# INDUSTRIAL SYMBIOSIS - SITUATION IN MAURITIUS

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***Abstract***
*Industrial symbiosis, a key field within industrial ecology, focuses on utilizing waste or by-products from one entity as resources for another, fostering environmental and economic advantages. Central to this concept is the reuse of resources and waste minimization, driven by collaborative opportunities and synergies often facilitated by geographical proximity (Chertow, 2000).*

*Essentially, industrial symbiosis establishes connections between companies or industrial facilities, enabling one organization's by-products or waste to serve as raw materials for another. By integrating industrial symbiosis practices, industries can significantly reduce waste generation and lessen the need to extract raw materials, repurposing waste from one sector as valuable inputs for another (Chertow, 2007). Various factors influence this approach, including environmental benefits, cost savings such as reduced greenhouse gas emissions, and addressing issues like natural resource scarcity and waste diversion from incinerators and landfills. Ultimately, industrial symbiosis leverages symbiotic collaborations and business partnerships to create closed-loop systems.*

*The paper's main aim is to present the idea of industrial symbiosis and the possibilities for industrial symbiosis in Mauritius. The paper analyzes the term industrial symbiosis, opportunities and challenges for industrial symbiosis. The third part of the paper studies the possibilities and challenges of industrial symbiosis implementation in Mauritius and presents good practice cases. Based on the research results, conclusions and recommendations for further research on this important topic are given.*

***Keywords:*** *Industrial symbiosis, opportunities, challenges, Mauritius*

## INTRODUCTION

Industrial symbiosis is a cooperation between several separate, often geographically close entities, i.e., companies working closely in industrial parks or clusters, exchanging different resources (e.g., by-products, water, energy and materials) (Chertow, 2007). Those resources are used as replacements for raw materials that would otherwise be bought from elsewhere or considered waste (Clift and Druckman, 2015). Industrial symbiosis has been essential to the circular economy concept in recent decades. Based on the circular economy, products are designed to be disassembled and reused, focusing on recovery from the end of the life cycle. Four sources of value creation are emphasized: Minimizing material consumption, maximizing successive cycles and time in each cycle, diversifying reuse throughout the value chain, and maintaining uncontaminated material streams. These principles drive material productivity and offer long-term advantages over traditional linear business models (Lamba et al., 2024). Based on the report (Ellen MacArthur Foundation, 2019), there are three main circular economy principles: 1) waste and pollution prevention, 2) materials use and reuse, and 3) natural systems regeneration. The first principle focuses on the importance of environmental impact at the design stage for reducing the use of virgin raw materials and, therefore, minimizing waste generation. The second principle focuses on extending the life cycle of materials and products using different strategies (i.e., reuse, repair, remanufacturing). The third principle emphasizes the prevention of environmental damage and the active improvement of the environment by returning valuable nutrients to ecosystems.

**Figure 1.** Industrial symbiosis illustration


Source: Chat GPT, 2024

The illustration highlights the mutual benefits and sustainable exchange within the framework of an eco-industrial park. It emphasizes the value for the participating companies and shows a network of interconnected industries that exchange resources such as energy, water, raw materials and waste products. Although industrial symbiosis and circular economy target sustainability, they have different focuses. The circular economy includes materials and products from different sectors. Industrial symbiosis focuses on industrial waste and by-products and represents a practical tool and targeted strategy for implementing a circular economy in industry by optimization of resource use. While it contributes to a more circular economy, it does not necessarily lead to the complete closure of material loops. On the other hand, the circular economy examines a broader perspective, including upstream methods, waste prevention, and a holistic attitude to sustainable development. Despite their different characteristics, the boundaries between the circular economy and industrial symbiosis are often blurred, and there is considerable overlap between the two concepts.

This paper explores the concept of industrial symbiosis and highlights recent research in the field. The first section offers a literature review, discussing the definition, challenges, and potential for developing industrial symbiosis. The second section provides an overview of prominent examples of industrial symbiosis globally and assesses its feasibility in Mauritius. Finally, the paper concludes with key findings and proposes directions for future research.

## LITERATURE REVIEW

The most traditionally used industrial symbiosis definition (IS) (Chertow, 2000) states that IS links traditionally detached businesses in a cooperative method to achieve competitive advantage through the physical exchange of materials, energy, water and by-products. The essential elements of IS are the collaboration and synergistic opportunities afforded by geographical proximity (Chertow, 2007). Lombardi and Laybourn (2012) presented a renewed definition of IS. This definition was summarized by Domenech et al. (2019) as follows: "Industrial symbiosis (IS) is a systems approach to a more sustainable and integrated industrial system that identifies business opportunities that leverage underutilized resources (such as materials, energy, water, expertise, assets, etc.)." Domenech et al. (2019) further explain that IS includes organizations working in different sectors of activity engaging in mutually beneficial transactions to reuse waste and by-products by finding innovative ways to source input and optimize the value of the residues of their processes, for example, by using waste or by-products from one activity as inputs for another activity."

The European Committee for Standardization (CEN) (2018) recently initiated the process to address the need to define IS. The agreement on IS was reached in 2019. They defined the IS as the use of underutilized resources (e.g., by-products, waste, energy, residues, water, capacity, logistics, expertise, equipment and materials) by one company or sector from another, with the result that the resources can be used productively for longer. However, this process is not yet complete, and CEN is planning a series of consultations and standardization dialogs to define the roadmap for the standardization of IS in 2025.

IS involves collaboration between companies or industries to exchange materials, by-products, energy and water to share services, utilities and facilities (Costa and Ferrão, 2010). The realization of IS requires the identification of potential symbiosis opportunities. Therefore, identifying viable opportunities for resource exchange between industries is critical to advancing IS in practice. There are different types of resources for IS synergies, and they include raw materials, by-products, energy resources, water, utilities and infrastructure assets, logistics services, expertise skills and specialized knowledge (Domenech and Davis, 2011; Erceg et al., 2017; Henriques et al., 2021; Fraccascia et al., 2021; Činčurak Erceg, 2024; Erceg et al., 2024).

This resource exchange results mainly from production processes that can be used by other processes of the same or another company to replace production inputs (e.g., energy, water, raw materials, waste) or to create new products (Albino and Fraccascia, 2015). Thus, industries that adopt IS can achieve economic and environmental benefits by simultaneously reducing production costs and creating environmental and social benefits for the companies (Tadeo et al., 2017; Yuan and Shi, 2009). The necessity for reducing the environmental impact and the growing demand for new resources have drawn attention to expanding IS practices regionally to achieve more effective results (Kokoulina et al. 2019).

Economic benefits (Maillé and Frayret, 2016) and improved profitability are often the main drivers of IS, usually resulting from sharing by-products or reduced waste disposal costs. Gabriel et al. (2017) have identified the pursuit of waste recovery opportunities as a new catalyst for IS initiatives. For energy-intensive industries, energy efficiency is a significant motivator (Karner et al., 2017). In addition, companies recognize the potential benefits of sharing services, utilities and knowledge (Wu et al., 2016). Studies (e.g., Golev et al., 2014; Rahman et al., 2016; Järvenpää et al., 2018) emphasize the complex nature of industrial symbiosis and highlight several barriers and facilitators that influence its adoption. Key facilitators for IS include economic incentives, supportive regulatory frameworks and increased awareness, while barriers include inadequate infrastructure, weak legal backing and limited access to information.

Industrial symbiosis encounters various financial, technical/technological, social, economic, regulatory, policy, management, informational, and geographical barriers and challenges. Additionally, different studies (Järvenpää et al., 2018; Rahman et al., 2016; Domenech Aparisi, 2010; Golev et al., 2014) have identified organizational barriers such as lack of trust between units, emotional resistance, risk and uncertainty, cultural differences, limited commitment to sustainable development, collaboration challenges and low community awareness. Golev et al. (2014) categorized barriers into two main types: 1) technical barriers and 2) non-technical barriers. Alternatively, they can be divided into 1) "hard" and 2) "soft" barriers (Järvenpää et al., 2018:78). Hard barriers relate primarily to technical and economic issues, while soft barriers relate to institutional, regulatory, social and cultural factors. Despite the extensive documentation of these barriers, Golev et al. (2014:142) point out a significant gap as there is a lack of real-world case studies detailing how these barriers are identified and overcome and a lack of a consistent methodology for analyzing them.

**Figure 2.** Common non-technical IS barriers


Source: adapted from Scaler, 2020; Erceg et al., 2024

On the other hand, there are some technical/technological ("hard") barriers to IS implementation. Studies (Heeres et al., 2004) mention waste exchange technical feasibility as an IS barrier. Van Beers et al. (2007) stated potential concerns for the capture, recovery and reuse of bioproducts. The authors further noted that many IS opportunities were prevented from being implemented due to the availability of recovery technologies. Additional technical barriers were connected to wastewater regeneration and reutilization of solid waste (Liu et al., 2018). Gibbs (2003) studied the situation in which local companies "do not fit together", Costa et al. (2010) stated nonexistence of manufacturing technology potential recycling technologies, and Sakr et al. (2011:1166) concluded that an important technical barrier is "the absence of local expertise capable of identifying and assessing industrial symbiosis opportunities."

Finally, Matti (2021) identified six key policy themes that directly or indirectly promote industrial symbiosis: eco-innovations, resource efficiency, materials security, green growth, pollution and waste reduction, and the reduction of greenhouse gas emissions.

## INDUSTRIAL SYMBIOSIS IN MAURITIUS

### *Mauritian Context*

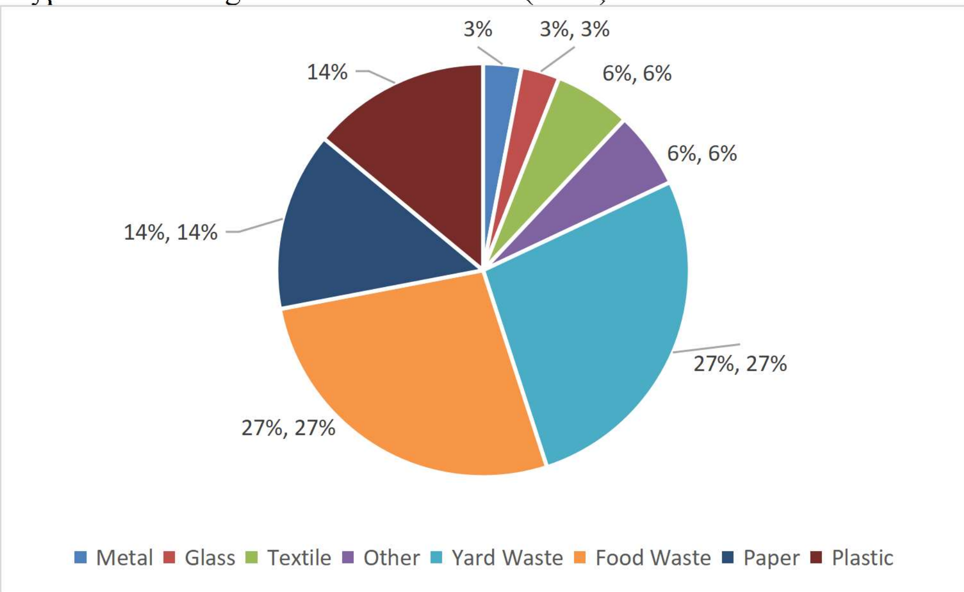
Located in the Indian Ocean, Mauritius has successively been occupied by the Dutch, the French and the British. The island gained independence in 1968 from the British, who occupied the island since 1810. Over the years, the Mauritian economy has undergone significant economic transformations. After independence, the island relied significantly on the agricultural sector, and following major economic reforms undertaken by different governments, the country evolved into a more diversified and dynamic economy. The service sector is the economy's central pillar, contributing to nearly 68% of the economy (Strafin, 2023). In 1992, the island was classified as a Small Island Developing State (SIDS) following the United Nations Conference on Environment and Development held in Rio De Janeiro. Although SIDS accounts for only 1% of the total GHG emissions, they face serious challenges such as natural calamities, including cyclones, climate change, biodiversity loss, waste management and global crisis (United Development Programme, (UNDP), 2023a). SIDS also faces limited natural resources such as energy, water, mineral and agricultural resources. According to UNDP (2023a), the island is not an exception to the other SIDS due to its vulnerability to external economic shocks and the impact of global warming, natural disasters and biodiversity loss. As a fast-developing economy that generates significant waste due to the increasing volume of industrial and economic activities, waste management has become a primary concern for local authorities and policymakers. This paper, therefore, focuses on the valorization of waste in a productive chain as part of the Industrial Symbiosis (IS) strategy (Cárcamo and Peñabaena-Niebles, 2022). The next part of the paper details the waste generation in the country, following the regulatory framework governing waste management and the various strategies and techniques adopted by companies to reduce solid waste and promote the use of clean energy, amongst others.

### *Waste Management in Mauritius*

Strategies to valorize waste aim to transform waste and by-products into valuable resources, thus reducing the need for new materials. Waste is any material that is discarded since it is no longer usable. Waste is classified into solid, liquid, gaseous, and hazardous waste. With the growing concern regarding environmental sustainability, innovative ways should be deployed to manage and dispose of waste responsibly and sustainably (Sharma et al., 2024). According to Kowlessur (2020), an average of 1.26 kg of solid waste is generated daily in SIDS. These solid wastes are dumped in open areas (UNEP/ISWA, 2024) or burnt in the backyard (Agamuthu and Herat, 2014).

As a SIDS, Mauritius generates significant waste annually, mainly from household items, industrial by-products, wastewater, industrial effluent, medical waste and gases produced from industrial processes. In 2021, the country produced 1,488 tons of waste daily (543,196 tons annually) (Ministry of Environment, Solid Waste Management and Climate Change, 2023). Figure 2 shows the different types of waste generated in the country. These wastes are disposed of at the Mare Chicose Landfill (Figure 4), the only landfill in Mauritius spanning over 48 hectares. Managing the waste at the national level costs the government around Rs1.5 billion. The activities include waste collection, transportation of the waste to the landfill, and the operation and maintenance of the landfill.

**Figure 2**: Types of wastes generated in Mauritius (2021)



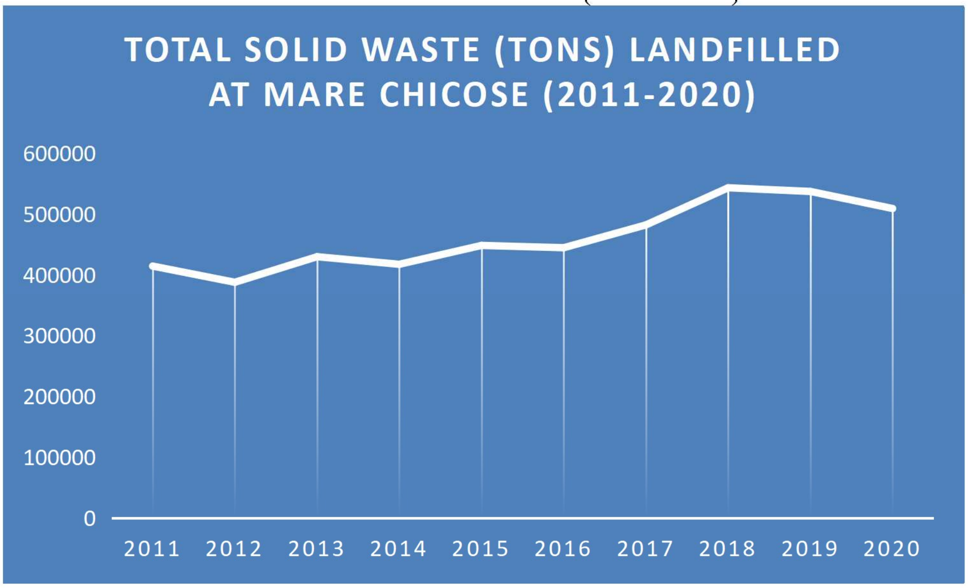

Source: Ministry of Environment, Solid Waste Management and Climate Change, 2023

With the growing volume of waste, waste management has become a serious challenge for the Mauritian government. Several factors have contributed to the increasing volume of waste, including:

- The population is increasing (presently, the population of Mauritius is around 1.3 million compared to 1.2 million and 900,000 in 2000 and 1980, respectively).
- Increase in economic activities (14.74 billion USD in 2018 and 4.73 billion USD in 2000)
- Increase in lifestyle - High consumption of packaged goods and other disposable items
- Industrialization - Constructing Smart Cities and other industrial buildings produces more industrial waste.
- Improvement in the standard of living leads to increased demand for products.
- Increase in the number of tourists visiting the country (from 732,000 in 2000 to approximately 1.3 million in 2024- this industry is considered one of the significant generators of waste throughout the different activities of the value chain such as accommodation and hospitality, transport, recreational facilities as well as the organization events and festival).

The increasing trend in the volume of waste (Figure 3) requires significant investment in waste management infrastructure, changes in waste management policy, and national public awareness campaigns.

**Figure 3:** Total Solid Waste landfilled at Mare Chicose (2011-2020)




Source: Ministry of Environment, Solid Waste Management and Climate Change, 2021

**Figure 4:** Mare Chicose Land Fill

Source: Luxconsult, 2024

Table 1 below details the types of waste disposed of at the Mare Chicose landfill site from 2019-2020.

**Table 1:** Types of waste disposed of at the Mare Chicose landfill site (2019-2020).

| Waste Material | 2019 | 2020 |
|---|---|---|
| Domestic and Commercial | 514,020 Tons | 475,942 Tons |
| Construction | 9,578 Tons | 16,082 Tons |
| Total | 537,147 Tons | 509,094 Tons |

Source: Ministry of Environment, Solid Waste Management and Climate Change, 2021

***The legal framework for managing waste in Mauritius***

The current legal framework for ensuring environmentally sound management of waste in Mauritius comprises the Environment Protection Act (EPA) of 2002, as amended in 2008, the Local Government Act (LGA) of 2011, as amended in 2018 (Ministry of Environment, Solid Waste Management and Climate Change, 2023) and the Waste Management and Resource Recovery Act 2023 (Mauritius National Assembly, 2023).The EPA (2002 as amended in 2008) and the LGA (2011 as amended in 2018) aim at protecting the environment and determining the local authorities' responsibilities in waste management, while the Waste Management and Resource Recovery Act (WMRRA) (2023) provides for a holistic approach in the management of waste in the country. The aim of the WMRRA (2023:13) is "*To provide for the regulatory framework to ensure the environmentally safe and sound management of solid and hazardous wastes and a sustainable waste management system through the adoption of a circular economy approach focusing on waste reduction, reuse, material recovery and recycling and to provide for matters related thereto*." The WMRRA (2023) aligns with the overarching principles of industrial symbiosis, which is based on the principles of the circular economy and the promotion of efficient use of resources and minimizing waste through the collaboration of multiple industries. Subsequently, several regulations have been promulgated under the EPA and the LGA to enhance environmental protection.

These regulations include the following:

- Environment Protection (Standards for Hazardous Waste) Regulations 2001
- Local Government (Dumping and Waste Carriers) Regulations 2 021
- Local Government Act (Registration of Scavenging Contractors) Regulations 2004
- Environment Protection (Collection, Storage, Treatment, Use and Waste Oil) Regulations 2006
- Local Government Act (Registration of Recycler and Exporter) Regulations 2013

Moreover, other regulations, including the Environment Protection (Banning of Plastic Bags) Regulations 2020 and the Environment Protection (Control of Single-Use of Plastic Products) Regulations 2020, have been issued to ban the usage of plastic bags and to control the single-use of plastic products, respectively. The Ministry of Environment, Solid Waste Management and Climate Change are considering making Mauritius a plastic-free country as soon as possible since plastic wastes account for more than 12% of the total waste, and this trend is likely to increase with the new trend of life.

***Regulations on waste management as a source- "Segregation at Source Regulations."***

As the landfill is becoming saturated, in 2023, the Minister of Local Government and Disaster Risk Management highlighted the importance of having a regulatory framework to manage waste at source, which will, inter alia, define the roles of the different stakeholders such as households, local authorities and the industrial sector amongst others on waste segregation (UNDP, 2023b).

On top of creating green jobs and developing a more sustainable Mauritius, the above regulation will also contribute to achieving SDG 12- Sustainable Production and Consumption, through the prevention, reduction, recycling and reuse of waste.

***Assistance from international institutions to enhance Waste Management Practices***

The Government of Mauritius has collaborated with international institutions to manage waste and promote the circular economy. For example, the United Nations Development Programme (UNDP, 2023) is currently supporting the country to enhance waste reduction. The UNDP aims to redirect as much as 70% of solid waste away from the nation's overloaded landfills. This aim is feasible, although, at the outset, it seems ambitious. Moreover, the United Nations Environment Programme (UNEP, 2023) aims to develop a roadmap for the circular economy to provide strategic orientation to bring circularity to key economic sectors of the Mauritian economy. The European Union (EU) has also been actively involved in the promotion of circular economy practices in Mauritius (EU, 2023)

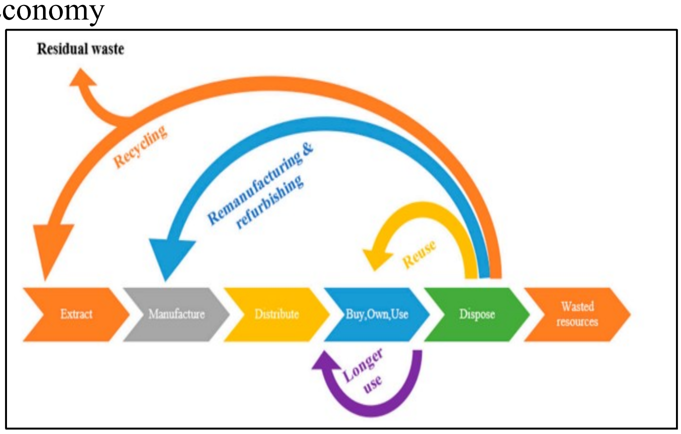
***Barriers and Challenges for efficient and integrated management of waste in SIDS***

SIDS, such as Mauritius, faced several challenges in sustainable waste management, including limited land area for proper disposal of waste, lack of population knowledge, lack of engagement to guarantee extensive recycling and disposal of waste in open dumps and inappropriate/uncontrolled landfills (Mata-Lima et al., 2021). Moreover, a study by Bhuckory et al. (2022) identified the lack of technical and financial means as a significant factor affecting the scope of an economically, environmentally, and socially sustainable solution to waste management in Mauritius. Similarly, Wosnick et al. (2024) emphasized the lack of an Integrated Solid Waste Management System (ISWMS) and inadequate resources as the significant constraints for managing e-waste in the Bahamas. In a similar vein, Assche et al. (2014) identified several challenges in the management of solid waste in Small Tourism Islands, including (i) institutional responsibility, (ii) motivation in participation, (iii) rigidity in policies, (iv) consumption pattern; (v) government adaptability; and (vi) political climate. These challenges deter SIDS from transforming the linear economy to a circular economy (Figure 5 Linear Circular Vs. Figure 6 Circular Economy).

**Figure 5:** Linear Economy


Source:Assche et al., 2014

**Figure 6:** Circular Economy




Source: Assche et al., 2014

## Discussions and Recommendations

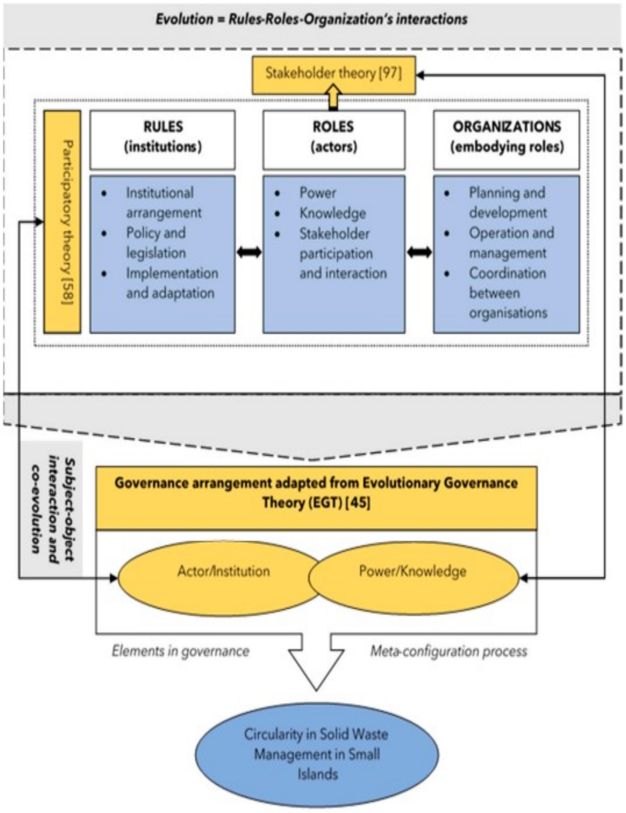
Waste management in Mauritius stands at a significant crossroads. The country has to manage the economic, environmental and public health challenges arising from waste generation through innovative solutions and means. While the regulatory framework for the reduction and management is set in place, it is apparent that sustainable waste management practices are overlooked by both the corporate world and citizens in general. Although the 3Rs concept (Reduce, Reuse and Recycle) is known to the public, strategies to implement them are limited. Several reasons may explain the citizens' and corporations' reluctance to create a circular economy where resources are continually reused. One of the reasons for this could be the differences in values, beliefs, and culture. The cultural context of a given society largely influences the success of a circular economy. For example, the culture of reusing and repairing items is not well anchored in the Mauritian context. Moreover, the education system does not provide enough grounds to shape learners' attitudes towards circular economy practices. On the other hand, being a small country with limited resources may also constrain the adoption and implementation of the circular economy. For example, waste management requires companies to overhaul their existing processes, which requires significant investment in infrastructure, technologies, and re-engineering.

The implementation of IS in Mauritius has already been studied. One of the studies identified the main polluting industries (Mauthoor et al., 2014), namely edible oil refineries, abattoirs and metal scrap recycling plans. In a follow-up study, Mauthoor (2017) proposed how artificial intelligence can be implemented and focused on the recycling of electric arc furnace slag as a concrete aggregate.

Hence, actionable recommendations should be made across various sectors to consolidate the circular economy. These recommendations pertain to the need for (i) segregating the wastes (paper, glass, wood, plastic and metal) generated by the corporations and citizens that recycle and reuse, (ii) investing in waste-to-energy technologies in partnership with the private sector through well-defined vehicles such as Build-Operate and Transfer (BOT), (iii) providing adequate disposal infrastructure such as accessible recycling centers, composting facilities to households and easy access to donation centers where people can drop off their items such as clothes, toys and household items for donations and (iv) changing the school curriculum at the grass root level to shape positive cultural attitude towards circular economy practices. Although these recommendations form part of the overall strategic plan for solid waste management (Ministry of Environment, Solid Waste Management and Climate Change, 2022), a strong signal (e.g., through intersectoral linkages) should be sent by the authorities to all the stakeholders to promote the circular economy as well as symbiosis and recycling activities. Furthermore, the local authorities should continue to collaborate closely with international institutions that provide technical and financial assistance and share technology and best practices to promote the circular economy and ensure the well-being of future generations. Moreover, since the waste-to-energy projects are long-term, the expected milestone/outcome must be adequately monitored to ensure the limited resources are effectively and efficiently employed. The government and local authorities should provide funds for research as it has been found that there is a paucity of data on waste generation, collection, and disposal, which may constrain the effectiveness of the waste management process at a regional level. On the political side, waste management should be on the high agenda of any government. As role models, political leaders should demonstrate a high commitment to safeguarding the environment and sustainability. Finally, different mediums (including national television, social media, local press, posters and pamphlets) should be used to undertake a national awareness campaign on the harmful effects of solid waste and waste reduction techniques.

Based on the work of Parmar et al. (2010), Van Assche et al. (2014) proposed a conceptual framework for the governance of solid waste management on small islands (Figure 7). Van Assche et al. (2020) and Fuldauer et al. (2019) further developed this conceptual framework.

**Figure 7:** Conceptual Framework for the governance of solid waste management on small islands




Source: Van Assche et al., 2014

Drawn from the stakeholder theory (Parmar et al., 2010) and the Evolution Governance Theory (Van Assche et al., 2020), the conceptual framework posts that "*the interaction between the aspects of rules, roles, and organizations gives rise to evolution in governance*" (Van Assche et al., 2014: 20). They recommended three steps to identity gaps in the current governance of solid waste namely:

1. Identify the governance categorization and assess how each dimension affects another,
2. Study the "*configuration between actor/institution and power/knowledge and how it co-evolves (meta-configuration) in the governance dimension of solid waste management on small islands.*"
3. "*observe governance arrangement through the object and subject construction from the meta-configuration.*"

## CONCLUSION

By exchanging resources such as energy, materials or water, industrial symbiosis offers the opportunity to reduce the costs of procuring raw materials and disposing of waste. By monetizing by-products or waste that would otherwise be disposed of, companies can tap into new revenue streams, improving their profitability and financial resilience. This approach maximizes resource efficiency and enables companies to make the best use of limited materials, reduce production costs and promote a more sustainable supply chain. Companies that innovate in the reuse of waste can gain a competitive advantage through sustainable business models and improved offerings.

In addition, industrial symbiosis contributes to regional economic growth by fostering cohesive industrial networks, attracting new businesses and increasing demand for local support services. This dynamic can be seen in global examples, notably the Kalundborg Industrial Symbiosis or the Kwinana Industrial Park in Australia, which have delivered significant cost savings and wider economic benefits to participating businesses. These financial benefits not only improve the performance of individual companies, but also strengthen the resilience and sustainability of the regional economy. As a result, industrial symbiosis is an effective model for advancing economic and environmental goals.

Considering that there is a lack of knowledge about the way waste is managed in developing countries (Cárcamo and Peñabaena-Niebles, 2022), this article seeks to contribute to the ongoing debate on the need and possibilities of promoting symbiosis and recycling activities in the Mauritian context. By advocating the practice of industrial symbiosis, this paper has sought to identify the use of available technologies to reduce the amount of waste sent to landfill or stored on site. By uncovering the potential of industrial symbiosis on the island, this paper has explored the potential of industrial symbiosis to contribute to industrial ecology. The conceptual framework proposed by Van Assche et al. (2014) can help Mauritius to find potential industrial symbiosis that can reduce waste and serve as an effective model to realize economic and environmental objectives.

This study is the beginning of a research that investigates the key factors for the establishment of industrial symbioses. Therefore, further research is needed to determine the potential of industrial symbiosis in Mauritius and to identify industrial sectors where industrial symbiosis has the greatest potential. There is also a need to identify the potential funding opportunities for the technology, the establishment of the legal framework and the involvement of stakeholders.

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