasize on "end of

the pipe" solutions such as landfilling or thermal treatment, despite being the least preferable recourse in the waste hierarchy [33]. Violation of the waste hierarchy is in itself a contravention of the precautionary principle, since the hierarchy's primary objective is to prevent the formation of wastes. This notion is inscribed into the principle of uncertainty, for preventing the formation of wastes would inherently diminish any environmental risks or uncertainties, reduce the costs of control and mitigation measures, and ultimately enhance the health and safety of the population. The fundamentals of the waste hierarchy, however, have been 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 [20].

Lebanon's negligence in applying the precautionary principle has led to the uncertainty regarding the potential future risks imposed by the waste sector to be even greater today than prior to the crisis. First, the long-term impacts of the crisis have yet to be accurately quantified. Second, the current and future ecological consequences of the newly established landfills, which have been linked with numerous environmental disasters, were under the threat of closure, and are still undergoing development, were not determined beforehand since comprehensive EIA studies were not conducted prior to their construction. The absence of an EIA allows for unforeseen risks to materialize, forgoes the opportunity to identify better possible alternatives, and may lead to the absence of proper mitigation measures, indicating that analytical studies ought to be conducted prior to the initiation of a project [34, 35]. Third, a long-term strategy for the sector remains unavailable as low diversion rates continue to be recorded, decentralization efforts remain insufficient, hundreds of open dumpsites have yet to be rehabilitated, a constant reliance of ad hoc emergency strategies persists, and the adoption of a publicly unpopular waste-to-energy strategy continues to be incited by the government.

As mentioned earlier, applying the precautionary principle can be driven by necessity. An accurate representation of the costs generated by environmental degradation on the nation's economy and on public health would elevate the sense of urgency needed for adopting environmentally sustainable practices. Currently, the benefits associated with positive environmental practices, such as dumpsite rehabilitation, and the costs associated with landfilling, environmental degradation, and open dumping, continue to be curtailed and underestimated through the exclusion of certain externalities [20, 24]. The principle of cost internalization can also be utilized to stimulate public perception regarding the need to minimize resource consumption and source segregation, and would also incentivize the rehabilitation of open dumpsites, whose negative implications will continue to dilate the longer they remain not remediated.

In the face of growing public recognition concerning the impacts of solid waste-related environmental complications, policy-makers are confronted with unprecedented public pressure regarding the need to address the environmental considerations associated with an SWM strategy. The findings of this study elucidated the latent factors implicated in Lebanon's dysfunctional SWM structure and sequentially highlighted the contingent relationship that adjoins them with various environmental management principles, while divulging the social, environmental, and economic repercussions propagated by each of the identified components. An adaptive structurally integrated strategy that can concurrently engage the various environmental management principles ought to be developed. Thus, each of the identified RCAs and environmental management principles cannot be addressed independently. Despite the presence of several postulates, the principles of environmental management are correlated in a manner where the application of one principle will complement and ameliorate several others. The principles with their ultimate objective the protection and promotion of the health and safety of populations predominantly can be categorized as follows:

- Market-based instruments in environmental management
  - Internalization of costs
  - Polluter-pays
- Determinants of risk perception
  - Precaution
  - Prevention
  - Uncertainty
- Democratization of environmental governance
  - Development of guidelines and standards
  - Subsidiarity
  - Conservation of social diversity
  - Multisectoral integration
  - Inter- and intra-generational equity.

Subsequent solid waste masterplans should be developed from the bottom-up and ought to adopt a precautionary approach to management, while utilizing economic measures to finance operational costs and disincentive waste disposal. Figure 2 depicts the measures that should be adopted in relation to the aforementioned categories.

Conclusions and recommendations

The cornerstone of any SWM framework involves the preservation of the health of the population and the environment. This research disclosed the underlying organizational factors that nominally contribute to the impairment of contemporary solid waste structures in developing countries, such as Lebanon, while denoting how violations to the principles of environmental management were reciprocated through the formation of these factors. It was determined that current SWM strategies are carried out irrespective of their social and environmental outcomes, as a result of being primarily driven by economic efficacy and political hegemony. The fundamental root causes for Lebanon's ongoing solid waste crisis are primarily compounded by the absence of economic measures, the centralization of decision-making authority, the inaccurate representation of the costs of an intervention, and the disregard to external variabilities. The integration of environmental management principles into solid waste strategies would rectify the intrinsic causal agents of a complication and allow for the development of a multi-criterion adaptive regulatory structure that absorbs the various components of SWM under a single scheme, where the conservation and preservation of capital is promoted, the administrative proficiency of public agencies is elevated, and alternative agendas are weighed.

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. The outcomes of this study delineated that a sustainable solid waste structure cannot be actualized if the interdependent fundamental regulatory tenets of environmental management (risk perception, democratization of governance, and sound economic modeling) are not collectively applied. The failure in addressing these conceptualizations would circumvent developmental efforts, leading to creation of a dysfunctional system consistently reliant on emergency-based ad hoc strategies beset on the precipice of failure. The environmental, social, and economic connotations of environmental management ought to be treated as being mutually inclusive, rather than exclusive, factors with parallel and equivalent repercussions.

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References

1. Daddi T, Frey M, Iraldo F, Nabil B (2011) The implementation of an environmental management system in a North-African local public administration: the case of the City Council of Marrakech (Morocco). J Environ Plan Manag 54(6):813–832
2. Famiyeh S, Adaku E, Amoako-Gyampah K, Asante-Darko D, Amoatey CT (2018) Environmental management practices, operational competitiveness and environmental performance: empirical evidence from a developing country. J Manuf Technol Manag 29(3):588–607
3. Gentil EC, Gallo D, Christensen TH (2011) Environmental evaluation of municipal waste prevention. Waste Manag 31(12):2371–2379
4. Pires A, Martinho G, Chang NB (2011) Solid waste management in European countries: a review of systems analysis techniques. J Environ Manag 92(4):1033–1050
5. Lozano M, Vallés J (2007) An analysis of the implementation of an environmental management system in a local public administration. J Environ Manag 82(4):495–511
6. Troschinetz AM, Mihelcic JR (2009) Sustainable recycling of municipal solid waste in developing countries. Waste Manag 29(2):915–923
7. Guerrero LA, Ger Maas G, Hogland W (2013) Solid waste management challenges for cities in developing countries – review. Waste Manag 33:220–232
8. Marshall RE, Farahbakhsh K (2013) Systems approaches to integrated solid waste management in developing countries. Waste Manag 33:988–1003
9. Mmereki D, Baldwin A, Baizhan L (2016) A comparative analysis of solid waste management in developed, developing and lesser developed countries. Environ Technol Rev 5:120–141
10. Chandrappa R, Das DB (2012) Solid waste management: principles and practice. Springer-Verlag, Berlin Heidelberg
11. Van der Sluijs JP (2007) Uncertainty and precaution in environmental management: insights from the UPEM conference. Environ Model Softw 22(5):590–598
12. Ambec S, Ehlers L (2016) Regulation via the polluter-pays principle. Econ J 126(593):884–906
13. Puig-Ventosa I, Sergio Sastre S (2017) An exploration into municipal waste charges for environmental management at local level: the case of spain. Waste Manag Res 35(11):1159–1167
14. Stavins RN, Wagner AF, Wagner G (2003) Interpreting sustainability in economic terms: dynamic efficiency plus intergenerational equity. Econ Lett 79(3):339–343
15. Brosius JP, Hitchner SL (2010) Cultural diversity and conservation. Int Soc Sci J 61(199):141–168
16. Ghimire KB, Pimbert MP (2013) Social change and conservation, vol 16. Routledge, London
17. Nordbeck R, Steurer R (2016) Multi-sectoral strategies as dead ends of policy integration: lessons to be learned from sustainable development. Environ Plan C Gov Pol 34(4):737–755
18. Tarantino A, Cernauskas D (2009) Risk management in finance: Six Sigma and other next generation techniques. Wiley, Hoboken
19. De Mast J, Lokkerbol J (2012) An analysis of the Six Sigma DMAIC method from the perspective of problem solving. Int J Prod Econ 139(2):604–614
20. SWEEP-Net (2014) Country Report on the solid waste management in Lebanon. The regional solid waste exchange of information and expertise network in Mashreq and Maghreb countries. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn and Eschborn, Germany
21. Ngoc UN, Schnitzer H (2009) Sustainable solutions for solid waste management in Southeast Asian countries. Waste Manag 29(6):1982–1995
22. World Bank (2011) Lebanon - Country environmental analysis. World Bank, Washington, DC
23. World Bank (2018) Strategic Assessment: a capital investment plan for Lebanon – investment opportunities and reforms. World Bank, Washington, DC
24. MOE/UNDP (2017) Nationally appropriate mitigation action in Lebanon's municipal solid waste sector NAMA proposal and

design document. UNDP low emission capacity building (LECB) programme. United Nations Development Programme, Ministry of Environment, Beirut, Lebanon
25. MOE/UNDP/ECODIT (2011) State and trends of the Lebanese environment. Wide Expertise Group, Lebanon
26. Human Rights Watch (HRW) (2017) As if you're inhaling your death: the health risks of burning waste in Lebanon. https://www.hrw.org/report/2017/12/01/if-youre-inhaling-your-death/health-risks-burning-waste-lebanon. Accessed 20 Dec 2018
27. Wilson DC, Rodic L, Scheinberg A, Velis CA, Alabaster G (2012) Comparative analysis of solid waste management in 20 cities. Waste Manag Res 30(3):237–254
28. Giannozzi E (2017) On the decentralization of solid waste management in Lebanon: a viable solution to the "waste crisis"?. Heinrich BÖll Stiftung Middle East, Beirut
29. Ahmad MS, Talib NBA (2015) Empowering local communities: decentralization, empowerment and community driven development. Qual Quant 49(2):827–838
30. Zotos G, Karagiannidis A, Zampetoglou S, Malamakis A, Antonopoulos IS, Kontogianni S, Tchobanoglous G (2009) Developing a holistic strategy for integrated waste management within municipal planning: challenges, policies, solutions and perspectives for Hellenic municipalities in the zero-waste, low-cost direction. Waste Manag 29(5):1686–1692
31. Oduro-Kwarteng S, Van Dijk MP (2013) The effect of increased private sector involvement in solid waste collection in five cities in Ghana. Waste Manag Res 31(10 suppl):81–92
32. Ren X, Hu S (2014) Cost recovery of municipal solid waste management in small cities of inland China. Waste Manag Res 32(4):340–347
33. Van Ewijk S, Stegemann JA (2016) Limitations of the waste hierarchy for achieving absolute reductions in material throughput. J Clean Prod 132:122–128
34. Jalava K, Pölönen I, Hokkanen P, Kuitunen M (2013) The precautionary principle and management of uncertainties in EIAs–analysis of waste incineration cases in Finland. Impact Assess Proj Apprais 31(4):280–290
35. Zubair S, Bowen D, Elwin J (2011) Not quite paradise: inadequacies of environmental impact assessment in the Maldives. Tour Manag 32(2):225–234