Public policy and technology choices for municipal solid waste management a recent case in Lebanon

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Cogent Environmental Science (2018), 4: 1529853
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Abstract: Municipal solid waste (MSW) is a natural accrual in various communities resulting from daily activities, which offers challenges and opportunities. Developed countries lean towards “upstream avoidance” type of solutions, while less developed countries use “downstream remediation” solutions. In between these two options, many hybrid solutions involve triage and final disposal of post-treated reduced MSW mass.

The aim of the present article is to briefly review the evolution of policies related to MSW, to address an illustrative case of a recent crisis in Lebanon, and to present the development of a multivariate analysis model on public attitudes towards MSW management. It explores incineration with air pollution control and energy recovery. Non-incineration solutions, including anaerobic digestion, may be more appealing provided the full process, its byproducts and risks, are better understood. Furthermore, the latter solution requires a higher level of investment, expertise,

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Dr. Michel Soto Chalhoub is an engineer and management consultant. His research addresses societal and environmental concerns. Michel is an industry practitioner in the U.S., Europe and the Middle East who served in senior management positions in major U.S. corporations such as Parsons Corp., Cap Gemini Ernst & Young, and InterPublic. Winner of several awards for innovative design, his projects include river protection, docking cells, theme parks, petrochemical facilities, and artificial reefs. He works at the nexus of engineering and public policy to provide strategic recommendations to decision-makers on issues that impact communities including municipal solid waste and water resource management. Michel holds a B.Sc. in Civil Engineering from l’Ecole Superieure des Ingenieurs, a M.Sc. and Ph. D. from the University of California, Berkeley, and a Master in Public Policy from Harvard University. He is a licensed Professional Engineer (P.E.) and Structural Engineer (S.E.) in the State of California, published extensively in academic journals, and served on emergency response teams to natural hazards and Code development committees.

ABOUT THE AUTHOR

PUBLIC INTEREST STATEMENT
Municipal solid waste (MSW) is critical to public health, yet several countries still face crises related to its management. The article proposes a framework for MSW analysis in the context of sustainable development, discusses a recent case in Lebanon, and presents an empirical regression analysis on public attitudes. Results show that simplified solutions must be considered including clean technology incineration with energy recovery (IER), along with other approaches such as anaerobic digestion. Lessons could be learned from European and Far Eastern countries that lack vast areas of land. Focus interviews and a quantitative regression analysis show end-user concerns about the ability of the public sector to manage MSW, and believe that sorting in households has had little effect on the final outcome. End-users have little trust in privatization given past monopolies on the MSW cycle, requiring capacity building in the public sector. It is also concluded that the upstream involvement of local communities in the design of a country-level environmental strategy would be key to success.
continuous quality improvement and supervision, especially in light of public management weaknesses in less developed countries.

A multivariate linear regression analysis model is developed and presented to describe public attitudes regarding MSW management. Linear regression was used to model a direct relationship between a response variable and several explanatory variables. A simplifying assumption is made to test the attractiveness of incineration with energy recovery (IER) including a process for air pollution control. In the multivariate analysis, the dependent variable is a composite index that describes the extent to which respondents agree with a potential IER solution. The independent variables include (1) the extent of public awareness-building about upstream triage, (2) privatization, (3) quality management in daily operations, (4) challenges in implementation and (5) reliability of public management authorities. The multivariate analysis showed that there is a statistically significant and positive correlation with a requisite quality in daily operations, and in technological upfront investment. It showed a statistically significant and negative correlation with the reliability of public management and privatization. As for public awareness about upstream household level triage, there was no statistically significant correlation. This last result seems counter-intuitive, but it may be due to the fact that respondents have low expectations about the impact of their actions on government decisions. The general public, faced with socio-economic problems, may not see household triage as a determining factor. Public perception is that triage ends up with a MSW collection and transport with a mixed dumping at final destination.

The analysis shows that prevention is preferred to remediation and that it requires supporting public policies to make it practical, especially in less developed countries. Bio-processes are well-accepted and may become part of the local practice once their long-term effects become better understood to mitigate potential risks. The IER option is perceived as technologically and financially viable and that clear public policies should be designed and implemented.

Subjects: Bioscience; Environmental Studies & Management; Mathematics & Statistics; Engineering & Technology; Urban Studies

Keywords: municipal solid waste; technology options; public policy; incineration with energy recovery; environmental impact

1. Introduction and brief policy background
Municipal solid waste (MSW) is one of the burning issues that are highly debated among scientists and policymakers, as it affects public health and the use of resources, especially in developing countries (Guerrero, Maas, & Hogland, 2013). Simply put, MSW is a byproduct material closely intertwined with our daily lives and is a result of basic living conditions. Therefore, the evaluation of MSW management requires taking into consideration socio-economic factors in tandem with technological options (Aye & Widjaya, 2006; Cheng, Chan, & Huang, 2002). Given the uncertainty related to each phase of the MSW life cycle, techniques were developed to assign weights to each parameter related to the involvement of stakeholders—public managers, households and communities (De Feo & De Gisi, 2010a).

The objective of the article is to develop and present a mathematical model that illustrates public attitudes towards MSW management. Prior to that, the article provides an overview of the evolution of MSW management policies, and discusses a recent waste crisis in which Lebanon was
engulfed. In a rare and historic public uproar, protesters took it to the streets of major coastal cities—including Beirut—and voiced their deep discontent about the lack of action shown by both the public sector entrusted with such issues and the private subcontractor (Daily Star, 2016).

Briefly reviewing the evolution of solid waste management helps put current crises in context. In most societies that went through large industrialization movements, solid waste management was driven by policy trends in combination with technology options at hand (Durgekar, 2016). The earliest trend is attributed to public health as it is generally accepted that garbage needs to be collected and removed from the vicinity of the household. Followed a second trend related to environmental activism in that the first trend needs to be met without imparting damage of the environment. The third trend is related to treating solid waste as a resource and not as a burden to society—hence, new solutions were introduced whereby MSW is utilized as an energy source (Wilson, 2007). However, the current overarching approach would be to minimize waste from the outset. This mindset addresses the full lifecycle of consumer products by designing them such that they generate the least possible residues (Marshall & Farahbashsh, 2013).

In the 1980s and 1990s, a post-normal approach was explored to address public issues that are characterized by uncertain facts, whose values are in dispute, where societal stakes are high and yet decisions are urgent (Funtowicz & Ravetz, 1993). Issues of solid waste in both developed and developing countries, indeed, face such issues and pose a challenge in the use of traditional science. Various engineering schools of thought came to compete over technological solutions, rather than solve societal problems (Organization for Economic Cooperation and Development [OECD], 2013).

Several developed countries went through the learning curve to establish systems and processes for MSW as we know it today. In the fourteenth century, Europe was plagued due to dumping of organic waste in the streets (Tchobanoglous, Thiesen, & Eliassen, 1978). In the late 1700s, cities in the US suffered public health problems as the practice was that household waste was collected by request of select property owners, and dumped in open sites (Melosi, 1981). Up till the 1890s, large amounts of MSW were a common scene in the streets and it was not until the 1920s that demographic pressures and increased population density in American cities brought progress in the construction of sewage networks and the establishment of public sector processes for solid waste management (Gibson, 1998; Melosi, 2000). It was during that era that ideas such as recycling and reuse of waste material appeared and were applied. For example, the nation’s first recycling center was established in New York City in 1898 (Dunson, 1999; Melosi, 1981). Residents were also required to separate waste into three categories—rubbish, comprising paper, glass, wood and metals; garbage, comprising organic food refuse; and other miscellaneous components (Tchobanoglous et al., 1978).

Increased public awareness about the dangers of waste dump sites led to the development of other approaches. Incineration, for example, is an early approach that appeared in Nottingham as far back as 1874, when it was presented as a new technology consisting of cremating large amounts of waste in a government-sponsored, organized manner (Kimball, 1992). Almost a century later, incineration with energy recovery gained attention as it was presented as part of acceptable policies with the 1965 U.S. Solid Waste Disposal Act, amended in 1970 by the Resources Recovery Act (Drobny, Hull, & Testin, 1971; Environmental Protection Agency [EPA], 1988). Within years, the concept moved to state-level regulations for organized solid waste management policies (EPA, 1988). However, what drove state policies for MSW management into local implementation was the 1976 Resource Conservation and Recovery Act, which was amended in 1984 to emphasize standards for sanitary landfills and strict measures for incineration and its impact on air quality.¹

Over the last few decades, comparative analyses among various methods of MSW management were performed, inclusive of anaerobic digestion and composting (Malinauskaite et al., 2017). Some
of the most commonly used still involve landfills and incinerators (Dijkgraaf & Vollebergh, 2004; Finnveden, Bjorklund, Ekvall, & Moberg, 2007; Quina et al., 2018). Relevant models balance waste treatment, as a necessity, with the potential benefit of recovering energy and raw materials generation, thus turning the process into a production operation (Consonni, Giugliano, & Grosso, 2005; Feo, Belgiomo, Rocca, & Napoli, 2003; Joseph, Snellings, Van Den Heede, Matthys, & De Belie, 2017).

Countries of low population density, sparsely inhabited land and comprising acres of unused desert may find landfills to be a possible solution. Not only do landfills provide a fast and inexpensive disposal, but they may be harnessed to generate byproducts related to energy generation and land conditioning (Benson, Barlaz, Lane, & Rawe, 2007; Huang, Zhao, Huang, Wang, & Tseng, 2017). Past research showed that soil fertility is affected positively or negatively by solid waste disposal depending on the ratio of organic material, or on the extent to which other components such as metals may be transmitted from the soil, to plants and into the human body (Fagnano, Adamo, Zampella, & Fiorentino, 2011; Gramatica et al., 2006; Leone, Gilman, & Flower, 1983). Therefore, countries with large surfaces have choices in terms of using landfills to generate energy if the adequate technology for sequestration is put to practice. On the other hand, countries with smaller land surfaces such as Japan realize that landfill site growth is unsustainable, and hence resort to incineration coupled with clean emissions exhaust technologies to curtail the downside of incineration in terms of air pollution (Yolin, EU-Japan Center for Industrial Cooperation, 2015; Zhao, Jiang, & Li, 2016).

2. Intertwined policy and technology options in MSW management

Considering solid waste as raw materials or input in the energy recovery process, a wide range of solutions, technologies and processes exist. Most of these solutions have positive and negative points, and therefore require a comparative study on a case-by-case basis before policy decisions are made (Huang, Ning, Zhang, & Fei, 2015; Tehrani, Karbassi, Ghoddosi, Monavvari, & Mirbagheri, 2009; Wan, Shen, & Choi, 2018). Several parameters have to be studied in parallel including land availability, absorption capacity of sanitary landfills and thermal waste treatment options (Consonni et al., 2005). Practically, MSW solutions often involve more than one type of technology, and rather use a set of integrated systems (Pařízek, Bébar, & Stehlík, 2008). An attractive process would integrate recycling, recovery and energy generation in a waste-to-energy (WTE) conversion. Therefore, one must look at the overall life cycle assessment (LCA) of these processes to determine the cost-benefit of each method (Bjorklund & Finnveden, 2007; Christensen et al., 2007; Hadžic, Voca, & Golubic, 2017; Hupponen, Gronman, & Horttanainen, 2018; Zhou, Tang, Chi, Ni, & Buekens, 2017).

Landfills have long been used as a disposal method, which then evolved to minimize impact on the environment. It relies on breaking down the waste components over a long period of time. Although landfill solutions have been around for a long time, they were used in more less developed countries where many landfills did not have energy conversion mechanisms (Parker, 1983; Pohland, 1991). According to the Environmental Protection Agency in New South Wales (EPA-NSW), “A landfill is an engineered, in-ground facility for the safe and secure disposal of society’s waste.” However, EPA indicates that landfills may have negative effects on fauna, flora, groundwater and surface water bodies. As such it imposes minimum standards to be met when applying for landfill permits under the Protection of the Environment Operations Act of 1997. No doubt, irrespective of the engineering design details used for landfills, EPA guidelines have policy implications that all stakeholders, especially the end-user in the local community, must have confidence in the overall management of the process. Further, beneficial use or reuse of waste should be central to public management strategies. The excerpt below summarizes the overall EPA objectives attributed to landfills (EPA-NSW, 2015).

“… Landfills should be sited, designed, constructed and operated to cause minimum impacts to the environment, human health and amenity.
The waste mass should be stabilised, the site progressively rehabilitated, and the land returned to productive use as soon as practicable.

Wherever feasible, resources should be extracted from the waste and beneficially reused.

Adequate data and other information should be available about any impacts from the site, and remedial strategies should be put in place when necessary.

All stakeholders should have confidence that appropriately qualified and experienced personnel are involved in the planning, design and construction of landfills to current industry best practice standards...

Even though EPA published its draft in 2015, landfills were historically considered as an attractive solution in many countries as they were, and still are, convenient and economical provided land areas are available such as in Australia or the US. Technically, refuse is spread in thin layers covered by soil. The layers are typically around 10–12 ft in thickness. Such sites witnessed poor vegetation growth for a variety of reasons particularly the presence of carbon dioxide (CO2) and methane (CH4) caused by anaerobic decomposition (Leone et al., 1983). In addition such sites were regulated against any future construction or the erection of structures. The idea of waste decomposition, whether solid or fluid, evolved in the 1980s and 1990s into an engineered approach that designs and monitors decomposition through anaerobic digestion facilities (Chalhoub, 1992).

As for MSW incineration, it relies on processing waste used as feedstock at very high temperatures, typically exceeding 850°C. Since this process makes air available to combustion, it generates carbon dioxide water, and other material including bottom ash with residual carbon (Zaman, 2010). Ferrous and non-ferrous post-combustion residues are also a source of reusable material (Brunner, 2011). As Brunner puts it:

“... Megacities can produce sufficient amounts of secondary resources for large-scale production of raw materials by urban mining, and cities are always in need of energy. Thus, combining recycling plants for metals such as iron, aluminum, and copper in cities with utilization of waste energy from such plants to fuel the city (heating and cooling, electricity) seems an attractive option for improving the sustainability of cities...”

Pyrolysis-gasification, consisting of incineration in absence of air, is considered an improvement over traditional incineration because it minimizes emissions (Malkow, 2004). In this context, WTE emissions data is an important factor in policy decision-making as it provides a map of the input-output ratios and relationships between emissions and energy production (Cherubini, Silvia Bargigli, & Sergio Ulgiati, 2008; Khoo, 2009).

Clearly, MSW management options are so varied and certain solutions are preferred to others depending on the country and its developmental level. A hierarchy that is commonly acknowledged in literature ranks MSW treatment techniques versus the developmental level of the country. In general, countries that enjoy a higher level of economic development, have a higher level of public awareness and, therefore, have easier time adopting waste avoidance approaches. Countries that are still struggling with developmental issues and whose populations are more focused on short-term gain or survival, resort to less costly low-tech approaches. It is important to clarify here that if the cost-benefit analysis is expanded to include social cost, for instance from environmental degradation or long-term human health hazards, then the results would be different and in favor of avoidance rather than a-posteriori treatment. At the bottom of the treatment hierarchy, you find the landfill approach without energy recovery (Figure 1).

The hierarchy in Figure 1 is not all encompassing. Consider the case of Japan, a country that is very tight on land surfaces and therefore cannot afford the proliferation of landfills. It compensates for that shortage by using incineration as an intermediate step on the way to final disposal. The Japanese practice focuses on optimizing a full cycle starting from collections, transport,
municipal waste incineration technologies, all the way to landfill of a reduced waste mass (MoE of Japan, 2012). The same logic applies to most countries that do have the technology, strict policies, public discipline and awareness, but lack land areas. However, the challenge is two-fold when dealing with countries that have no horizontal space to accommodate landfills, and in addition, lack socio-economic and technological means to apply the same solutions as Japan. Case in point is the East Mediterranean and in particular Lebanon (Chalhoub, 2016).

3. The MSW crisis in Lebanon

Most issues related to MSW are common to less developed countries, but the case of Lebanon is worth mentioning as it reached an all-time high by 2015 year-end, and is still unresolved. Prior to the 1975 civil war, household garbage collectors were full time employees in the public sector who toured door to door on a daily basis, typically starting in the afternoon till early evening.

In the 1960s, it was common in Lebanon to have public sector employees perform door-to-door household garbage collection, trucking to remote sites, dumping and burying. The 1975 civil war brought many discontinuities in public services, and most notably in MSW management. Most public sector services suffered severe setbacks due to lack of safety and security, localized strife at the neighborhood level, public sector budget challenges and demographic movements. Households took it upon their own hands to dispense of their garbage which led to the two most obvious practices; dumping at a remote site or small-scale neighborhood-level incineration.

Between 1975 and 1989 solid waste was not the only sore point because most public services suffered. A combination of security, safety and budget problems crippled whatever was left of government or municipal services. MSW became a matter of localized effort by inhabitants or warring factions to collect and dump without treatment (Nuwayhid, Ayoub, Saba, & Abi-Said, 1996; World Bank. The International Bank for Reconstruction and Development, 1999). In early 1990s, with peace accords and an overall orientation towards privatization of several public sector services, including the reconstruction and rehabilitation of downtown Beirut, a private company was assigned the entire MSW process. Shortly after the Taef accord which received mixed reviews by policy analysts, many public services were put in private hands, including MSW. The MSW contract was described as monopolized by a private company. The new mode of MSW management between 1991 and 1999, and took a branded image with private employees, trucks, signs, branded color codes and regular collection routes. Garbage dumps were identified and the process consisted of collecting MSW from street bins daily and transporting the bulk to remote disposal.
sites, including a major dump in Burj Hammoud, a densely populated town north of downtown Beirut (Council for Development and Reconstruction [CDR], 2012). In 1998, policymakers decided to interrupt garbage dumps in Burj Hammoud where the dumps reached unacceptable “physical” heights. A mountain of household garbage could be seen and smelled, add to that insects and rodents a stone’s throw from homes. So the Naameh landfill, some 18 km south of Beirut, was adopted as a short-term alternative targeting a capacity of about 2.2 million tons of MSW over six consecutive years, i.e. till 2004. The sole private contractor did not process the tonnage progressively so the Naameh landfill remained open well beyond its intended lifetime triggering inhabitants’ protests and blockage. As a result of public pressure, it was shutdown in July 2015 (Chalhoub, 2016; Daily Star, 2015a, 2015b; Nature Conservation Center [NCC], 2016).

The sole subcontractor refrained from collections, so households creatively resorted to dumping trash on street corners, under bridge ramps and underpasses, in crevices between buildings, and of course on the Lebanese shore. It was estimated that the Lebanese daily per capita average solid waste production was close to 1 kg. Political debates went in circles, accusations about corruption and kickbacks came in vogue … while solid waste piled up in the streets. New types of breathing, skin and headache problems appeared causing health hazards (Chalhoub, 2016; Daily Star, 2015c).

A shocking scene came about in October 2015 when heavy rains transported down the streets tons of household trash (Daily Star, 2015d). In the following months, MSW continued to accumulate vertically and resulted in mountains of garbage with decomposition liquids oozing in the streets. A political proposal caught researchers and practitioners by surprise when it declared that an arrangement was being discussed with foreign firms to “export” Lebanese garbage overseas. That was another proposal that faced public opposition as it did not offer a sustainable solution. A simple cost-benefit analysis showed several flaws in the garbage export project. Public pressure rose again on policymakers to seriously support a sustainable local solution for MSW (Chalhoub, 2016; Daily Star, 2016).

The lesson learned was clear. Affluent or not, communities generate solid waste in varying compositions. Although past research efforts were geared towards looking for correlations between waste generation and standards of living, it neither offered a solution to local communities, nor helped design national policies. Countries enjoying communal discipline and a sense of unified environmental purpose at a neighborhood level can realize better results with triage, composting and incineration combined with advanced air pollution technology for pre-sorted solid waste components. When glass, plastics, pulp-based material and metals are separated upstream, incineration becomes more focused, reduces the input mass by orders of magnitude and yields an output that is easier to manage (Chalhoub, 2015).

Reflecting back on the case of Lebanon, it is important to note that household refuse constitutes the majority of its solid waste. Despite the 1997 Environment Emergency Plan, which followed a two-year study, aimed at establishing and implementing sustainable solutions, the country is to-date suffering from waste mismanagement. The greater Beirut area (GBA) was supposed to lead in terms of applying modern practices, but the 1995–1997 study fell short of predicting MSW generation over a ten-year horizon. Comparing 2001 projected to actual data shows that Lebanon generated 1.44 million tons of MSW compared to what was projected for that year back in 1995, which estimated 990,000 tons; a 37% underestimation. Most likely, the reason behind this underestimation is that the study made too many assumptions about public attitudes instead of surveying them. It was over-optimistically assumed that campaigns, public awareness programs and reliance on public managers to curb waste generation and promote recycling, would yield results, while in reality such factors did not materialize as hoped; hence, the wide discrepancy in data (Ministry of Environment, Lebanon, 2001). Further, instead of moving from planning to execution in 2002 and beyond, problems were left unattended until recent crises caused residential streets to be filled with garbage causing serious health hazards, as described earlier in this section. Public unrest built up with a growing feeling that public authorities were not decisive enough in attending to a solution. The Lebanese crisis was a major focusing event that motivated
the use of a linear regression analysis to gauge public attitudes towards upstream triage, potential privatization of the whole garbage cycle, issues of quality management, implementation mishaps such as the ones that occurred in both Burj Hammoud and Naameh, and in general, public perception of how reliable public management authorities are.

As for the composition of MSW in Lebanon, it includes a large percentage of organic materials (63%) in GBA and a national average of 52% which did not change over the past four years (Table 1, and Figure 2). On the outset this suggests a favorable condition for composting. But to optimize a composting solution, a consistent waste separation needs to be instilled and practiced at the household, neighborhood, municipal and plant levels, which cannot be guaranteed. Experience has shown that Lebanon had no success with such practices. Case in point, the 2015 crisis came about only a few years after a decision was taken by the Lebanese Council of Ministers in 2010 to develop a proposal for the management of waste in all Lebanese territory, namely adopting thermal decomposition and the conversion of waste into energy in major cities. The objective was to involve the private sector in a turnkey manner from collection to final treatment, and to give incentive to local municipalities to embrace the plan for potential “…thermal treatment and composting plant locations...” However, the public uproar about past practices related to dumping sites such as in Naameh, and open air burning such as in Hbaline, displayed lack of public trust in government promises (CDR (Council for Development and Reconstruction), Lebanon, 2012; Chalhoub, 2015).

As presented in subsequent sections, a multivariate regression analysis is performed taking into consideration variables that are directly relevant to the issues experienced in Lebanon including public attitudes toward public management, privatization and influence of household recycling and triage decisions on final outcomes in MSW management. In particular, waste triage at the household level was included as part of the regression analysis because this step in the overall MSW cycle rests in the hands of the end user prior to the involvement of public authorities or contractors in the collection step of the process.

<table>
<thead>
<tr>
<th>MSW Component</th>
<th>GBA (%)</th>
<th>Lebanon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>63</td>
<td>51</td>
</tr>
<tr>
<td>Paper and cardboard</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Plastic</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Glass</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Textiles</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Metals</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Construction/Demolition</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>
4. Incineration with clean air technology as an option

If waste is considered as fuel for incineration, there are basic properties that are targeted. Its regular availability around the year and its lower calorific value (LCV) must be above a certain level. Therefore, data cannot be transferred from one region to another. The average LCV is recommended to be at least 6 MJ/kg, although more recent studies favor a higher range, around 7 or even 8 MJ/kg. According to past World Bank studies, a minimum annual provision of 50,000 metric tons of MSW and a weekly plant input variation of less than 20% must be met to run the operation. But such figures cannot be generalized as they depend on local community developmental level, urbanization and growth (Chalhoub, 2015; World Bank, 1999).

Simplified models help determine the appropriateness of solid waste as a fuel in incineration plants without resorting to auxiliary fuel, based on Ash content or ignition residuals, A, combustible fraction, C, and moisture of raw dump, W. Using a Tanner triangle to assess the combustibility of solid waste results in a feasible zone where A is less than 60%, C is greater than 25% and W is less than 50%. Within this context, waste composition is another important factor. The ash and water free calorific value, \(H_{\text{awf}}\), greatly depends on the specific component of solid waste. Plastics and polyethylene command a \(H_{\text{awf}}\) around 45 MJ/kg, paper and cardboard range in between 16 and 19 MJ/kg, and food refuse and vegetables between 15 and 20 MJ/kg. Considering that in Lebanon organic content is 53% and plastics is 12%, paper and cardboard is 15%, while in other countries such ratios may be significantly different, waste as incineration and energy recovery fuel may require differences in design. For instance, surveys from 22 European countries showed a lower mean on organic (23%), on plastics (7%), but higher on paper and cardboard (25%), while in Philippines organic account for 45%, plastics 23% and paper 12% (Chalhoub, 2015; World Bank.

On the incineration output side, energy is a benefit and emissions are a liability. Pollutants comprise dust particles, HCl, SO\(_2\), NO\(_x\) and HF, among others. A basic emissions control system, for example, through electrostatic precipitators, at minimal investment, would remove particulate matter. More advanced flue gas treatment technologies require significantly higher investments, a more complex operations management expertise, preventive periodic maintenance and monitoring systems. The survey clarified the hazardous effects of air pollution, and provided a simplified description that pollution prevention can be managed through state-of-the-art high investment technology. As such, the environmental engineering treatment for a comparative study in between sub-options of air cleansing technologies in future incineration plants was left outside the scope of this article (Chalhoub, 2015).

5. Empirical analysis of public attitudes toward MSW management options

Our empirical research included two stages; a first stage consisted of focus interviews and a second stage followed with a regression analysis. We started with focus interviews in four communities in Byblos County. Interviews helped identify and confirm issues that the public sees as serious defects in public management, especially in relation to MSW. Lack of transparency, a monopoly on MSW management granted by the government to a private company, extended periods of dumping in the open, were all identified during the first stage as serious issues. There were strong remarks about a low tech incineration site in Hbaline, a small village East of Byblos, which stained the blue sky in an otherwise pristine natural setting. “It is either the smell of rotting garbage, or the smell of incineration smoke, . . ., we are given no other choices, . . .” commented a commuter who drives through Hbaline daily.

Upstream triage of garbage was attributed to households whereby small local campaigns spurred inhabitants to sort garbage. Focus interviews showed concerns in that even if households sorts their garbage, once collected by third parties, they end up again in one heap. During the focus interview stage, the majority of participants (65.2%) expressed readiness to start or to continue putting effort in household level triage. Of that percentage, 78.3% viewed household triage as an additional effort that will have no effect on the final outcome; while a
meager 9.8% viewed it as effective. "... No matter what we do at the household or even the neighborhood level ... no matter how many bins and colorful dumpsters we implement in our community ... all that garbage is then taken by the contractor and dumped in one heap irrespective of our triage ..." complained a respondent. Another finding from focus interviews is that inhabitants faced a dilemma as to whether to support public sector operations or the intervention of private companies. "If we rely on local municipalities for waste management, we face preferential treatment, but if we hand the matter to a private company, we become totally dependent on its profit-making techniques," commented a respondent who lives in Beirut but spends summers in Byblos County. Most respondents (69.5%) had similar concerns expressed in different ways. Some even voiced their suspicion of corruption in granting potential privatization contracts, especially those who were dissatisfied with the current company holding a monopoly of the MSW entire cycle. Other respondents (34.4%) commented on open incineration and wished there could be a technical solution to avoid air pollution. Although the overall advantages of clean technologies were discussed, specific engineering design methods about how to upgrade an incineration plant into a facility that treats and cleanses exhaust fumes prior to their final release in the air were kept out of scope while interacting with focus interview respondents. The objective was to avoid biasing the discussion toward a mere focus on technical products, and to gauge public attitudes at large by considering the respondent as an end-user and a beneficiary of public management in MSW matters. Majority of respondents (70.2%) were weary of the lack of transparent plans for treatment sites, especially those where incineration was expected, and the weakness of the public sector in project management.

In a second stage, we turned to a quantitative analysis to narrow down the questions into a proposed solution—incineration with clean energy recovery and clean technology. From the preliminary results above we identified five areas to study with a quantitative approach as described in the following sections. A multivariate linear regression analysis was chosen here to study the relationship between a dependent variable and a set of independent variables. The dependent variable was defined as an index representing public attitudes toward handling MSW in an "Incineration with Energy Recovery" mode. The choice by the author of this quantitative analysis was motivated by the fact that any technology solution, whether based on anaerobic digestion or incineration, would have a dim chance to succeed if communities are not fully aware, convinced and engaged in executing the technical solution.

5.1. Multivariate analysis—linear regression analysis model
A multivariate analysis was performed to gauge public attitudes about solid waste management in Lebanon. To help weed through the maze of policy options that were debated in the country for the past 18 months, a simplified IER policy option was described to respondents. Other multivariate statistical analysis methods are also widely used such as the principal component analysis (PCA) method. PCA may be used as a complementary method to a multiple linear regression analysis to confirm the selection of its independent variables. Alternatively, the linear regression expression is developed while observing the significance level of each independent variable in explaining the dependent variable. The author focused on studying the dependence of the regression variable Y on X₁ through X₅. For awareness purposes, the introduction of the survey included a description about two other options; landfill and anaerobic digestion, but then asked the respondent to provide their input regarding IER. It was explained that IER would use incineration with the requisite technology to cleanse exhaust emissions and minimize air pollution to levels significantly below ambient pollution from other sources. Three hundred and seventy-six questionnaires were disseminated, of which 229 included replies to all five items representing the independent variables. A five point likert scale was used for each independent variable with 1 being least applicable or strongly disagree, and 5 being most applicable or strongly agree.
5.1.1. The model

The first independent variable, $X_1$, represents the extent to which public awareness about handling solid waste on the outset, at the household level, would affect the attractiveness and acceptability of IER. The rationale behind this variable is that several studies showed that incineration leaves behind inorganic materials with the bottom ash with metals and other non-perishable components. Whether precious metals or ferrous materials, the recovery from bottom ash is feasible. However, the process would be more efficient if upstream triage is practiced (Grosso, Motta, & Rigamonti, 2010; Muchova, Bakker, & Rem, 2008).

The second independent variable, $X_2$, represents the affinity with privatizing the MSW cycle, in that private entities would be responsible for public communication, color coding for triage, neighborhood collection, transportation, incineration and energy redemption. As seen with many public services in less developed countries, privatization has been long debated as it offers advantages and disadvantages (Fahmi, 2005). Cost reduction is often stated as an intended objective of privatization. However, it has been shown that cost savings are not systematic in the privatization of solid waste management (Bel & Warner, 2008). Studies by OECD found that municipal services offered through private entities are more expensive than the municipal service provision (OECD, 2000). In 1965, empirical studies in the US for over 24 municipalities in St. Louis County, Missouri, showed that there is no significant cost difference between public and private solid waste service provision (Hirsch, 1965). In 1974, similar results were reached in a statewide study in Montana, USA (Pier, Vernon, & Wicks, 1974). More recent studies show that there are some savings from privatizing the solid waste management cycle but that this effect erodes over the subsequent few years (Dijkgraaf & Gradus, 2008). Still, it is expected that privatization would improve efficiency through technology and private sector work productivity. One of the main points gleaned during focus interviews is that the privatization process itself may suffer from corruption and kickbacks. In Lebanon, a country known for its liberal and open economic practices, privatization has seen a tumultuous past.

The third independent variable, $X_3$, represents the requisite quality management in daily operations. As seen in previous sections, operating an incineration plant is broader than just the technical burning process but rather encompasses a full cycle. A panoramic view is critical to assess supply of waste as fuel, demand on energy and pollution control in a fully coordinated cycle. Concerns voiced during focus interviews revolved around short-sightedness of management style in the region and Lebanon in particular, whether in the public or private sector. In addition, since air quality is a public good, the issue opens a whole range of questions traditionally related to the tragedy of the commons and the free rider effect.

The fourth independent variable, $X_4$, represents challenges in implementation. A major concern that transpired during focus interviews is that the speeches and even the written plans may be completely different from the actual execution of the idea. Several respondents asked about potential locations of such facilities. However, specific location selection was kept outside the scope of the questions and replies to maintain an overall view on the issue, rather than trigger reactions based on the respondent’s address. Nevertheless, such issue must be dissected in great detail in a follow-up study where location should be of paramount importance in the survey. This would be part of a study that puts forth a tangible execution plan with a back-up study on all parameters affecting emissions and dispersion of stack exhaust with ambient physical properties such as wind direction, speed, neighboring communities and their existing levels of industrialization, and physical geographic coordinates.

The fifth independent variable, $X_5$, addresses the reliability of public management and authorities from an end-user perspective. This particular point triggered a reply in light of recent national history known for its lack of success in public management including the 20-year civil war, to political deals and settlements such as the Taef agreement, to the Normandy garbage mountain
and land-grab into Mediterranean sea, to the telecom bidding crisis, and more recently the neighborhood garbage crisis of 2015, and to-date in 2016. All things considered, it was important to include it because any technology option regarding MSW management is unavoidably linked to potential public policy analysis and public management. The simplified mathematical model is expressed as:

\[
Y = \beta_0 + \sum_{i=1}^{5} \beta_i X_i
\]  

5.1.2. Regression analysis results

Analysis results from the multivariate linear regression analysis were interpreted using a 5% significance level. The coefficient of determination, \( R^2 \), for the overall equation is 74% showing an acceptable comparison between the estimated \( Y \)-value and actual \( Y \)-value. The \( R^2 \) value measures how close the data are to the fitted regression line. A coefficient of determination of 74% was found to be satisfactory in that the selected model explains most of the variability of response data around its mean. The F-statistic is 128 and the degrees of freedom measure, \( df \), is 223. The regression sum of squares \( SS_{\text{reg}} \) is 176 while the residual sum of squares \( SS_{\text{resid}} \) is 61. The multivariate linear regression model computation resulted in the following relationship between the dependent and the independent variables:

\[
Y = 0.955 + 0.0099X_1 - 0.0468X_2 + 0.5695X_3 + 0.2787X_4 - 0.1096X_5
\]  

Having checked the overall validity of the resulting linear regression expression, we turn to the coefficients and their standard error values. All \( p \)-values or \( se \) values were found to be less than 0.05 with the exception of \( se_1 \) which is equal to 0.052, i.e. still very close to 0.05. The large \( R^2 \) value combined with small \( se_1 \) values make potential collinearity among independent variables of a lesser concern and hence there was no major effort extended on reducing the equation dimensions any further then the five independent variables with the use of complementary methods such as PCA. In terms of explaining the dependent variable \( Y \), it is found that there is a statistically significant and positive correlation with the independent variable \( X_3 \) representing requisite quality management in daily operations with a standard error \( se_3 = 0.050 \) \((\leq \alpha = 0.05)\). This result is somewhat expected. The Lebanese end users at large are cognizant of modern management techniques and the importance of their application to achieve expected results. There is also enough awareness in Lebanon that strict managerial quality techniques are not observed locally. It is found that there is a statistically significant and positive correlation with the independent variable \( X_4 \) representing requisite technological upfront investment that poses challenges in implementation with a standard error \( se_4 = 0.048 \) \((\leq \alpha = 0.05)\). Clearly, public attitudes show awareness about the importance of emitting clean air and a reluctance to go for a tradeoff between getting garbage off the streets while returning air that causes health hazards.

It is found that there is a statistically significant and negative correlation with the independent variable \( X_5 \), representing the reliability of public management with a standard error \( se_5 = 0.032 \) \((\leq \alpha = 0.05)\). There have been past public management failures in other sectors such as transportation, water and power, all of which are intimately related to the MSW cycle. Therefore, it is most likely that any solution related to MSW management with public sector involvement or responsibility would find a negative correlation with acceptance by end users. It is also found that there is a statistically significant and negative correlation with the independent variable \( X_2 \) representing agreement with privatization with a standard error \( se_2 = 0.028 \) \((\leq \alpha = 0.05)\). As for the independent variable \( X_1 \), representing public awareness about upstream household level triage, no statistically significant correlation was found. The regression coefficient is positive but the standard error is \( se_1 = 0.052 \) \((\leq \alpha = 0.05)\). Note that the error is very small to the 5% significance level, and that \( X_1 \) would be considered to be significant at a 10% level. Keeping with the 5% significance level, this last result may be partially related to the low expectations about the impact of household actions on public policy outcomes. Household-level triage is marginalized by the garbage collection and
6. Discussion and interpretation
Empirical results from this field work are overall in good agreement with results from other countries. Our results related to household triage, although important, yielded a statistically insignificant relationship, most likely due to how the full cycle is managed by the MSW collections company. In a MSW study on Thailand, and another one in Ghana, the involvement of household was also highlighted and the need for better communication and coordination between residents and local municipalities was identified as an opportunity for improvement (Boateng, Amoako, Appiah, Poku, & Garsonu, 2016; Yukalang, Clarke, & Ross, 2017). Regarding privatization, there are both positive and negative attributions to handing MSW management control to private parties. Our results yielded a statistically significant and negative correlation. In a study on MSW privatization conducted in Botswana, Egypt and a number of other countries also led to conclusions that capacity building in eth public sector is preferred to privatization. The same studies emphasize the importance of capacity building rather than subcontracting or privatizing MSW, and the perception of respondents that such management should reside in the hands of the public sector despite the advantages of privatization at large in other sectors. These finding are consistent with ours in relation to privatization and the requisite quality in service of a public entity to succeed (Bolaane & Isaac, 2015; Fahmi, 2005).

Our results showed that upfront technology investment is required in order to make IER solutions viable. Comparative studies to seek corroboration with other countries would be somewhat challenging for this particular independent variable because technology investments depend on several parameters. Those parameters are very different from country to country, and are distributed all along the value chain. Nevertheless, upfront technology planning and investment is described as one key success factor (Elagroudy, Warith, & El Zayat, 2016; Schubeler, Wehrle, & Christen, 1996; WEC—World Energy Council, 2016).

7. Future research recommendations
The inquiries during the focus interview phase, the preliminary results from qualitative data, and the results from the quantitative regression analysis pointed out that future research may include other independent variables. Using the present regression analysis as a pilot project, several other factors could be explored by collecting data from other counties such as Kesrouane County or Batroun County, Lebanon. Such broader data collection allows for the investigation of data samples from areas that are at different stages of rural development, education, employment rate, commercialization, public transport networks that may ease MSW collection and processing, maturity of municipal services, and urbanization. Upon expanding the dimension of potential independent variables, other multivariate methods such as PCA would be used upstream to reduce the total number of independent variables into the principal factors affecting the analysis outcome, prior to performing a linear regression analysis.

8. Conclusions
Municipal solid waste issues are of paramount importance as they bear directly on public health and the economy. Further, MSW requires a multidisciplinary convergence between technology or engineered solutions and public policy design, taking into consideration socio-economic factors. MSW management evolved as countries became industrialized and was influenced by environmental activism and a pro-active effort to identify alternative sources of energy. Mismanagement of MSW is more exacerbated in less developed countries. Across a range of solutions, the most desirable ones comprise waste avoidance, and the least desirable ones revolve around traditional landfills. A correlation between MSW public policies and the developmental level of the country was presented
in literature. However, this cannot be generalized because hybrid solutions are developed on a case-by-case basis depending on the country’s limitations in land area or in technological sophistication.

A set of focus interviews was conducted to identify areas of concerns from the end-user perspective. Local community engagement, transparency, adoption of cleaner technologies and better planning and implementation were pointed out by most respondents. Following the qualitative interview stage, a multivariate linear regression analysis was used. The majority of respondents in the focus interviews stage expressed concern about the current state of affairs in MSW management in Lebanon. These concerns were taken as a basis for the selection of regression analysis variables to gauge public attitudes. Incineration with energy recovery and clean exhaust technology was explored as a solution and its attractiveness to the public was tested. The dependent variable is an index quantifying the extent to which respondents agree with IER, while the independent variables address awareness building about upstream triage, privatization, quality management in daily operations, technology and investment challenges in implementation, and reliability of public management authorities. Results showed a statistically significant and positive correlation with quality in daily operations and in technological upfront investment, but showed a statistically significant and negative correlation with the reliability of public management, and privatization. Upstream household level triage, although important in future community orientation, was not found statistically significant. There are various explanations to this latter counter-intuitive result related to respondents’ low expectations and simmering socio-economic problems. Overall, IER is perceived as a viable option but requires strict public policies.

Future research should include other factors such as the location of potential incinerators. This was kept out of scope during this phase of the study for simplicity. Other factors such as gender, age and occupation, would also be an interesting follow-up to see how respondents may be predisposed for or against a certain MSW solution. It is recommended that follow-up research be focused on upfront triage and the role of household-level waste management, involvement of local authorities such as municipalities, and collaboration schemes with contractors and investors. In fact, some of the recent proposals in Lebanon consider imposing fines on those who do not abide by certain triage rules. However, highly regulated approaches may not offer sustainable solutions as culture- and incentive-based approaches would.

Funding
The author received no direct funding for this research.

Competing Interests
The author declares no competing interests.

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Cover Image
Source: Author.

Citation information
Cite this article as: Public policy and technology choices for municipal solid waste management a recent case in Lebanon, Michel Soto Chalhoub, Cogent Environmental Science (2018), 4: 1529853.

Note
1. RCRA Public Law 94–580.

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