The role of waste-to-energy in waste management in Egypt: a techno-economic analysis

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Abstract

Purpose – Egypt has set plans to transform into a green economy which requires major reforms in the waste sector as one of the most vital sectors crucial for this transformation. This study aims at inspecting the current status of the Egyptian waste sector to highlight the major policy reforms needed. Furthermore, it assesses the economic viability of establishing waste-to-energy (WtE) projects under the current regulations that govern the sector.

Design/methodology/approach – The study employed an inductive analytical approach to scrutinize the institutional and regulatory framework of the waste and WtE sectors. Furthermore, a novel techno-economic analysis was conducted to assess the profitability of a WtE plant that employs moving grate incineration technology.

Findings – The analysis of the waste sector revealed its deteriorating state and the dire need for immediate restructuring through more stringent regulations to establish an integrated waste management system (IWMS) that incorporates WtE technologies as well as a number of corrective actions that would help enhance the sector. Additionally, the techno-economic analysis revealed the need to amend the current WtE regulation to comprise a gate fee as an indispensable revenue stream for WtE projects.

Originality/value – This study is one of a few studies that uses a new technique of analysis to explore the potential role that WtE projects can play in Egypt as a part of an IWMS that aims at transforming the waste sector into a resource sector while providing a renewable and sustainable source of energy.

Keywords Waste-to-Energy, Solid waste management, Sustainable development, Green businesses, Renewable energy

Paper type Research paper

1. Introduction

Egypt has been trying to accelerate economic growth and achieve sustainable development for years. Nevertheless, the country has been suffering from drastic economic and environmental problems as a result of adopting a growth pattern that did not truly pursue sustainability. In recent years, following the declaration of the sustainable development goals (SDGs), Egypt formulated its sustainable development strategy 2030 that integrated the vision of transforming into a green economy that fulfills the three pillars of sustainability.

This transformation necessitates drastic restructuring of vital sectors in the economy including the waste sector. Hence, this paper showcase the current solid waste management

(SWM) practices that prevail in Egypt and assesses the impact of integrating waste-to-energy technologies (WtE) in the context of an integrated waste management system (IWMS) in the country. WtE projects can be considered an optimum form of green businesses to be established in Egypt to serve the dual purpose of supplying a sustainable renewable energy source while mitigating pollution from escalating amounts of municipal solid waste (MSW).

This study constitutes a relatively new area of research in the Middle East and North Africa (MENA) region which emerged from the growing interest in the role of green businesses such as WtE in the context of a green economy. Accordingly, the aim of this study is to broaden the knowledge of the prospective role of waste-to-energy technologies in enhancing the Egyptian waste sector. Hence, it investigated the institutional and regulatory framework that govern the Egyptian waste sector to evaluate its efficacy and offer adequate suggestions to enhance its status and the role that WtE can play in this.

Very few studies have investigated the role of waste-to-energy in Egypt. The sector is still in its initiation phase and assessing the practicality of WtE projects is still obscure. Accordingly, this paper offers a novel - approach to examining WtE potential through conducting a techno-economic analysis of an incineration based WtE plant to allow for calculating various profitability indicators to assess the economic viability of such projects under current regulations.

The paper is organized into six sections, the first section is the introduction, followed by an in-depth analysis of the Egyptian waste sector, the third section overviews the emerging WtE sector, the fourth section demonstrate the advantages and challenges of the WtE sector in Egypt, the fifth section showcase the techno-economic analysis of establishing a WtE project in Egypt and the final section is the conclusion and policy implications.

2. The Egyptian waste sector

Solid waste management (SWM) is one of the most severe problems facing environmental management in Egypt. The waste problem in Egypt can be attributed to multifaceted factors including fast population growth, growing economic activity, industrialization, urbanization, lack of awareness, illiteracy, unrestrained slum areas, lack of clear policies, the multiplicity of waste sources and components, the limitations of the existing devices managing them in terms of traditional waste collection and disposal systems, the behavior of individuals and institutions, human and financial resources shortage as well as scarcity of landfill sites for final waste disposal. This needs to be addressed by the government through nonconventional solutions to avoid, reduce, reuse and recycle waste (Egyptian Environmental Affairs Agency (EEAA), 2019; Ministry of Environment, 2016). Accordingly, Egypt has seen a huge surge in the generated waste which resulted in adverse impact on public health, the environment and natural resources. The current waste management system (WMS) in Egypt do not guarantee proper treatment or disposal of waste. However, the waste generated in Egypt has the potential to be turned into useful products (Chemonics Egypt and Cleantech Arabia, 2018).

2.1 The regulatory and institutional framework of the Egyptian waste sector

The legislative and institutional framework of the waste sector in Egypt is blurry. There is no single entity responsible for waste management, instead the responsibility of waste management is spread between different entities according to the waste stream. Up till 2020 the country had no unified SWM law. The sector was mainly administered by Law No. 38 /1967 on General Public Cleanliness and Law No. 4 of 1994 which is the main law for environmental protection in Egypt as well as the Public Private Partnership Law No. 67 of 2010 (the PPP Law) which represent the enabling framework to invest in the infrastructure of the sector and incorporate investors from the private sector (Ministry of Environment, 2016).

In addition, Prime Minster Decree No. 3005 of 2015 established the waste management regulatory authority (WMRA) as an independent service authority in affiliation with the Ministry of Environment (ARE, 2015). WMRA was given a wide range of responsibilities to enhance waste management in Egypt but has fallen short to fulfill those responsibilities. Hence, a study by the National Energy Corporation (TARSHEED) (2017) recommended that the regulations and structure of WMRA should be reformed which took place in Law 202 of 2020.

Law 202 of 2020 for regulating waste management was established to be an inclusive law to enhance waste management in Egypt. It integrated the concept of sustainable development for the first time in waste related regulations in Egypt. Accordingly, it dissolved WMRA and replaced it with a new one transferring all its responsibilities, liabilities and employees to the new one. In addition, law 202 encompassed important articles that were missing from previous laws such as Articles 15 and 16 which stipulated that the producer or owner of waste should follow the waste hierarchy and shall bear all costs related to the application of environmentally safe IWMS. Moreover, open incineration was banned in Article 20 and Article 40 stipulated that all open unregulated landfills are to be closed within two years from the issuance of the law. Article 25 stipulated that the prime minister in coordination with the electricity and renewable energy minister shall set a feed-in-tariff (FiT) for electricity from WtE projects according to technical and economic studies to reach the value that would encourage investment in this field. The law also stipulated multiple penalties for the violators of the law articles. Most notably, article 32 in the law established new bodies called municipal waste integrated management units (MWIMU) which are entities responsible for integrated management of municipal waste (ARE, 2020). The examination of the long anticipated Law 202 reveals that although it called for a proper IWMS and integrated WtE projects as part of waste handling processes, there is no significant difference regarding WMRA's roles and responsibilities from the previous regulation to guarantee the new authority's performance and ensure its success in managing and reforming the waste sector.

The institutional framework for the sector remains relatively unclear. It comprises of multiple stakeholders including governmental authorities, informal waste collectors, the private sector and waste management and recycling companies. Generally, the waste sector stakeholders can be categorized into two main groups: First, the central government. Second, the private and informal sector including the informal waste collectors' community, contracted SWM operators, nongovernmental organizations (NGOs), recycling and waste management firms and international donors.

2.2 Waste sector in Egypt

The analysis of the Egyptian waste sector reveals that it is characterized with inefficient and old waste collection, handling, treatment, storage and disposal techniques. Municipalities are the first level in the SWM system in Egypt as waste collection and transportation is their responsibility. Nevertheless, municipalities are generally present in urban areas while many rural areas lack an operative system to collect and transport waste. Hence, a network of informal waste collectors and traders exists as an active player in the collection and preprocessing of waste especially MSW as informal collectors collect MSW in parallel to the government. Therefore, most of the separation and preprocessing for recyclables are carried out informally (Chemonics Egypt and Cleantech Arabia, 2018).

The collection process of MSW suffers from huge inefficiency as it is mainly carried out through individuals, companies and institutions that use different inefficient methods for collecting, sorting and disposal of solid wastes from households, industries and the service sector. The collection is either carried out by small waste companies with a license to collect from houses, or by the traditional informal waste collector. A service fee is paid monthly voluntarily by the waste producer (households, etc . . .) with no commitment to pay if waste generators refuse to receive this service. This monthly fee is a uniform rate unrelated to the volume of the generated waste with a price disparity in the charge among households and among households and other economic entities and among different locations. Moreover, there is no precise data of the number of people benefiting from this service or the profits resulting from it (no receipts). Another fee is imposed on all households by municipalities pertaining to street cleansing and general services of waste management, this 2.5% charge is mandatory regardless of whether the household pays for a private contractor for waste collection or not. As for waste transportation it is poorly handled either by open transport vehicles that scatter waste or through the traditional small cart vehicles. After collection, the waste is handled, segregated and preprocessed by the traditional waste collectors mostly from the informal sector, this sorting process is carried out on roads or in the collection boxes distributed on the roads. MSW in Egypt is separated into two categories: recyclable materials with economic value like paper and carton boxes that are sold to traders and organic waste which is left piled up in the streets or is openly burned causing pollution and methane emissions. Land disposal remains the general management strategy for MSW, disposal usually takes place in open dumpsites that lack sound health and environmental specifications turning it into a grave source of pollution due to waste accumulation and subsequent reactions and fumes from the self-combustion of waste in these areas (EEAA, 2019; Ministry of Environment, 2016; Ministry of Environment, 2001).

The Egyptian Environmental Affairs Agency (EEAA) set extensive rehabilitation requirements for public dumpsites/landfills (location properties, operation requirements, safety measures, data records and payment system) (Ministry of Environment, 2021). Nevertheless, landfills in Egypt still lack the basic sanitary requirements and remain a major source of pollution imposing grave health and environmental problems. Furthermore, the lack of public awareness and guidance for citizens to adopt proper SWM practices has resulted in water supplies contamination due to the inappropriate disposal of solid waste (SW) in drains and waterways causing serious environmental problems and compromising public health and natural resources. Additionally, street cleanness has declined and open waste incineration pollution has increased (Ibrahim and Mohamed, 2016).

In an effort to enhance the current deteriorating solid waste management system (SWMS) some initiatives were recently taken by the government including a plan executed by the ministry of environment (MoE) to collect the accumulated waste in some governorates like Alexandria, Port Said and Ismailia and regulating the dumpsites surrounding Cairo to decrease self-combustion of waste in these sites (The Ministry of Environment, 2018a). Another initiative was the launch of an application called "Dawar" in some districts in Cairo to be further expanded across Egypt that permits users to capture and upload pictures of streets containing waste to allow the application to find the location through global positioning system (GPS) and direct a team to clean it (Egypt Today, 2018). Another initiative to sort waste from the source began in some areas in Cairo such as 6^{th} of October, and New Cairo and some cities including Alexandria and Delta. This waste sorting process categorizes waste into three types: paper, metal, and plastic (Hammad, 2019). In addition, an electronic system for waste monitoring has been applied in September 2019 by the MoE in seven cities: Cairo, Alexandria, Gharbia, Giza, Qena, Assiut and Kafr El-Sheikh (Egypt Today, 2019). Moreover, a green national initiative was adopted to decrease and limit the use of plastic bags and offer alternatives to them in an attempt to endorse sustainable development, convert to a green economy and incorporate sustainable consumption and production (SCP) in Egypt (The Ministry of Environment, 2018a, 2018b). Finally, a government program was set to improve the SWMS to raise waste collection, management and transportation efficiency to 80% –up from 20% in 2015– and recycling to 25% by 2030 (The Ministry of Environment, 2018a).

2.3 Egyptian waste statistics

One of the major issues that exacerbate the waste problem in the country is that there is a huge discrepancy in Egyptian waste statistics (generation, collection and disposal rates) as the waste data is mostly inconsistent and defective due to the existence of multiple agencies with various calculation techniques and the fact that there are no weighing facilities at disposal sites and no tradition of waste sampling and analysis.

Egypt's annual total wastes are estimated about 100 million tons (Farag, 2019a). The main streams of waste in Egypt are: agricultural waste (34%), cleansing of canals and irrigation networks (28%), MSW (23%), construction waste (6%) and industrial waste (5%) (Chemonics Egypt and Cleantech Arabia, 2018). Statistics show that the total annual MSW has amplified above 36% since 2000 with an estimated 2–3% growth per year (Ministry of Environment, 2016; Ibrahim and Mohamed, 2016). The average generation rate of SW for Egyptians ranges from 0.3 kg/capita/day in rural areas to 1.0 kg/capita/day in large cities with establishments like resorts and hotels having high rates of 1.5 kg/capita/day (Ministry of Environment, 2001). Accordingly, the average rate of waste generation is 0.67 kg/capita/day compared to the global average of 0.74 kg/capita/day and the regional average of 0.81 kg/capita/day (Kaza *et al*., 2018).

According to waste statistics by the Central Agency for Public Mobilization and Statistics (CAPMAS) (2018) 87,747 thousand ton of waste were disposed of in Egypt in 2018 with 4,447 thousand tons of waste in Cairo alone. Table 1 shows the quantities of waste disposed in 1,000 ton between 2012–2018. Based on associating waste growth rates with the steady population growth of 2.5% it can be predicted that MSW reached 89.89 million tons in 2019, 92.137 million tons in 2020 and 94.44 million tons in 2021 without adding the impact of Covid-19 pandemic which will inflate this number drastically.

Around 65% of MSW in the country is generated in urban areas and 35% in rural areas. In terms of the efficiency of waste collection, it varies drastically ranging from 90% in high-income locations to 10% in rural areas (Ministry of Environment, 2001). According to the CAPMAS around 44.8% of households dispose their waste in the street while the remaining 55.2% dispose it by private waste collectors and companies (Egypt Today, 2018). There are a few landfills in the capital of each governorate and in some large cities which are properly managed; otherwise, informal dumpsites exist in every town and village in Egypt.

In terms of collection, an average 60–69% of the total MSW generated is collected while the remainder accumulate in streets and residential areas; of the collected MSW 10–15% is recycled, 7% is composted, 7% is disposed in sanitary landfills while the rest is disposed in open dumpsites or is openly burned (Ministry of Environment, 2016; Ibrahim and Mohamed, 2016). Egypt has around 84 open dumps, 7 unspecified landfills and around 1,500 informal waste collection companies with more than 360,000 workers who usually work in bad conditions (Hammad, 2019; Kaza *et al*., 2018). According to the World Bank 1.5% of the gross

Year	Total quantities disposed during a year
2012	79.5
2013	36.4
2014	12.1
2015	17.6
2016	17
2017	21.1
2018	87.7

Source(s): Table developed by the authors, Data from Central Agency for Public Mobilization and Statistics CAPMAS (2019)

Table 1. Quantities of waste disposed in 1,000 ton

domestic product (GDP) is lost in the country (about $5.7bn a year) due to nonrecycling and utilization of waste adding to that the cost of handling waste and its environmental impact (Hammad, 2019).

MSW composition in Egypt (national averages) shows the domination of organic waste with 55–60%, followed by plastics 13% [1], paper/cardboard 10%, glass 4% and metal 2%. Rural areas have higher percentages of organic waste than urban areas at 70–80%, followed by plastic waste 6%, paper and cardboards 4%, glass 2%, metals 1% and others 6% (Chemonics Egypt and Cleantech Arabia, 2018).

2.4 Greening the solid waste sector

The analysis of the SW sector in Egypt reveals the pressing need to be transformed into a green sector. Egypt relies heavily on importing materials for industries and due to the floatation of the Egyptian pound the cost of these imported materials tripled since 2015 meanwhile waste price amplified by an average of 30%. This created a competitive advantage to the locally recycled material compared to the imported ones which resulted in increasing the demand on recycled material (Chemonics Egypt and Cleantech Arabia, 2018). In addition, environmental sustainability was included as a key pillar in Egypt's SDS 2030 with objectives to decrease pollution and establish an IWMS (The Ministry of Environment, 2018a).

Greening the SW sector necessitates transforming conventional SWM practices to promote waste evasion, reduction, reuse, recycling as well as recovery. As suggested by Elagroudy *et al.* (2016) the significance of a green SWMS is that it will help realize multiple SDGs including goal No. 1: no poverty, goal No. 3: well-being and good health; goal No. 8: decent work and economic growth; goal No. 7: clean and cheap energy, goal No. 11: sustainable communities and cities; goal No. 12: sustainable production and consumption patterns; goal No. 13: climate action by mitigating the GHGs and goal No. 17: global partnership for sustainable development. Accordingly, this greening process necessitates moving away from the business as usual model to an economically and ecologically feasible business model that strive for both achieving economic benefits through changing the outlook that MSW is a liability and realizing that it is a possible resource for new economic activities and job creation while enhancing the environment and human wellbeing. Accordingly, a sustainable SWM contributes to the realization of the green economy through constructing a circular economy with minimal amount of waste and harmful materials. Hence, greening the SW sector in Egypt is essential to achieve green growth through waste reduction, resource preservation, lower emissions, effective use of energy and material, new jobs as well as protecting human health. This greening process can be attained through fulfilling the three pillars of sustainable development. Economic sustainability can be achieved through the formation of new businesses, producing secondary material, creating more jobs, providing affordable energy and minimizing the amount of waste disposed. Social sustainability is achieved through realizing healthy and safe working conditions as well as addressing social factors in the sector like child labor and social protection. Environmental sustainability of the sector entails that resources go through a life cycle analysis to endorse manufacturing of nonhazardous products to minimize the amount of waste generated while promoting sustainable consumption and applying strategies for waste prevention.

Greening the Egyptian waste sector is not an easy process as it necessitates business innovation. Generally, startups and small and medium enterprises (SMEs) are more responsive than large firms to innovate. Green businesses are the embodiment of sustainability. Since being green is the new trend in entrepreneurship, entrepreneurs in Egypt are becoming increasingly aware that establishing ecofriendly/green businesses can serve the dual purpose of solving environmental issues while enhancing the bottom line (Chemonics Egypt and Cleantech Arabia, 2018; Egypt Independent, 2016). Accordingly, there has been a surge in the establishment of green startups since 2011 in some fields including waste and water management, agriculture and renewable energy. Although there is no official data on the number of firms in Egypt that work on solving environmental issues, it is estimated that a minimum of 10% of new startups are green (Egypt Independent, 2016; Cairo Climate Talks, 2016).

3. Overview of waste-to-energy in Egypt

In line with the waste hierarchy, if reusing and recycling are not feasible, eco-friendly energy recovery techniques such as WtE are to be used. In the Egyptian context, the second and ninth pillars of the Egyptian SDS 2030 are particularly important for the development of the WtE sector in Egypt as they demonstrate that within the SDS 2030 vision an innovative sector like the WtE that provides a renewable energy source with an efficient resource management that protects and enhances environmental quality is one that is needed and highly encouraged.

The potential of WtE application depends on the specific economic, social and political conditions of the country. Middle Income countries like Egypt are characterized with a high demand for energy coupled with a high increase in waste generation especially MSW with unsustainable WMS. Accordingly, WtE technologies have a high potential if it adheres to the needs of the country and is supported with strong investment incentives and suitable regulatory framework for WtE to properly operate taking into account that the selection of the WtE technology depends mainly on the nature of the waste stream (World Energy Council, 2016).

By 2050, Egypt plans to raise the share of electricity from renewables and waste to 55% of the total output of energy (Hammad, 2019). The infant WtE sector can greatly contribute in realizing this goal. Given that the Egyptian WtE sector is still in its initiation phase it has to be endorsed by the government – through proper regulations and an enabling environment to encourage investment in the sector.

3.1 Egyptian waste-to-energy regulations

The WtE sector in Egypt is regulated by Feed-in-Tariff (FiT) Decree No.41 of 2019 which stipulated the rate upon which the Egyptian government will purchase electricity from WtE projects (thermal facilities, landfill biogas (LFG), and waste water treatment sludge). The FiT has two rates. First, a rate of 1.4 Egyptian pound (EGP)/Kilowatt-hour (kWh) for electricity produced from MSW or LFG sold to the national grid. The second rate is 1.03 EGP/kWh for electricity sold to the national grid generated from waste water treatment plants sludge. The FiT is fixed over a 25-year contract held between the governorate and the WtE facility located in it. The land for the facility is allocated by the governorate on a concession term for the duration of the electricity purchase agreement between the governorate and the electricity distribution company. It is stipulated that the governorate is responsible for supplying the needed quantity of waste to produce electricity for the WtE company with no cost. The FiT set the total installed capacity of electric power production plants from WtE at 300 megawatt (MW) during the first five years from the decree. In addition, the station has to have a maximum capacity of 20 MW and a minimum capacity of 500 KW to be connected to the medium voltage network (11 or 22 kilovolt (kV)) with the station owner bearing the cost of connecting the station with the nearest medium voltage access point (ARE, 2019; Waste Management Regulatory Authority (WMRA), 2019; Farag, 2019a, b).

3.2 A snapshot of waste-to-energy statistics and current projects

With an average of 0.67 kilograms of generated waste per capita per day in Egypt and through the utilization of WtE technologies, this waste could generate 7.5 terawatt hours (TWh) of electricity per day with the prospect of diverting one of the utmost challenging waste streams to a useful use (Nasr, 2019; Chemonics Egypt and Cleantech Arabia, 2018). The selection of the WtE technology depends mainly on the volume and nature of the waste stream. An important determinant of the amount of generated energy is the calorific value (CV) of waste, which shows the amount of energy that can be generated from each type of waste (World Energy Council, 2016). Table 2 shows the CV of different waste fractions.

There are diverse options for utilizing energy from MSW such as district heating and electricity. The paper is only considering obtaining electricity from MSW as Egypt does not have the infrastructure for connecting district heating. Therefore, the paper calculated the potentially obtainable electricity from MSW through considering the physical composition of Egypt's MSW following Chen (2018) and Ouda *et al.* (2017). The potential of energy recovery from waste can be estimated using its CV as follows:

$$\text{Energy Recovery}(\text{GWh/y}) = NCV\left(\frac{Mj}{kg}\right) \times W\left(\frac{t}{y}\right) \Big/ 3600$$

Where NCV is the net calorific value/lower heating value (LHV) in Mega Joule (Mj/kg), W is the dry weight of waste (ton/year), 3,600 is a conversion factor.

Table 3 shows the energy recovery potential from each waste stream. Accordingly, Egypt has the potential to produce 28,060 Gigawatt hours (GWh/y) of electricity by utilizing WtE incineration technologies which is approximately 3.5 times the amount of electricity produced by the high dam in Aswan.

The WtE sector in Egypt is still in its developing stage. However, some small scale WtE plants are in operation in the country. For instance, numerous cement plants convert industrial and agricultural waste into fuel to power their plants (Nasr, 2019). In addition, following the cabinet approval of the WtE FiT, a number of proposals to construct WtE projects were directed to the ministries of environment and electricity from foreign and Arab investors with the value of \$2bn (Farag, 2019b).

MSW fractions	Net calorific value (MJ/kg)
Plastics	35
Textiles	19
Paper	16
Other materials	11
Organic material	4
Glass	0
Metals	0

Source(s): Table developed by the authors, data from the World Energy Council (2016) and Haukohl (2016)

Table 2.
Approximate net calorific values for common MSW fractions

Waste fraction	GWh/y
Energy recovered from organic waste	31,302
Energy recovered from paper and cardboard	22,359
Energy recovered from plastics	63,582
Energy recovered from glass	0
Energy recovered from metal	0
Energy recovered from other materials	23,057
Total energy recovery potential (GWh/y)	140,300
Efficiency rate of incineration plants (20%)	28,060

Source(s): Table developed by the authors

Table 3.
Energy recovery potential from each waste stream

4. Advantages and challenges of waste-to-energy projects in Egypt

Waste-to-energy projects offer numerous benefits for Egypt. First it provides a sustainable solution to the persisting waste problem with its adverse economic, social, environmental and health effects. Moreover, Egypt has a high and growing energy demand which WtE projects can help fulfill through its main outputs.

Apart from electricity and heat, WtE projects can generate fuels that can be used in transportation (World Energy Council, 2016). This can lead to a drastic decrease in the fuel consumption by vehicles leading to both economic and environmental gains. Furthermore, the use of biomass in heavy industries like cement has multiple advantages including solving the challenges associated with biomass, decreasing emissions and is considered a viable energy source (Messenger, 2016).

From an economic perspective, the WtE sector is expected to open up new investment opportunities and encourage foreign investment as international financial and technical feasibility studies reveal a return of about 18% through investing in the SW sector (Hammad, 2019). Additionally, The WtE sector has a high rate of job creation due to its nature which requires a broad range of direct jobs. In view of that, it generates job opportunities for the unskilled and semiskilled labor in waste accumulated areas. Hence, these projects can help enhance the livelihood of economically stressed communities in the country (Chemonics Egypt and Cleantech Arabia, 2018).

On the other hand, the establishment of WtE projects in Egypt is faced with multiple challenges that can hinder their development. First, the Egyptian waste composition, which makes investing in WtE plants challenging as most of the waste is organic with low energy potential adding to that the initial sorting by the informal sector which further reduces the waste energy potential (Hammad, 2019). Second, the cost of generating energy from WtE technologies is not always competitive compared to other sources of energy adding to that the high construction and operating costs of these projects (Nasr, 2019; Elagroudy *et al.*, 2016). Third, the FiT rate determined for WtE projects is not a sufficient source of revenue as these projects depend on receiving a gate fee which is a charge imposed on a given amount of waste taken by a waste treating facility, it is a main source of revenue for accepting waste by these projects which was not stipulated by the FiT decree.

5. A techno-economic analysis of a waste-to-energy project in Egypt

As aforementioned, the Egyptian WtE market is still in its initial phase. Hence, the paper conducted a techno-economic analysis for an incineration based WtE project to assess the economic viability of these projects under the FiT regulation. The analysis for such projects in Egypt is deemed problematic for several reasons: First, there are no clearly defined costs for the Egyptian WtE market, accordingly the paper calculated the estimated costs of constructing a WtE incineration plant using an inductive analytical approach based on calculating the maximum capacity allowed by the FiT decree and scaled the project to meet this capacity. Second, the revenues of these projects generally consist of: a gate fee, the revenue from selling the generated electricity to the grid as well as the sale of the bottom ash and recovered metals from MSW. Hence, the revenues of these projects were totally undermined when the FiT set only the selling price for electricity and did not include a gate fee adding to that it required investors to be responsible for the costs of connecting to the grid.

The paper assessed the feasibility of establishing a WtE plant that employs moving grate combustion technology in the area of Mokattam in Cairo (due to its proximity to major waste disposal sites). The choice of this particular technology is due to the fact that it is a very common technology for processing MSW with the advantage of not requiring separation of different waste streams before processing which is suitable for the Egyptian case. Consequently, the range of estimated costs and benefits were chosen in accordance to previous studies conducted in other countries of WtE plants that relies on this technology. In view of that, a technical assessment of the plant capacity and production was carried out to allow for proper estimation of the costs and revenues associated with the hypothesized plant. Given that the costs and benefits were estimated over the time horizon of the project (25 years); the paper used the discounted cash flow method. To assess the combined profitability of the project a 9.25% discount rate was used an average of the discounted rates in 2020 provided by the Central Bank of Egypt (CBE)-(Central Bank of Egypt, 2020).

The estimated economic costs of the proposed WtE plant comprised of construction/investment costs and costs of operation and maintenance-cost of land acquisition was excluded since it will be provided by the municipality based on concession term as stipulated by the FiT-these costs were estimated in the United States (US) dollar. The economic benefits of the project included revenues from energy sale according to the FiT, revenues from the sale of recovered metal according to the world price of recycled metal, and revenues from the sale of bottom ash according to world prices; these revenues were also calculated in US dollar.

5.1 The technical aspects of the plant

The estimated amount of energy yield by the plant is calculated as follows:

$$E_{(Kwh/y)} = Plant\ Capacity \times 1000 \times 8760$$

Where E is the estimated energy yield in Kwh/year.

1,000 is the conversion factor from Mw to Kw.

8,760 is the theoretical operational hours per year.

Thus the plant can produce 175,200,000 Kwh/year or 175.2 GWh/year.

According to the Egyptian waste stream, the energy produced from 1 kg is calculated based on the existing waste components as shown in Table 4.

Thus, the amount of electrical energy produced by 1 ton of Egyptian waste assuming that the efficiency rate for the moving grate incineration project is 20% can be calculated as:

$$E_{per\ tonne\,(\mathrm{kWh/ton})} = \left(\frac{NCV\left(\frac{Mj}{kg}\right) \times W(t) \times 1000 \times 1000}{3600} \right) \times 0.2$$

Where NCV is the net calorific value

Table 4. Energy produced from each waste component

Waste components	Percentage of each fraction in waste per kg	Net calorific value (MJ/kg)	Energy produced per each component per kg (MJ/kg)
Food/Organic Waste percent	56%	4	2.24
Paper and cardboard percent	10%	16	1.6
Plastic percent	13%	35	4.55
Glass percent	4%	0	0
Metal percent	2%	0	0
Other waste percent	15%	11	1.65
Total			10.04

Source(s): Table developed by the authors

W is the waste volume

1,000/3,600 is the conversion factor from Mj to Kwh

1,000 is the conversion factor from ton to kg

0.2 is the efficiency rate

As a result, 1 ton of Egyptian waste has the potential of producing 558 kWh/ton. For simplification it will be assumed that 1 ton produces 550 kWh of electricity. Accordingly, the required tonnage of feedstock for the plant can be estimated as follows:

$$\mathrm{T}_r = \frac{E}{E_{per\ tonne}}$$

Where T_r is required tonnage of feedstock calculated as tons/per year

E is the estimated energy yield in Kwh/year

$E_{per\ tonne}$ the amount of energy produced from 1 ton of waste in Kwh

Based on the above calculations, the plant needs to process around 318,545 tons per year or approximately 873 tons per day (TPD) to fulfill its maximum capacity of production. Table 5 shows the main results of the plant's technical analysis.

5.2 Estimating the economic aspects of the plant (costs and revenues)

The investment cost for a MSW incineration plant is governed by numerous factors especially the plant size, the waste volume and composition, the lower heating value (LHV) of waste, the plant's efficiency, etc. Tehrani and Haghi (2015) estimated equations to estimate investment and operating costs of a MSW incineration plants as a function of the number of the processed metric tons per year by the plant. As suggested by Tehrani and Haghi (2015) the cost formula to calculate the investment cost of an incineration plant is:

$$I = 2.3507 \times C^{0.7753}$$

where I is the investment cost in million dollars

C is the plant capacity (1,000 metric tons of waste/year).

Accordingly, the hypothesized WtE incineration plant needs an investment of $205.1 million or $644 per ton of annual capacity.

The operating and maintenance costs of the proposed plant consists of fixed operating costs, variable operating costs and maintenance costs. The annual maintenance and operational cost is estimated as 4% from the initial investment cost. Following Tehrani and Haghi (2015) the operating and maintenance cost function is estimated as follows:

Technical variable	Estimated amount
Estimated energy from 1 ton of Egyptian MSW	550 kWh of electricity
Estimated plant production of electrical energy	175,200,000 Kwh/year or 175.2 Gwh/year
Estimated plant capacity	318,545 tons per year or 873 tons per day

Source(s): Table developed by the authors

Table 5. A summary of the technical analysis of the plant

$$A = 0.0744 \times C^{0.8594}$$

Where A is the annual operating and maintenance cost in millions of dollars per year

C is the plant capacity (1,000 metric tons of waste/year).

Accordingly, the operating and maintenance cost of the hypothesized plant will be \$10.5m or \$33.1 per ton of annual capacity.

As aforementioned the FiT did not allow these projects to receive a gate fee. Hence, the proposed plant revenues will only comprise of three components: the tariff of selling electricity to the grid, the revenue from selling recovered metals and the revenue from selling the bottom ash. The FiT decree set the purchasing price of electricity generated from these plants at 1.4 L.E for each Kwh. Thus, based on the above calculated plant production, the plant will receive a revenue of 245,280,000 L.E from selling electricity to the grid, converting this figure using an average of 2020 exchange rate of 15.6 then the revenue per year is \$15,723,077.

The chief by-product of MSW treatment in WtE incineration plants is incinerator bottom ash (IBA). IBA represents 85% of the solid resulting from the combustion process. This bottom ash comprises inert noncombustible materials resulting from the combustion process as well as ferrous and nonferrous materials that are recovered after the incineration process-mainly aluminum foils and scrap metal-. These metals are extracted from the ash and utilized as secondary raw material. Approximately 1 ton of incinerated MSW produces 57.5 kg of bottom ash which is sold to be used for concrete production as well as road construction (Maldonado-Alameda *et al.*, 2020; Margallo *et al.*, 2014).

Based on the previous technical calculations of the proposed WtE project, a total of 18,316.3 tons per year (t/y) of bottom ash can be produced with an average selling price of \$6 based on the Recycled Materials Resource Center (2021). Hence, a revenue of \$109,898 is expected from selling bottom ash for industrial purposes. Furthermore, based on the 2% of metal composition of the Egyptian MSW stream the amount of recovered metal is estimated to be 6,370.9 t/y with an average selling price of \$250 per ton based on Letsrecycle.com (2020). Hence, the revenue from selling recovered metals is estimated to be \$1,592,725 annually. Thus, the estimated total revenue for the WtE plant in a year is \$ 17,520,000. Table 6 shows the estimated revenues and costs for the WtE plant.

5.3 Results and discussion

The paper conducted a profitability analysis of the project using the estimated costs and benefits to evaluate its economic viability under the current regulations. Accordingly, indicators including the pay-back period (PBP), the net present value (NPV), the internal rate of return (IRR) and the benefit-cost ratios (BCR) were calculated which all yielded negative results under the current FiT rate (see Table 8). These results are consistent with the fact that the gate

Table 6. The costs and revenues of the proposed waste-to-energy facility under the FiT

Revenues			Costs		
Electricity to the Grid	1.4 L.E per kwh	\$15,723,077 per year	*Investment Costs*	\$644 per ton	\$205,100,000 In the Construction year
Metal Recovery	\$250 per ton	\$1,592,725 per year	*Operating and Maintenance Costs*	\$33.1 per ton	\$10,500,000 per year
Bottom Ash	\$6 per ton	\$109,898 per year			
Total Revenues		*\$17,425,700*			

Source(s): Table developed by the authors fee which is a major revenue component for these projects was overlooked by the regulation which only set the FiT rate. Hence, a sensitivity analysis was conducted through adding a gate fee to assess the impact of adding this revenue stream on the project's profitability.

An average gate fee was estimated at $100 per ton based on 2021 world estimates (Letsrecycle.com, 2021). Consequently, the gate fee for the proposed project will amount to $31,854,500 annually. Adding this to the previously calculated revenue stream increases the total annual revenue to $49,280,200 a year. The results of the estimated costs and revenues of the proposed WtE facility after adding the gate fee is presented in Table 7. In view of that, the profitability indicators were recalculated based on the new revenues to allow for a comparison of the project profitability with and without a gate fee as shown in Table 8. The results clearly demonstrate that the project is economically feasible only under the assumption of the existence of a proper gate fee.

6. Conclusion and policy implications

Achieving an inclusive green economy is rather a complex and multidimensional process as it necessitates reshaping policies to encourage businesses transformation to become green while incorporating natural assets as a critical input into the production function. Egypt's plans to transform into a green economy are still in their initial phases of implementation. Accordingly, this transformation requires comprehensive reforms targeting vital sectors such as the waste and energy sectors.

Egypt has long suffered from inadequate waste management that resulted in waste accumulation all over the country leading to grave health and environmental problems as well as losing a high potential income stream. Although further investigation is needed, the findings of this paper contributes to a better understanding of the current status of the waste and WtE sectors in Egypt. The scrutiny of the waste sector has revealed the need for major policy reforms that comprise a mix of abiding laws and financial incentives to be applied in the sector. In terms of

Revenues			Costs		
Electricity to Grid	1.4 L.E per kwh	$15,723,077 per year	*Investment Costs*	$644 per ton	$205,100,000 in the construction year
Gate Fee	$100 per ton	$31,854,500 per year	*Operating and maintenance Costs*	$33.1 per ton	$10,500,000 per year
Metal Recovery	$250 per ton	$1,592,725 per yea			
Bottom Ash	$6 per ton	$109,898 per year			
Total Revenues		*$49,280,200*			

Source(s): Table developed by the authors

Table 7.
The costs and revenues of the proposed waste-to-energy facility with the gate fee

Indicator	Without a gate fee	With a gate fee
NPV	−$138,427,038	$168,232,775
BCR	0.547893491	1.549452866
IRR	−1%	19%
PBP	11.8	4.2 years

Source(s): Table developed by the authors

Table 8.
A comparison between the profitability of the project with/without a gate fee

regulations, the paper suggests an amendment of the current law 202 in order to convert the waste sector into a resource sector by treating waste as an economic product. Furthermore, there is a need for new laws that necessitate waste separation at the source. Most significantly there is a necessity for consistency, persistency, and monitoring to ensure the fulfillment of laws, plans and strategies that should be coordinated with the laws and plans of both the energy sector and the emerging WtE sector to guarantee proper targets and results while incorporating WtE as a fundamental element in the establishment of an IWMS.

To ensure proper management of the waste dilemma in Egypt, there is an imminent need for the establishment of a reliable data center that collects accurate statistics on different waste streams to allow for proper analysis, handling and treatment of waste. In addition, the waste sector services must be renovated to create an adequate waste collection and segregation system for different waste streams.

Segregation and recycling centers should be disseminated across the country to fully exploit the waste potential through proper recycling and reuse activities and utilizing unrecyclable waste to enhance the feedstock available for WtE projects. Furthermore, to encourage recycling, the paper suggests the use of ample financial incentives supported with awareness campaigns to help change citizens' habits of handling MSW and increase their recycling activities. Besides, the paper recommends that the government utilize financial incentives such as tax exemptions and environmental certificates with manufacturers and retailers to encourage them to apply waste reduction techniques such as the take back programs for their products which will help reduce the volume of MSW disposed and amplify recycling activities.

The paper's analysis of the emerging waste-to-energy sector uncovered two major challenges that hinder its development: financial and technical challenges. Financial challenges arise from high capital and operating costs associated with these projects versus a low revenue stream. For that reason and taking into consideration the current FiT regulation and the findings of the techno-economic analysis; the paper proposes the amendment of the current FiT to allow for a proper gate fee to ensure the profitability of WtE projects and attract investment opportunities. Moreover, there is a need for the government to consider the role that financial incentives such as subsidies and tax exemption schemes as well as technical support can play in encouraging investment in WtE especially by targeting small and medium enterprises (SMEs) which will help disseminate small scale WtE projects across the country. As for the technical challenges facing WtE in Egypt, they mainly arise from the low quality of waste used as a feedstock which impedes these projects success which can be enhanced through adequate waste collection and segregation system to enhance waste quality and ensure the success of these projects.

Note

1. Zhang *et al.* (2021) argued that plastics have huge environmental consequences because of their special characteristics i.e. nonbiodegradability. Recovering energy from plastics can be done by end-of-life treatment.

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Annex 1
Abbreviations

BCR	Benefit-Cost Ratios
CAPMAS	The Central Agency for Public Mobilization and Statistics in Egypt
CBE	Central Bank of Egypt
CV	Calorific Value
EEAA	Egyptian Environmental Affairs Agency
FiT	Feed-in-Tariff
GWh	Gigawatt hours
IBA	Incinerator bottom ash
IRR	Internal Rate of Return
IWMS	Integrated Waste Management System
kV	kilovolt
kWh	Kilowatt-hour
LFG	Landfill Biogas
LHV	Lower Heating Value
MJ	Mega Joule
MoE	Ministry of Environment
MSW	Municipal Solid Waste
MWIMU	Municipal Waste Integrated Management Units
MW	Megawatt
NCV	Net Calorific Value
NGOs	Non-governmental organizations
NPV	Net Present Value
PBP	Pay-back Period
PPP	Public Private Partnership
SCP	Sustainable Consumption and Production
SDGs	Sustainable Development Goals
SDS 2030	Sustainable Development Strategy: Egypt's Vision 2030
SMEs	Small and Medium Enterprises
SW	Solid Waste
SWM	Solid Waste Management
SWMS	Solid Waste Management System
TPD	Tons Per Day
TWh	Terawatt Hours
WMRA	Waste Management Regulatory Authority
WMS	Waste Management System
WtE	Waste-to-Energy

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