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Transforming Waste Management in Egypt Through Extended Producer Responsibility in Automotive and Transportation

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ABSTRACT

The policy proposal of Extended Producer Responsibility in Egypt's automotive and transportation industry is discussed in this research as a viable solution for major waste management issues. From the best practices observed on the international level and having regard to the country-specific socio-economic environment of Egypt, the study suggests comprehensive and step-by-step anatomy that might be best adapted to adoption in the given country context. Simulations for hypothetical modeling on some of the main automobile components including tires and batteries, indicated that recycling rates could rise from an initial 10% to over 50% after 10 years under EPR. The framework also points to the creation of approximately 15,000 new jobs and the achievement of 20% cost savings on municipal waste management. One of the most important elements is the capacity to support the participation of informal waste pickers in the formal system, providing them with the training and motivation, that will secure an environmentally sound approach, as well as social inclusion. This work therefore provides a clear guideline for policymakers and stakeholders to SMADE to implement an effective, reflective, and fair manner of waste management which complements Egypt's Vision 2025 and other Universal sustainable developments.

INTRODUCTION

Egypt as a country is at a crossroads in regards to its waste disposal. Increased production and use of plastic, rubber, and electronic wastes emanating from vehicles; coupled with increased informal sector participation in recycling, these risks overwhelm the nation's environmental management capabilities (Elshahawany et al., 2017). The absence of well-coordinated order systems, intended to help handle the end-of-life vehicles and the parts that result from them, makes the system inefficient and environmentally unfriendly. As such there is a need for a framework that solves these and incorporates most developed nations' best practices within Egypt's socio-economic structure (Bagwasi, 2023).

Internationally, EPR is a great success in discharging responsibilities in Waste management challenges encountered in nations such as Germany and Japan are well equipped with systems that guarantee the recyclability of vehicular parts and indulgent elimination of risky materials(Gupt & Sahay, 2015). Nevertheless, such systems, as it has been seen, have to be introduced in a developing country like Egypt with a certain specific approach and proper planning. Hence, this paper aims to examine the applicability of EPR on Egypt's automotive and transportation industries and the possible environmental and economic benefits, prospects, and impediments covering infrastructure, policy, and stakeholder engineering (Morgan, 2024).

Based on global best practices, and adopting, adapting, and integrating them into the Egyptian realities, this research seeks to develop a framework that is compatible with Egypt's sustainability initiatives. This exploration is not only a research project but it is also a guide with a variety of

specific initiatives to build a better future in one of the fastest-growing global areas.

Extended Producer Responsibility has now received global acknowledgment as an important policy instrument for dealing with waste management problems as the producers are given responsibility for their products. This concept has been stretched a lot and it has been adopted in many fields especially the automobile and transport industries which are notably among the major producers of wastes (Abdelati et al., 2024). The previous studies offer important learnings when it comes to specific EPR frameworks, including how they can be managed and adopted in nations like Egypt, where the management of waste has structural issues and socio-economic dynamics (El-Wahab et al., 2021; Trang & Li, 2023).

Literature reviews of reverse supply chains for EoLV present how EPR systems enhance the recycling and reuse of automotive components (Gan & He, 2014). Besides, through encouraging manufacturers to effectively approach waste management, both the efficiency of resources and the amount of negative effects on the environment are improved. This is so because the informal sector heavily manages the waste produced by vehicles in Egypt with a high likelihood of inefficiency and polluting the environment (Abdelati & Abdelwali, 2024). African countries' vehicle regulation studies show that domestic policies need to consider the EPR standards to cope with the high levels of used vehicles and related waste generation (Arshad, 2024; Mihai et al., 2024).

The actual specifics of environmental costs can be seen by comparing such areas as EPR implementation offers the right structured framework in life cycle assessments of vehicle components such as tires. The results call for well-developed EPR systems, that encourage environmentally sound collection and recycling, illustrating possibilities for Egypt's improvements of recycling. In the same vein, studies on the environmental performance of polymers involved in the automotive industry also support this idea of EPR as a mechanism that promotes the evolution of materials design for sustainable products (Dong et al., 2021; Abdelati & Abdelhafeez, 2023).

Successful examples of EPR implementation across the world show that there is a lot of knowledge to draw upon for Egypt. For example, Japan's End-of-Life Vehicle Recycling Act demonstrates high recovery rates with minimal quantities of hazardous wastes. Extended EPR frameworks in Germany have demonstrated the effectiveness of the involvement of all stakeholders within the policy framework for recycling (Alardhi et al.). Such examples point out that for sustainability, the policy mechanism should be robust, the infrastructure functional, and the participation of producers and consumers very active (Scheinberg et al., 2016).

Lessons from the integration of informal recyclers into Europe's formal waste management systems further underscore the relevance of EPR to Egypt. Though resourceful, informal recycling networks usually operate without environmental safeguards in place. The integration of such networks into a structured EPR framework can enhance efficiency and ensure better environmental practices while responding to the socio-economic realities of the waste management sector in Egypt.

Studies from the Middle East have identified a growing interest in EPR, especially regarding the waste management of end-of-life vehicles. Such works identify that policy formulations, in this context, have to be specific, together with infrastructure and stakeholder involvement (Abdelati, 2023). On plastic waste management in Egypt, the same feeling is derived in EPR can function as a game-changing tool for sustainable waste management both in the automotive and transport sectors (Ayetor et al., 2021; Harun et al., 2023).

The literature already available on the subject provides a strong basis for the proposal of an EPR framework suited to the needs of Egypt. Drawing from the successes of other countries and taking into consideration the peculiar challenges of the local context, Egypt is well-placed to effect a transformation in its waste management landscape. This would not only reduce environmental degradation but also ensure economic growth and social justice, in line with larger goals of sustainability and perhaps set a standard for similar initiatives within the region.

METHODS

This research will adopt a structured approach to test the viability of implementing Extended Producer Responsibility in Egypt's automotive and

transportation sectors. It puts together a comprehensive comparative study of successful international EPR systems with hypothetical modeling across Egypt's unique socio-economic and environmental conditions to produce a practical framework that corresponds to global best practices yet addresses local challenges.

It will therefore start with a critical review of the EPR policies that have been undertaken by countries like Germany and Japan, which have been very successful in managing end-of-life vehicles and automotive waste. Recovery rates, efficiency within the recycling system, and the roles of producers and government agencies analyzed will be key metrics in this review. These cases will be of particular value since they have proved large waste challenges and possibilities of fostering sustainable practices. Insights from these systems were critically analyzed for elements that could be adapted to Egypt, with a focus on scalability, stakeholder engagement, and infrastructure development (Alardhi et al.).

Due to the unavailability of actual data specific to Egypt, hypothetical modeling was used in the research to project possible outcomes under an EPR framework. These baseline metrics were developed from estimates in the existing literature on Egypt's informal recycling sector, assuming an initial recovery rate of 10% for tires, batteries, and plastics. Hypothetical projections were then made, assuming that under EPR policies, recycling rates would improve by 5% annually, based on observed trends in comparable systems globally. The model projects that recovery rates will increase and waste sent to the landfill will decrease, along with its associated economic benefits, over the ten-year implementation period.

To make this framework actionable as well as inclusive, a detailed stakeholder analysis has been conducted. Through government agencies, private producers, informal recyclers, and consumers, key stakeholders have clear responsibilities and attribution in the process. It placed particular emphasis on integrating the informal sector into the formal waste management system. The approach was seen as fundamental to tapping into acquired skills while the environmental standards would be achieved. Training and financial incentives have, among other initiatives, been combined in a model for facilitating this.

The proposed framework also offers phased implementation starting with high-result-generating areas of application as in the cases of tire and battery recycling (Andersen, 2024; Kotak et al., 2021; Krishnakumar et al., 2023; Norman, 2023; Ornes, 2024). These waste streams were chosen because of their large environmental impact and because it was relatively simple to set up collection and recycling schemes based on best practices in the international context. Pilot projects are proposed as a pragmatic approach so that issues of process refinement and development of support structures, as well as evaluation of stakeholders' engagement, can be put into practice before the extension of the system to other parts of the automotive value chain (Abdelati & Abdelwali, 2024).

This methodology of integrating international ideas with regional possibilities means that the proposed framework is not only academically sound but also feasible. The systematic approach enables the identification of the problems and prospects of EPR in Egypt before offering suggestions for its development, as provided in this study.

Figure (1) illustrates the challenges in waste management, the proposed EPR framework, and its resulting benefits in Egypt.

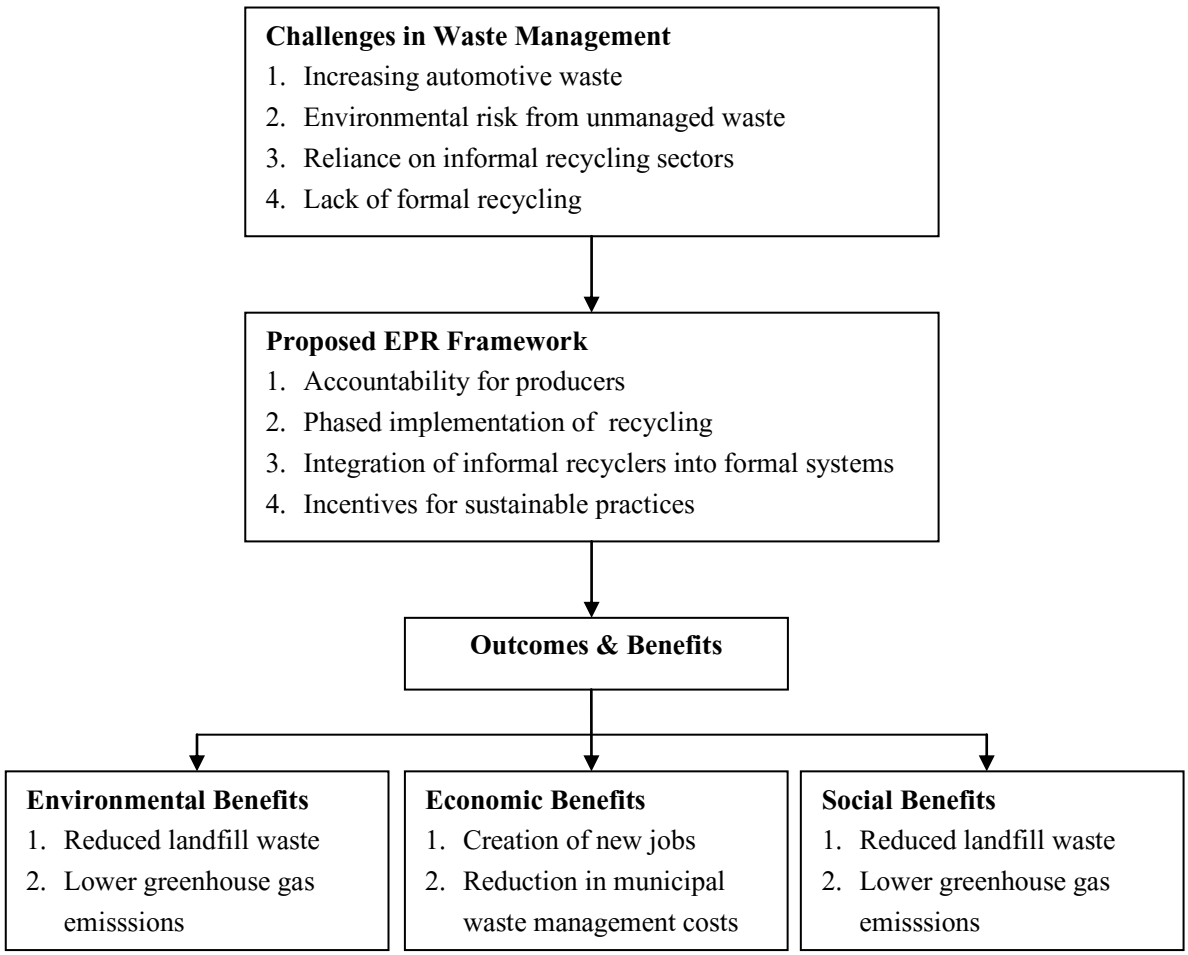

Figure 1. The Importance of Implementing Extended Producer Responsibility in Egypt

RESULTS AND DISCUSSION

These findings are indicative of a promising outlook for Extended Producer Responsibility in Egypt's automotive and transportation sectors. Indeed, an examination of global benchmarks and modeling outcomes specific to Egypt's context makes it clear that an EPR framework could address key waste management challenges while providing measurable environmental and economic benefits.

Projected improvements in recycling rates are significant. Considering an estimated baseline recovery of about 10%, under the stimulus provided by an effective EPR regime, automotive waste recovery rates-such as tires and batteries could easily exceed the 50% mark well before a decade. For example, tire recycling alone is saving nearly 1.5 million units from entering landfills, and similarly, battery reprocessing could prevent over 200,000 units from ending up in landfills or worse each year. These results not only align with global success stories, such as the German recycling systems but also show that such achievements can also be achieved in Egypt through adapted implementation.

Economic forecasts also underpin the value of EPR is formalizing recycling industries through the framework could result in approximately 15,000 new jobs created over ten years in collection, processing, and sorting-related activities. Simultaneously, municipalities would be able to decrease their waste management costs by some 20%, so far as the burden falls increasingly on producers, because of the end-of-life product management. Meanwhile, actual producers would diminish cost through the reutilization of the recovered materials and a rendering of the supply chain both greener and leaner.

These results are not without their challenges, either. The dependence of Egypt on informal networks for recycling is a very complex barrier to the formalization of recycling processes. While the informal networks are very helpful in the current setup, most lack environmental safeguards and are outside the legal framework. The successful

integration of informal recyclers into the EPR framework is critical. Practical solutions-such as training programs and financial incentives can ensure their expertise is tapped into while improving compliance with environmental standards.

There is also the concern for infrastructure that still needs to be addressed. The lack of proper collection and processing centers might also be a disadvantage of the framework. To this, much capital is outlay through, PPP, to set functional, efficient recovery plants and arrange the networks to accommodate the flow of large volumes of waste.

The social impacts can be summed as follows: With regard to social impacts, it comes as no surprise that the described environmental benefits are equally impressive. If implemented and causing enhanced recycling rates as well as reduced landfill reliance, EPR has the potential to greatly reduce greenhouse gas emissions and preserve natural resources. The outcomes noted above dovetail nicely with Egypt's Vision 2030 goals and thus, present EPR not solely as a waste management solution but, in fact, as a development strategy par excellence.

These results reveal that whilst the potentially wider benefits of EPR are significant, successful implementation is not for the faint-hearted and should be approached with carefully planned and phased implementation. Selecting high-priority automotive wastes like tires and batteries enables swift and strategic generic infrastructure and key stakeholder approaches before a broad number of automotive wastes are included under the framework. If stimulating the implementation of suitable policies, new forms of EPR could revolutionize how Egypt approaches the management of its waste in terms of sustainability, participation, and feasibility.

Figure (2) shows the projected increase in recycling rates over 10 years under the proposed Extended Producer Responsibility (EPR) framework, highlighting a rise from an initial 10% to 50%, demonstrating the potential effectiveness of the system. Figure (3) illustrates the annual diversion of waste from landfills under the EPR framework, with 1.5 million tires, 200,000 batteries, and 700,000 plastic units expected to be recycled annually.

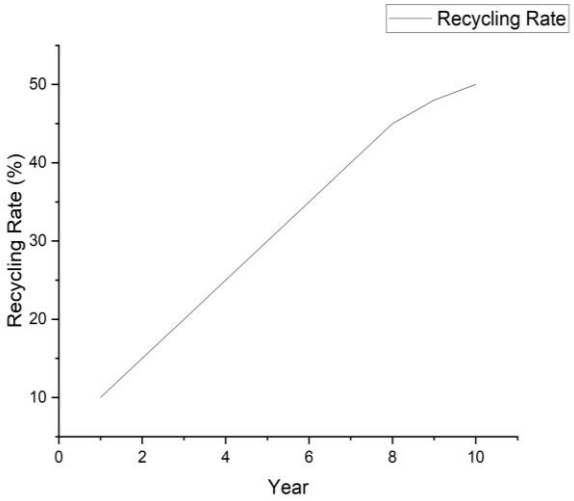

Figure 2. Projected Recycling Rate Over 10 Years Under EPR Framework

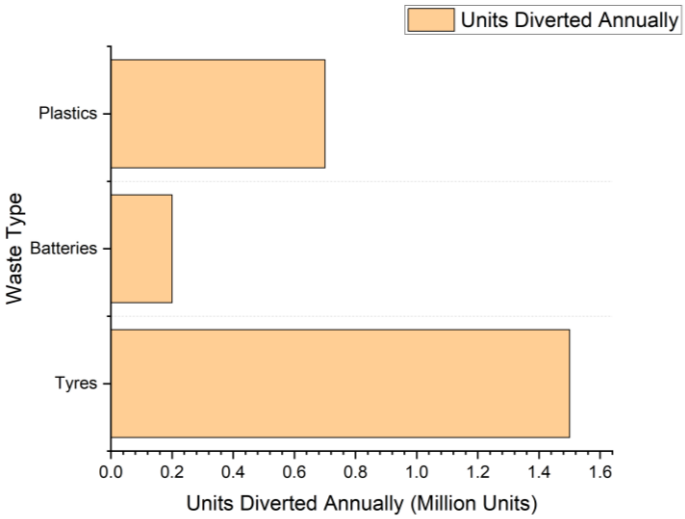

Figure 3. Annual Waste Diversion by Type (Tyres, Batteries, Plastics)

Proposed Framework for Egypt

The case of EPR in the automotive and transportation industries of Egypt presents an opportunity to meet pressing issues of waste management that intersect with Egypt's overarching sustainability priorities. In making the recommendations, the proposed framework takes into consideration only factual experiences that are adaptable globally while putting into consideration regional peculiarities.

As a key part of the framework, it is recommended that everyone's duties and responsibilities are clearly defined. Manufacturers should be made to take responsibility for their products from the end user stage where they will be called upon to take back the waste materials, recycle and properly dispose of them. They entice different levels of accountability that can be supported by tax exemptions for sustainable activities, and fines for noncompliance. They should also use design that facilitates recyclability of their products hence decreasing the level of harm done to the environment from the production phase.

This is particularly so because the government has a crucial responsibility of ensuring the development of effective regulatory structures that require compliance with the EPR principles. From the policies' perspective, one must state that they should outline objectives and standards of behavior that are expected from all the stakeholders and [should provide] means of control and supervision. Such relational structures can help to coordinate investments associated with the creation of such structures, as collection and recycling facilities, as well as distribute financial and operational tasks.

Noting that Egypt's informal sector plays a significant role in the current recycling mechanisms, the framework seeks to find a proper structure to increase efficacy and legal conformance. In this context, informal recyclers have a wealth of knowledge but cannot implement it safely and are not affiliated with the law. It comprises offerings like training programs, financial rewards, and other forms of recognition to make sure that their inputs fit well into a concrete system. This automatically enhances the efficiency of recycling as well as brings about social integration and economic opportunities.

The proposed framework looks at a step-by-step implementation approach, prioritizing high-impact waste streams such as tires and batteries. These were chosen out of the range of parts due to their environmental impact and recyclability, thus very ideal for the early pilot projects. Early work could focus on an effective gathering system, infrastructure recycling development, and regulatory testing. Lessons from the pilot programs would help in extending the framework to other vehicle parts with the assurance that the progress of the framework would be progressive and manageable.

All of these will require financial incentives and public awareness campaigns to ensure participation. Subsidies on producers who reach their recycling targets and penalties for failing to comply will incentivize the use of sustainable methods. At the same time, informing consumers of their role within recycling systems will encourage them to take an active interest and make the system work efficiently.

The proposed framework brings together the three cornerstones of stakeholder involvement, scalability, and sustainability to meet the unique challenges of Egypt while realizing important environmental and economic opportunities. Done thoughtfully and with continuous commitment, Egypt has an opportunity to establish a system that will not only mitigate the impact of automotive waste but also set a leading benchmark for sustainability in the region. This comprehensive approach ensures that Extended Producer Responsibility becomes a cornerstone of Egypt's transition to a more sustainable and inclusive waste management system.

Figure (4) presents the progression of recycling rates for tires, batteries, and plastics during the three phases of EPR implementation, demonstrating phased improvements and cumulative benefits over time. Figure (5) highlights the step-by-step activities, immediate results, and long-term benefits of implementing Extended Producer Responsibility in Egypt.

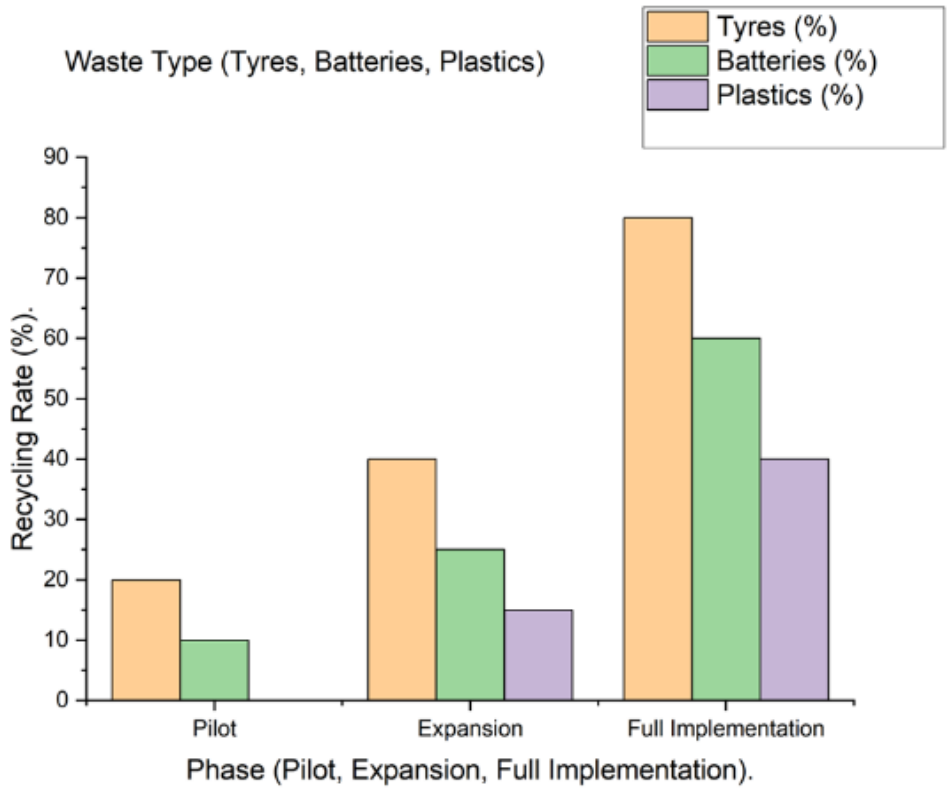

Figure 4. Recycling Progress Across Implementation Phases by Waste Type

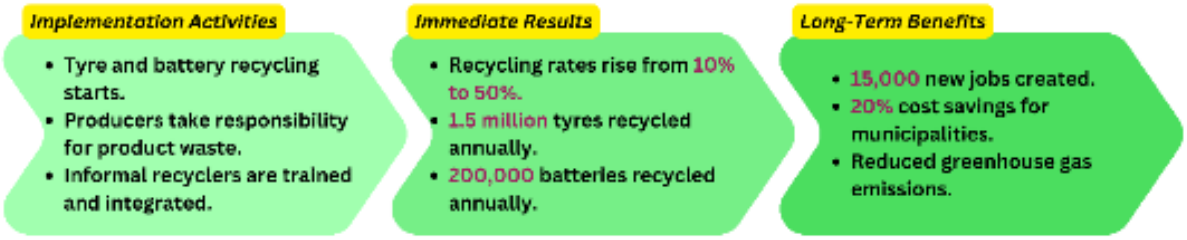

Figure 5 Impact of Implementing Extended Producer Responsibility in Egypt

CONCLUSION

Extended Producer Responsibility applied to automotive and transportation industries in Egypt may revolutionize emerging waste management when it comes up with positive outcomes in these aspects; environmental, economic, and Social. From this work, it can be seen that by putting into operation EPR the rates of recycling could rise from half a dozen to over fifty within ten years thus lifting the dependence on the landfill while at the same time having fewer impacts on the environment. Also, the legal recognition of recycling businesses may generate about 7,500 jobs in addition to saving approximately 20% of municipal consumption expenditures on waste administration.

The elements of the proposed framework highlight the integration and coordination of different stakeholders such as producers, government authorities, and informal recyclers. The cohesion of informal recyclers in the market through formal training in employment and undertaking reward programs enhances the safety and standard compliance of their services. The phased approach to implementing the system starting with identifiable high-impact waste streams such as tires and batteries offers a clear and realistic strategy to expand the system to solve and realize other similar sustainability issues.

Though the framework deals with the problem areas of low physical infrastructures and nullable informal sector supremacy, it needs robust policy

backing, PPPs, and interest continuity from all the relevant stakeholders. The proposed approach to addressing waste management will not only address the current and urgent concerns of waste management and its difficult implications in Egypt but will also create the foundation for Egypt's long-term Vision 2030 and the global sustainable development goals. According to the insights of this study, there is a clear and practical vision for a better way forward on sustainability.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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