INDUSTRIALIZATION IN THE ERA OF CLIMATE CHANGE: ADDING THE "CIRCULARITY VARIABLE" TO THE EQUATION?

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Abstract

Industrial development is crucial for countries to achieve a steady and equitable economic growth whereas industrialization is closely related to social and economic growth, job creation, and improved livelihood of people. Despite its benefits, industrialization can negatively impact human health and ecosystems through contributing to global warming and climate change. While industrial activities remain a significant contributor to environmental pollution, deployment of innovative solutions such as circular economy business models, additive manufacturing, and green technologies can reduce industrial carbon footprints. Hence, this study intended to uncover questions about the degree to which the current industrialization in the Sub-Sahara Africa (SSA) region has considered social, economic and environmental dimensions. Specifically, the study intended to: 1) establish the degree of compliance to industrial sustainability, and 2) map drivers, opportunities and challenges to industrialization in SSA. A systematic review, guided by standards of Preferred Reporting Items for Systematic Review and Meta-Analysis, was employed

with consultation of different databases such as Emerald, Nature, and Science Direct. The findings revealed different factors that motivate industrialization in SSA countries, including country's intention to achieve ambitious social, economic growth, and climate change targets, policies that support investments, and the presence of robust infrastructure. Also, industrialization in SSA poses several opportunities, including leveraging emerging technologies in the agriculture value chain, harnessing circular economy principles for efficient resource use, enactment of policies for low-carbon subsidies, job creation, and reduced unemployment. Additionally, industrialization is challenged by lack of focused industrialization strategy, coordination of available resources, infrastructures, and absence of environmental governance coordination mechanisms between different stakeholders. The findings therefore, provides vital contribution to government policy making institutions about degree of compliance to industrial sustainability, and key drivers, opportunities and challenges to industrialization for informed decisions. This study recommends that SSA countries should accelerate the adoption of innovative business solutions including circular economy models to enhance resource efficiency, minimise carbon footprints and unlock opportunities across-sectors, particularly within the agricultural value chain.

Keywords: *Sustainable industrialization, Climate change, PRISMA, Industrial ecology, SSA*

1.0 INTRODUCTION

Industrial development is crucial for countries to achieve a steady and equitable economic growth, where industrialization is closely related to their own economies leading to significant growth rates, diversified economy, job creation, and improved livelihood of people (Abdu et al., 2021; Lugina et al., 2022; Hao et al., 2024). Despite the benefits, industrialization can negatively impact human health, and quality of ecosystems through contributing to climate change and global warming. Following evidence provided by the Intergovernmental Panel on Climate Change (IPCC), global warming is mostly caused by emissions of Green House Gases (GHGs) like carbon dioxide (CO_2) and Nitrous oxide (N_2O) (Wang & Su, 2019). Climate change, primarily driven by industrial activities, is especially reliant on non-renewable energy sources and has emerged as a significant global challenge that threatens countries' achievements of the global Sustainable Development Goals, especially Goal 13 on climate action (Wadanambi et al., 2020; Lyakurwa, 2024). Wadanambi et al. (2020) revealed a close relationship between industrialization and climate change such that global warming increases with increased emission of GHGs, including CO_2, N_2O, hydro fluorocarbons (HFCs), and water vapor, which are mostly generated from human-led activities, including industrialization. Also, the ever-increasing population has resulted in higher levels of production outputs, such that great product demand and consumption with increased production activities through industrialization have ultimately contributed to increased GHGs emissions. Liu et al. (2022) reported that CO_2 emissions from industrial activities reached 34.9 $GtCO_2$ in 2021, representing a 4.8% increase compared to 2020 levels. This underscores the critical need to integrate

low-emission technologies into national industrialization agenda. Moreover, Bhatt et al. (2023) report that the earth's atmosphere gains approximately 3 ppm of CO_2 annually, projecting concentrations to reach a critical threshold of 450 ppm by 2047, whereby to restore atmospheric CO_2 to a safe level of 316 ppm, an emission reversal rate of 23.3% is recommended. These emissions are mostly generated by humans, GHGs, combustion engines, cement, and heavy metal industries. To date, industries are considered to be the major environmental polluters, causing human diseases such as cancer, cardiovascular diseases, reproductive problems, and prenatal central nervous system disorders.

Shetty et al. (2023) identified heavy metals, particulate matters, pesticides and plastics as the major environmental pollutants caused by various industrial processes with severe impacts to human health, including glucosuria, genetic toxicity, anemia, and damage to the kidney, liver, and brain. Considering the cost and benefits of industrial development, the industrialization of any country should be informed by policies that integrate sustainability issues, that is, social, economic, and environmental aspects. Typically, industrialization is characterised by the use of machinery and mechanised processes that were previously done by humans, a transformation facilitated by technological advancements, geographical expansions, enormous population growth, and creation of large geographic regions (Tumain, 2021; Amoroso et al., 2022; Hao et al., 2024). The current industrialised economic model is primarily linear, where resources are extracted, used, and then discarded as waste (Krstić et al., 2022). The industrialization which is fueled by the linear economic model, has been a significant driver of environmental degradation and climate

change. The extraction, production, and disposal of materials, along with the energy-intensive nature of industrial processes, have led to depletion of natural resources and release of GHG emissions (Lyakurwa, 2014; Roslim et al., 2024). With a growing population and an expanding middle class, the demands for natural resources are expected to increase substantially, further exacerbating the sustainability challenges (Maja & Ayano, 2021).

Moreover, climate change has affected urbanization patterns, especially in Sub-Saharan Africa (SSA), where negative agricultural impacts due to changing climate patterns have driven rural populations into cities, further stressing urban infrastructure (Maheshwari et al., 2020; Zeleke et al., 2023). This phenomenon has led to significant environmental degradation, resource depletion, and exacerbation of climate change (Demestichas & Daskalaki, 2020; Ajong et al., 2024). To mitigate the environmental impacts of industrialization, sustainable development strategies should be integrated into industrial policies. Central to this transition is the adoption of a circular economy (CE) business model. The CE has emerged as an alternative to decouple economic growth from resource consumption by designing out waste, keeping materials and energy in circulation, and regenerating natural systems (Yang et al., 2018). The CE model promotes sustainability in sectors such as energy, industry, and waste management (Vilariño et al., 2017). According to Eisenreich et al. (2022), the CE is based on three key principles, that is, designing out waste and pollution; keeping products and materials in a closed loop; and regenerating natural systems. Industrial design research has explored how design knowledge can support the transition to the CE by fostering system changes to achieve durability, optimal

re-use, refurbishment, remanufacturing, and recycling of products and materials (Van Dam et al., 2020). Many studies have highlighted the potential for a transition to CE to represent a new sustainable growth path, and a business opportunity for the manufacturing industry (Lyakurwa, 2014; Haas et al., 2023; Tiwari et al., 2024). However, realising this potential requires overcoming challenges such as financial constraints, lack of technological infrastructure, and limited awareness among policymakers and industry leaders (Tumain, 2021; Sulich, 2022; Shen & Zhang, 2023). Despite the significant role of industrialization in driving economic growth in the SSA, there is a critical gap in understanding how the region can balance this growth with sustainability dimensions.

In spite of the fact that industrial activities have led to substantial GHG emissions and environmental degradation, research addressing how SSA can mitigate these impacts remains limited. While CE strategies, such as resource efficiency and waste reduction, have been widely applied by industries in the developed regions (Rweyendela & Kombe, 2021; Feleke et al., 2021; Alizadeh et al., 2023), their integration in the SSA countries including Tanzania, is still under-explored. This presents a gap in understanding how the CE business models can be adapted to the SSA countries for industrial sustainability (Mhlanga et al., 2024). Furthermore, barriers to CE adoption, including technological, financial, and regulatory challenges, have not been sufficiently analysed, leaving the SSA without a clear path to sustainable industrialization (Debrah et al., 2022). The absence of practical frameworks for integrating CE principles into the SSA's industrial policies further exacerbates the gap, hindering the region's ability to pursue industrial growth both economically

viable and environmentally sustainable (Mungai et al., 2022). This study therefore, intended to uncover the degree to which the current industrialization move in the SSA including Tanzania have considered social, economic, and environmental dimensions in their development strategies, exploring key drivers, opportunities, and challenges to industrialization process. Specifically, the study intended to: 1) establish the degree of compliance to industrial sustainability (i.e., balancing social, economic and environmental dimensions), and 2) map the drivers, opportunities and challenges of sustainable industrialization in the SSA.

2.0 LITERATURE REVIEW

2.1. Underpinning Theory

This study was guided by the Industrial Ecology (IE) Theory which endeavours to understand environmental improvement in industry based on the analogy of industrial systems and natural ecological systems (Gibbs & Deutz, 2005). IE narrates various aspects crucial for industrial sustainability such as pollution prevention, product life cycle, re-use and recycling, design for the environment, green accounting, as well as keeping materials and energy in a closed loop (circularity). This theory views processes and industries as interacting systems and not isolated components in a linear resource flow. The theory's conceptual definition provides a solid foundation to present industrial design where different production systems (i.e., value adding facilities) are connected into an interdependent web that minimises the amount of resources such as materials and energy that sink to the environment (disposal) or are lost in the course of production. The network of industries focuses on shifting from minimizing waste of a particular facility through pollution

prevention, and control, towards minimizing material flows and waste produced by larger system. IE encourages industrialization which shifts from dealing with localised environmental impacts through application of environmental sustainability concepts including cleaner production, and eco-efficiency towards optimal use of vital resources and waste reduction specially at firm level (Lowe, 1997). Additionally, IE provides a holistic conceptual framework for the significant and systemic industrial change necessary to eliminate environmental harm. Hence, the industrialization of SSA countries should employ the IE concepts for a just and sustainable industrial development.

2.2. Empirical Literature

Industrialization in Tanzania has become a major development agenda during the fifth and sixth political regimes where old industries were renovated and new ones are introduced, though the process has been since independence in 1961. The history of industrialization in Tanzania can be viewed in four (4) distinct phases. Phase 1(1961-1967) marked a mixed economic system such that the economy was led by the private sector while the government embraced industries inherited from the colonial rule. During this era, the majority of industries were manufacturing consumer goods such as food, beverage, and textile products, whereby value-added industries were designed to feed manufacturing industries abroad, in Europe in particular. Phase 2 (1967-1985) was marked by the Arusha Declaration of 1967 which adopted a socialist blueprint prior to structural economic reforms, during which manufacturing industries declined and were largely substituted by imported goods. However, due to low performance and capacity of the private sector, the government decided to take control of the economy

by nationalizing all major means of production. Thus, all private sector operations in the manufacturing, banking and other services were seized. In this phase, the country attained the highest level of industrial development never experienced in her history, the number of industries increased from 220 during independence to more than 2000 in 1970 whereby 7000 industries had registered trademarks, had the capacity to meet 70% of the domestic demand consumer goods, as well as increase in the absolute and relative labor productivity in the country (Awinia, 2023; Mwinuka & Mwangoka, 2023). Despite the good intention of the government to take full control over the economy, the nationalization led to negative economic shocks from overvaluation of currency, and forex shortage that hindered importation of raw materials. Additionally, the oil crisis of 1973-74, and severe drought of 1974-75 that eroded traditional cash crops including sisal, cashew nuts, coffee, tea, and war with Uganda 1978-1979 badly hit the Tanzania economy which led to initiation of the national economic survival programmes in 1981-82 (Awinia, 2023; Mwinuka & Mwangoka, 2023).

Phase 3 (1986-1995) marked by Structural Adjustment Programmes (SAP) and Economic Recovery Programmes (ERPs) that promoted the role of the market in the economy, but under government control, on reduced government control, and involvement in the country's investment, trading and manufacturing sector. Phase 4 (1996-2020) was marked by establishment and implementation of Sustainable Industrial Development Policy 2020 (SIDP) that intended to establish an industrial sector focusing on human development, job creation, and economic transformation for sustainable development, balancing the economic, social, and environmental dimensions

of development. The SIDP policy was implemented in three different stages: First (1996-2000), marked with rehabilitation and consolidation of all existing industries via capital financing and restructuring. Second (2000-2010), concentrated on the newly established intermediate goods, and light capital goods and machinery industries in order to promote export manufacturing with consideration of emerging technologies to exploit natural resources in the country. Third stage (2010-2020), worked to ensure sustainability of all established industries in the previous phases, and provision of major investment in basic capital goods (Nnyanzi et al., 2022; Lugina et al., 2022). Lessons learned from the four phases of industrialization in Tanzania shows that industrialization is a process, guided by several national and global goals, such that achievement of the Sustainable Development Goals (SDGs) was the first priority.

Lugina et al. (2022) revealed that industrialization in manufacturing offers opportunities for economies of scale which are less available in agriculture and service sector, though the linkage and spillover effects between the manufacturing and service are claimed to be stronger in manufacturing than in other sectors. According to Nnyanzi et al. (2022) and Lugina et al. (2022), manufacturing industry has played a significant role in economic development of many countries in East Asia and Europe, with ever-decreased role in the economic development of Africa, that have partly caused by the shift of the industrial structure from manufacturing to service. Abdu et al. (2021) documented that manufacturing industries in Nigeria are characterised by heavy labour intensity, low productivity, frequent power outage and rationing that hinders development of the manufacturing sector. Kyule and Wang (2024) found that

industrialization in Kenya contributed 10% of the economic growth whereby the low level of industrialization is associated with snail phase economic growth experienced in many African countries.

In Tanzania, majority of manufacturing Small and Medium Enterprises (SMEs) use non-renewable energy sources mainly fossil fuels for lighting or to power machines during power outages, facilitated by several factors such as easy access and availability, affordability and low investment cost, energy efficiency compared to renewable sources which call a need for policy intervention to effectively deploy renewable energy sources (Lyakurwa, 2024). Mwinuka and Mwangoka (2023) documented that the performance of Tanzania's manufacturing industry has remained stagnant for years, compared to other sectors of the economy despite the government efforts, and policies formulated including Development Vision 2025; the Integrated Industrial Development Strategy; the 2018 Blueprint to create fair business environment by promoting investment and trade for Special Economic Zones, and Export Processing Zones as well as promoting the SMEs. Hence, low level of industrialization shown by the low manufacturing sector's contribution to the Tanzania's GDP (Mwinuka & Mwangoka; Lyakurwa, 2024).

While the SIDP 2020 presents a framework, and different strategies for sustainability, yet industrialization in SSA faces significant challenges including inadequate infrastructure, limited access to renewable energy, and inadequate human resources (Bishoge et al., 2020), ineffective coordination in implementing industrial policies (Gasparatos et al., 2017; Aliyeva, 2021), poor export diversification, and limited

value-addition in manufacturing sector (Gasparatos et al., 2017)), and inadequate regulations among the SSA countries that make it difficult to change from the traditional linear way, hence, cannot implement and enforce environmental standards (Aliyeva, 2021). Generally, many studies have either focused on industrialization process in Africa, or industrialization and climate change, but few have been done to establish the degree of compliance to industrial sustainability as well as drivers, opportunities and challenges to sustainable industrialization in the SSA.

3.0 MATERIAL AND METHODS

This study employed a Systematic Review, guided by standards of Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) with consultation of different databases like Taylor and Francis, Scopus, PubMed Central, Elsevier, SAGE Journals, Directory of Open Access Journals, and Emerald. Mallick et al. (2023) documented that a Systematic Literature Review (SLR) is a crucial questioning tool for a transparent and holistic synthesis of research results. A SLR involves various phases in the search for an initial sample such that the results are generated through three distinct steps, namely database filtering, title screening and exclusions, abstract reading, as well as a full text reading. The combination of different keywords was used in search for the initial article sample including "circular economy" AND ("industrialization and climate change" OR industrialization strategy/policy OR drivers and challenges to industrialization OR “industrial sustainability in SSA” OR "industrialization opportunities" OR manufacturing sustainability in the SSA. The initial search results were then screened via three (3) stages as follows:

Stage 1: Filtering of the Taylor and Francis, PubMed Central, Elsevier, SAGE Journals, Directory of Open Access Journals and Emerald databases. In this stage only, articles from peer-reviewed scientific journals were included in the sample, that is, source type filter, in which conference proceedings, working papers, research reports, book reviews short communications as well as unpublished dissertations were excluded. All journal articles written in languages other than English including Chinese and Arabic were also dropped. In addition, all fields that were not directly related to the study theme, such as Geology, Mathematical modelling, nuclear physics, Electronics, Electrical Engineering, and Genetics, were excluded.

Stage 2: Screening and research title exclusion. In this step all titles were read to validate the content and identify potential articles to be included or excluded in the analysis. All articles that did not focus on industrialization and climate change, sustainable industrialization or industrialization policy and legal frameworks in support of industrialization strategy in the world, or SSA specifically or in broad sense were not considered.

Stage 3: Abstract and manuscript reading. Each article with significant potential to systematization in relation to the study topic was comprehensively analysed with extraction of all articles which had significant contributions to the discussion about industrial sustainability, that is, social, economic and environmental considerations, as well as drivers, barriers, and opportunities of sustainable industrialization in the SSA. All articles which did not fit the scope of this study were discarded because of various reasons like industrialization in the era of

climate change is explained in the context for the research where there is no implication on sustainable industrialization in the SSA, or articles that presented very specific technical issues such as chemical reaction, waste management and control, industrial ecology, materials failure, and its science. Others were articles detailing a general scope whose discussion lies on changes in business management dynamics with inadequate discussion on how industrialization relates to climate change and global warming, or how industrialization policies and regulations are designed to address climate change issues specially in the SSA, in which Tanzania is part. The extracted data from sampled articles was categorised into three key groups that best narrates the concept of industrialization in the era of climate change, drivers to industrialization as well as challenges and opportunities, followed by synthesis to see if industrialization complies' sustainability dimensions. At last, the synthesis of various literature from studies conducted in the SSA countries facilitated the formulation of key drivers, barriers and opportunities to industrialization.

4.0 RESULTS AND DISCUSSION

4.1. Degree of Compliance with Industrial Sustainability

The first specific objective was to establish the degree of compliance with industrial sustainability, defined as the balance among social, economic, and environmental dimensions. The findings about the degree of compliance with industrial sustainability in the selected SSA countries are presented (Table 1). Neri et al. (2018) defines industrial sustainability as an industrial strategy that intends to achieve occupational health and safety standards, eco-efficiency, as well as energy efficiency systems through balancing the social, economic and

environmental dimensions of sustainability, which is an important parameter to policy-makers and industrial decision makers.

Table 1: *Degree of Compliance with Industrial Sustainability*

Category	**Policy/strategy definition**
Sustainable Industrial Development Policy (1996-2020), Tanzania. Mission: "To contribute towards the achievement of the overall national long-term development goals as contained in the Development Vision 2025; and to enhance sustainable development of the industrial sector". Objective: "This policy is geared towards human development, creation of employment opportunities, economic transformation for achieving sustainable economic growth, environmental sustainability and equitable development" (United Republic of Tanzania [URT], 1996).	
Social	1. Improve human quality of life and welfare 2. Increase employment opportunities 3. Increase job creation from the informal sector activities and small industries.
Economic	1) Increase personal income 2) Increased production capacity in the economy 3) Develop agro-allied industries including food, textile, building materials, leather and leather products. 4) Promote small scale industries and informal sector activities, with potential for job creation and income generation.
Environmental	1. Ensure sustainable production capacity and creation of job opportunities. 2. Conduct environmental awareness to all stakeholders. 3. Provide efficient use of raw materials and energy. 4. Eliminate toxic materials, reduction of emissions and wastes at source.
National Industrial Policy 2018, Zambia. Vision: "To be an industrialised and competitive nation with a diversified, innovative and globally competitive industrial base, which contributes to sustainable growth and	

Category	Policy/strategy definition
employment creation by 2027". Objective: "To transform Zambia from a producer and exporter of primary products into a net exporter of value-added goods utilizing local primary resources with increased citizens' participation" (Republic of Zambia, 2018).	
Social	1) Provide quality health services 2) Promote human capital development - trained in different fields 3) Promote employment creation and growth 4) Promote gender-equality in accessing and exploiting economic resources.
Economic	1. Develop manufacturing sector, such as food processing, textile, and garments 2. Increase production efficiency by utilizing natural resources 3. Improve industrial production and productivity via ICTs promotion 4. Promote development of small and medium enterprises, 5. Formalise micro, small and medium enterprises (MSMEs) 6. Promote MSMEs product quality.
Environmental	1) Promote environmentally sustainable industrial production 2) Adopt cleaner technologies and compliance to environment regulations 3) Promote efficient use of raw materials.
Republic of South Africa (2012). Policy on Development of Special Economic Zones in South Africa 2012. Aim: "Provision of special economic zones as an effective tool for industrial development, and is flexible and rigorous enough to be responsive to the development needs of all regions, as well as needs of investors and other key players" (*Policy On The Development of Special Economic Zones In South Africa (2012)*.	
Social	1. Accelerate creation of needed jobs and develop human capital 2. Develop a world class social infrastructure 3. Develop human-centered plans - livelihood of normal citizens.

Category	Policy/strategy definition
	4. Train staff to acquire critical skills and competencies required by the industry. 5. Develop skills strategy to facilitate short-, medium- and long-term skills
Economic	1) Promote growth of value addition of minerals and other natural resources 2) Develop a world class industrial infrastructure 3) Develop plans with a focus on economic necessary for regional development
Environmental	1. Develop environment management plans, standards, quality and productivity. 2. Develop plans with integration of environmental issues.
	National Industrial Policy 2011, Rwanda. Vision: "Competitive industrial and advanced services sectors producing over $1.5 billion of exports by 2020, while increasing the number of off farm jobs." Objective: "the broad goal is promoting the growth of the economy with the target of becoming a middle-income country by 2020 - requiring GDP growth of at least 8% on average per annum" (Republic of Rwanda, 2011).
Social	1) Increase personal income 2) Provide capacity building support to manufacturers 3) Design courses that are focused on the management and technical needs of firms
Economic	1) Promote agro-processing, soaps and detergents, leather & building materials 2) Increase investment on energy, mainly renewable energy sources e.g., wind, solar 3) Development of special economic zones & industrial parks 4) Mobilise long term funding for industrial development through BRD
Environmental	1. Enforce the establishment of industry specific waste management systems 2. Sensitise Industrialists and enforce cleaner production systems in all industries

Category	Policy/strategy definition
National Industrial Policy 2020, Uganda. Mission: "The Policy mission is to accelerate sustainable industrial transformation through an increased developmental role of the State, reduced cost of production, and improved quality of manufactured goods" Objective: "To foster growth of the Industrial Sector, anchored on inspiring structural transformation with a principle focus on increased value addition of local raw materials and products with comparative advantage for social-economic transformation; increased exports of manufactured products by facilitating industries to increase production and match market demands in terms of both quality and quantity; increased employment in the industrial sector through establishment and promotion of industries that create large-scale employment opportunities, ensuring inclusive growth and sustainable development; and Increased adoption of environmentally sustainable technologies by the manufacturing sub sector" (Republic of Uganda, 2020).	
Social	1) Develop skilled human resources to increase productivity and efficiency 2) Ensure deliberate investments for gender sensitive industrial promotion 3) increase share of jobs from manufacturing sub-sector to total formal jobs
Economic	1. Accelerate use of research innovations and adoption of appropriate technologies 2. Accelerate industrial development e.g., fruits, tea, cassava, cotton, and leather 3. Increase industry sector contribution to GDP
Environmental	1) Promote resource-efficient and environmentally sustainable industrialization 2) adopt cleaner and more efficient technologies 3) Ensure efficient use of resources and circular economy (recycling of waste, waste disposal) and resources, e.g., energy and water.
National Industrialization Policy 2012, Kenya. Mission: "To promote and sustain a vibrant, globally competitive and diversified industrial sector for generation of wealth and employment through the creation of an enabling environment" Objective: "Enable the industrial sector to attain and sustain annual sector growth rate of 15% and make Kenya the most competitive	

Category	Policy/strategy definition
and preferred location for industrial investment in Africa leading to high employment levels and wealth creation" (Republic of Kenya 2012).	
Social	1. Capacity building and skills upgrading for the manufacturing sector staff 2. Identify growth and employment constraints operating at the macroeconomic level 3. Facilitate the creation of productive employment in the manufacturing sector
Economic	1) increase productivity and competitiveness 2) Strengthen local production capacity to increase domestic goods 3) Develop at least 2 Special Economic Zones and 5 SME Industrial Parks 4) Facilitate access to affordable finance for the manufacturing sector 5) R&D and commercialize research findings for sustainable industrial growth
Environmental	1. Promote sustainable development of Micro, Small and Medium Industries 2. Facilitate innovation, adoption of cleaner technology

The findings from the reviewed policies and guidelines in Tanzania, Zambia, South Africa, Uganda, and Kenya revealed that all established policies aim to balance the social, economic, and environmental dimensions of sustainability (Table 1). For instance, social aspects were reflected in statements emphasizing the improvement of human life and welfare, job creation, and the promotion of gender equality and equity, among others. The results are in line with Okereke et al. (2019) and Denu et al. (2023) that industries in Africa consider social sustainability through compliance with human rights, equity, and ethical practices across firms. However, the study noted that its implementation is still at an early stage. The economic aspects

were reflected in various economic characteristics, including increased personal income, the promotion of small-scale industries particularly privately owned enterprises and the expansion of production capacity. These findings are consistent with Lugina et al. (2022) and Opoku and Yan (2019), who documented industrialization strategies, policies, and guidelines in Africa that integrate social, economic, and environmental dimensions of sustainability. With regard to environmental issues, the findings indicated careful consideration, as reflected in policy key performance indicators such as promoting environmental awareness and education among key stakeholders, ensuring efficient use of raw materials and energy, and adopting cleaner technologies, including circular economy approaches that keep materials in circulation.

Furthermore, the results align with previous studies that emphasised integration of environmental concerns into the industrialization agenda to prevent adverse impacts of industrial development, such as human health risks and the deterioration of ecosystem quality (Okereke et al., 2019; Musah & Yakubu, 2023). A key lesson from the study findings is that SSA countries have developed policies that adhere to social, economic, and environmental aspects, not only to comply with international frameworks but also to contribute to the achievement of the SDGs. In this regard, the results align with Industrial Ecology (IE) theory, which emphasises keeping materials in circulation through the use of digital and innovative business solutions such as cleaner technologies to ensure efficient utilization of raw materials, minimise human health risks, prevent environmental degradation, and enhance people's livelihoods.

4.2. Drivers, Opportunities and Challenges of Sustainable Industrialization in the SSA

The second specific objective was to map the drivers, opportunities, and challenges of sustainable industrialization in SSA. Drivers here refers to factors, catalysts or structural conditions or environment that initiate, propel, and sustain the transition to an industrial economy; Opportunities are the enabling or potential benefits and growth areas created by the industrial activities or internalization process; and challenges are barriers, bottlenecks, or obstacles that hinder the pace and success of the industrialization process (United Nations Industrial Development Organization [UNIDO], 2020). The findings are presented (Table 2).

Table 2*: Drivers, Opportunities and Barriers to Sustainable Industrialization in SSA*

Category	Category definition	Source
Drivers	● Ambitious to social and economic growth and climate change mitigation targets. ● Strong government commitment to accelerate green industrialization. ● Emergence of industry 4.0 technologies e.g., artificial intelligence, internet of things, big data and drones ● Sustainable supply of renewable energy for industrial processes. ● Good infrastructure and communication system. ● Firm size and resources ● Economic condition of the country, ● Factor endowments as well as characteristics like demography and	Okereke et al. (2019); Wanyama et al. (2024); Musah & Yakubu (2023); Mwinuka & Mwangoka(2023); Tumaini (2021); Haraguchi et al.

Category	Category definition	Source
	geography ● Policymakers and legislation on investments i.e., public and privately funded as well as education ● Development of the financial sector ● Investment in physical capital ● Adoption of appropriate industrial policies	(2018); Lugina et al. (2022).
Opportunities	● Cross-border resources for sustainable transition within the low-income countries. ● Exploit emerging technologies to enhance irrigation sustainability and food security. ● Enhance exploitation of renewable energy sources and reduce pollution. ● Adoption of circular economy principles e.g., reuse, recycle, reduce. ● Enactment of subsidies that promote low-carbon technologies. ● Enactment of strong policies and regulations that support sustainable industrialization. ● Creation of decent jobs, and countries' graduation to middle income. ● Reduction of unemployment and poverty alleviation. ● Increase contribution of industries on national GDP. ● Increased awareness of norms and standards that encourage energy efficiency ● Introduction of environmental management system, potential for CO_2 emission reduction. ● Capacity building to acquire needed skills and knowledge by industries. ● Introduction of appropriate government incentives ● Shift to modern machines and equipment.	Okereke et al. (2019); Wanyama et al. (2024); Musah & Yakubu (2023); Evans et al. (2018); Ajong et al.(2024); Mwinuka & Mwangoka (2023); Tumaini(2021); Haraguchi et al.(2018); Lugina et al., (2022)

Category	Category definition	Source
	● Development of the agricultural products value chain. ● Strong linkage between academic institutions/universities and the industry. ● high institutional stability leading to sound investment climate ● Enactment of strong economic policies and reforms. ● Increased local production capacity ● Increased trade openness ● New technologies and innovations	
Challenges	● Environmental governance coordination mechanisms between different stakeholders. ● Appropriate policy and legal framework to support current industrialization. ● Coordination of available resources including skilled personnel, materials, machines, …… ● Infrastructure to support industrialization e.g., energy, water, ICTs ● High initial cost associated with emerging technologies ● Technical expertise. ● Energy consumption rise, ● Environmental degradation, pollution (emission of greenhouse gases), global warming and climate change. ● High production cost of goods and services. ● Low customer demand of products ● Poor access to technology ● Poor enforcement of laws and regulations. ● Lack of focused industrialization strategy by sector	Okereke et al. (2019); Wanyama et al. (2024); Musah & Yakubu (2023); Ajong et al. (2024); Mwinuka & Mwangoka (2023); Tumaini(2021); Haraguchi et al. (2018)

The findings identified several driving factors for sustainable industrialization in SSA, including strong government commitment to green industrialization, reliable supplies of renewable energy for industrial processes, the adoption of appropriate industrial development policies and guidelines, the emergence of Industry 4.0 technologies such as artificial intelligence, the internet of things, big data, and drones, and the availability of robust infrastructure and communication systems, among others. These results are consistent with the study by Luken et al. (2019), which identifies key drivers of green industrialization in Sub-Saharan Africa, including enforced environmental regulations, efficient technologies, green investment interests, availability of financial resources, government support, and improvements in energy supply and efficiency. These drivers also documented by several other scholars (Haraguchi et al., 2018; Okereke et al., 2019; Tumaini, 2021; Lugina et al., 2022; Musah & Yakubu, 2023; Mwinuka & Mwangoka, 2023; Wanyama et al., 2024).

Also various factors were identified as potential opportunities of industrialization in the era of climate change like cross-border resources for sustainable transition within the low-income countries, exploit emerging technologies to enhance irrigation sustainability and food security, enhance exploitation of renewable energy sources and reduce pollution, adoption of circular economy principles such as reuse, recycle, reduce; enactment of subsidies that promote low-carbon technologies, reduction of unemployment and poverty alleviation as well as introduction of environmental management system, potential for CO2 emission reduction. Despite the existence of various drivers and opportunities, several challenges to industrialization

in SSA were identified. These include weak environmental governance and coordination mechanisms among stakeholders, inadequate policy and legal frameworks to support current industrialization, limited coordination of available resources such as skilled personnel, materials, and machinery, insufficient infrastructure to support industrialization including energy, water, and ICTs; the high initial costs associated with emerging technologies, and the absence of sector-specific industrialization strategies. The results are consistent with studies by Wanyama et al. (2024), Haraguchi et al. (2018), Okele et al. (2019), Ajong et al. (2024), and Musah & Yakubu (2023).

5.0 CONCLUSION AND RECOMMENDATIONS

This systematic review provides an insight on the degree to which industrialization policies in the SSA have integrated the social, economic and environmental dimensions in their industrial development in terms of compliance to industrial sustainability, drivers, opportunities and challenges. Although industrialization has significant contribution to the economic growth in the majority SSA, yet it is accompanied by emission of GHGs which exacerbates global warming and climate change. Synthesis of industrialization policies in Tanzania, Zambia, South Africa, Rwanda, Uganda, and Kenya revealed that all industrial sustainability dimensions (i.e., social, economic, and environmental) are clearly articulated, indicating government efforts and commitment towards implementation of directives from the global north. Despite the recognition of social and environmental dimensions in the economic growth, there are several drivers, opportunities, and challenges to industrialization in the studied SSA countries. Different social, economic, technological, legal and environmental factors were

found to motivate industrialization in the SSA countries. For example, country's intention to achieve the ambitious social, economic growth, and climate change targets via strong dedication to green industrial development; leveraging Industry 4.0 technologies (i.e., artificial intelligence, internet of things, big data, machine learning, robotics and drone) to achieve productivity, efficiency; supply of renewable energy for different industrial operations; robust infrastructure that support internet connection, transportation of materials and products, water supply and energy. Other drivers include firm size, availability of resources (e.g., materials, machines, skilled manpower, and working methods), as well as policies that support investment in various sectors of the economy.

Industrialization in the SSA also presents several opportunities in the region, including leveraging emerging technologies in the agriculture value chain leading to food security, harnessing circular economy principles for efficient resource use, enactment of low-carbon subsidies resulted from formulation of industrial policies that promotes green growth, job creation, and reduced unemployment rate. Other opportunities are staff training to cope with emerged industrial technologies, installation of modern machines and equipment, enactment of government incentives to promote industrial efficiency and local production, development of a strong sector based industrialization strategies (i.e., Tanzania whose more than 80% population depend on agriculture to earn daily living, and given her financial constraints, can decide to fully industrialise the agriculture sector), as well as an opportunity to create a very strong academic institutions/university and industry linkages that drives innovation and country's skills development.

At last, despite the vast opportunities, yet industrialization in the SSA is challenged by absence of environmental governance coordination mechanisms between different stakeholders; appropriate policy and legal framework to support it; coordination of available resources including skilled personnel, and materials; infrastructure to support the industrialization including energy, water, and ICTs. Other challenges are high initial cost associated with emerging technologies, technical expertise, global warming and climate change, low customer demand of products, access to technology, enforcement of laws and regulations as well as lack of focused industrialization strategy by a specific sector. To conclude, the findings of this study provide vital contribution to government policy making and planning institutions in the SSA about the need for mainstreaming circular economy practices in the industrialization agenda for industrial sustainability. The study recommends that SSA countries accelerate the adoption of digital and innovative solutions including circular economy business models, green technologies and automated manufacturing systems, to enhance resource efficiency, minimise carbon footprints and unlock opportunities across sectors, particularly within the agricultural value chain.

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