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Citation:

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REVIEW ARTICLE

Current Status, Emerging Challenges, and Future Prospects of Industrial Symbiosis in Africa

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Received: 21 March 2022 / Revised: 21 March 2022 / Accepted: 26 June 2022 / Published online: 16 July 2022
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Abstract

The concept of industrial symbiosis have contributed to the achievement of a circular economy—a production and consumption model that promotes sustainability and also benefits countries economically, socially, and environmentally. There exists a variety of literature that highlights several cases of the application of industrial symbiosis in different geographical locations of the world. However, only a few of these studies have investigated its prevalence in Africa. Therefore, the goal of this study is to analyze the few cases of industrial symbiosis in Africa, highlight the current status, the current regulatory context, the challenges to the implementation of this model, and propose new paths for industrial symbiosis in Africa. The study carried out shows that there exists good potential for industrial symbiosis to thrive in Africa, owing to the type of economic activities and the waste generated in Africa. It also shows that if industrial symbiosis is implemented on a larger scale, it would contribute to the reduction of carbon emissions, reduce waste, and help Africa make more efficient use of its resources. However, for this to become a reality, concrete, well-thought-out actions must be taken at various levels to encourage all organizations to develop great synergy. Providing specific Industrial symbiosis-focused legislative frameworks, funding intervention from the government, and involvement of the government in the implementation of concise action plans are some aspects that can help increase the prospects of industrial symbiosis in African countries.

Highlights

- Over the years, even though most countries in Africa have enacted laws to tackle the production, use, and recycling of waste products, the actual implementation has not been achieved yet.
- Thus, African countries are yet to completely embrace the circular economy idea in their path to sustainable development.
- A coordinated national approach that operates across multiple sectors may be critical for the growth of industrial symbiosis in Africa.
- Again, enhancing the legislative framework to promote industrial symbiosis and decrease bureaucracy in the process of by-product classification, providing tax relief, facilitating access to support funds, educating and supporting businesses, and encouraging industries that can act as anchor tenants are just some of the ways Africa can excel in establishing industrial symbiosis on a sustainable basis.

Keywords Industrial symbiosis · Circular economy · Sustainability · Africa · Industrial ecology · Eco-industrial parks

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Introduction

Urban municipal waste constitutes a significant proportion of waste streams generated in Africa. Empirical evidence (Couth and Trois 2010) has shown that on average, the organic content for urban municipal solid waste in Africa is above 56%, the degradation of which contributes significantly to greenhouse gas emissions and other forms of environmental pollution. This urban waste is poorly managed because of a lack of funding for public service and the dearth of human and technical resources (Ferreira et al. 2019). There has also been a rapid growth in Africa's population in the last decade (Chirisa 2008) which has put upward pressure on the demand and consumption of natural resources and energy. Han et al. (2017) and Fayiga et al. (2018) also reiterated that this population growth is closely related to urbanization and has increased environmental resource depletion, carbon emissions, and hence, environmental degradation and extreme pollution. Though some scholars (Qudrat-Ullah and Nevo 2021; Nathaniel and Iheonu 2019) argue that the environmental degradation due to increased industrial activities could lead to economic growth, it is important to also highlight that such growth anchored on environmental degradation may not be sustainable. Neves et al. (2019) suggest that for a rapidly growing population, the adoption of a circular economy may reduce the consumption of resources and the attendant environmental consequences without posing a threat to sustainable economic growth. The authors refer to this as the construction of industrial symbiosis (IS) networks across the different sectors and industries of the economy, as opposed to a linear economy.

While the foundation of circular economy is categorized into four: optimum utilization of existing resources, natural capital preservation, the renewable flow of products and resources, and risk reduction (Twigger 2016), a linear economy is characterized by huge amounts of easily accessible or cheap materials and energy, and also focuses on take–make–dispose approach towards an economy's production chain (Gardetti 2019).

Van Fan et al. (2021) described industrial symbiosis as a system which engages conventionally distinct industries in a collective approach to mutual benefits involving the physical exchange of energy, materials, water and/or by-products (Chertow 2000). In different regions of the world, government agencies, business outfits, and non-governmental organizations are intensifying efforts to promote industrial symbiosis. The author further believes that industrial symbiosis is predicated on the collaboration and synergistic possibilities offered by geographic proximity. Boons et al. (2011) also believe that the application of industrial symbiosis has been the focus of many studies.

Such applications are more pronounced in Europe (Neves et al. 2019), with a popular case being the industrial symbiosis network in Kalundborg, Denmark. Scholars suggest that this network is a brainchild of a self-directed initiative of companies contributing water solutions in the country. Over the years, the network has grown both in terms of the number of constituting symbioses and the number of participants and is still successful to date.

Again, industrial symbiosis has been classified under industrial ecology by different scholars (Lee 2012; Chertow 2000; Yuan and Shi 2009) and was popularized by Frosch and Gallopoulos (1989). It suggests that the wastes produced by a company can be used as a productive input in another company within the same economy. The aim of industrial symbiosis is to promote cleaner and sustainable production in a way that protects the environment, reduces the emission of greenhouse gases (CO₂ notwithstanding) and minimizes waste generation. Desrochers (2001) further argues that industrial symbiosis should be viewed in terms of the biological symbiosis where two seemingly unrelated species exchange energy, materials, or information in a mutually beneficial manner. Thus, industrial symbiosis involves some sort of mutually beneficial exchange between two different industrial entities. Industrial symbiosis also contributes several environmental, economic, and social advantages while promoting sustainability (Neves et al. 2020) as it brings together entities that are conventionally separated to cooperate among them in sharing resources. Costa and Ferrão (2010) also added that the emergence of industrial symbiosis is a multi-industrial and collective approach aimed at improving environmental and economic outcomes through the use of by-products or wastes as substitutes for raw materials.

Though tremendous progress has not yet been recorded in the area of industrial symbiosis in Africa, some industrial symbiosis networks have been implemented in a few African countries. East African countries are the most cited as success cases of industrial symbiosis implementation in Africa because they are continuously developing sustainable systems of waste exchange between industries and are increasing the synergy of key players in their respective economies. Alfaro and Miller (2014) report the application of industrial symbiosis in a smallholder farm in Liberia, West Africa. They further explain that this form of system integration meant increased productivity and decreased waste on the farm. Oguntoye et al. (2019) also reveal that the Gauteng Industrial Symbiosis Programme (GISP) in South Africa contributes about 10% of the total sub-Saharan African Gross Domestic Product (GDP) or about 7% of the GDP of the entire African continent. This further implies that opportunities in South Africa (Madanhire and Mbohwa 2016) and Africa in general for growing

an economy still abound in the implementation of industrial symbiosis. Madanhire and Mbohwa (2016) also discuss how the construction of an eco-industrial park (EIP) in Harare Metropolitan, Zimbabwe, has brought a 20% reduction in the amount of industrial wastes disposed of in landfills and improved the previous unsustainable use of resources, water, and energy. For the North African country of Egypt, ElMassah (2018) believes that industrial symbiosis within the eco-industrial parks of Borg El-Arab industrial zone has created opportunities for by-product exchange between the industries. The author further identifies that there is still a huge prospect to increase environmental outcomes of the Borg El-Arab industrial city and align it with national and international sustainability goals. Rweyendela and Mwegoha (2021) investigated the application of industrial symbiosis in Kilombero Sugar Company Limited (KSCL), the largest sugar refinery in Tanzania, which involves the exchange of molasses, bagasse, boiler ash, and filter cake among the seven constituent units of the company. Their study suggests that with the industrial symbiosis application, KSCL achieved resource optimization through the minimization of negative environmental effects from emissions and increased revenue generation due to resource recovery. Similarly, Damgaard et al. (2019), in their investigation of the opportunities and scope of industrial symbiosis in Kenya, opine that huge opportunities for industrial symbiosis exist in the country. They, however, added that more consideration should be given to issues that play out in the application of industrial symbiosis within the Kenyan context, such as lack of trust between different companies and between companies and relevant authorities, insufficient and inefficient environmental infrastructure, etc. These issues often affect the success of industrial symbiosis implementation in developing countries but are rarely considered in the mainstream research on industrial ecology.

Although the African countries' case studies discussed have emphasized the crucial role of industrial symbiosis in achieving sustainability in Africa while attaining the United Nations Sustainable Development Goals (SDGs), there are still few cases of industrial symbiosis in some African regions, especially central Africa and North Africa, in extant literature. Moreover, and to the best of our knowledge, none of the existing publications has investigated industrial symbiosis in the holistic African context; their focus has either been on one country's case or, at most, the perspective of one region. Given these research gaps, there seem to be some difficulties in understanding how the industrial symbiosis networks in different African regions can leverage each other to enhance productivity in the continent with the by-products or wastes that would otherwise be released into

the environment to cause more carbon emission. The gaps also imply that more research is needed on how to optimize resource consumption in Africa. Again, while some studies have examined the challenges and determinants of industrial symbiosis networks' development, their applicability to the African context has not been verified.

Therefore, this study aims at a holistic discussion of industrial symbiosis, with Africa in perspective. To do this, we review the existing case studies of industrial symbiosis in Africa published in peer-reviewed journals and other reputable extant literature and investigate the state-of-the-art as well as Africa's legal institutional environment for industrial symbiosis. The study further examines the major challenges to the growth of synergy relationships across the entire African regions in implementing industrial symbiosis and suggests new strategies for the upscaling of industrial symbiosis in Africa. Some of these identified strategies have been juxtaposed with some best practices in industrial symbiosis literature drawn from other regions of the world to ensure that Africa's success in creating new industrial symbiotic relationships also aligns with the global sustainability goals. Grant et al. (2010) buttress this in their assertion that the primary medium of identifying best synergy frameworks involves mimicking similar success cases from different contexts. Lastly, this study will discuss the prospects of industrial symbiosis in Africa based on the existing realities and offer relevant recommendations.

The paper, excluding the introduction, is divided into different sections as follows: the second section focuses on the research methods used to address the highlighted objectives. The third section shows the results and analysis of Africa's reality in terms of industrial symbiosis networks with emphasis on Africa's key industries, wastes and emissions, and legal environment; and highlights the major challenges and strategies for upscaling industrial symbiosis in Africa with reference to other successful regions. Finally, the last section focuses on the major conclusions, recommendations, and directions for future research.

Materials and Methods

For the objectives of this study to be achieved, an expansive review of the literature was carried out on the meaning, importance, challenges, and barriers of Industrial symbiosis with regards to the African continent from different databases. A systematic literature review approach was used to source for the publications of this study which includes choosing, documenting, and reviewing databases that have the meaning of industrial ecology and industrial symbiosis, its location of study, and the criteria for proper screening of

the articles to select those most relevant for this review and this was done and concluded within 38 days for a good data to be captured. A review of the content was carried out, and the articles were studied to examine the challenges and barriers of industrial symbiosis existing in Africa to arrive at a conclusion from the factors obtained and to proffer necessary solutions in mitigating them. In searching for the primary article, “industrial symbiosis”, “industrial ecology” and Africa were used as keywords. This was then modified for more specificity to include North, South, East, and West Africa.

A total of 25 publications were used for this review, which was painstakingly selected based on their location (country) of publication such as South Africa, Kenya, Ethiopia, Tanzania, and Ghana with topics such as, but not limited to, “Facilitating Industrial Symbiosis Programmes in Developing Countries: Reflections from Gauteng” by Oguntoye et al. (2019), “Industrial symbiosis in Tanzania: A case study from the sugar industry” by Amani et al. (2020), “Applicability of Industrial Ecology Strategies for the Corporate Environmental Management: Selected Cases of the Eastern and Northern Zones of Tanzania” by Felichesmi (2013), and a number of articles from various Journals accessed through Google, Google scholar such as Elsevier Journals, Journal of Industrial Ecology, Elgar online, Springer Journals, ResearchGate, LEAD Journal, DTU Library, MDPI, and TIPS. All publications that analyzed industrial symbiosis cases in Africa were added to the study. Furthermore, the review extended to cover cases of industrial symbiosis that are already in existence and its challenges in Africa: in government publications, Small and Medium Enterprises, business associations and technical, theses (assertion), and dissertations. After collecting and screening the publications which was done painstakingly, a thematic breakdown, which is a method for analyzing qualitative data, was performed to properly distinguish and characterize the cases arising from industrial symbiosis in Africa. Southern Africa has proven to achieve a lot as the pioneer of the first African industrial symbiosis programme in South Africa (Kasese et al. 2016). A study by ElMassah (2018) showed that Africa is currently recycling only 4% of its estimated 70–80% recyclable municipal solid waste (MSW), while its MSW collection rate is only 55%. Organic wastes constitute 57% of the total MSW generated in sub-Saharan Africa, considerably higher than its proportion of the total global MSW according to the World Bank (Hoornweg and BhadaTata 2012). This review will help to distinguish and single out the challenges and analyze (breakdown) the problems of industrial symbiosis encountered in Africa.

Results and Discussion

Industrial Symbiosis in Africa

Current Status of Industrial Symbiosis in Africa

Global climate issues have influenced the development of several international agreements and brought about the recommendation for the implementation of more sustainable policies that would result in a successful fight against climate change (UN SDG 13). According to United Nations Fact sheet on Climate Change (2006), Africa is the continent most vulnerable to the impact of climate change. Because of this, countries in Africa have started undertaking steps aimed at ensuring sustainability, such as creating awareness about the Sustainable Development Goals (SDGs) via various platforms and forming inter-ministerial committees and task forces to guarantee that global goals and country planning procedures, aspirations, and priorities are in sync. However, African countries still have a lot to do to attain a sustainable economy.

Africa is a minor source of greenhouse gas emissions, accounting for about 2–3% of the world’s carbon dioxide emissions but suffers significantly from the impacts of climate change. This compromises the continent’s developmental efforts (United Nation Factsheet on Climate Change 2006). Again, the average value of CO₂ emissions in 2018 was 0.8 metric tonnes per capita in Sub-Saharan Africa, with South Africa contributing the highest value of 7.5 metric tonnes per capita (World Bank 2018). In comparison with the global average of 3.9 tonnes per capita, the region’s emissions contribution is quite insignificant. In addition to this, the manufacturing industry of several countries in Africa is heavily dependent on the procurement of raw materials. For instance, Nigeria’s manufacturing sector contributes 10% of the country’s total GDP (Manufacturing Statistics 2016), Egypt’s manufacturing sector contributes one-fourth of the country’s GDP (Statista 2020a, b), while 25% of South Africa’s GDP comes from its manufacturing sector (Statista 2020a, b). These numbers indicate how crucial the manufacturing industry is in the aforementioned countries.

The economies of many countries in Africa are heavily dependent on the agricultural and mining sector. About 60% of the continent’s workforce are employed in the agricultural sector which generates about 32% of its GDP growth on average (World Bank 2008). Exporting minerals such as gold, copper, and diamond also contribute significant revenue to the continent.

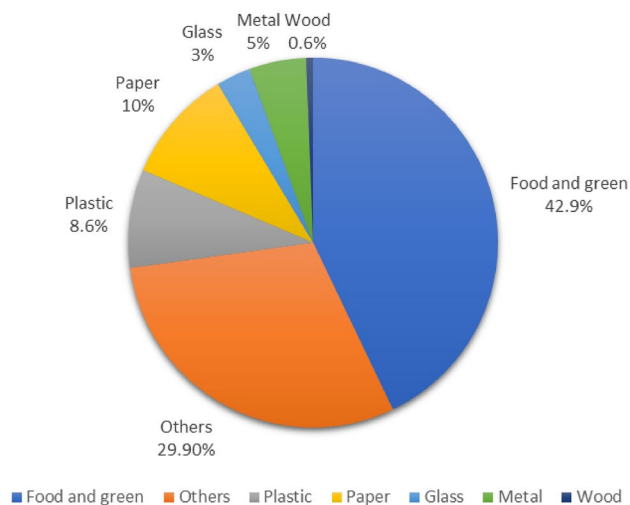


Fig. 1 Municipal solid waste composition streams in sub-Saharan Africa in 2016 (Source Kaza et al. 2018)

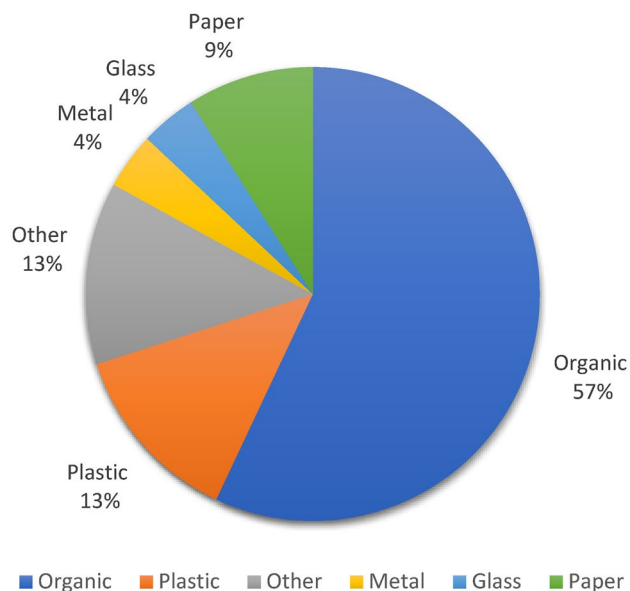


Fig. 2 Projected municipal solid waste composition streams in sub-Saharan Africa in 2025 (Source Hoornweg and Bhada-Tata 2012)

Though on average, waste generation in Africa is less in comparison to other parts of the world (UNEP 2018), the total garbage generated by all economic activity and households in Africa has been increasing, reaching about 180 million tonnes at the rate of 0.5% per capita per day in 2019 (for a 1 billion population). This corresponds to 5500 kg per inhabitant, according to Ncube et al. (2021). On an individual basis, Africa's rate of waste generation per capita is estimated at 0.46 kg per person per day, which is the lowest globally, though national averages range from 0.11 to 1.57 kg per person per day (Silpa et al. 2018).

Furthermore, by 2050, annual garbage creation is expected to triple from 174 million tonnes in 2016 to 516 million tonnes. For Sub-Saharan Africa, Urban waste generation in Africa increased from 123.7 million tonnes per year in 2015 to 165.1 million tonnes per year in 2020 and is expected to increase to 210.0 million tonnes per year by 2025 (UNEP 2018). Silpa et al. (2018) further predict that sub-Saharan Africa will account for about 15% of the total global waste by 2050.

In 2016, at a rate of 0.5% per capita every day, about 180 million tonnes of garbage were generated, the majority of which was food waste and green waste, taking 42.9% of the total waste, Fig. 1 shows the waste composition of Africa in 2016, while the projected waste composition forecast of Africa in 2025 is shown in Fig. 2. Table 1 depicts the population concentration and waste distribution of four major cities in the four regions of Africa. These cities' statistics are used to extrapolate the population concentration and waste distribution of the four regions of Africa since they are the most populated cities in these individual regions. These cities are Cairo (North Africa) (Statista 2021; Worldometer 2021a, b, c, d), Lagos (West Africa) (Macrotrends 2021a, b, c; Worldometer 2021a, b, c, d), Johannesburg (South Africa) (Macrotrends 2021a, b, c; Worldometer 2021a, b, c, d), and Nairobi (East Africa) (Macrotrends 2021a, b, c; Worldometer 2021a, b, c, d).

Ninety percent of Africa's garbage is disposed of on land, most commonly in uncontrolled and managed dumpsites (Hoornweg and Bhada-Tata 2012). Since it is considered an inexpensive way of getting rid of solid waste, controlled and uncontrolled dumping is the most popular type of trash disposal in Africa (Hoornweg and Bhada-Tata 2012). There are about 5000 illegal dumpsites in Lagos—Nigeria (Adegbeye 2018), over 70 illegal dumpsites in Nairobi—Kenya (Njoroge et al. 2014), and in Tanzania, 70% of the waste is either informally disposed of (Palfreman 2015), burned, or illegally dumped. Controlled disposal is often below 35% and 68% in low- and lower-middle-income nations, respectively (UNEP 2015). In Freetown, Sierra Leone, only around half of the total waste is disposed of at the two major dump sites, leaving 127 tons of waste uncollected and placed improperly, thereby posing threat to the people's health and the environment (UN Human Rights Council 2018).

Africa is currently recycling only 4% of its estimated 70–80% recyclable municipal solid waste (MSW), while its MSW collection rate is only 55% (Hoornweg and Bhada-Tata 2012). Organic wastes account for 57% of all MSW generated in Sub-Saharan Africa, which is significantly higher than the global average according to the World Bank (Hoornweg and Bhada-Tata 2012). In addition, plastic as a percentage of MSW is also higher in Sub-Saharan Africa than the global average, at 13%. Due to the processing of fresh food and the use of less packaging in

Table 1 MSW distribution and characterization across some economic cities of Africa (Source Emenike et al. 2013)

Parameters	Johannesburg (South Africa)	Nairobi (Kenya)	Cairo (Egypt)	Lagos (Nigeria)
Population (millions)	4.4	3.1	9.12	8
Waste generation (per capita) kg/day	0.7	0.65	0.8	0.63
Waste composition organic/putrescible	13	58.8	60	56
Garden waste	21	NA	NA	NA
Paper	18	11.9	10	14
Plastic	10	15.9	12	4
Glass	4	1.9	3	3
Metal	3	2	2	10
Textiles	3	2	2	NA
Ash	2	NA	NA	NA
Fine/residue	23	NA	NA	NA
Building rubbles	1	NA	NA	NA
Other/miscellaneous	2	9.7	11	13

NA not available

sold goods, the waste composition is characterized by a high percentage of organic waste (UNEP 2018). Statistically, organic waste accounts for 57%, plastic accounts for 13%, paper or cardboard for 9%, glass for 4%, metal for 4%, and various materials for the remaining 13% (UNEP 2018).

Hazardous wastes generated in Africa fall into a range of different categories, hazardous home waste, medical waste, e-waste, used lead-acid batteries (ULAB), nano-waste, and marine litter are all included. The average hazardous waste generated in Africa is an average of 314,000 tonnes per year with Nigeria grossing the highest value of 2,469,000 tonnes per year closely followed by Egypt with a value of 1,440,000 tonnes per year (Victor and David 2020).

All the statistics above showed that countries in Africa are yet to fully embrace the circular economy concept in their sustainable development process. In countries where there has been little or no effort to embrace the concept of industrial symbiosis, there have been research carried out to put forward models that can help integrate waste management practices in other sectors of the economy such as agriculture. One of these research outputs is the one carried out by Amare et al. (2017) in Liberia, where they examined the advantages of integrated material and energy flows in smallholder farming, and by implementing industrial symbiosis principles, it is expected that farmers in less developed countries can attain an increase in food output and revenue while promoting resource efficiency and cleaner production.

In Ghana, 14.4% of its labor force is in the industrial sector and they contribute 24.5% to the country's GDP when compared to 18.3% GDP's contribution by the 44.7% population in agriculture. She, therefore, developed the "one district one factory" policy with the aim of reducing rural–urban migration and promoting industrialization (CIA

2017). Given Ghana's enormous waste management difficulties, which are likely to worsen, it is necessary to implement IE, which should be integrated into the one-district-one-factory policy implementation framework (Nukpezah et al. 2019).

Southern Africa has proven to achieve a lot as the pioneer of the first African industrial symbiosis programme in South Africa. Though the Western Cape Industrial Symbiosis Programme (WISP) has found over 1000 potential synergies between enterprises in the Western Cape since its establishment in 2013, there are still barriers that need to be overcome to achieve sustainable waste management practices. This ranges from technical, logistics, legislative, economic, to capacity barriers (Kasese et al. 2016).

Going to North Africa, not much has been recorded in terms of promoting sustainable waste management practices. The sugar industry in Tanzania has contributed immensely to the country's economy, accounting for 8.5% of the total value added to the manufacturing industry in 2016 (GASP 2016), consequently, providing jobs for more than 30,000 people in Tanzania (Tanzania Invest 2016). Internally, the Kilombero Sugar Company Limited (KSCL) have imbibed some form of industrial symbiosis by redirecting some of its waste and by-products from landfills to producing alcohol, therefore, reducing environmental impacts and producing quality sugar for consumption. Again, in Northern Africa, Egypt's economy is rising at a 4.3% annual rate and developments in crucial industries such as automobiles, manufacturing, chemicals, and electronics are sharply met with an increase in the country's CO₂ emissions (World Bank 2017). On the other hand, the government, though a supporter of sustainable industrial development, after launching "Egypt's Vision 2030" in 2015, is yet to have a functioning eco-industrial park—EIP (ElMassah 2018).

In East Africa, the manufacturing industry in Kenya has contributed on average, 10% to the country's GDP. Therefore, the country has designed the Special Economic Zones (SEZs)/Industrial parks (IPs), to reduce GHG emissions and promote waste recycling. Whereas a study carried out by Khisa et al. (2016) identified the barriers that the combined effect of the SEZ laws, as well as the waste management regulations of the Environmental Management and Coordination Act (EMCA), posed to the adoption of waste and by-product exchange through industrial symbiosis, and recommended that these two regulations be changed to include green growth ideas that can help the country's SEZs/IPs progress as a circular economy.

Solid waste contributes to climate change on a worldwide scale and is one of the most polluting sources in the oceans (Kaza et al. 2018). As estimated by the Organisation for Economic Co-operation and Development (OECD), about 712,000 people died in Africa due to dirty air in 2013, a 36% increase compared to the 1990 figure. Africa's population is predicted to increase from 1.2 billion in 2015 to over 2 billion by 2040 (UNEP 2018). The amount of rubbish generated grows in lockstep with the population and urbanization. In 2015, urban Africa generated 124 million tonnes of garbage annually. By 2040, this quantity is predicted to rise to 368 million tonnes (UNEP 2018). The mismanagement of waste poses a great threat to people and the environment, and this can be felt more in Africa due to the lack of effective waste management. Hence, for targets to be achieved, it is, therefore, imperative for African countries to do more in pursuing integrated waste management practices in all sectors to promote a circular economy, consequently, meeting societal, economic, and environmental goals.

All the statistics presented above shows that African countries are yet to fully embrace the circular economy concept in their sustainable development process. African countries show promises of a thriving symbiosis network if adopted, especially since industrial symbiosis not only helps to combat the waste problem in the continent but also helps Africa attain a sustainable circular economy that will help fight the problems of climate change and preserve the continent.

Africa's Legislative Context Related to Industrial Symbiosis

To achieve the international requirement on reduction of greenhouse gas emissions through efficient use of resources, Cui et al. (2018) opine that an industrial symbiosis is a vital tool if proper legislative frameworks are put in place. Over the years, various governmental policies and laws have been enacted with regards to industrial waste management in Africa as well as several submissions have been made towards projecting the benefits associated with IS practice; however, there is no central directive that gives cognizance

to the importance of industrial symbiosis and also provides support information for its implementation in Africa as a continent.

On the contrary, some relatively industrialized countries on the continent have embarked on conceptualizing a circular economy (a derivative of industrial symbiosis) policies and framework, it is hoped that the implementation will be in full scale as the level of industrialization increases in the continent. With the aid of some governmental acts in South Africa, the practice has been recognized and there have been great results recorded in this regard (O'Carroll et al. 2017). The National Environmental Management Act 2008 sets waste hierarchy as the basis for waste management decision-making. The act identifies waste hierarchy as a decision-making tool for waste exchange which leads to waste minimization, reuse, recycling, and waste recovery as well. This act, in the long run, may foster industrial symbiosis practice within the South African economy. Furthermore, there is also an Industrial Policy Action Plan 2018/2019 in South Africa which highlights that industrial symbiosis is an instrument to achieving green industry with reference to the reduction of carbon intensity in production processes (O'Carroll et al. 2017). This action plan is designed to further foster industrial growth and development at the national level by identifying important initiatives which are to be supported and implemented (South Africa Department of Trade and Industry 2016).

Kenya is another country in Africa with a good legislative framework that has promoted resource efficiency with its emerging industrialization. In addressing and promoting green growth, a product of industrial symbiosis, the Kenyan Government developed several strategies which are enshrined in several policy documents that serve as a framework in achieving the needed goal required in addressing infrastructural gaps and environmental degradation, thus, setting the pace for a symbiotic industrial ecosystem (Irene Jepkoru 2020).

The Kenyan Industrial Transformation Program 2015 is a precursor policy that positions the country at a comparative advantage by creating an enabling environment that fosters industrial development, thus, prioritizing the drive towards a low-carbon economy. Further to this, the program seeks to assign implementation teams with dedicated responsibilities which focus on flagship projects and dedicated delivery units to drive the industrial transformation noting the importance of industrial symbiosis (Irene Jepkoru 2020). Besides, Kenya's industrial transformation program rests on Kenya's vision 2030 policy. The policy is a pillar to hasten the country's goal of achieving a clean, safe and sustainable environment by the year 2030.

Another framework that intends to foster industrial symbiosis is the Special Economic Zones (SEZ) Act 2015 which establishes regulatory provisions binding operation within

these economic zones, operating license issuance, and procedures for renewal. In addition, the Act also makes provision for the rights of the operators and developers while the permitted activities within the SEZs are listed. On the global scale for Africa, the level of industrialization seems to be a limiting factor to the practice of Industrial symbiosis as few countries within the continent are industrialized. However, with the hope of Africa becoming industrialized in the future, there is a need for a clear recommendation and implementation plan by the African Union (AU) through a specialized committee in harnessing resource efficiency to foster industrial symbiosis practice. This will be a road map for all member states to follow (Olayide 2015).

Industrial Symbiosis Networks in Africa

Africa has only a few recorded cases of industrial symbiosis. Most of the documented symbiotic networks in publication and literature are domiciled in the Southern African region with local government authorities and local companies playing a key role through social networking and community engagement (Oguntoye et al. 2019). Brent et al. (2008) highlighted interactive information sharing, and a dedicated drive to develop environmental resilience and a sustainable community as the driving factors responsible for the thriving industrial ecology networks and eco-industrial parks in South African municipalities. Instances of industrial symbiosis programs are on the rise, with the developing network broadly dominated by private, public organizations and citizens' participation.

Some practical IS examples exist in South Africa. IS initiatives in the country are mostly driven by the need for improved industrial waste management, cleaner production, and the creation of eco-industrial parks. Initial IS initiatives in South Africa such as the National Cleaner Production Centre of South Africa (NCPC-SA) in 2010, was driven primarily by the need to protect the environment through reducing waste going to rapidly filling landfills and socioeconomic prospects such as resource management and job creation. The Western Cape Industrial Symbiosis Program (WISP) was adapted from the facilitated IS program developed by International Synergies Limited (Oguntoye et al. 2019). The South African region of Gauteng is notable for being a leading industrial province in the country and the region also hosts a very large proportion of South African processing industries (Zyl 2010). The study conducted by Olamide et al. is a practical example that shows the procedure deployed in the execution of Facilitated Industrial Symbiosis Programs (FISPs). With Gauteng accounting for 10% of Sub-Saharan Africa's GDP and 7% of the entire African GDP, it was a perfect model for the study conducted by Oguntoye et al. (2019). Still, in the Southern African region, a conceptual study using a five-step anchor tenant model,

created a virtual eco-industrial park in Harare, Zimbabwe (Madanhire and Mbohwa 2016). The study focused on how the IS concept could be implemented in developing economies. Potential exchanges which could occur in the industrial zones of the Harare metropolitan area were highlighted. It also highlighted peculiarities associated with developing economies that should be considered when attempting to implement IS concepts in such contexts. The study discovered that the informal sector accounts for the majority of industries in developing economies with a vast number of small private enterprises (SMEs) unlike the large factories in industrialized countries. The key proposition of the study is the establishment of infrastructural networks to link the businesses and aid the exchange of by-products.

Studies in Eastern Africa have shown the potential of ecosystem symbiosis in environmental management and ecosystem conservation. Ramin et al. (2020) in their study on the Ruaraka industrial park located in Nairobi (Kenya) enumerated the role of intra-company connections. The study emphasized the synthesis of the water network and the impact of various manufacturing companies with each having multiple units' processes. A study conducted by Rweyendela and Mwegoha (2021) further emphasizes the relevance of industrial symbiosis to achieve sustainability. This was in their study on industrial symbiosis in Tanzania with Kilombero Sugar Company limited as the case study. The study reveals considerable progress both environmentally and economically. With concerted efforts between industry, academia, national governments, and international organizations, industrial symbiosis networks could significantly increase in Africa (Rweyendela and Mwegoha 2021). Mbuligwe and Kaseva (2006) made an assessment of the practices employed in Tanzania to manage industrial waste and recover valuable resources. It was revealed that recovering resources from industrial waste is an effective strategy to improve waste management efforts. The Tanzanian case highlighted the relevance of international collaboration and assistance in facilitating the implementation of industrial ecology and sustainable manufacturing in Africa. Further efforts in the East African region is Mauritius which operates an elaborate and effective solid waste management plan which aims at 40% recycling of generated waste. Their plan towards a circular economy targets improving waste collection and resource recovery. Being a steadily improving economy, the country has experienced industrialization and economic diversification. The primary strategy of waste management in the country is recycling and it is carried out mainly by the private sector with absolutely no energy recovery. The public sector uses composting and landfill disposal as its waste management strategy. A quantitative analysis was made by UNIDO to assess the potential industrial symbiosis networks which could be established among both private and public organizations. 23 firms that were analyzed

in the study were drawn majorly from the textile, chemical, food, and print/media industries. The qualitative study identified the different types of waste generated among the industries, an estimate of the gross amount which could be generated at the national level was taken to determine which industry would be suitable for the IS project (United Nations Industrial Development Organisation (UNIDO) 2016).

A case study research strategy was quantitatively conducted by ElMassah (2018) to determine the opportunities of by-product exchange that could transform the industrial area into an EIP. Borg El-Arab is an industrial city in Egypt that holds great potential of becoming an EIP. With 1271 factories as of 2017, the area produces huge amounts of waste which could be feedstock for industries in the zone. Analytics showed that the Third industrial zone generated the highest volumes of solid wastes, making it the ideal candidate for conversion into an EIP. The majority of industries in this area are in the food sector. Eleven possible exchanges were identified and a pilot EIP was developed based on collated data. The pilot EIP proposed a resource recovery facility that consists of some by-product substations which will receive, separate, treat and market by-products. To close the production loop and enhance the by-product exchange in the EIP, the report also recommended the establishment of new industries that could utilize the waste streams.

With regard to the West African region, Nukpezah et al. (2019) conceptualized the possibility of applying IE in Ghana. The framework was developed based on a company that produces cassava starch. The company supplies high-grade starch to industries in the pharmaceutical and brewing sector and also foreign markets. The study identified the production model of the plant, material flows, exchanges, and potential exchanges. It was discovered that by-products from the cassava company were supplied to an informal market; however, strategic and productive material exchanges were possible. In addition, a case study of the Songhai farm in the Benin Republic reveals how industrial ecology encourages sustainability. The farm operations are based on the principle of zero emissions and it integrates crop farming, aquaculture, livestock rearing, and the cultivation of mushrooms, exotic produce, vegetables, and biomass (Olayide 2015). Further, conceptual integration of material and energy flows within a smallholding was analyzed by Alfaro and Miller (2014). The study applied optimization techniques, linking IS to integrate farming research (IFR). This considers the fact that the majority of Africa is unindustrialized and depends on smallholder farming and husbandry. This provides an opportunity for improved farm outputs and reduced waste hence giving room for IS and sustainable development in the African agro space which is traditionally subsistence focused. The study highlighted the different units of a farm system namely, the piggery, rabbit farm, fish farm, rice paddies, crop garden, and rice mill. It gave the baseline scenario

of the input sources and established conceptual synergistic links among them. Table 2 highlights the key industrial symbiosis cases in each of the regions of Africa.

Current Development, Challenges, and Future Prospects of Industrial Symbiosis in Africa

Africa appears to have made significant efforts to facilitate measures and plans that can help push the continent towards economic advancement through reduced carbon dioxide emissions, little to no adverse effects on climate change, and improved resource consumption. This is evidenced by the industrial symbiosis cases in Africa highlighted above. However, there is still a large margin for further growth. The challenges and future prospects that the African continent faces in terms of industrial symbiosis development are diverse.

The initiation of environmental measures facilitated by various countries in Africa cannot be detached from the backdrop that has taken place due to the global economic crisis. The entirety of the measures enacted had economic consequences, resulting in an economic contraction and a minimization in purchasing power due to lay-offs and wage cuts, which affect companies in many ways. However, in the region of South Africa, the introduction of the Western Cape Industrial Symbiosis Programme (WISP) in 2014, which was the first executed industrial symbiosis program, led to the diversion of waste from landfills, which brought significant economic benefits and the creation of four permanent jobs (O'Carroll et al. 2017). Consequently, Madanhire et al. (2018) crafted the idea of innovating industrial areas into eco-industrial parks (EIP) in South Africa, as this may fill in as a source of motivation to potential organizations to improve their ecological execution in terms of waste, energy, and materials' management.

Industrial symbiosis has been extensively practiced in different countries with diverse social, economic, and political contexts. However, it has contributed to improved environmental sustainability, economic and social developments. In Africa, only limited cases of industrial symbiosis have been reported in the literature. With the exception of the Western Cape Industrial Symbiosis Programme (WISP) which was an innovative approach to efficient management of resources and waste minimization for businesses in the region of South Africa, alongside, the creation of Eco-Industrial Park (Madanhire and Mbohwa 2016) in the region of Kenya, South Africa, and Egypt, which has a bigger organizational integration and subsequently more participants, most of the existing industrial symbiosis networks are made up of small organizations and limited participants (ElMassah 2018). Although industrial symbiosis has been considered as important steps towards achieving laid down goals on environmental sustainability by African Union and

Table 2 Existing industrial symbiosis networks and eco-industrial parks in Africa

Region	Country	Initiative	Activity	Participating industries	Characteristics	Limitations	Ref
Southern Africa	South Africa	Facilitated Industrial Symbiosis Program (Western Cape, Gauteng and KwaZulu-Natal)	Industrial waste exchange	Food and beverages, textiles, construction, metals and electronics, chemicals, pharmaceuticals, wood and wood products	Free facilitation service that matches the supply and demand for secondary raw materials of manufacturing companies to divert waste from landfill	Poor resource quality, unviable resource amounts, legislative, economic and logistic limitations	Kasee et al. (2016), O'Carroll et al. (2017), Cape Town; Africa's first (2020)
Region	Country	Initiative	Activity	Participating industries	Characteristics	Limitations	References
Southern Africa	South Africa	Sedibeng District Municipality	Industrial waste exchange	Metals, chemicals	Identification of waste streams and evaluation of reuse potential	Concerns about the confidentiality of information, logistics	Brent et al. (2008) Sedibeng District Municipality (DC42) (2021)
Southern Africa	South Africa	Limpopo EIP	Eco-industrial park		Zero solid-waste eco-industrial and integrated nature park, tourism area, residential eco-estates, fossil-free energy		Dyble (2021)
Northern Africa	Egypt	Borg El-Arab EIP	Eco-industrial park	Food manufacturing, textiles, metal, electrical and electronic, paper, construction, chemicals, plastic, engineering	By-product exchange	Absence of industries to utilize waste streams	ElMassah (2018)
Eastern Africa	Tanzania	Kilombero sugar company limited (KSCL)	Symbiotic exchange of by-products	Co-located units in the sugar plant; sugar factories, alcohol distillery, wastewater treatment plant, internal power plant, agriculture system	Materials and energy exchange, utility sharing	Unstable by-product supply, outdated technology, absence of other industries, lack of information, passive government support	Rweyendela and Mwego (2021)
Kenya	Kenya	Ruaraka Industrial zone	Symbiotic exchange of waste, water; eco-industrial parks	Food, pharmaceuticals, paper, rubber and plastic, healthcare, glass	Transforming the industrial area into an EIP through identifying and facilitating the exchange of solid waste and water among industries in the zone	Limited information on quantity and quality of residues, poor infrastructure and regulation	Damgaard et al. (2019) Ramin et al. (2020)
West Africa	Liberia	Konia farm	Integrated material and energy flows	Farm production units: rice mill, fishpond, rabbit farm, piggery, guest house	System integration of individual farm unit processes to maximize farm output and minimize waste	Lack of practical information on yield quantity of different farm units to determine the certainty of project viability	Alfaro and Miller (2014)

Table 2 (continued)

Region	Country	Initiative	Activity	Participating industries	Characteristics	Limitations	Ref
	Ghana	Company X (cassava starch production)	Material flow and exchange, closing material and energy loops		Utilizing by-products from cassava starch processing as inputs for further production. By-products also serve as feedstock for composting and biogas plant and animal feed. Treatment of wastewater for reuse	Lack of quantitative information on material flows and assessment of economic viability	Nukpezah et al. (2019)

the world generally, its implementations have been lackluster and probably still not sufficient for symbiosis relationships to be established more consistently. In addition, although legislation ponders the possibility of waste becoming classified as a by-product, which encourages the use of substances or products as they no longer have to comply with the administrative requirements associated with waste management, the process involves administrative costs and does not always conform with required conditions that are easily achievable. Moreover, companies have difficulty obtaining results, likewise considering a substance as a by-product from the public authorities responsible.

Furthermore, increasing taxes have limited the government's role in promoting industrial symbiosis. Positive impact can be made by encouraging connections and synergies among businesses coupled with making resources available. The National Industrial Symbiosis Programme by the United Kingdom, the creation of the National Pilot Circular Economy Zone Program, the National Eco-Industrial Park Demonstration Program in the People's Republic of China, also the National Eco-Industrial Park Development Program in South Korea, employs different forms of actions to improve industrial symbiosis—for example, the United Kingdom follows the 'push-up' strategy. While China follows the 'top-down' approach—these are some of the examples of established plans that have propelled the increase in the number of symbiosis. In addition to these examples, Africa can use the experience gained in implementing WISP and Eco-Industrial Parks to create a collective plan at the continental level. Furthermore, while there is a set of action plans defined for the enhancement of symbiosis relationships, it is important to enhance the process and to create mechanisms for the dissemination and encouragement of companies in form of tax reduction for companies that engage in more sustainable waste treatment practices and the creation of funds specially designed to increase industrial symbiosis. It would also be beneficial to promote legislative changes that would drive organizations towards the applicability of industrial symbiosis and facilitate waste streams such as streamlining and reducing bureaucracy in the application process for by-product classification.

An advocate, who promotes the concept of industrial symbiosis to companies and enlightens them on expected benefits that can accrue to companies if they participate in this practice, is also very important for the creation and development of symbiosis. This method has been extensively used in Poland, the United Kingdom, Belgium, Italy, and France. Africa can incorporate electronic waste registration systems in various regions as employed in countries such as Portugal, which will allow documentations of waste generation and management and products placed on the market within specific waste streams. These documentations may be vital for the promotion of new relationships

(Neves et al. 2019). This data may serve as a facilitating entity that analyses the possible symbiosis, in advance with the quantification of some of the potential benefits to achieve and promote with the companies trusting relationships, this sets the foundation of the industrial symbiosis networks. This facilitating role can be performed by different entities, whether public or private, such as local authorities and private or public organizations. Regional governments also have a crucial role to play in creating industrial symbiosis relationships as they relate closely with businesses and have an interest in developing the municipality from an economic and environmental point of view. In light of these, the example of Eco-Industrial Parks in South-to-East Africa depicts how important regional government is and how it can act as a driving force for symbiosis relations. This, however, does not replace the need for the central government to provide necessary information and periodical sensitizations to local authorities so that they are motivated to take action to trigger the establishment of industrial symbiosis networks. Table 3 highlights, in tabular form, the current development, challenges, and future prospects of industrial symbiosis in Africa.

Conclusion

This study shows that there have been only a few applications of industrial symbiosis in the industries in Africa. Over the years, even though most countries in Africa have enacted laws to tackle the production, use, and recycling of waste products, the actual implementation has not been achieved yet. Following an examination of the known instances of industrial symbiosis documented in the literature, it was concluded that there is a lot of work to be done especially in countries such as Ghana and Nigeria where there is a higher concentration of economic activities, Municipal Solid Waste, and lesser application of industrial symbiosis.

African countries have yet to completely embrace the circular economy idea in their path of sustainable development. In nations where little or no effort has been made to embrace the notion of industrial symbiosis, research has been conducted to develop models for integrating waste management methods into other sectors of the economy, such as agriculture. Countries such as South Africa and Kenya Africa have demonstrated considerable accomplishments as the pioneer of the first African industrial symbiosis programme in Africa through the enactment and implementation of a sound legislative framework that has promoted resource efficiency in both countries, most notably Kenya, as well as its emerging industrialization. The study also revealed that the majority of the application of industrial symbiosis was established through self-organized activities and that the number of individuals in the networks is typically reduced.

Table 3 Depicting current developments, challenges, and future prospects of industrial symbiosis in Africa

Region	Current developments	Main challenges	Future prospects
South Africa	WISP and eco-industrial parks	Complex regulatory framework, around the reuse/recycling of waste materials. High cost of mobility and logistics services Weak interest for the use of post-primary/alternative materials. Challenging and lengthy enterprise development process. Poor appetite for increased capital investments. Lack of large-scale solutions for disposable materials	Provision of funding, implementation, and alignment of inter/intra governmental coordination to scale facilitated industrial symbiosis, required for sustainable industrialization in the country Greater sustainability of production and consumption methods in human-controlled systems targeted to strike a balance on the growing amount of waste by industries
West Africa	Agriculture frameworks	IS and IE are mainly western constructs that are focused on a long time horizon of sustainability Lack of institutional framework and historical data to promote projects	Highlight potential industrial symbiosis in regions with low industrial symbiosis and suggest action plans needed to be employed
East Africa	Eco-industrial parks	The political, economic, and environmental barriers to circular economy in Kenya, Tanzania, and Egypt have to be overcome by key stakeholders so that countries can adopt a development blueprint that enjoys low emission levels, efficient use of resources, and is socially inclusive through the creation of green jobs	Implementation of industrial symbiosis to various countries and regions in Africa, employing the case study of sugar industries in Tanzania

Sources: Suzanne (2018), Ignatio (2016) and Olayide (2015)

The study on industrial symbiosis in African countries enabled the identification of several avenues for future research aimed at increasing the number of networks of symbiosis. As a result, future study could concentrate on fixing the challenges mitigating the full implementation of industrial symbiosis, quantifying the environmental, economic, and social impacts of industrial symbiosis cases in Africa to determine the practice's contribution to the country's sustainable growth and to facilitate the dissemination of findings among various stakeholders to foster new industrial symbiosis relationships.

From the study, political, cultural, and economic constraints must be overcome to advance industrial symbiotic partnerships. A coordinated national approach that operates across multiple sectors may be critical for the growth of industrial symbiosis in Africa. Enhancing the legislative framework to promote industrial symbiosis and decrease bureaucracy in the process of by-product classification, providing tax relief, facilitating access to support funds, educating and supporting businesses, and encouraging industries that can act as anchor tenants are just some of the ways Africa can excel in establishing industrial symbiosis on a sustainable basis. It would be important to push for the implementation of legislative reforms that encourage industrial symbiosis and enable waste streams in Africa, such as sensitizing citizens through seminars, town hall meetings, stakeholders meetings, streamlining, and decreasing bureaucracy in the by-product classification application process.

Acknowledgements The authors would like to acknowledge “The Pan African Research Group” PARG for providing the platform for the conduct of this research. Special acknowledgement also goes to the Director, Chima Cyril Hampo, and the entire executives of the group, we acknowledge their instrumental efforts in ensuring that this research had a successful outcome. The authors acknowledge with gratitude the valuable comments provided by Olawale E. Olayide on a previous version of this article.

Funding No funding was received for conducting this study.

Declarations

Conflict of interest All the authors declare that they have no conflict of interest.

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