Journal of Cleaner Production 280 (2021) 124047

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Towards a circular economy for sustainable development: An application of full cost accounting to municipal waste recyclables

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ARTICLE INFO

Article history:
Received 16 November 2019
Received in revised form
18 July 2020
Accepted 29 August 2020
Available online 6 September 2020

Handling editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Circular economy
Sustainability
Sustainable development
Municipal waste recyclables
Pay-as-you-throw (PAYT) full cost accounting approach
Emerging market

ABSTRACT

From a circular economy perspective, the municipal waste (MW) sector remains a valuable input source for waste recyclable re-industrialization among food, pollution, and energy. In this study, different accounting approaches and scenarios for sustainable MW management are explored to find the most cost efficient and profitable approach. The Full Cost Accounting (FCA) method is adopted as the basis of analysis in this study where an integrated sustainable framework for the Pay-As-You-Throw (PAYT) pricing model is developed and designed that can optimize MW management in attaining 'zero waste disposal' at the lowest cost as well as generating economic, environmental and social benefits. Using waste management data from 27 councils in Egypt and two different PAYT methods (i.e. weight-based and volume-based) under three case scenarios, this study documents that the prepaid bag system under the volume-based PAYT method leads to the lowest waste costs and creates more incentives for households in terms of economic, social and environmental benefits. These findings have various implications for the policy makers, government councils, waste managers, businesses and communities in the adoption of volume based PAYT schemes for cost-effective, profitable and socially acceptable reusing and recycling of waste. Such valuable addition to MW management can contribute to the environmental and socially sustainable development in emerging markets and in moving towards a circular economy model.

1. Introduction and overview

From the circular economy perspective, this study explores an advanced costing approach under the 'Full Cost Accounting' (FCA) called 'Pay-As-You-Throw' (PAYT) pricing model for municipal waste (MW) management in the Egyptian municipal councils to assess their dynamic cost efficiency in resource recovery from MW systems. The circular economy concept presents the integration of economic activity and environmental wellbeing in a sustainable way and is gaining weight as an alternative to the 'make, use, dispose' paradigm (European Commission, 2011). The recent 'Global Waste Management Outlook' (GWMO) has estimated about 7–10 billion tonnes of solid waste generation each year from urban households, commerce, industry and construction activities (UNEP and ISWA, 2015) which poses a severe threat to the environment and ecosystems. The entrenched linear economic activities in depleting natural resources that began in the 17th century industrial revolution has ignored the long-term environmental damage causing high social and environmental cost to the society. The linear economy exclusively focuses on economic need with the core principles of 'take, make, dispose' over exploiting resources and technological innovations for economic growth. Linear economy models involve extracting resources and using them to make products and then disposing them in landfill. In contrast, the concept of the circular economy replaces the 'dispose' aspect with 'repair, refurbish, recycle' by giving circular criteria to the life cycle of the products. It emerged as a paradigm shift with core principles 'take, make, reuse' that respond to environmental and societal needs while using natural resources. A circular economy values resources by keeping materials and products in use for as long as possible. Such a shift to a circular economy model requires eco-innovations of resources to manifest the needs of environmental resilience, despite the tendency towards economic growth (Scheel,

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https://doi.org/10.1016/j.jclepro.2020.124047

2016).

The circular economy allows the value of resources, materials, and products to remain on the marketplace for as long as possible, minimizing waste and the use of resources. Maximizing the use and value of resources brings major economic benefits, innovation and growth. However, safe disposal and recycling of materials often remain challenging for various reasons such as poor management and enforcement, regulatory disparities, lack of infrastructure and high cost of waste recycle systems etc., which can have environmental and associated public health impacts. One of the key outputs of diverse industrial and social activities is waste management from production activities and municipal sources. Although management of municipal solid waste is a priority in urban cities, the methods used for collection and disposal to date are far from perfect and cost effective, meaning that solid waste is not disposed of properly. Open dumping and burning methods are used excessively and heavily pollute the environment, endanger lives through the spread of highly infectious and deadly diseases, clog up sewerage systems and damage basic infrastructure. In many countries including Egypt in the Middle East and North Africa (MENA) region, and except for the majority of OECD countries, the antiquated systems of collecting, separating, weighing or sampling of solid waste and disposal are irreparably damaging the environment. Given that solid waste continues to be generated at an abnormal rate, the challenges are twofold – (i) the need for effective control and disposal of waste for sustainable development, and (ii) to have cost efficiency benefiting all stakeholders for appropriate waste management.

From the perspective of solid waste management, the cost effectiveness of separated waste collection and proper management for identification and separation of municipal waste (MW) is a key approach to promote the responsible use of waste as an economic resource. According to the principles of a circular economy, recycling implies additional costs for separated MW collection. The segregation and separation of household waste at source have been identified as key waste management methods to optimize MW management (Malinauskaite et al., 2017). While the circular economy is a comparatively new concept within the sphere of sustainability championed by the Ellen McArthur Foundation starting in 2010 (Ellen MacArthur Foundation, 2017), the MW sector appears to be one of the core integrated parts among food, pollution and energy security that can threaten all sustainability efforts from a circular economy perspective (Stankovska and Dimitrieska, 2017). Tisserant et al. (2017) argue that innovative waste treatment methods encompass the circular economy approach starting from waste generation until waste is reused and/or recycled. The circular economy concept is based on 'take, make and reuse' (see Egypt Business Directory, 2018 for more details) with its 3Rs principle of 'reduce or reduction, reuse and recycling' materials consisting of the characteristics of low consumption, low emission and high efficiency (Wang et al., 2014). Such a circular economy framework clearly illustrates the strong links between the environment and the economy and the minimization of the primary natural resource use (Ghisellini et al., 2016). It emphasizes a combined view of the three main aspects i.e. environment, resources and economic benefits (Lieder and Rashid, 2016) to achieve the ultimate goal of 'zero waste disposal' via the reuse, repair, restoration and recycling of existing materials and products and ensures that resources return to the value chain after use of a product. Reusing and recycling of waste can also significantly contribute to environmental and social sustainability.

While resource recovery or saving from municipal waste systems does require the cost-benefit analysis being economically feasible, achieving 'cost efficacy' is the key to promoting the responsible use of MW management as an economic resource that benefits all stakeholders. From management accounting perspectives, cost efficiency is the priority in dealing with operational activities relating to MW for sustainable development. In other words, the solutions of MW management should not only be environmentally sustainable but should also be cost-effective, profitable and socially acceptable (Malinauskaite et al., 2017). However, lack of accurate information on actual waste composition, collected and treated is one of the main barriers to waste management planning (Tisserant et al., 2017). So, the growing demand for information in business and society is driving accounting to become progressively complicated and integrated with organizational, economic and societal processes and activities. The much more important development aspect is the interaction between accounting including sustainability accounting and reporting (Thomson, 2007) and sustainability-related issues such as food security, pollution, and energy security. Nonetheless, little is understood concerning such interaction (Contrafatto and Burns, 2013). This is more challenging for an emerging economy like Egypt as compared to a developed economy. The application of FCA, under the umbrella of Environmental Accounting Management tools, helps to integrate environmental and social sustainability matters into decision-making. Nadeem et al. (2018) contend that FCA can effectively measure both direct and indirect costs and benefits (both internal and external) of an organization that leads towards the transition to a circular economy. While a number of FCA methods and tools have emerged over the last two decades with different goals and scope of the assessment, the FCA method of this study on MW in Egypt is more aligned with the United States Environmental Protection Agency's (USEPA, 1997) method for FCA that includes externalities in the cost/benefit assessment. These externalities are real costs to society, but they are not reflected in the price of MW services (Jasinski et al., 2015). In fact, in the existing MW pricing system in Egypt, the cost of external impacts is borne by society/households and neither business nor households consider or pay the full cost of MW services.

Therefore, the use of the advanced environmental costing approach FCA, and in particular the PAYT pricing model briefly described below, allows shared responsibility and benefit for municipal councils, businesses and households for recyclable commodities. In fact, the application of waste management using PAYT schemes reveals the effectiveness of PAYT schemes in both costs and waste reduction that would support the transition to the circular economy by providing a stable operating environment for all stakeholders (consumers, manufacturers, councils) and minimizing social and environmental costs to society. In waste management systems, the main purpose of PAYT strategies is to support a more sustainable management of waste flows from an economic, social and environmental point of view. This is usually based on the waste hierarchy process to produce lower flows of waste, first by both reducing polluted waste at source and re-using products and, secondly by increasing recycling rates by avoiding landfill. Such PAYT application generates economic benefits as well as environmental benefits in terms of both waste reduction and increased recycling rates (Karagiannidis et al., 2008; Lakhan, 2015; European Commission, 2015). Thus, the main scientific research question is to investigate an integrated sustainable framework for a PAYT pricing model designed from an accounting perspective, and then to explore the possible implementation methods of a PAYT program (Elia et al., 2015) in the Egyptian MW management service. As a case study, the research specifically bases on the FCA method where PAYT is modified and calculated for Egyptian municipal councils (for details, see Fig. 3 and Equations (1)–(3)). PAYT has two streams relating to costs and benefits of the scheme. For waste disposal, reuse and recycling purposes, on the one hand, the cost aspect follows the introduction of a mandatory charge through fixed costs (FCF) for construction and operational facilities and a variable cost (VCF) including direct (DC) and indirect (IC) costs for the reduction of waste generation and increases in recycling rates. On the other hand, the benefit aspect flows from food saving value (FSV) consumed and reduced, recyclable waste price (RWP), compost value (COMV), energy saving value (ESV) and savings from greenhouse gas emission (GHG). Considering both costs and benefits together, the total waste charge under a PAYT scheme (i.e. fee collection or pricing) can be determined for households and businesses that eventually integrates with sustainable development from a circular economy viewpoint. This is how the application of FCA (PAYT scheme) can support transition to the circular economy by combining both economic and environmental challenges and providing a stable operating environment.

The contribution of the present study firstly derives from the fact that the MW sector has a strong public benefit component to reach the best MW management that result in the lowest cost with highest circular economy benefits (food, pollution, and energy). In Egypt, the MW is not separated or sorted at source before collection, but waste pickers remove recyclables at disposal sites prior to collection processes by municipalities. The growing stream of MW in Egypt, either solid or food wastes, requires a sustainable waste management strategy (Egypt's Vision, 2030 Website, 2016), in addition to raising people's and organizational awareness towards this problem (Elmenofi et al., 2015). To adopt separated waste collection schemes and for raising public awareness, implementation of the PAYT accounting approach is essential. There are three technical pillars to implementing the PAYT approach: identifying the waste generator, measuring the waste amount that needs treatment, and unit pricing per emptying household and/or per kg or tonne. Both councils and households would get direct benefits of a cost-effective MW management system. Therefore, this study contributes to highlighting the best collection method that leads to the lowest cost and maximum benefit for all interested parties in MW management systems in Egypt by considering direct and indirect benefits to achieve sustainability. A second benefit is to support the design and the application of the effective PAYT accounting approach for pricing MW collection systems in Egypt by integrating economic, environmental and social aspects which are still lacking in the literature and in real practice. The proposed PAYT model aims to fill this gap by designing an integrated framework to support policy makers and waste managers in the adoption of PAYT schemes. It can create substantial economic, social & environmental benefits for industry, energy & food security, especially if it is managed properly with reasonable implementation of an integrated sustainable weight-based or volume-based PAYT costing approach. Such an accounting approach is still lacking in the literature and real practice in Egypt. Therefore, it is expected that the paper would contribute to the reevaluation of the current policy measures and the modification of the pricing policy design for municipalities.

The remainder of the paper is organized as follows: Section 2 briefly highlights the existing Egyptian municipal waste management and strategic vision 2030 for adopting the circular economy approach. Section 3 describes the methodology undertaken for an integrated sustainable framework for the PAYT accounting model for pricing MW collection systems, Section 4 extends the comparative analysis of the results and discussion with a suggested PAYT scenario implementation in Egypt (two suggested PAYT methods, i.e. weight-based pricing model and volume-based pricing model, have been proposed for implementation in Egypt). Finally, Section 5 proceeds with conclusions of the study.

2. Egyptian municipal waste composition and strategic vision 2030

The incremental growth in population, urbanization and income will double food demand over the next 50 years. On the other hand, the Food and Agriculture Organization (FAO, 2013) estimates that food loss and waste (FLW) "in the Near East and North Africa (NENA) amounts to 250kg/capita/year valued at over USD60 billion/year, or USD120/capita (conservative estimate). NENA natural resources lost due to FLW amounts to 42 km^3/year of water (food production and supply chains), and 360 million ha/year of land" (Mediterra, 2016b, p.194). In Egypt, food losses of the available cereals between harvesting and final consumption range from 13% to 15% (FAO, 2013). Additionally, 29% of the loss of fresh vegetables occurs in Egypt at post-harvest stage (Mediterra, 2016b). Therefore, edible and non-edible food waste represents a considerable proportion of MW in Egypt, as presented in Table 1 below. Table 1 illustrates the MW composition in Egypt compared with some developed countries. It is clear from Table 1 that Egypt's MW differs considerably from that in developed countries. The reasons for this range from lack of awareness and poverty to affluence in Egypt's urban population. In addition, much of the recyclables retrieved from MW occurs at various stages.

Again, from the circular economy perspective, reuse and recycling are vital waste management approaches. Waste management technologies could reduce the environmental impact of food waste with economic gains (HLPE, 2014) by sorting, re-using, composting and bioenergy (Maalouf and El-Fadel, 2019). From the waste management perspective, less waste can save both money and energy and it also means more efficient use of raw materials. Table 2 illustrates the recycled and landfilled percentage of MW flows in different developed countries compared with Egypt. It is evident from Table 2 that Egypt's recycled MW and landfill substantially differ from that in developed countries. However, Egypt's Strategic $^{\text{Vision 2030}}$ (see Egypt's Vision, 2030 Website, 2016) sets targets to reduce the percentage of hazardous waste disposed after safe treatment and/or recycling from 7% to 30% in 2020 and then to 100% in 2030. Concurrently, the percentage of MW regularly collected and managed in a suitable manner will increase from the current 20% (by collection efficiency 60%) to reach 40% in 2020 (by collection efficiency 80%) and then to 80% in 2030 (by collection efficiency 90%). These MW management targets in Egypt may lead the country through the circular economy.

3. Methodology for integrated sustainable framework for PAYT pricing model using full cost accounting approach for MW collection system

As mentioned earlier, achieving cost efficiency is the key to promoting the responsible use of waste as an economic resource that can benefit all stakeholders in any jurisdictions. MW management needs to be environmentally sustainable as well as cost-effective. In this study, different accounting approaches and case scenarios for sustainable MW management are explored to find the most cost efficient and profitable approach. In doing so, from the methodological perspective, Egyptian waste management data has been collected, firstly where the primary information is mostly from websites, books, journals, etc. as well as a lot of facts and data from international and national reports. Secondly, the FCA method is adopted as the basis of analysis in this study where an integrated sustainable framework for the PAYT pricing model is developed and designed. It is considered as the most effective collection system

Table 1
MW Composition by Country (percentage of weight).

	Organic/Food (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
World	46	17	10	5	4	18
Egypt	**60**	**10**	**12**	**3**	**2**	**13**
Australia	47	23	4	7	5	13
United States	25	34	12	5	8	16
France	32	20	9	10	3	26
Germany	14	34	22	12	5	12
Japan	26	46	9	7	8	12
Canada	24	47	3	6	13	8

Source:Hoornweg and Bhada–Tata (2012).

Table 2
Recycled MW and landfilled flows in different developed countries compared with Egypt in 2017.

Country/region	Share of MW recycled (%)[a]	Share of MW landfilled (%)[b]	Share of MW in total solid waste (%)
Egypt	12	88	25
Australia	46	47	30
United States	44	42	40
European Union	29	19	37
Japan	19	9	29
Canada	41	55	44

[a] Percentages may not add some treatments, such as reuse and composting.
[b] Landfill includes non-controlled dumping sites; it also includes waste disposal by incineration etc., being the least preferred option.
Source: Ministry of Environment (2017); Tisserant et al. (2017).

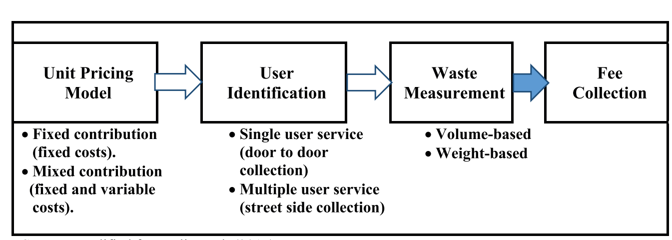
that has proven to give the highest yield to boost sorting technology such as focusing on the products design stage (Maurer, 2016) and designing Pay-As-You-Throw schemes (Elia et al., 2015). Thirdly, using the FCA method, three case scenarios are analyzed and compared based on the PAYT pricing model. These scenarios are: (A) PAYT is not implemented, (B) PAYT is implemented but no waste reduction occurs, and (C) PAYT is implemented and waste reduction occurs.

It is noted that these case scenarios explicitly exhibit the difference between the pricing model without PAYT (case scenario A) and pricing model with PAYT (case scenarios B and C). In the absence of a PAYT scheme, the other pricing model is usually a household or commercial 'flat rate' to be paid to the municipals for the waste management services. These fees mainly depend on the commercial and non-commercial activities. In addition, there are fee charges to informal garbage collectors and disposal of household or commercial waste, while additional one-off or recurring charges may also incur for landfill and burning facilities depending on the need of household or commercial firms. In aggregate, the 'flat rate' pricing model (case scenario A) appears to be more expensive than the PAYT pricing model (case scenarios B and C) for all stakeholders, as evidenced in the case analyses for scenarios A, B and C in sub-section 4.2 below. In fact, the former pricing model does not capture the impacts associated with environmental and social externalities. Further, it is highlighted here that in this study, the case scenario B refers to 'traditional PAYT pricing model' that extends to case scenario C as 'modified PAYT pricing model' by integrating some direct and indirect aspects of the economic, environmental and social benefits. Although Fig. 1 below demonstrates the traditional PAYT pricing model under the FCA method, this study extends it to Fig. 2 below incorporating environmental and social impacts (resource recovery or saving) which is known as the integrated sustainable framework for the PAYT pricing model. The environmental and social impacts/benefits range between direct to indirect ones derived from a modified PAYT pricing model. On one hand, the direct social benefits could be related to food saving, health, job creation and the recycle waste market. On the other hand, the indirect environmental benefits are linked to improved air quality, greenhouse gas emission and energy saving value. The integrated sustainable framework for the PAYT pricing model is reflected in the case scenario C documenting solid advantages over case scenario A and, to some extent, over case scenario B. As such, the methodology is described below stating the application of the traditional PAYT pricing model with relevant figures and mathematical equations and then extends to the integrated sustainable framework for the PAYT pricing model. Accordingly, the three case scenarios are analyzed and interpreted to identify the best cost-effective and resource recovery or saving scenario that supports sustainable development towards a circular economy.

3.1. Application of PAYT pricing model

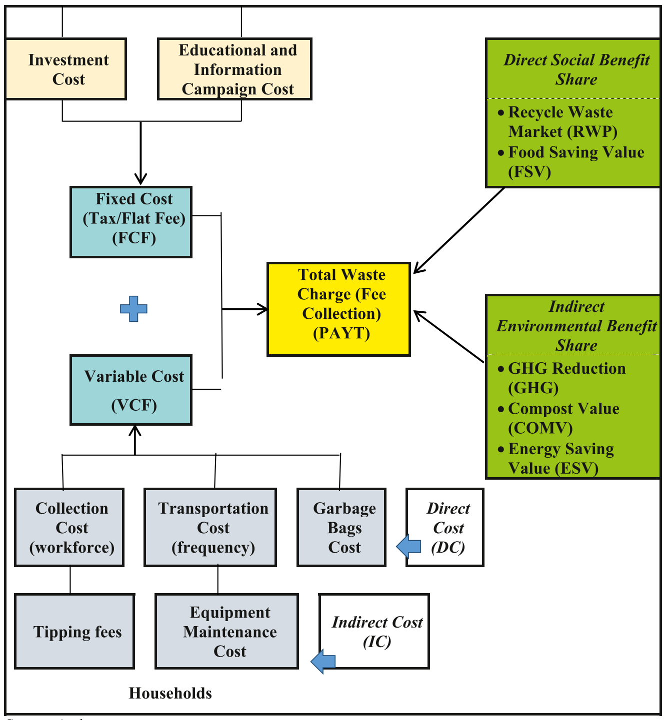
The main steps to follow in a PAYT system are the identification and measurement of waste under the unit pricing model, as presented in Fig. 1 below. Alternative PAYT methods have also been investigated in the literature, however the single user service (door to door collection) is more common for household MW collection services (Elia et al., 2015). According to the classification proposed by the U.S. EPA (U.S. Environmental Protection Agency, 1997), the costs include:

a) *Up-front costs* which include the initial investment to purchase and establish the essential equipment and technology to collect



Source: Modified from Elia et al. (2015).

Fig. 1. Main steps in a PAYT system.



Source: Author

Fig. 2. Integrated sustainable framework for PAYT pricing model using FCA approach. Source: Author

waste, such as vehicles. As well, it may cover the cost of public awareness information campaigns about the new and updated MW service.

b) *Operating costs* which include all costs that may vary with the waste collected, transported and final disposal. Also, it covers workforce, fuel and purchase costs for garbage bags, in addition to managing waste collection activities on a daily basis.

Adopting PAYT charging models which are defined as unit or variable rate pricing models when applied in MW management systems, requires evaluation for new organizational issues which increases the waste management service complexity level compared to the adoption of flat charging models (Elia et al., 2015). Under PAYT models, each citizen must pay for the overall service cost based on their actual quantity of waste they throw away. The most popular accounting system for MW management that applied PAYT strategies is the FCA method (Weng and Fujiwara, 2011; Karagiannidis et al., 2008; D'Onza et al., 2016).[1] Weng and Fujiwara (2011) evaluated the MW management system effectiveness in Taiwan using an integrated cost–benefit analysis with more focus on financial cost effectiveness of MW systems. On the other hand, Karagiannidis et al. (2008) adopted the full cost accounting method to estimate the waste management cost and household waste charges in Greece using different "polluter-pays" scenarios, and D'Onza et al. (2016) proposed a methodology for calculating the full collection costs from various waste types.

As this study's analysis focuses exclusively on the waste collection process, measuring the full cost of collection activities requires estimating the direct and indirect variable costs where the fixed costs are charged as a fee on electricity use in Egypt. The estimated direct costs include the garbage bags, labour, vehicles and fuel that are used or involved in the MW collection activities.

Currently, two main approaches are used to define the fee pricing/charging model. The first approach is to calculate the fee based on a single contribution that differs according to the level of service consumption while the second approach is based on a mixed model where both fixed and variable contributions exist. Thus, following the basic charging model of Elia et al. (2015), a Municipal Waste Collection Fee (MWCF) is charged to the ith user where i is the governorate/council which is based on two main components defined in Eq. (1):

$$MWCF_i = FCF_i + VCF_i \tag{1}$$

where, FCF_i is the fixed costs of the MW management service which covers the basic fee, and VCF_i is the variable costs which covers the ith user fee contribution. FCF_i which is generally estimated based on different parameters rather than depending on the collected waste from a user. For example, it may depend on net income of citizens, total number of residents in a house, or the commercial/non-commercial activities of users, etc.

In this paper, FCF_i is based on the estimated investment cost for the proposed program[2] by the Central Department of Waste Management of the Egyptian Environmental Affairs Agency (EEAA) in 2014 to improve the MW system. Again, VCF_i is estimated based on the actual quantity of collected waste from the user which is defined in Eq. (2):

$$VCF_i = \left[Q_{NR}(DC + IC)_{NR} + \sum_{j=i}^{k} Q_j (DC + IC)_j \right] \tag{2}$$

where Q_{NR} and Q_j are, respectively, the quantity in tonnes from non-recyclable (organic/food) and recyclable waste flow collected from the i user (i.e. the governorate/council). DC and IC are the unitary costs for direct and indirect costs including garbage bags, collecting, transporting, maintenance and tipping for final treatment and/or disposal.

The inclusion of direct and indirect environmental and social costs/benefits in the MW charging fee has been suggested by prior studies to give a more comprehensive view for the local governments about the integrated performance level of the MW management processes (for more reading see Weng and Fujiwara, 2011). To do so, the PAYT pricing model in Fig. 2 uses the FCA method. By applying FCA, it is possible to expand traditional PAYT models to involve direct and indirect environmental and social benefits (which are considered as cost reduction or savings) due to the impact of MW collection services on other industrial activities and resources such as food security, environmental pollution and energy security. Accordingly, Fig. 2 below presents the proposed integrated sustainable framework for the PAYT pricing model design using the FCA approach.

[1] FCA generally refers to 'the process of collecting and presenting information for each available alternative, in order to conclude to a decision, and may be considered in terms of environmental, economic and social impacts. FCA aims at recognizing, quantifying and allocating the cost related to a process, or a product, by counting, where appropriate also, the environmental and social cost' (Karagiannidis et al., 2008, p. 2801).

[2] The proposed program covers the investment costs related to improving the MW system's administrative and setup costs; direct and indirect fixed costs. It includes removal of accumulated solid waste; prevent further accumulations by improving the efficiency of collection and transport; establish mobile and stationary transfer stations; control dumpsites and improving its efficiency; establish centres for waste recycling; and establish sanitary landfills. To execute the proposed program, the estimated financial allocations required are EGP3,2954 million in 2014, which reached EGP7,000 million in 2017 which is approximately USD437.5 million (where USD1 = L.E.16).

The integrated sustainable framework for the PAYT pricing model is an expansion of the PAYT charging model in Eq. (2) for pricing interrelated environmental and social impacts (saving resources) of the MW collection service that is based on a source waste separation approach. Thus, the integrated charging model proposed for the ith user is defined in Eq. (3):

$$VCF_i\left[\left[\sum((Q_{NR}-Q_{NRR})FSV)_i\right]-(Q_{NR}(DC+IC)NR)+\left(\sum_{j=1}^{k}((Q_j-Q_{jR})RWP_j)-\left[Q_j(DC+IC)_j\right]\right)\right]_i+\left[\sum_{w-1}^{k}(Q-Q_R)(COMV+ESV-GHG)\right]_i+\left[\sum_{w-1}^{k}(Q)GHG\right] \tag{3}$$

where.

- Q_{NR} is the quantity of tonnes from non-recyclable (organic/food) waste flow collected from the ith user (where the ith user is the governorate/council).
- Q_{NRR} is the quantity of consumed tonnes reduced by reusing (eatable) non-recyclable (organic/food) waste.
- FSV is the food saving value per tonne consumed and reduced.
- DC and IC are the unitary costs for direct and indirect costs including garbage bags, collecting, transporting, maintenance and tipping for final treatment and/or disposal.
- Q_j is the quantity in tonnes from recyclable waste flow collected from the i user.
- Q_{jR} is the expected reduction in quantity of the recyclable waste j.
- RWP_j is the recyclable waste j price.
- Q is the total quantity of wastes.
- Q_R is the expected reduction in total quantity of wastes (recyclable and organic/food) flow collected from the ith user.
- COMV is the expected unitary savings from compost value.
- ESV is the expected unitary savings from energy saving value; and,
- GHG is the expected unitary savings from greenhouse gas emission respectively, for each tonne of waste reduced due to adopting one of the door-to-door collection methods including weight-based accounting and volume-based accounting.

3.2. Waste collection methods and budget allocation

Waste collection methods vary from one country to another based on the level of awareness, investment cost and the

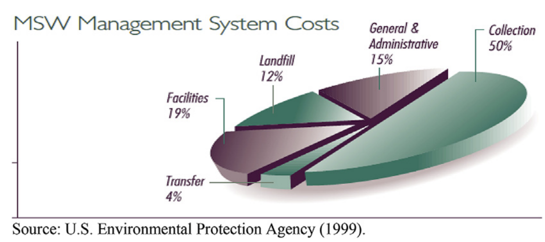


Fig. 3. Typical MW management budget allocation.
Source: U.S. Environmental Protection Agency (1999).

Table 3
General MW data in Egypt.

MW Data	2015	2017
Estimated population	93.78 million	94.8 million
Number of households	17.3 million	23.5 million
Waste generation rate (tonne/year)	22 million	22.9 million
MW generation rate per capita (kg/cap/year)	235	235
MW generation rate per capita (kg/cap/day)	0.65	0.65
• *Collection of residual waste*	Yes	Yes
Responsible authority	Public and private municipal cleansing service	Public and private municipal cleansing service
Collection method	Contracted or delegated service	Contracted or delegated service
Collection mean	Back-loading truck	Back-loading truck
Collection frequency	7 days/week	7 days/week
• *Separate Collection of recyclables*	No	No
Responsible authority	n/a	n/a
Collection method	Manual informal collectors	Manual informal collectors
Collection means	n/a	n/a
Collection of green waste	No	No
Transportation	n/a	n/a
• *Treatment*		
Existence of treatment	No	No
Transfer station	Yes	Yes
• *Final disposal*	Semi-controlled landfill	Semi-controlled landfill
Average distance to landfill (km)	Varied	Varied
Collection of bulky waste	n/a	n/a
• *Variable cost*	30USD* (in 2014)	32USD**
Direct 66%: Collection, transport and disposal cost per tonne	19.8USD/tonne***	21.12USD/tonne***
Indirect 34%: Maintenance and other costs per tonne	10.2USD/tonne***	10.88USD/tonne***
• *Fixed cost*		
Proposed program investment costs to improving MW system.	470.8USD* million (in 2014)	437.5USD** million

Source: Gathered from National Solid Waste Management Programme (NSWMP, 2013) and The Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries (2014) and Ministry of Environment (2017). * 1USD = 7L.E.; ** 1USD = 16L.E.; *** Calculated Value.

Table 4
Waste prices and savings (averages).

	USD/TONNE
* Dry Bread - 6% of total food waste***	109.4
* Plastic	343.8
* Metal	843.8
* Paper & cartoon	96.9
* Glass	23.5
* Others	60.2
** Compost value	25
** Energy value	70
*** GHG reduction value	33.54

Source: * http://www.albawabhnews.com/2547362.
** http://www.almasryalyoum.com/news/details/1180425.
*** Nakhla et al. (2013), **** Capone et al. (2016).

participants' ability to use high technology such as Internet of Things (IOT) (Mustafa and Ku Azir, 2017). Each collection method such as door-to-door, curb-side pick-up, community bins, self-delivered, contracted or delegated service has its advantages and disadvantages. Single user service (door to door collection) is the most common for household MW services (Elia et al., 2015). Egypt has been classified as a medium income country with an average 62.5% collection rate (Hoornweg and Bhada-Tata, 2012). This indicates that Egypt's collection costs are high ranging from 50% to 80% of the MW management budget, especially with the lack of community and household participation. US-EPA (1999) indicates the typical MW management budget usually allocated is presented in Fig. 3 below.

4. Description of results on suggested PAYT scenario implementation in Egypt

Table 3 below presents the general MW management system data in Egypt for the years 2015 and 2017. It reveals that the yearly MW generation rate is 22.9 million tonnes in 2017 while the per capita generation rate is 235 kg/year and 0.65 kg/day. With a weekly collection frequency, the average direct variable cost in 2017 is USD21.12 per tonne and the indirect variable cost is USD10.88 per tonne, i.e. total USD32. The estimated fixed cost for improving the MW system is USD437.5 million.

Now, assuming the year 2017 as an implementation year, data have been collected from 27 Egyptian governorate/councils for their demographic municipal data, waste-production (recyclables and non-recyclables), and financial and market prices for recyclables. The database spreadsheet is generated and developed, and essential calculations and assumptions are considered to estimate all waste streams for the implementation year 2017. That is, the unit prices are calculated for waste to be recycled and the expected environmental and social revenues/savings. The unit price is calculated for each PAYT accounting method (i.e. weight-based accounting using number of tonnes and volume-based accounting using number of prepaid garbage bags) to calculate the potential costs/revenues/savings, taking into account the potential reduction in waste generated which is stated as an average of 35% (The Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries, 2014).

Table 4 below shows waste prices and savings calculations and indicates that metal would cost the highest on average USD843.8 per tonne followed by plastic USD343.8 per tonne. Next is dry bread (USD109.4 per tonne), paper and cartons (USD96.9 per tonne), grass (USD23.5 per tonne), and others (USD60.2 per tonne). Again, the estimations of this study reveal that for 27 Egyptian governorate/councils, the average compost value is USD25 per tonne while the energy value is USD70 per tonne and the GHG reduction value is USD33.54 per tonne. From an environmental perspective in Egypt, the reduction of GHG per tonne appears to be highly significant with a positive implication for all shareholders.

Again, the total municipal waste collection fee (MWCF) is calculated with fixed (FCF) and variable (VCF) costs (see Eq. (1)) that should be charged for each tonne. Table 5 below presents the results for the two different stages/aspects (i.e. before and after implementing PAYT) on their different VCF cost (see Eq. (3)) for collecting, transporting and final disposal. It is noted that the difference between them is the prepaid bag cost per tonne (USD6.25 per tonne). Table 5 shows the percentage of recyclables is 44% while non-recyclables is 56% for the 27 Egyptian governorate/councils. The direct and indirect costs for the former are USD9.29 and USD4.49 per tonne and for the latter USD11.83 and USD6.09 per tonne. For recyclable waste, the total variable cost per tonne before implementing PAYT is USD14.08 while for non-recyclable waste, it is USD17.92. In total, the variable cost per tonne before implementing PAYT is USD32 and after implementing PAYT is USD44.5, which includes USD12.5 for prepaid bag costs per tonne for both recyclables and non-recyclables.

To compare results, the two PAYT accounting methods are differentiated (i.e. weight-based accounting using number of tonnes and volume-based accounting using number of prepaid garbage bags) by applying the integrated sustainable pricing model under three case scenarios as mentioned below by their charging bases:

- Case scenario A: PAYT is not implemented.
- Case scenario B: PAYT is implemented but no waste reduction occurs.
- Case scenario C: PAYT is implemented and waste reduction occurs.

In the comparative analysis of the results, the investment cost (fixed cost) is the same in all PAYT cases whether waste reduction has occurred or not. By contrast, for all implementation scenarios, the operational cost will be potentially reduced by the monetary savings earned directly due to revenues from marketing recyclables.

4.1. Case scenario A: PAYT is not implemented

Under the current MW collection and disposal system in Egypt,

Table 5
Total variable cost per tonne for collecting, transporting and final disposal.

	Food/Organic - non-recyclable (Q_{NR}) 56%	Recyclable (Q_j) 44%	Total USD
Direct Cost (DC) - USD	11.83	9.29	
Indirect Cost (IC) - USD	6.09	4.79	
Total Variable cost per tonne before implementing PAYT - USD	17.92	14.08	32
Prepaid garbage bags cost per tonne - USD	6.25	6.25	12.5
Total Variable cost per tonne after implementing PAYT - USD	24.17	20.33	44.5

Source: Author calculation and Ministry of Environment (2017).

Table 6
Profit, full cost and interrelated effect per MW tonne collected under PAYT accounting methods without waste reduction - Case scenario B.

		Mean	St. Dev.	Min.	Max.
Weight- based	Full cost per tonne (USD)	63.09	28.69	28.84	135
	Profit per tonne (USD) after considering recyclables value.	21.85	28.66	−50[a]	56.05
	Benefit per household (USD) after considering recyclables value.	22.01	39.98	−77.5[a]	132.43
	Profit per tonne (USD) after considering compost, energy and GHG values.	83.31	28.66	11.46	117.51
	Benefit per household (USD) after considering compost, energy and GHG values.	89.11	70.52	9.17	281.02
Volume-based	Full cost per tonne (USD)	41.49	28.37	7.56	112.63
	Profit per tonne (USD) after considering recyclables value.	43.46	28.32	−27.63[a]	77.33
	Benefit per household (USD) after considering recyclables value.	45.72	42.56	−22.1[a]	182.85
	Profit per tonne (USD) after considering compost, energy and GHG values.	104.92	28.32	33.83	138.79
	Benefit per household (USD) after considering compost, energy and GHG values.	112.82	90.63	25.19	411.44

[a] (−) sign means extra cost should be incurred by governorate or household to cover total MW collection costs.

residents indirectly pay a ‘flat fee’ for the waste management service via their electricity bill, in addition to informal charges. The fee mainly depends on the household activities which are either commercial or non-commercial. The fee ranges from L.E.10/month (USD0.63) per household to L.E.60/month (USD3.75) for shops and commercial activities. Under this case scenario, all household wastes are not separated or sorted before collection and no additional investment cost for the PAYT program will be considered. The results indicate that the total MW cost management under case scenario A (without considering any revenues earned from marketing recyclables) is USD732.5 million from which $410 million is for organic food waste (non-recyclables). Total recycled wastes (12%) are approximately USD88 million while the rest (88%) are USD644.5 million land filled for 27 Egyptian municipal councils. The total flat fee revenue charged based on the number of households (23.5 million in 2017) is around USD177.5 million/yr (L.E. 2818 million in 2017) for 27 Egyptian councils. This indicates the severe gap (USD555) between cost (USD732.5 million) and collected fees (USD177.5 million) under case scenario A, where PAYT is not implemented. That is, MW collection costs in 27 Egyptian councils are much higher (>50%) than collected fees under the no PAYT program.

4.2. Case scenario B: PAYT is implemented but no waste reduction occurs

By adopting a PAYT program, residents directly pay for the services of waste collection based on the amount of wastes they throw away. The amount of waste is measured by two PAYT accounting methods such as weight-based and volume-based. Table 6 below presents the findings of these two PAYT accounting methods. When PAYT is implemented even without any waste reduction occurring (case scenario B), the prices for recyclables covers both variable and fixed collection costs leading to cost savings per tonne which indicates a profit for the governorate/council. Where a negative sign value occurs, it means an extra cost per tonne should be incurred by the governorate or per household to cover the total MW management cost. Additional environmental and economic values from composting and energy generation are a bonus as shown in Table 6 below, although extra costs have to be added to mitigate or reduce the GHG emissions during composting and recycling activities and until final treatment or disposal. After considering indirect environmental and economic values generated from MW collection with source waste separation by households, the overall value for the total cost per tonne or per household is profitable under both PAYT accounting methods.

More specifically, full costs per tonne under the weight-based scheme are USD63.09 while under the volume-based scheme they are USD41.49. It is notable that the net yield for recyclables under the volume-based scheme is better compared with the weight-based scheme probably because the weight-based scheme is more labour intensive. By implementing a volume-based scheme, each MW could generate 51% (USD43.46) profit per tonne above the full MW management costs and 52% (USD45.72) benefit generated per household compared with only 25.7% (USD21.85) profit per tonne and 25.9% (USD22.01) benefit generated per household by the weight-based scheme, respectively. Again, both profit per tonne for governorate/council and benefit per household from composting, energy and GHG emission values are higher under the volume-based scheme (USD104.92 and USD112.82 respectively) than the weight-based scheme (USD83.31 and USD89.11 respectively).

4.3. Case scenario C: PAYT is implemented and waste reduction occurs

In general, the overall waste disposal rate has been decreased by 25−45% in countries and communities that have established a PAYT system (The Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries, 2014). In the analysis in this study, an average of 35% potential reduction is estimated in the amount of waste generated. This reduction is expected to decrease total collection costs which in turn is expected to increase profit and benefit share per tonne.[3]

Table 7 below illustrates the paired analysis *t-test* for councils per tonne under two PAYT accounting methods (i.e. weight-based accounting and volume-based accounting), in addition to recyclables, and environmental and social values under case scenario B and C compared against case scenario A (after exclusion of a charged flat fee). As fixed investment costs are the same under case scenarios B and C, the outputs are mainly affected by variable cost differences. In case scenario B, average variable costs for weight-based and volume-based methods are USD22.91 and USD12.76, respectively. Again, in case scenario C, average variable costs for weight-based and volume-based methods are USD23.14 and USD12.89, respectively. In both cases for the average variable cost per tonne, the volume-based method is less costly than the weight-based method. It is noted that the average variable cost per tonne under case scenario C is slightly increased compared with case scenario B. Similarly, while the values of recyclables are much higher in case scenario C than case scenario B, the reverse is evident for the environmental and social value. These are because transportation and maintenance costs are affected by collection

[3] To encourage households to separate waste at source, incentives are usually extended to the solid waste management sector to develop its infrastructure. Incentives could be granted either by profit share or by fee waiving. Profit share is implemented by using partial tax holiday or full tax holiday, where full or only a portion of recyclable waste profits and income will be exempted. Fee waiving is implemented by direct cancellation of collection fees for recyclable waste is an example.

Table 7
T-test to difference in the means versus 'Case Scenario A' waste collection per tonne.

	Average MW full cost/benefit per tonne	Average Differences	*t-value*	*Sig.*
Case scenario B:				
Weight- based – Variable	22.91	1.86	7.20	0.00*
Weight- based – Full	63.09	42.04	3.12	0.00*
Volume-based – Variable	12.76	−8.30	11.00	0.00*
Volume-based – Full	41.49	20.42	0.09	0.93
Recyclables value	84.91	63.85	16.04	0.00*
Enviro & social value	61.46	40.41	7.25	0.00*
Case scenario C:				
Weight- based – Variable	23.14	2.08	7.12	0.00*
Weight- based – Full	84.95	63.89	4.47	0.00*
Volume-based – Variable	12.89	−8.16	10.96	0.00*
Volume-based – Full	63.14	42.08	2.22	0.03*
Recyclables value	109.41	88.35	25.23	0.00*
Enviro & social value	51.69	30.63	3.59	0.00*
Case scenario A	21.05			

Note: All p-values are two-tailed; * Coefficient is significant at the 0.01 level (two-tailed).

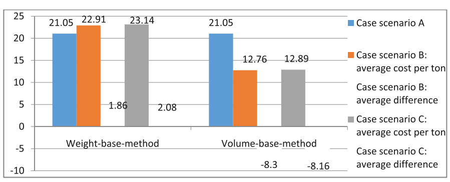


Fig. 4. Average variable collection costs per tonne comparison under three case scenarios A, B and C.

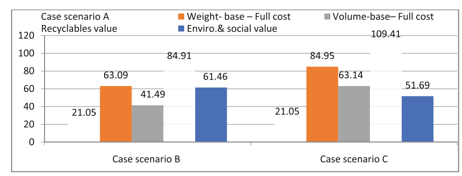


Fig. 5. Full costs of MW management per tonne against economic (recyclables), environmental and social values for two PAYT accounting methods under three case scenarios A, B and C.

frequency (daily), as well as by the quantity of waste collected.

The results from this study shown in Table 7 reveal significant differences in the means of MW collection cost per tonne in favour of the volume-base method (t-value 11.00 with p-value <0.01 and t-value 10.96 with p-value <0.01) versus the weight-base method (t-value 7.20 with p-value <0.01 and t-value 7.12 with p-value <0.01) under both case scenarios B and C respectively, and against case scenario A (see Fig. 4).

Furthermore, the differences in the means are significant under both case scenarios B and C for recyclables, environmental and social values (see Fig. 5). However, Table 7 reveals that recyclables are likely to be much higher in case scenario C (t-value 25.23 with p-value <0.01) compared with case scenario B (t-value 16.04 with p-value <0.01). For environmental and social values, the results indicate a limited advantage for case scenario B over case scenario C (t-value 7.25 with p-value <0.01 and t-value 3.59 with p-value <0.01).

On the other hand, Table 8 below also shows the paired analysis *t-test* for households under two PAYT accounting methods (i.e. weight-based accounting and volume-based accounting), in addition to recyclables, and environmental and social values under case scenario B and C compared against case scenario A (after exclusion of charged flat fee). As fixed investment costs are the same under case scenarios B and C, the outputs are mainly affected by variable cost differences. Here, in case scenario B, average variable costs for weight-based and volume-based methods are USD25.14 and USD14.00, respectively. Again, in case scenario C, average variable costs for weight-based and volume-based methods are USD16.55 and USD9.23, respectively. In both cases for the average variable cost per household, the volume-based method is less costly than the weight-based method in Table 8, which is similar to Table 7. However, notably unlike Table 7, in Table 8 the average variable cost per household under case scenario C is much lower as compared with case scenario B. Similarly, as per Table 8 the recyclables value and environmental and social value per household are much lower in case scenario C than case scenario B. These findings clearly document the suitability of the integrated sustainable framework for the volume-based PAYT pricing model under the FCA method (i.e. Fig. 2) generating economic, environmental and social benefits. Therefore, the case scenario C under the volume-based (not weight-based) 'modified PAYT pricing model' presents the best cost-effective and resource recovery/saving scenario that supports sustainable development towards a circular economy.

The results of the analysis in Table 8 indicate significant differences in the means of MW collection variable costs per household. They are similar under both case scenarios B and C ($t \approx 5$ with p-value <0.01) as well as having an inverse relationship with costs per household in case scenario A, under both PAYT accounting methods (i.e. volume-based and weight-based) (see Fig. 6). However, in the same context, the differences in the means of MW collection full costs per household are insignificant. Additionally, the differences in the means of recyclables are significant under both case scenarios B and C with the same t-value (see Fig. 7), whereas environmental and social values are significantly higher under case scenario B (t-value 5.47 with p-value <0.01) compared with case scenario C, which reported a relatively insignificant small t-value (1.60) probably due to the reduction in total MW collection amounts under case scenario C.

5. Discussion and conclusions

Countries considering adopting the circular economy approach and PAYT need to determine whether the charge for MW services will be based on volume-based or weight-based of the waste collected. Both weight-based and volume-based methods are very different in design and equipment requirements. In a volume-based

Table 8
T-test for the difference in the means versus case scenario A waste collection per household.

	Average MW cost/benefit per household	Average Differences	*t-value*	*Sig.*
Case scenario B:				
Weight- base – Variable	25.14	−9.8	5.37	0.00*
Weight- base – Full	70.72	35.79	0.09	0.93
Volume-base– Variable	14.00	−20.94	5.33	0.00*
Volume-base– Full	59.58	24.64	1.22	0.23
Recyclables value	92.7.	57.76	5.29	0.00*
Enviro & social value	67.10	32.04	5.47	0.00*
Case scenario C:				
Weight- base – Variable	16.55	−18.39	5.36	0.00*
Weight- base– Full	62.13	27.19	0.89	0.38
Volume-base– Variable	9.23	−25.71	5.33	0.00*
Volume-base– Full	54.81	19.87	1.86	0.07
Recyclables value	77.64	42.70	5.28	0.00*
Enviro & social value	56.43	8.89	1.60	0.12
Case scenario A:	34.93			

Note: All p-values are two-tailed; * Coefficient is significant at the 0.01 level (two-tailed).

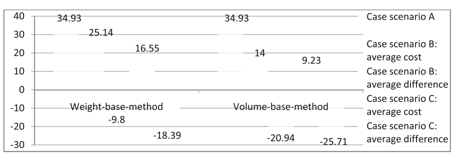


Fig. 6. Average variable collection costs per household comparison under three case scenarios A, B and C.

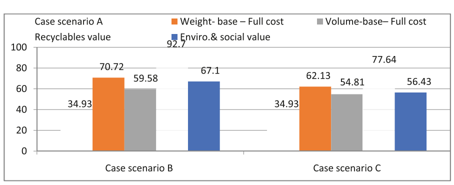


Fig. 7. Household contribution to MW full cost, economic (recyclables), environmental and social values for two PAYT accounting methods under three case scenarios A, B and C.

program, residents are charged for waste collection based on the number of bags or cans they use, indicating size of waste containers. On the other hand, in a weight-based program, waste is weighed at the curb where collection crews measure the amount of waste residents set out for collection and they are billed for collection and disposal accordingly. Although most countries use volume-based systems which are significantly less expensive to set up, operate and manage than weight-based systems, to administer the MW service as part of their transition to the circular economy, Egypt neither adopts the circular economy approach nor the volume-based or weight-based system in MW collection programs. The current method of waste management in council in Egypt is a 'flat rate' on collection and disposal of waste for all residents irrespective of the volume or weight of waste as described in Section 4 under case scenario A: 'is not implemented.' Unlike the PAYT volume-based or weight-based system, this flat rate system is much more costly without having any sustainable benefits in terms of social and environmental aspects in order to support the transition towards the circular economy. Therefore, in this paper, Egypt has been taken as a case study where the application of an effective PAYT accounting approach for pricing MW collection systems has not yet been developed.

Building on prior literature and practical experience gained from other countries, the integrated PAYT model proposed in this study under a volume-based system aims to achieve cost efficiency and financial benefits for both municipal councils and households. Therefore, in this study 27 council waste management costs, benefits and the resulting municipal charges are considered by using FCA for the two different PAYT methods (i.e. weight-based and volume-based) under three case scenarios for implementation. The integrated PAYT framework is to support policy makers and waste managers in the adoption of PAYT schemes. Based on the experiences documented in other countries, both a fixed and a variable fee in Egyptian municipal councils are adopted in this study rather than a 'flat rate' only, depending on the amount of waste generated. This is because, on the one hand, waste collection fees charged should reflect the cost structure of waste disposal which includes both fixed and variable costs while, on the other hand, levying fees on collected waste quantities may only increase illegal disposal activity. Therefore, the fixed fee inclusion in the service fee will help to mitigate such practices. Furthermore, in order to incentivize more collection of separated waste at source, fees on the collection of residual organic food waste could be used to fund source separation activities. Therefore, fees are set only on residual organic food waste and providing the service of collection for recyclables without charges, or they may go further by buying separated recyclables from the user.

Comparative analysis in this study identifies the differences in unit costs of the waste collection and the best method in financial terms for both households and the municipal councils. The results reveal that both PAYT methods (i.e. weight-based and volume-based) will reduce the cost incurred by the councils and for households, if anticipated waste reduction occurs (i.e. case scenario C). The variable cost (collection, transportation and final disposal costs) for the volume-based method (garbage bags-based) will be decreased by an average of 39% per tonne in all cases compared with weight-based methods which is slightly increased by 9.5% per tonne. This is because weight-based methods require more labour to do the weighing process. However, the variable costs per household under both case scenario B and case scenario C (PAYT based) are lower than case scenario A (without PAYT). If a family is willing to achieve waste reduction (under case scenario C), the percentage of variable cost reduction for the household will be higher for the volume-based method (74%) against the weight-based method (53%). Therefore, the volume-based bag method creates more incentives for households because it has the lower variable charge (USD14/bag/year - case scenario B (volume-based)) and, after reduction efforts, the variable waste charges may decrease by 34% (USD9.23/bag/year - case scenario C (volume-based)). The prepaid garbage bag scheme leads to the lowest waste charges for both case scenario B and case scenario C. Thus, the highly suggested method to be implemented in Egypt is based on a prepaid garbage bag system under the volume-based modified PAYT method (under case scenario C). This can generate a cost-effective scheme. The weight-based method is less applied in practice, as it is more labour intensive, and complicated to design and manage.

Again, there are incentives for the municipal councils to implement PAYT for environmental, social, sustainability and economic savings from recyclables. However, successful implementation of PAYT needs to establish a continuous promotional campaign taking effective actions versus illegal diversions while creating adequate and enduring incentives for households which is essential. It is noted that generally the total amount of recyclables and the quality of supplied secondary materials are affected by the level of source separation for MW. For example, recovering recyclables from mixed waste tends to reduce its marketing possibilities because of its possible contamination. Conversely, separate collection of separated MW from households at source can lead to increases in the costs of the waste collection process. On the other hand, as illustrated in Fig. 8 below, source separation for MW results in profitability for both councils and households. Further, it creates significant economic, environmental and social benefits for industry, energy and food security if it is managed properly with reasonable implementation of the integrated sustainable PAYT cost accounting approach. It is suggested that for evaluating the impact, a review must be conducted after an adequate implementation period for the charging method in terms of economic, environmental and social performances. For economic performance, it is important to ensure that the full cost of the overall MW management service including the value of recyclables is covered. While environmental performance could be evaluated, for example by the

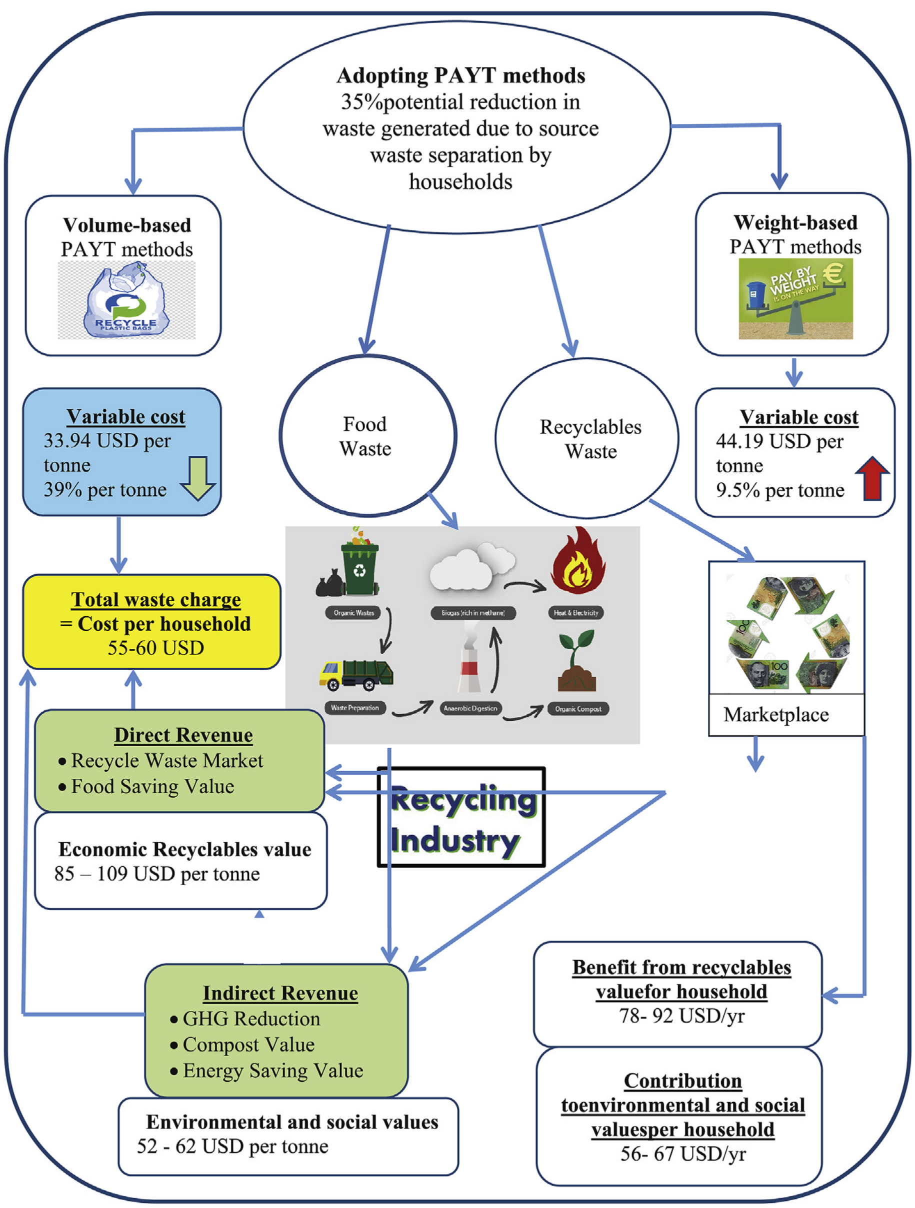


Fig. 8. Illustration of how the described model has been applied.

reduction in GHG rates due to incremental flows of recycled waste, the assessment of social benefits could be made by reductions or exemptions for low income citizens.

Thus, this study has a strong public benefit component to reach the best MW management that result in the lowest cost with the highest circular economy benefits in an emerging economy context. There are increasing demands from councils, communities and businesses to adopt low cost MW management systems that extend sustainable benefits (i.e. environmental, social and economic) to all stakeholders and the society. While developed countries are at the forefront in this space, emerging and developing countries are still catching up. This study sheds some light on an emerging market's MW recyclable management cost accounting approach (i.e. FCA based modified PAYT pricing model) for achieving cost efficiency and contributing to broader environmental, climate and social issues. These findings have various implications for the policy makers, government councils, waste managers, businesses and communities in the adoption of PAYT schemes for cost-effective, profitable and socially acceptable reusing and recycling of waste that can contribute to environmental and social sustainability. These outcomes can be generalised to other emerging economies for achieving their sustainable development and cost efficiency.

However, this study is not free from limitations. First and foremost, the data sample (27 municipal councils) might not be considered large enough for the cross-section study. Also, a circular economy takes all sectors and industries into account, though only a few industries are selected in Egypt as the core of circular economy. Second, a country specific context may be an issue e.g. Egypt in MENA. Each country, either developed or emerging, has its distinct institutional and socio-cultural settings. For example, the findings or experience in one country may not be exactly the same as in other countries or regions. Third, in terms of the methods applied, the study is a scenario-based case study on two alternative PAYT pricing models from a circular economy context. These limitations of the current study can be overcome by future research. It is expected that future research may undertake further in-depth analysis on a larger sample size, industry sectors and data periods. Future research studies should consider capturing other emerging countries for a comparative analysis among emerging economies by controlling their institutional, regulatory and socio-economic features. Future research potential also lies in the application of other empirical and qualitative methods to review a comprehensive circular economy approach. This approach fosters innovation and new business models for economic, social and environmental benefits. It is important to explore a better understanding of the sustainability and circular economy relationship in a greater depth from the viewpoint of municipal waste management and the impact on businesses, customers and society as a whole.

CRediT authorship contribution statement

Mona Abou Taleb: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Omar Al Farooque:** Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Update

Journal of Cleaner Production
Volume 294, Issue , 20 April 2021, Page

DOI: https://doi.org/10.1016/j.jclepro.2021.126375

Journal of Cleaner Production 294 (2021) 126375

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Corrigendum to “Towards a circular economy for sustainable development: An application of full cost accounting to municipal waste recyclables” [J. Clean. Prod. 280 (2021) 124047]

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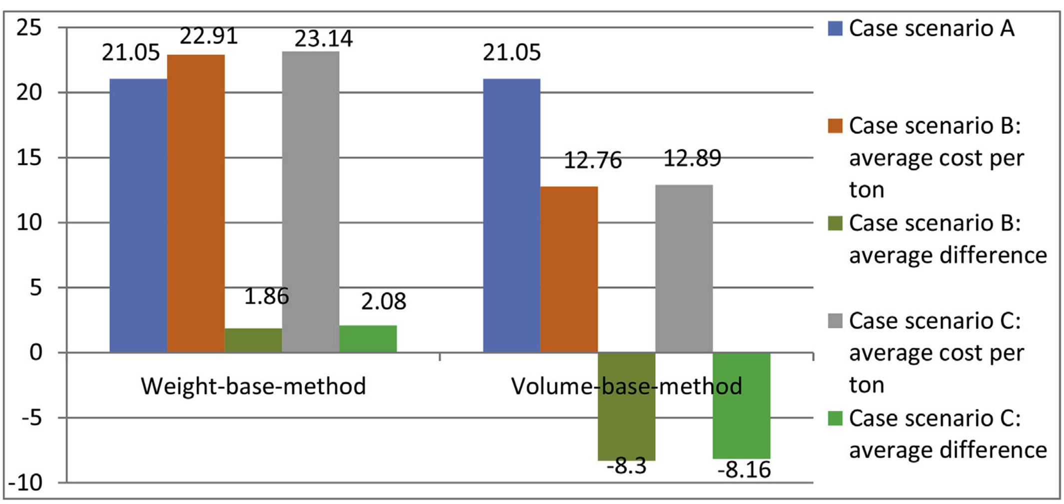

Fig. 4. Average variable collection costs per tonne comparison under three case scenarios A, B and C.

DOI of original article: https://doi.org/10.1016/j.jclepro.2020.124047.
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https://doi.org/10.1016/j.jclepro.2021.126375

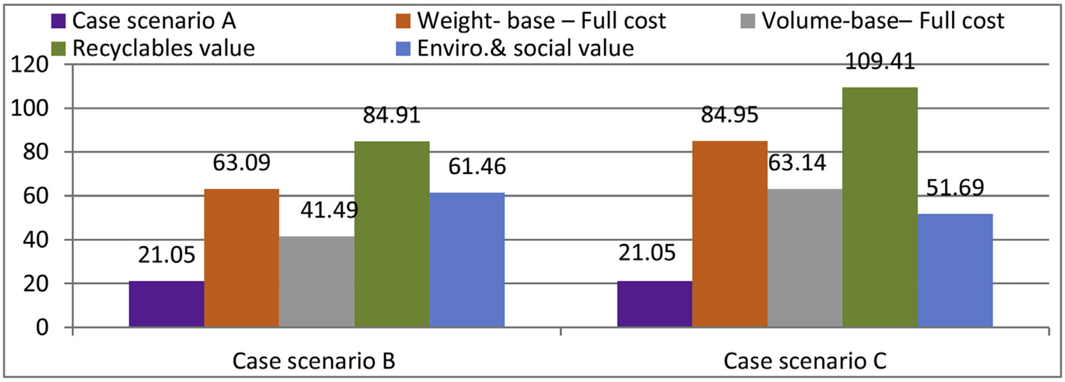

Fig. 5. Full costs of MW management per tonne against economic (recyclables), environmental and social values for two PAYT accounting methods under three case scenarios A, B and C.

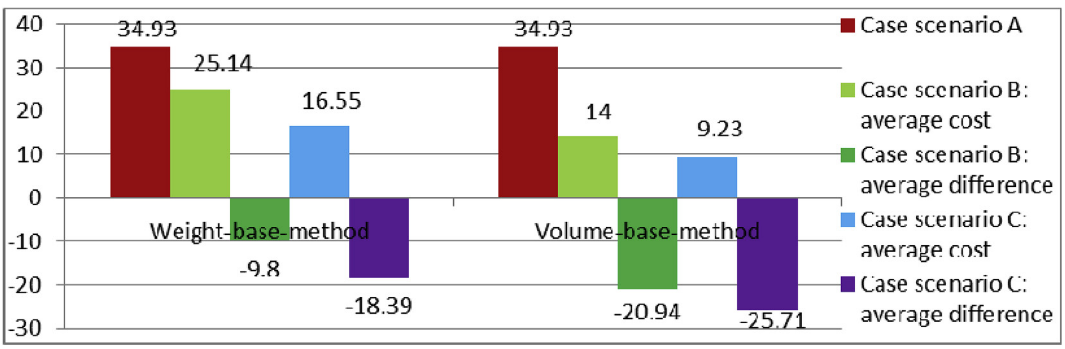

Fig. 6. Average variable collection costs per household comparison under three case scenarios A, B and C.

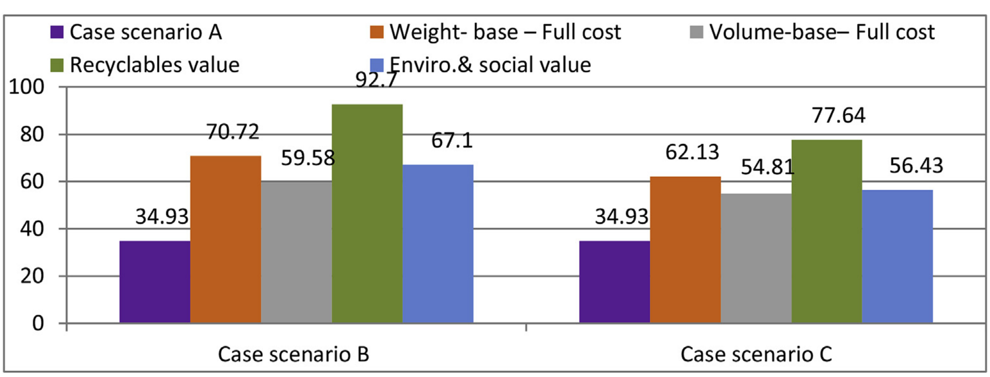

Fig. 7. Household contribution to MW full cost, economic (recyclables), environmental. and social values for two PAYT accounting methods under three case scenarios A, B and C.

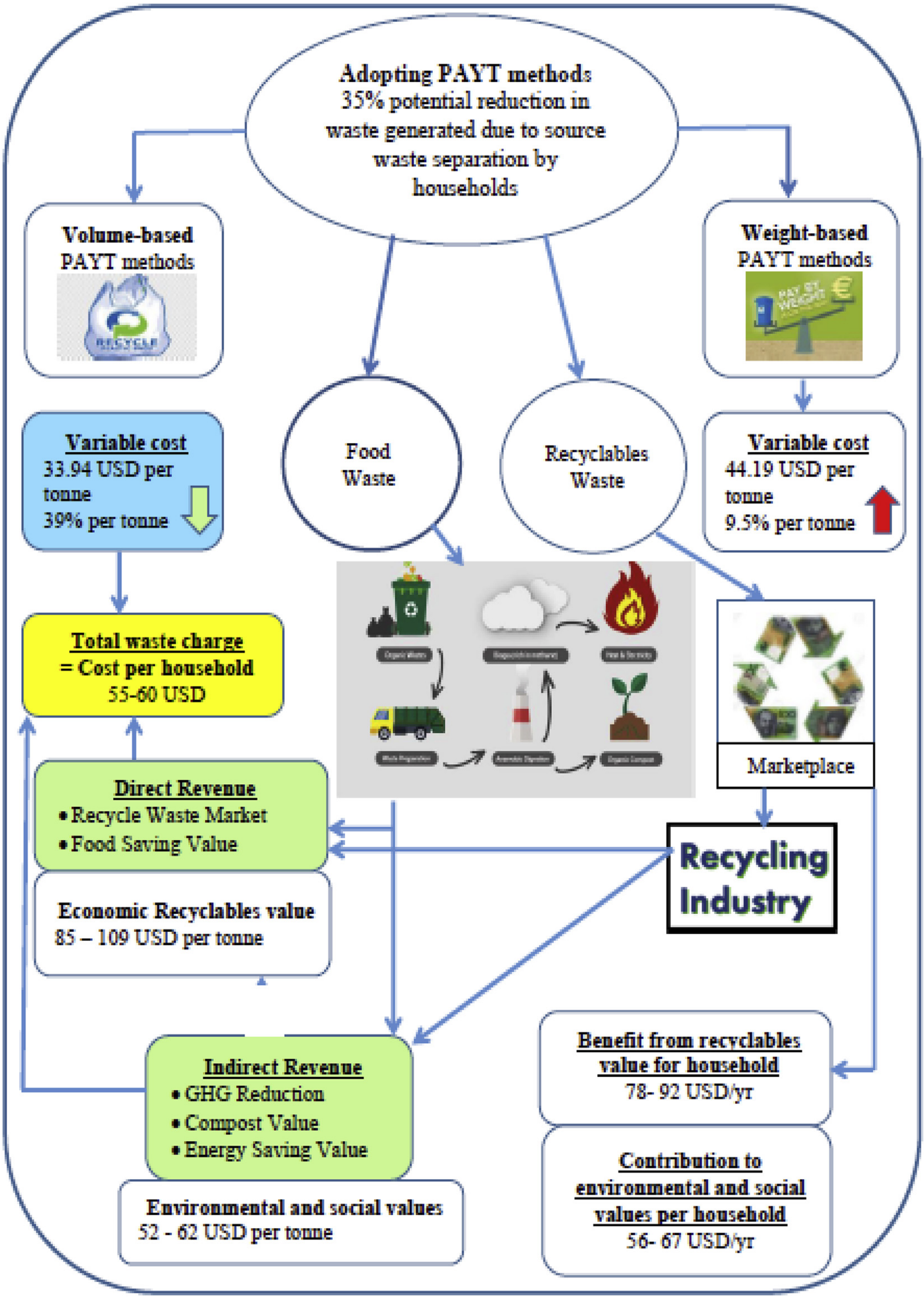

Fig. 8. Illustration of how the described model has been applied.
The authors would like to apologise for any inconvenience caused.