Technology and Public Policy Options for Solid Waste Management: Application to Recent Cases in the East Mediterranean

By

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Municipal solid waste (MSW) management has a range of possible solutions whereby the most desirable ones revolve around waste avoidance or waste reduction from the outset, all the way to the least desirable traditional landfill. Evidence in literature shows a correlation between public policies addressing MSW and the level of development of the country under consideration in that the more developed the country, the more solutions lean towards "upstream avoidance management." The less developed the country, the more solutions lean towards "downstream disposal or remediation" such as landfills. In between these two options, there is a wide range of hybrid solutions that combine triage, collection, and final disposal of post-treated reduced MSW mass.

The paper briefly reviews critical MSW problems, including a recent crisis in Lebanon. It then explores incineration with air pollution control and energy recovery as a public policy option. Upstream solutions would have been desirable but they require a more advanced stage of public awareness, operational quality management, sense of public responsibility, and infallible national level policies. Modern non-incineration solutions, including anaerobic digestion, may be more appealing provided the full process, its byproducts, microorganisms, and risks, become better understood. Furthermore, the level of investment, expertise, and continuous quality improvement and supervision are more demanding for the latter solution, especially in light of public management weaknesses in less developed countries.

The paper then presents a multivariate linear regression analysis of public attitudes regarding MSW management. Given the range of solutions for MSW and the parameters that affect technology and policy choices, a simplifying assumption is made to test the attractiveness, or lack thereof, of incineration with energy recovery (IER) coupled with a process for air pollution control. Lessons learned from the United States and countries where incineration was compared with landfill options depend on the availability of vast, sparsely or unpopulated land area. This prerequisite is inexistent in small, densely populated countries such as Lebanon and others. 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. Although challenges in implementation include managerial issues, that variable was centered on technological or financial challenges. For practical implementation reasons, intermediate solutions that entail building an IER facility lacking air pollution control systems, then upgrading it gradually, was not offered as an option in the survey. As a result, the technological and financial components were highly correlated in that technology requirements to make the facility pollution-free would be planned upstream, and implemented upfront in the construction process using costly high-end air pollution equipment.

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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 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 simmering socio-economic problems, may not see household refuse triage as a determining factor. Also, household triage is perceived to be of no relevance to MSW collection and transport processes, and mixed dumping at final destination.

The review and present analysis show that prevention is preferred to remediation but that it may not be practical in less developed countries. Bio-processes are well-accepted but are perceived to be complicated and risky in that microorganisms are not studied in enough depth to get a clear view of long term effects. The IER option is perceived as a technologically and financially viable solution but that clear public policies should be designed and implemented.

Introduction

Municipal solid waste (MSW) is one of the current issues that are highly debated among scientists and policy-makers, as it affects public health and the use of resources, especially in developing countries (Guerrero et al., 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 and Widjaya, 2006; Cheng et al., 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 and De Gisi, 2010a).

Over the last few decades, comparative analyses among various methods of MSW management were performed, of which the most common ones involve landfills and incinerators (Dijkgraaf and Vollebergh, 2004; Finnveden et al., 2007). Relevant models balance waste treatment, as a necessity, with the potential benefit of recovering energy, thus turning the process into a production operation (Consonni et al., 2005; Feo et al., 2003).

Countries enjoying 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 et al., 2007). 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 et al., 2011; Leone et al., 1983; Gramatica et al., 2006). 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).

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 (Tehrani et al., 2009). 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 (Parizek et al., 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 (Christensen et al., 2007; Bjorklund and Finnveden, 2007).

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 most 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 United States. Technically, refuse is spread in thin layers covered by soil. The layers are typically around ten to twenty feet 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 ^{o}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 (Khoo, 2009; Cherubini et al., 2008).

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).

Figure 1. MSW solution versus developmental level.

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).

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. The story goes decades back but for the sake of focus on current state of affairs, only a recent history is in scope. In 1998, policymakers decided to interrupt garbage dumps in Burj Hammoud, a densely populated town on the northerly outskirts of downtown Beirut, the Capital, 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 kilometers 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 (Daily Star, 2015a; Daily Star 2015b; Chalhoub, 2016; 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 (Daily Star, 2015c; Chalhoub, 2016).

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 (Daily Star, 2016; Chalhoub, 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 (MoE, LEDO, 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.

MSW Component	GBA (%)	Lebanon (%)
Organic	63	51
Paper and cardboard	18	17
Plastic	7	10
Glass	5	9
Textiles	4	3
Metals	3	3
Construction/Demolition	-	5
Other	-	2

Table 1. Proportions of solid waste components (source: CDR, 2012)

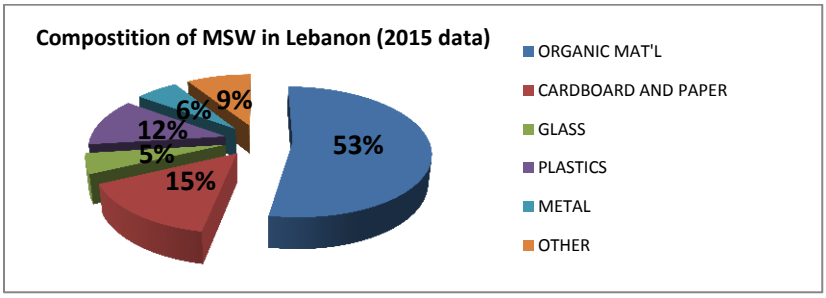

Figure 2. Proportions of solid waste components (source: Nat. Cons. Ctr., 2016)

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 last 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, 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.

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 (World Bank, 1999; Chalhoub, 2015).

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_{awf}, greatly depends on the specific component of solid waste. Plastics and polyethylene command a H_{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, 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% (World Bank, 1999; Chalhoub, 2015).

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).

Regression Analysis

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 last eighteen months, a simplified IER policy option was described to respondents. 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*.

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 (Muchova et al., 2009; Grosso et al., 2010).

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 and 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 et al. 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 and 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:

$$Y = \beta o + \sum_{i=1}^{5} \beta_i X_i$$

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 F-statistic is 128 and the degrees of freedom measure, d_f, is 223. The regression sum of squares SS_{reg} is 176 while the residual sum of squares SS_{resid} is 61. The resulting expression is:

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

Having checked the overall validity of the resulting linear regression expression, we turn to the coefficients and their standard error values. It is found that there is a statistically significant and positive correlation with 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 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 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 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 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 X_2 representing agreement with privatization with a standard error $se_2 = 0.028$ ($\leq \alpha = 0.05$). As for 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 $se_1 = 0.052$ ($\geq \alpha = 0.05$). 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 dumping process used by the sole subcontractor who does not discriminate in between MSW components but rather collects and dumps mixed bags. This is another possible reason why the public may perceive itself to be of little relevance to MSW collection, transport, and dumping process.

Conclusions

Excessive and mismanaged MSW raises health, logistical, economic, and political concerns that are 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. Although many researchers established a correlation between MSW public policies and the developmental level of the country under study, hybrid solutions are developed on a case by case basis depending on the country's limitations in land area or in technological sophistication. Incineration with energy recovery and clean exhaust technology is explored as a solution and its attractiveness to the public was tested using a multivariate linear regression analysis of public attitudes. 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.

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