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Employment effects of industrial symbiosis in the Tanzanian sugar sector

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Executive summary

The employment effects of industrial symbiosis – a circular economy strategy at the inter-firm level – are gaining prominence. This study examines the Tanzanian sugar sector to enhance an understanding of how the transition to a more circular, resource-efficient economy through industrial symbiosis affects employment in the sector. Data were collected using company surveys and semi-structured interviews with representatives of key stakeholder groups, including academics, government ministries, producers and sugar industry regulators. Three sugar factories were visited on site to conduct the surveys. Thematic analysis and simple descriptive statistics were then used to complete the analysis.

The findings of the study include the following:

- The circular transformation of the sector has already begun, with all three companies surveyed having adopted some form of industrial symbiosis. Bagasse cogeneration plants, with a combined capacity of 35 megawatts, were the most common industrial symbiosis initiative adopted.
- The adoption of industrial symbiosis has positive employment effects, having led directly to the employment of around 248 people – approximately 3.1 per cent of the total workforce employed in the three firms surveyed. No company reported industrial symbiosis-related job losses.
- The jobs created encompass a range of occupations, from highly skilled positions, such as engineers, scientists and technicians, to low-skilled roles, such as assistants and cleaners. The latter account for about 54.4%, and their jobs are relatively low-quality.
- Current industrial symbiosis activities are driven mainly by business opportunities linked to efforts to cut high energy costs and meet the growing demand for ethanol.
- Limited policy incentives, policy fragmentation, lack of specific skill-related policies, food security concerns, limited competition, automation, insufficient supply of by-products, and ethical and religious concerns emerged as key constraints for industrial symbiosis and the related positive employment outcomes.
- Sugar producers, industry regulators and support organizations, including social partners, must work together to create an environment that facilitates the expansion of industrial symbiosis activities and propels positive employment outcomes.

While the Tanzanian sugar sector has the potential to become a model for industrial symbiosis, additional policy efforts are required. This study concludes by outlining a number of critical issues that need to be resolved if industrial symbiosis is to prosper and open pathways for more employment opportunities.

Foreword

The world of work is experiencing important social changes in relation to technology, innovation, demographics, organization of work and production, and environmental protection, which are redefining the role of work in society. In this context, the Research Department of the International Labour Organization (ILO) deems it essential to analyse and study such changes at a global level, especially with regard to their employment effects.

Over the past few years, production and technological innovation have played a pivotal role in the growth of the green economy and, by promoting the circular economy, have contributed to advancements towards the Sustainable Development Goals. One expression of the circular economy is industrial symbiosis, which engages traditionally separate entities in a collective approach designed to exploit and maximize the competitive advantages stemming from the physical exchange of materials, energy, water and by-products in production processes.

The economic and environmental effects of industrial symbiosis networks have been thoroughly examined, and yet their employment impacts have been neglected. The research presented in this paper offers an innovative approach, as one of the first reports to analyse the relationship between employment and industrial symbiosis in Africa. For this reason, the findings will be of interest not only to researchers dealing with the just transition and green jobs on a global level, but also to workers' and employers' organizations and to leaders and policymakers in charge of employment and environmental policies.

The present study on Tanzania was prepared under the technical direction of Maria Sabrina De Gobbi of the ILO Research Department in Geneva, in collaboration with the ILO Country Office for the United Republic of Tanzania, Burundi, Kenya, Rwanda and Uganda and with the ILO Decent Work Team for Eastern and Southern Africa. This report is part of a larger research project on the employment impacts of industrial symbiosis networks in Africa and Latin America.

We extend our Deep appreciation to Wellington Chibebe, the former Director of the ILO Country Office for the United Republic of Tanzania, Burundi, Kenya, Rwanda and Uganda, and Jealous Chirove, an employment specialist from the same Office, for the technical and logistical support provided. This study could not have been completed without the invaluable technical support of Mette Grangaard Lund, Green Jobs Junior Professional Officer within the ILO Green Jobs Global Team in Geneva, and Gary Rynhart, Regional Specialist in Employers' Activities at the ILO Decent Work Team for Eastern and Southern Africa in Pretoria. Last but not least, appreciation is due to external collaborators Amani George Rweyendela and William John Mwegoha, without whom the preparation of this study could not have been possible.

Richard Samans
Director
ILO Research Department

List of abbreviations

CMS	Condensed Molasses Solubles
FIT	Feed-in Tariffs
IS	Industrial symbiosis
ILO	International Labour Organization
IPP	Independent Power Producer
SBT	Sugar Board of Tanzania
TPAWU	Tanzania Plantation and Agricultural Workers Union
TPC	Tanganyika Planting Company
TUICO	Tanzania Union of Industrial and Commercial Workers
MFA	Material Flow Analysis
MW	Mega Watts
NSI	National Sugar Institute
OHS	Occupational Health and Safety
PPA	Power Purchase Agreement
SEA	Strategic Environmental Assessment

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This paper was authored by Amani G. Rweyendela of the University of Dodoma and Prof. William J. Mwegoha of Mzumbe University in Tanzania. We express our deepest appreciation to all the participants and organizations that contributed their time, insights and expertise to this study. The authors would also like to express their sincere gratitude to the ILO for its invaluable support and funding, which made this research project possible. Its commitment to promoting decent work, social justice and inclusive labour practices has been instrumental in shaping this study. Furthermore, we are grateful for the collaborative environment fostered by the ILO, which facilitated meaningful engagement and exchange with various stakeholders. We also extend our thanks to the ILO Country Office for the United Republic of Tanzania, Burundi, Kenya, Rwanda and Uganda for its unwavering support.

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Lastly, we thank Sabrina de Gobbi for her expertise, support and dedication in supervising and supporting this research project.

The authors are solely responsible for any errors or omissions.

Data confidentiality

The data utilized for the analyses presented here may contain sensitive information pertaining to the companies that have generously contributed to this research. As a result, we have chosen to remove all direct references to the names of companies or individuals linked to the cases examined. Similarly, while seeking to accurately reference all of our sources, we avoided mentioning the locations of the cases investigated unless such information was present in the name of a bibliographic source.

Any questions and inquiries should be sent to RSEARCH@ilo.org.

Contents

1. Introduction

The concept of the circular economy is gaining traction among politicians, scholars and business leaders as a solution to some of the world's most pressing sustainability issues with regard to methods of production and consumption (European Commission 2020; Petit-Boix and Leipold 2018; Vanhuyse et al. 2021). A circular economy offers an alternative to the linear model that has dominated modern industrial society, with raw materials at one end and waste products at the other (Bruel et al. 2019). It strives to close, slow or narrow the input and output loops (Bocken et al. 2016) on the basis of "the principles of designing out waste and pollution, keeping products and materials in use and regenerating natural systems" (Ellen MacArthur Foundation, n.d.). Thus, circular business models, especially industrial symbiosis, are touted as essential tools for transitioning to more sustainable societies (Neves et al. 2019; Yang et al. 2022).

Industrial symbiosis-related structural changes in organizations and the wider economy inevitably alter labour demand (Cecere and Mazzanti 2017; ILO 2019; Liu et al. 2020). For example, new jobs are created as new technologies, product lines or facilities are added to the existing production system. Some employees will be substituted, such as in shifting from waste incineration and landfilling to resource recovery or from fossil fuels to renewables. Certain jobs may be eliminated without replacement, such as when the use of certain materials is discontinued. And, lastly, many existing jobs (especially roles such as construction workers, metal workers, electricians and plumbers) may be redefined or transformed as day-to-day working methods, profiles and skill sets are greened (ILO 2019; Sulich and Sołoducho-Pelc 2022; UNEP 2018). According to a recent global study produced by the International Labour Organization (ILO), by 2030, efforts to develop a circular economy will produce around 78 million jobs, while at the same time destroying nearly 71 million (ILO 2019). As decent employment is essential for individuals' socio-economic standing and social well-being – and is even a fundamental human right (ILO 2013) – understanding the employment effects of industrial symbiosis is crucial to inform a socially just circular transition.

However, despite extensive research on the industrial symbiosis phenomenon (Neves et al. 2020), focus continues to be placed on the economic and environmental dimensions, with the social aspects, especially employment, receiving scant and sporadic attention (Geissdoerfer et al. 2017). Moreover, while many ex-ante macroeconomic modeling studies have demonstrated how the circular transition can result in net employment creation, there are still relatively few ex-post studies, with the exception of those that focus on the creation of green jobs in the renewable energy industry (Liu et al. 2020). This raises the challenge of how to optimize circular activities and match future labour supply with the labour demands of the industrial symbiosis model, especially in the global South, which represents only 16 per cent of the global evidence base on the socio-economic consequences of the circular economy (Saliba et al. 2023). Further research is therefore needed to enhance understanding of which skills are suited to circular jobs in this region.

Such research is especially important in the context of developing nations like Tanzania, where the majority of workers are concentrated in the informal sector, which is characterized by jobs of low quality and low pay (ILO 2019). Ongoing political debates have focused on sustainable industrialization as an economic growth strategy to solve the country's persistently high unemployment and poverty rates (Kamat et al. 2019; Kinyondo et al. 2016). The sugar industry is considered a strategic sector for generating employment opportunities in the country and a significant component of industrial and agricultural policies (Sulle 2017). As a result, much policy attention is paid to this sector. Gopinath et al. (2018) highlight the many possibilities for implementing industrial symbiosis within the sugar industry. There is a growing corpus of illustrative work in Tanzania and elsewhere (Correia de Souza et al. 2018; Rweyendela and Mwegoha 2021; Shi and Chertow 2017; Yang and Feng 2008; Zhu et al. 2008), but the issue of employment has received little-to-no attention.

This study investigates the direct employment effects of industrial symbiosis activities in the Tanzanian sugar sector. The aim is to better understand how the transition to a more circular, resource-efficient economy through industrial symbiosis in this sector would affect employment. This research contributes to the limited literature on the employment effects of industrial symbiosis in general and the stream of research on industrial symbiosis in developing African countries. The understanding gained is expected to serve as a foundation for developing a more enabling policy environment to promote wider acceptance of industrial symbiosis and foster job creation.

Accordingly, the following seven specific research questions were investigated:

1. What is the current state of industrial symbiosis activity in the sugar industry?
2. What are the quantitative and qualitative employment effects of industrial symbiosis networks?
3. What are the factors of success for determining positive employment impacts in industrial symbiosis, especially the qualitative effects on job formalization and employment for women?
4. What are the barriers to achieving positive employment results in industrial symbiosis (if any)?
5. What actions can the private sector and national and local governments take to promote employment creation through industrial symbiosis and to improve job quality?
6. What specific skills are needed in jobs created through industrial symbiosis (if any)?
7. Are such skills available in the Tanzanian labour market?

2. Literature review

2.1 What is industrial symbiosis?

The process of defining and interpreting the concept of industrial symbiosis is still evolving. Nevertheless, its most distinguishing characteristic entails a system of symbiotic exchanges of production wastes, by-products and utility, as well as other forms of collaboration among co-located, traditionally separate industrial entities (Chertow 2000). While symbiotic exchanges can include by-products/wastes, infrastructure/utility-sharing, and joint services provision (Chertow 2007), this study focuses on arrangements that convert waste outputs from one process into raw material for another process or product line, which is the primary concern of industrial symbiosis (Chertow 2000) and the most significant form of industrial symbiosis in the sugar industry (Gopinath et al. 2018).

2.2 Industrial symbiosis in the sugar industry

The sugar industry produces huge amounts and varieties of wastes and by-products that can be utilized to produce various secondary products through industrial symbiosis. Gopinath et al. (2018) set out a number of waste valorization pathways for achieving optimal resource utilization and zero-waste in the sugar industry. The examples below describe some of the main valorization routes (Gopinath et al. 2018; Rweyendela and Mwegoha 2021; Veana et al. 2014; Zhu et al. 2008):

- Energy industry: Bagasse from sugar mills can be burned in cogeneration boilers to generate electricity, which can then be distributed to sugar mills and nearby communities. It can also be used to produce biofuels via pyrolysis. In addition to sugarcane bagasse, sugarcane straw (including cane stubble, tops and leaves) can also be used in cogeneration boilers.
- Construction industry: Residual bagasse ash has many applications in the construction industry. It can be used as an inert filler or supplementary cementitious material in cement production to enhance the durability and mechanical properties of cement. It can also be used to produce alkali-activated binders and unburnt bricks, as fine aggregates. Carbonation filter mud can be used for similar purposes
- Chemical and beverage industry: The molasses produced in sugar refineries are widely used as a feedstock in distilleries for producing industrial ethanol/alcohol.

- Pulp and paper industry: The bagasse from sugar mills can be used in pulp and paper mills to make paper.
- Fertilizer industry: The press (filter) mud from the carbonation process and the molasses from alcohol factories can be processed to make compound fertilizers.
- Food industry: Sugarcane bagasse and molasses can be used in the food industry to produce invertase, a key enzyme in the manufacturing of sweeteners.

2.3 Drivers of and barriers to the development of industrial symbiosis

Numerous drivers of and barriers to industrial symbiosis have been identified in the literature. Baumgarten and Nilsson (2014) classified the factors into five broad categories: technological, social, economic, policy-related and information-related. These are summarized in table 1.

Table 1. Drivers of and barriers to industrial symbiosis

Category	Subcategory	Drivers
Economic	Financial	Access to public grants
		Possibility of economic gains for companies
	Market-related	Companies promoting their "green profiles"
		Gaining a competitive advantage
		Increased access to new markets
		Increased opportunities for innovation
Social	Relational	Human drivers: strong, enthusiastic and committed leaders
		New businesses/value chains
		Building trust and embeddedness
	Synergy-related	Connecting businesses: local public authorities are crucial
		Local processes are the most important for greening the economy
Technical		Access to infrastructure
		Presence of industries from different fields involving different material flows
Information-related		Knowledge and training; capacity-building and awareness-raising
Policy-related		Overarching strategy for the development of circular economy/industrial symbiosis
		Environmental regulations
		"Green" criteria for public procurement
		Government intervention

Category	Subcategory	Drivers
Economic	Financial	High investment costs
		Lack of access to (long-term) financing
		Lack of substantial private (risk) finance
		Long payback period
		Uncertainty about the profitability of the partnership
	Between companies	Weak cross-sectoral cooperation
	Market-related	Market failures: costs associated with environmental damage and climate effects are poorly reflected in market prices
		Availability of raw materials
Social	Individual	Reluctance to change
	Organizational	Companies lack time and resources to work on issues other than their core business
		Lack of trust; competition among companies in the network
		Strong focus on core business; SMEs not actively looking to engage in symbiosis projects with other companies
Technical		Long physical distances between the industries
		Lack of technical solutions for managing by-products
Information-related		Lack of knowledge about possible side-streams, collaborating partners, and so on
Policy-related		Lack of comprehensive and coherent strategies
		Strong interest in existing industrial structures
		Uncertainties in legislation

Source: Baumgarten and Nilsson 2014; Golev et al. 2015; Lombardi 2017; Neves et al. 2019; Papathanasoglou et al. 2016; Walls and Paquin 2015; Yang et al. 2022.

2.4 Direct, indirect and induced employment effects

The employment effects of industrial symbiosis operations can be direct, indirect or induced. Direct employment refer to jobs maintained or created for industrial symbiosis activities, such as waste recovery and processing (Park et al. 2015). Indirect employment refers to jobs generated in upstream and downstream industries associated with industrial symbiosis activities, such as construction waste management facilities, merchant enterprises and wholesale reused materials (Liu et al. 2020). Induced employment effects are additional jobs created by economic activities and the spending patterns of direct and indirect workers (Liu et al. 2020). While combining these three types of occupations provides a comprehensive picture of the employment effects of industrial symbiosis activities, this study focuses on direct employment. Direct jobs allow for a more exact and accurate measurement of employment effects.

2.5 Quality of employment

The term “employment quality” has several dimensions, from a single task and work environment to the broader labour market systems in which jobs are conducted (Burchell et al. 2014; Muñoz de Bustillo et al. 2011). Thus, no single combination of variables can sufficiently define the term (Findlay et al. 2013). In an effort to offer a systematic definition, the ILO launched the concept of “decent work” in 1999 (Burchell et al. 2014). The ILO defines decent work as productive work for women and men in conditions of freedom, equity, security and human dignity (ILO 1999). The ILO Decent Work Agenda has four pillars: promoting full and productive employment, ensuring workplace rights, expanding social protection and promoting social dialogue, with gender as a cross-cutting theme (ILO 2013). In this context, what constitutes decent work is determined by various characteristics, such as: employment opportunities; productive work and adequate earnings; decent working time; a balanced work, family and personal life; work stability and security; work that should be abolished; equal treatment and opportunity in employment; safe working environments; social dialogue; social security; and workers’ and employers’ representation (ILO 2013). These characteristics offer useful indicators when examining employment quality.

2.6 Factors influencing the employment effects of industrial symbiosis

With regard to the conditions that influence the employment effects of the circular economy, the literature identifies a range of contextual factors, including the following (Caspersen & Navrud 2021; Ellen MacArthur Foundation 2015; Gomes et al. 2022; ILO 2019; Liu et al. 2020; Vaquero et al. 2021):

- Government policies and regulations: Policies that encourage the development of circular economy initiatives, such as infrastructure investment or tax breaks for enterprises, may result in job creation. Conversely, policies that oppose the circular economy or impede its implementation may stifle job creation.
- Industry sector: The circular economy has the potential to generate jobs across a range of industries, including waste management, construction and manufacturing. The exact industries most affected by the circular economy will vary depending on the local circumstances and the sort of circular economy initiatives adopted.
- Size and type of business: The employment effects of the circular economy may vary according to the size and type of the enterprises engaged. Major corporations can create jobs through supply chain optimization and closed-loop manufacturing technologies, while small firms can benefit from new product development, service innovation and resource efficiency.
- Geographic location: The circular economy may affect jobs differently depending on the geographic location. For example, most circular jobs are located in the global South but the bulk of these are informal.
- Skills and education: The transition to a circular economy may require new skills and education for workers. Different skills will be needed in low-, medium-, and high-skilled occupations. Workers may, for instance, need to learn new techniques for repairing, refurbishing or repurposing products or handling waste streams. Therefore, the availability of and level of investment in training and education programmes will influence workers’ ability to participate in the circular economy.
- Consumer behavior: Changes in consumer tastes and preferences, such as a rise in demand for recycled-content items or for services that emphasize resource efficiency, can open up new business opportunities and employment creation.

2.7 Overview of existing empirical studies

While some studies examine the employment effects of the circular economy at the macro level, the empirical literature on employment effects at the inter-firm level is rather limited. A recent study in Argentina by the ILO found that industrial symbiosis activities produce 19 per cent and 52 per cent of jobs in the whey and wood sectors respectively, with the greatest effect occurring in the value chain (Abriata and Masut 2021). On the qualitative side, the authors identified an uneven impact, given that, while industrial symbiosis reduced the risk of working in sawmills, the jobs created by the networks increased gender and educational disparities in employment opportunities. Similarly, another study conducted by the ILO in Colombia discovered that industrial symbiosis operations had the potential to create and retain jobs (Ríos and Rodríguez 2021). Job creation happened mostly in large enterprises owing to the development of new waste sorting and classification activities, whereas retention occurred as a result of workers completing additional tasks connected to industrial symbiosis. The study identified various roles that stakeholders could play to promote industrial symbiosis and positive employment impacts, such as the need for governments to provide tax breaks to firms that implement industrial symbiosis strategies and the need for workers' associations to provide avenues for dialogue to improve working conditions.

As far as the right skills for circular jobs are concerned, the literature is somewhat inconclusive. Some authoritative works (European Commission 2021a; 2021b; ILO 2019) underscore the importance of diverse skills adapted to different green tasks. According a report by the ILO, approximately 2 per cent of the global workforce will be affected, with the majority of job allocation and relocation occurring within mid-skill occupations (ILO 2019). More recently, the European Commission (2021b) reported a shortage of skilled workers in the category of jobs with high green potential, which is particularly notable within the categories of professionals and managers.

In Africa, the link between industrial symbiosis and employment is an uncharted topic. Several studies have been conducted to establish the prevalence of industrial symbiosis in Liberia, South Africa, Kenya, Egypt, Zimbabwe and Tanzania (Oni et al. 2022). In Tanzania, only three studies have been reported to date, which have focused on characterizing the physical manifestations of industrial symbiosis networks, the underlying factors and the economic and environmental benefits (Rweyendela and Kombe 2021a; 2021b; Rweyendela and Mwegoha 2021). In this context, the current study contributes to filling this knowledge gap by investigating the topic in Tanzania, with a particular focus on the sugar sector.

2.8 Overview of the Tanzanian sugar industry

Sugarcane development in Tanzania began in the early 1920s when the Tanganyika Planting Company factory was established in Moshi, and large-scale commercial sugar production started in the 1960s (Sulle and Dancer 2019). Since its privatization between 1998 and 2001, the industry has grown steadily in terms of cane production area, capital investment and revenue earned (Sulle 2017). In recognition of the social, economic and political importance of this sector, the Government of Tanzania has implemented three main policy measures to improve the business environment; the enactment of the Sugar Industry Act of 2001, and the establishment of the Sugar Board of Tanzania and the National Sugar Institute. The Sugar Board of Tanzania is mandated to regulate the industry, whereas the National Sugar Institute was established to develop the requisite labour force for the sugar sector. Overall, these policy initiatives are designed to encourage the development of the sector with a view to maximizing its numerous socio-economic and environmental benefits.

The construction of new facilities and the extension of current ones are supporting the expansion of the sector. There are currently seven sugar factories in the country, one of which is still under construction. Table 2 outlines the operational sugar factories, as well as those that are being built.

Table 2. Overview of sugar projects in Tanzania

Manufacturer	Region	Year established	Installed/planned capacity (TPA)
Kilombero Sugar Company Limited	Morogoro	1961	130,000
Tanganyika Planting Company Limited	Kilimanjaro	1930	100,000
Kagera Sugar Limited	Kagera	1982	105,000
Mtibwa Sugar Estates Limited	Morogoro	1973	50,000
Bagamoyo Sugar Limited	Pwani	2022	30,000–35,000
Mkulazi Holding Company Limited	Morogoro	Under construction	250,000
Manyara Sugar Company Limited	Manyara	2003	8,000

TPA: Tonnes per annum
Source: AsokoInsight 2022; Sulle 2017

3. Methodology

3.1 Research design

An exploratory research design was applied, using case studies and qualitative research approaches as deemed appropriate. This comprehensive approach is recommended for comprehending and discovering little-known phenomena (Creswell 2014). Yin (2014) suggests using a case study design to gain an in-depth understanding of a given phenomenon and its contextual conditions. This is a popular approach in industrial symbiosis research (see Rweyendela and Mwegoha 2021; Yang and Feng 2008; Zhu et al. 2008). Moreover, the employment effects of industrial symbiosis are an emerging research area, making case study research useful for building and extending theory (Eisenhardt 1989). Because each case is a complex entity situated in its own context (Stake 2005), a multi-case study approach was necessary to illuminate contextual variations and similarities (Barratt et al. 2011; Stake 2005).

3.2 Sampling

Research participants, both sugar enterprises and individuals, were sampled purposefully (Benoot et al. 2016). The final sample depended on the individual's or company's willingness and availability to participate in the research. For the survey, the target personnel were those with first-hand information on industrial processes, waste management and human resources, including process and production engineers, environmental managers and human resource managers and officers. The research team targeted diverse key informants, including managers of enterprises, representatives of employers' organizations, government officials, academics and experts in labour and industrial waste management. Key informants were sought for the qualitative interviews. The initial respondents were identified through the research team's personal and professional networks, and a snowballing technique (Jalali and Wohlin 2012) was employed to identify additional respondents. The final sample comprised 14 respondents. Annex C provides a summary of the respondents. To ensure anonymity, the list contains sector/expertise information without specific names or roles.

3.3 Data collection

Data collection was carried out in two phases. The first phase involved mapping physical flows within the sugar companies. The aim of this phase was to survey the current state of industrial symbiosis activity in terms of physical energy and material flows and associated employment aspects. The overall methodological approach used was material flow analysis, a popular methodology used in industrial ecology to account for a system's physical flows and estimate the derived social, environmental and economic indicators (Brunner and Rechberger 2004; Sendra et al. 2007). The empirical task involved characterizing the industrial processes, major inputs, major outputs and derived employment indicators. Access to the companies was gained through official requests. To ensure anonymity and confidentiality, each firm was given a code name.

The research team collected data through three main techniques:

- Physical site observation: site visits to locate plants, industrial processes, and resource stocks and flows;
- Document review: a review of websites and other corporate documents to identify relevant information;
- Surveys of staff and managers of enterprises using a questionnaire (Annex A).

The second phase involved examining the perceptions and lived experiences of key actors. Here, emphasis was placed on capturing key actors' perceptions, opinions and experiences of the employment effects of industrial symbiosis activity. Data were collected through semi-structured, in-depth interviews with key informants using an interview guide (Annex B). The interview guide consisted of ten questions in total. Each question was structured around one or more research questions. This enabled the collection of open-ended data and more inclusive responses from the participants. It also made it possible to probe, ask follow-up questions and seek clarification where necessary.

The fieldwork was carried out between January and May 2023. The same person conducted all the interviews to ensure cohesion and consistency. Each interview lasted approximately 45–60 minutes. A total of 14 interviews were performed with representatives of key stakeholder groups. Comprehensive notes were taken during each interview. The participants were assured that their statements and information would remain anonymous. After completing the fieldwork, the individual interviews were code-numbered before being analysed.

3.4 Data analysis

The interview and survey data were analysed both qualitatively and quantitatively. The comprehensive notes from the interviews were examined carefully and analysed using the six steps of thematic analysis (Braun and Clarke 2006): 1) familiarizing oneself with the data; 2) generating initial codes; 3) searching for themes; 4) reviewing the themes; 5) refining and naming the themes; and 6) producing the report. Following the recommendations of Barratt et al. (2011), data from each case company were organized and analysed separately before being compared across cases. The basic characteristics of industrial symbiosis activity and employment effects were summarized with descriptive statistics, using count data and percentages. The results were then interpreted to answer the research questions.

4. Results

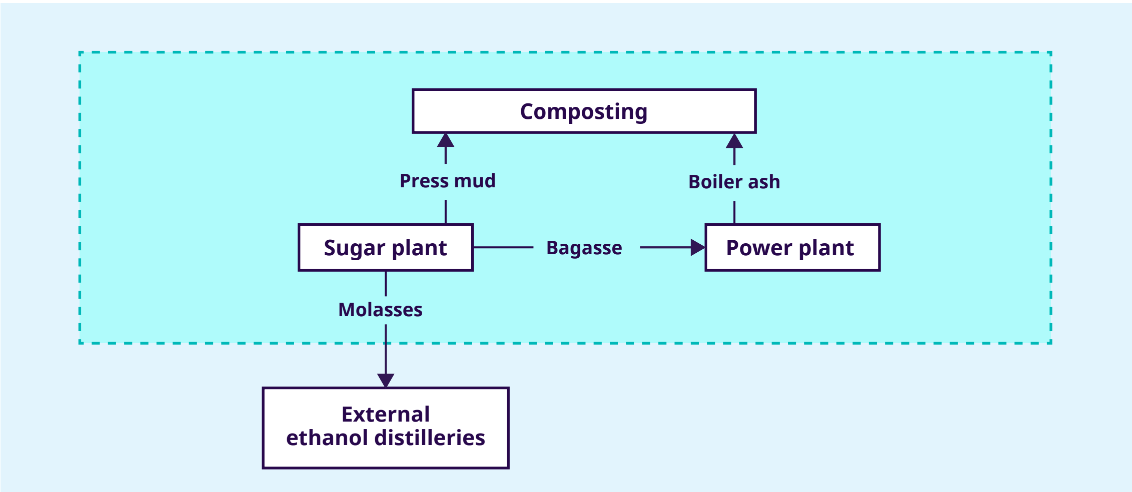
4.1 Forms of industrial symbiosis and the associated employment effects

4.1.1 Case-by-case analysis

Case 1: Alpha Sugar Company Limited

Internally, the analysis revealed that only one main symbiotic exchange occurs (Figure 1), namely the use of sugar factory bagasse as a feedstock for a 20-megawatt internal power plant. The generated electricity meets the company's energy needs, with the excess complementing the national grid. The internal applications include industrial activity, irrigation, office power and employee quotas. A portion of the molasses is sold to outside distilleries, while the remainder is used as animal feed by the company's employees and the local villages.

Figure 1: Material flow model for Alpha Sugar Company Limited



During peak season, the company employs approximately 1,900 people. Industrial symbiosis operations have directly created approximately 88 jobs across various occupations, as summarized in table 1. This equates to approximately 4.6 per cent of the overall workforce. Table 2 describes the social welfare conditions. According to respondents, these figures have not changed considerably in the past five years.

▶ Table 3. Overview of occupations associated with industrial symbiosis operations at Alpha Sugar Company Limited

Occupational group (official title)	Task and duties performed	No. of jobs (2022)	Experience require-ment	Educational require-ment	Skills requirement	Women em-ployed	Working contract
Boiler operators	Operate the boiler	9	2 years	Certificate	Boiler operations	0	Permanent
Engineers	Conduct operational tests, inspect and maintain systems	9	3 years	Bachelor's degree	Mechanical and water resources engineering	0	Permanent
Laboratory scientists	Collect samples, conduct labora-tory analyses, and prepare reports	6	1 year	Diploma	Analytical skills; data analysis; communication skills	0	Permanent
Mechanical assistants	Assist mechani-cal engineers	12	1 year	Diploma	Boiler and turbine mechanics; communication skills	0	Permanent
Plumbers	Install, repair and maintain plumbing fixtures	12	1 year	Certificate	Plumbing installation; repair and maintenance; communication skills	0	1-year contract, renewable
Assistants	Prepare bagasse bottom ash	30	None	Primary education	Communication skills	0	1-year contract, renewable
Compost operators	Conduct mixing and composting processes	10	Not Indicated	Primary education	Manure handling and composting	10	1-year contract, renewable

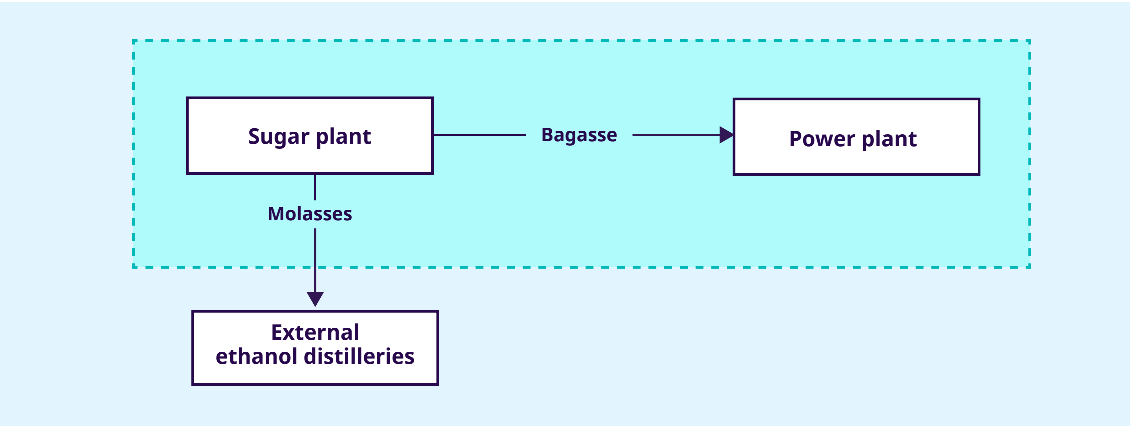
▶ Table 4. Overview of social welfare conditions for workers associated with industrial symbiosis operations at Alpha Sugar Company Limited

Social welfare aspect	Key findings
Number of new enterprises created and formalized owing to industrial symbiosis activities	Two
Total number of jobs formalized	All jobs are formal
Average wage per month	Varies with occupation and experience but above minimum national wage
Working hour limits	Eight hours per day
Workplace hazard protections in place	The company has an occupational health and safety policy, and all work-ers are given personal protective equipment and receive regular training
Reported occupational health and safety incidents per day/week	Four incidents per week reported
Unionization rate	Not disclosed
Social dialogue opportunities and activities (such as consultations, negotiations and workplace coopera-tion, including the parties involved and the frequency)	Internal meetings and workplace cooperation with an independent chemical company

Case 2: Beta Sugar Company Limited

Figure 2 depicts the symbiotic relationships identified at Beta Sugar Company Limited. As illustrated, there is just one internal industrial symbiosis arrangement, namely the use of bagasse for power generation in a 5-megawatt power plant. Other sugar manufacturing waste and by-products are stored on site or sold to external third parties. Press mud is not used in the agricultural fields because it is incompatible with the soil type in the region. The molasses are sold to domestic and international markets, including those in Kenya and Uganda.

Figure 2: Material flow model for Beta Sugar Company Limited



The company employs approximately 1,500 individuals in total. Industrial symbiosis operations have generated a substantial number of direct jobs. When fully operational, the power plant directly employs more than 63 staff members across various occupations, representing some 4.2 per cent of the workforce. Tables 5 and 6 summarize the employment and working conditions at the company.

Table 5. Occupations linked to industrial symbiosis operations at Beta Sugar Company Limited

Occupational group (official title)	Task and duties performed	No. of jobs (2022)	Experience require-ment	Educational requirement	Skills requirement	Women employed	Working contract
Engineers	Perform trouble shooting, conduct maintenance and repairs, oversee safety and compliance, and provide supervision	7	4 years	Bachelor's degree	Electrical or mechanical engineering, including piping and instrumentation; management; communication skills; leadership; computer skills	0	Fixed term (1 year), extendable
Plant operators	Monitor processes and communicate with other staff	8	3 years	Diploma	Communication skills; computer skills	0	Fixed term (1 year), extendable
Casual workers	Perform picking, lifting and loading, cleaning and sorting	45	None	Primary education	Communication skills	0	Temporary

▶ Table 6. Overview of social welfare conditions for workers associated with industrial symbiosis operations at Beta Sugar Company Limited

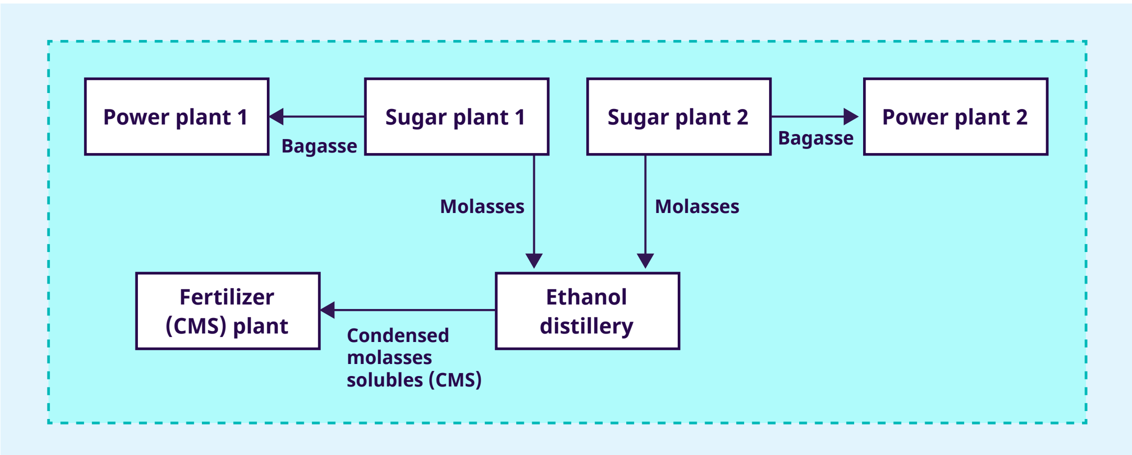
Social welfare aspect	Key findings
Number of new enterprises created and formalized owing to industrial symbiosis activities	One
Total number of jobs formalized	All industrial symbiosis-related jobs are formal
Average wage per month	Varies with occupation and experience but above minimum national wage
Working hour limits	Eight hours per shift
Workplace hazard protections in place	There is a safety management system in place, and safety equipment is provided
Reported occupational health and safety incidents per day/week	None since the start of operations
Unionization rate	All eligible workers are permitted to join a trade union. The main unions are the Tanzania Union of Industrial and Commercial Workers and the Tanzania Plantation and Agricultural Workers Union. Around 70 per cent of eligible workers are unionized.
Social dialogue opportunities and activities (such as consultations, negotiations and workplace cooperation, including the parties involved and the frequency)	Internal meetings with management in groups, and external meetings with trade unions

Case 3: Gamma Sugar Company Limited

The analysis revealed four major symbiotic exchanges within six integrated industrial units, as depicted in Figure 3, namely:

- Direct application of press mud/filter cake from sugar production as a soil conditioner in agricultural fields;
- Utilization of bagasse from sugar production as fuel in two power cogeneration plants with a combined capacity of 10 megawatts, diverting nearly 14,000 tonnes of bagasse from landfill each day;
- Utilization of molasses from sugar production as feedstock in ethanol production;
- Utilization of condensed molasses solubles (CMS) as feedstock in a fertilizer/CMS factory that produces fertilizers for agriculture.

▶ Figure 3: Material flow model for Gamma Sugar Company Limited



The company employs around 4,500 people during the peak season. Industrial symbiosis operations have created some 97 direct jobs across various occupations, as summarized in tables 7 and 8. This represents about 2.2 per cent of the overall workforce.

▶ Table 7. Occupations linked to industrial symbiosis operations at Gamma Sugar Company Limited

Industrial symbiosis unit	Occupational group (official title)	Task and duties performed	No. of jobs (2022)	Experience requirement	Educational requirement	Skills requirement	Women em-ployed	Working contract
Power plant 1	Foreman	Perform maintenance and servicing	1	2 years	Diploma/ degree	Electrical skills; mechanical skills; communication skills	0	Permanent
	Technician	Measure and monitor processes	4	1 year	Certificate	Electrical skills; mechanical skills; piping and instrumentation	1	Permanent
	Operators	Conduct unit processes and operations	4	None	Secondary education (Form IV)	Unit opera-tions; safety; troubleshooting	1	Permanent
	Casual worker	Perform fuel feeding, de-ashing and cleaning	28	None	None	Communication skills	4	Temporary/ seasonal
Power plant 2	Foreman	Perform maintenance and servicing	1	2 years	Diploma/ degree	Electrical skills; mechanical skills; communication skills	0	Permanent
	Technician	Measure and monitor processes	4	1 year	Certificate	Electrical skills; mechanical skills; piping and instrumentation	0	Permanent
	Operator	Conduct unit processes and operations	4	None	Secondary education (Form IV)	Unit opera-tions; safety; computer skills; troubleshooting	0	Permanent
	Attendant	Oversee outside environment	4	None	None	Multiple skills	0	Permanent
Ethanol distillery	Factory manager	Manage and oversee factory operations	1	5 years	Bachelor's degree	Engineering and management; computer skills; communication skills	0	Permanent
	Maintenance manager	Maintain and repair facilities	1	3 years	Bachelor's degree	Electrical or mechanical engineering; diagnostics	0	Permanent
	Laboratory manager	Manage laboratory operations	1	3 years	Bachelor's degree	Laboratory science; engineering; management	1	Permanent
	Production team lead	Manage the production team	4	3 years	Bachelor's degree	Production engineering; computer litera-cy; management	1	Permanent
	Operators	Operate units	24	None	Certificate	Unit processes and operations	0	Permanent
	Laboratory technician	Conduct laboratory analyses	4	1 year	Diploma	Laboratory science	2	Temporary/ seasonal
	Sample collector	Collect samples	2	None	None	Communication skills; accuracy	2	Temporary/ seasonal
CMC plant	Plant manager	Manage plant operations	1	3 years	Bachelor's degree	Management, engineering; computer skills; communication skills	0	Permanent
	Infield supervisor	Perform supervision	1	2 years	Diploma	Management	1	Permanent
	Operator	Operate units	3	None	None	Communication skills	0	Temporary
	Mixer	Perform mixing	4	None	Primary education	Communication skills	0	Temporary
	Cleaner	Perform cleaning	1	None	None	Communication skills	0	Temporary

▶ Table 8. Overview of social welfare conditions for workers associated with industrial symbiosis operations at Gamma Sugar Company Limited

Social welfare aspect	Key findings
Number of new enterprises created and formalized owing to industrial symbiosis activities	Four
Total number of jobs formalized	All industrial symbiosis-related jobs are formal
Average wage per month	Varies with occupation and experience but above minimum national wage
Working hour limits	Eight hours per shift
Workplace hazard protections in place	The company has a health and safety management system
Reported occupational health and safety incidents per day/week	Minor incidents only, which occur rarely
Unionization rate	About 80 per cent of all eligible staff
Social dialogue opportunities and activities (such as consultations, negotiations and workplace cooperation, including the parties involved and the frequency)	Limited to regular internal meetings and consultations with workers' organizations

4.1.2 Comparison across cases

Table 9 provides a comparative overview of the quantity and quality of jobs created in industrial symbiosis-related activities in the Tanzanian sugar sector. The findings indicate that industrial symbiosis networks within the Tanzanian sugar sector are still developing. When comparing the scale and scope of industrial symbiosis activities across the three cases, it is clear that, in each case, the company has engaged in some form of industrial symbiosis but with varying degrees of ambition. The Beta Sugar Company Limited has the fewest symbiotic linkages, with bagasse usage in power cogeneration being the only existing symbiotic activity. Bagasse power cogeneration appears to be a well-established symbiotic activity in the Tanzanian sugar industry, with every case study reporting at least one plant. The Gamma Sugar Company Limited reported the most symbiotic linkages. In addition to two bagasse cogeneration plants, two other industrial units had been integrated to utilize residues: an ethanol distillery and a fertilizer plant. The other two companies, on the other hand, did not have integrated ethanol distilleries and therefore exported their molasses to external independent distilleries.

The internal and external symbiotic exchanges within the companies surveyed have contributed significantly to environmental protection by redirecting waste disposal and lowering greenhouse gas emissions. Although exact quantities were not available, all companies reported using bagasse and molasses in some way, either internally or externally. Sugar production processes, especially cane crushing and juice extraction, are very energy-intensive. Two of the three surveyed companies reported being energy self-sufficient thanks to bagasse cogeneration, with the third working to that end. The combined capacity of the three firms' cogeneration plants is approximately 35 megawatts – a considerable contribution to the national power supply.

Meanwhile, the data show that industrial symbiosis activities in the three sugar companies have directly led to the employment of around 248 people, equivalent to 3.1 per cent of the total workforce. Although the number of direct jobs created appears to be proportional to the size of the industrial symbiosis network (namely, the number of industrial symbiosis-related enterprises), the overall job creation potential is determined by the labour intensity of industrial symbiosis operations. For example, despite having just one industrial symbiosis-related unit, Alpha Sugar Company Limited has created nearly the same number of direct jobs as Gamma Sugar Company Limited, which has six industrial symbiosis-related units. Most jobs are created in old, labour-intensive cogeneration plants. Labour intensity is relatively low in new cogeneration plants and ethanol distillery operations because of the high level of automation, and in fertilizer plants because few activities are performed.

Lastly, the findings reveal variations in job quality in different industrial symbiosis-related occupations. These range from good-quality, skilled occupations, such as engineers, scientists and technicians, to relatively poor-quality, unskilled temporary roles, such as assistants and cleaners. Table 9 shows that female workers account for only 9.3 per cent of the direct jobs created. Largely owing to the seasonal nature of sugar production activities, most workers are employed temporarily, especially low-skilled workers such as casual workers. The findings also reveal that 54.4 per cent of the jobs are temporary, implying that the majority of workers face job insecurity. Furthermore, these workers typically execute simple activities under direct supervision and stringent punctuality, resulting in minimal autonomy. The majority of the remaining 45.6 per cent of workers, on the other hand, are skilled workers who enjoy some degree of task complexity, autonomy and higher wages. They also benefit from possibilities for skill development and career advancement.

Additionally, the physical work environment is relatively good; all the companies surveyed reported having robust occupational health and safety management systems to reduce workplace hazards. The prevalence of workplace accidents and incidents is generally low across the three cases. In addition, eligible and willing workers are free to join trade unions and participate in social dialogue activities, and the majority have done so. However, the findings show that workers lack adequate opportunities for social dialogue beyond the regular meetings with management representatives and trade unions. This is, therefore, one area where further improvement is necessary.

▶ **Table 9. Comparative overview of workers employed in industrial symbiosis operations**

Company	Total workforce	Number of industrial symbiosis-related enterprises	Number of jobs created	Number of female workers	Number of temporary workers	Unionization rate
Alpha Sugar Company Limited	1,900	2	88 (4.6%)	10 (11.4%)	52 (59.1%)	Not disclosed
Beta Sugar Company Limited	1,500	1	63 (4.2%)	0 (0%)	45 (71.4%)	70%
Gamma Sugar Company limited	4,500	4	97 (2.2%)	13 (13.4%)	38 (39.2%)	80%
Total	7,900	7	248 (3.1%)	23 (9.3%)	135 (54.4%)	

4.2 Success factors for positive employment effects

During the second part of the study, key informants were interviewed to identify the most important factors influencing the employment effects of industrial symbiosis in Tanzania. Respondents identified various overarching and sector-specific factors. Two main enablers/drivers and eight barriers were reported, as described below and in the following subsection.

High energy costs

Several interviewees cited high energy costs as one of the primary drivers of industrial symbiosis and its consequences for employment in the sugar sector. They noted that typical sugar companies consume a lot of energy. Given the high price of energy from the national grid and the proven viability of cogeneration technology, all sugar companies have been compelled to develop power cogeneration plants, through which they can meet their energy requirements with some energy to spare. Sugar companies' increasing use of bagasse-fed power cogeneration plants has led to increased job opportunities. Respondents also highlighted that, without cogeneration systems, most sugar companies would be unable to make a profit, which would have a detrimental impact on both direct and indirect employment.

A growing market for ethanol

According to several respondents, there is a widening gap between demand and supply for industrial and potable alcohol in Tanzania. Respondents noted that a number of small- and medium-sized alcoholic beverage enterprises are booming in Tanzania and neighbouring countries, such as Kenya and Uganda, leading to an increased demand for ethanol. This is prompting sugar firms that have not yet established distilleries to do so, which is, in turn, creating employment opportunities in the construction and operation of ethanol plants in sugar complexes. At the time of writing this report, one sugar mill in Tanzania was constructing an ethanol distillery to meet the growing demand, and another sugar mill already had a distillery up and running.

4.3 Barriers to positive employment effects

From the key informant interviews, it became apparent that there are eight main barriers to the adoption of industrial symbiosis and its positive employment effects. They are described and illustrated in the following subsections.

Limited policy incentives

Limited policy incentives constitute an important macro-level barrier to business expansion into ethanol production and further cogeneration. The interview findings indicate that there are few incentive programmes to encourage sugar companies to venture into ethanol production and increase cogeneration.

The respondents noted two pressing issues. The first is the lack of a clear policy on feed-in-tariffs that would set a minimum purchase price for power purchased from independent power producers. The interviewees lamented that, while the adoption of individual power purchase agreements was a commendable step in the right direction, the implementation of such agreements was riddled with issues such as bureaucracy and payment delays.

The second issue noted by respondents was the lack of a policy on blending. According to the respondents, Tanzania has no standards for blending bioethanol from sugarcane with petrol. These factors create uncertainty and deter commercial-scale investment in bioenergy production, including cogeneration and bioethanol.

Policy fragmentation

Policy fragmentation is a problem that is closely tied to the issue of inadequate policy incentives. Respondents remarked that the country's different national and sectoral policies are too narrowly focused to address the big picture. They emphasized the missing link between the agriculture and energy industries in particular. They cited the National Energy Policy (2015), which is essentially quiet on the importance of cogeneration and biofuels derived from sugar waste products. Similarly, despite noting the potential of biofuel and bio-electricity production in the sugar sector, the National Agriculture Policy (2013) provides little direction on integrating the sugar sector with the energy sector. No designated policy instruments are in place to encourage investment in waste and by-product utilization. The absence of a stand-alone sugar policy further aggravates the situation.

Lack of specific skills-related policies

The Tanzanian Government has recognized skills development as a priority for the sugar industry, especially through the establishment of the National Sugar Institute. However, some respondents were concerned that, while the National Sugar Institute exists to develop requisite skills for the sector, there are no real education and training programmes specifically designed to promote industrial symbiosis.

Food security concerns

The issue of food security further complicates the policy environment. According to industry sources, the sugar production deficit in Tanzania has caused periodic sugar shortages, which have threatened food security. The Government's sugar strategy has focused on sugar production to avoid a food/co-product conflict. The sources noted that sugar is the most sought-after – and most profitable – product from sugarcane; investment has therefore focused on increasing sugarcane production and yield per hectare rather than diversifying into other co-products. They added that the high start-up costs of ethanol distillery plants and the absence of subsidized finance further aggravate the situation. Diversification was viewed as an evolutionary process, with the expectation that sugar companies would diversify when conditions allowed. The sources stated that some companies had already done so and that others would do the same as long as it was financially viable.

Limited competition

The interviews with key informants revealed virtually little competition in the sugar sector. Currently, Tanzania has only seven sugar mills, of which six are fully operational. This situation is exacerbated by the unlikelihood that new competitors will enter the market and by the strong protections in place against sugar imports. According to some academics and industry insiders, this creates a market environment that lacks sufficient incentives to stimulate competitive rivalry and innovation, which would push companies to make full use of the potential of industrial symbiosis and produce more green jobs.

Automation

According to industry insiders, automation constitutes a major barrier to employment generation through industrial symbiosis in the sugar industry, especially in linked ethanol distilleries and cogeneration plants. Ethanol is highly flammable and can form explosive vapour clouds. Consequently, distillery owners rely on automated systems to reduce the risk of human error and prevent accidents caused by improper handling of flammable materials. At a more general level, sugar industry experts added that the industry is shifting towards production systems that increasingly rely on mechanization and digitization, thereby reducing labour demand. It was highlighted, for example, that most of the activities of modern cogeneration systems are automated, which decreases the need for causal workers to perform tasks such as de-ashing. In this context, significant uncertainties surround labour intensities and direct employment opportunities in future industrial symbiosis networks in the sector.

Insufficient supply of by-products

Another significant hurdle mentioned by interviewees was the scarcity of molasses. It was noted that most alcohol-based industries in the country were already starved of feedstocks. The shortage was most severe during the peak of the coronavirus disease (COVID-19) pandemic, when alcohol-based sanitizer and disinfectant businesses boomed. It was further remarked that the existing supply of molasses in sugar mills is insufficient to justify investment in alcohol plants and to allow for the full-capacity utilization required for economic viability. This predicament is exacerbated for independent alcohol producers by the risk that sugar mills will vertically integrate and establish their own alcohol plants, thereby effectively cutting off the raw material supply.

Another significant aspect compounding this problem is the distance from sugar factories, which is too long to justify investment in storage facilities that pool bagasse from diverse sources. According to respondents, this factor has substantially impacted the financial viability of private investments in ethanol distilleries outside of sugar mill operators.

The same is true for power cogeneration. A major barrier to further power cogeneration development is associated with fluctuations in bagasse supply. Industry insiders said that sugar plants experience seasonal fluctuations in their bagasse supply throughout the year, with abundant feedstock available during the crushing season and shortages during the off months. This has discouraged investment in expanding power cogeneration facilities, which would generate further employment opportunities.

Ethical and religious concerns

Ethical and religious considerations appear to be an important barrier, especially to investors concerned about the social impact of and religious objections to alcohol production and consumption. The liquor business consumes most of the ethanol generated in sugar mills in Tanzania, followed by the chemical industry and other sectors. According to some respondents, investors with ethical and religious concerns have refrained from expanding their operations to include ethanol distilleries, thereby effectively foregoing job creation opportunities. Table 10 outlines the key drivers and constraints identified in the current study.

Table 10. Key drivers and barriers

Drivers	Barriers
▶ High energy costs ▶ A growing market for ethanol	▶ Limited policy incentives ▶ Policy fragmentation ▶ Lack of specific skills-related policies ▶ Food security concerns ▶ Limited competition ▶ Automation ▶ Insufficient supply of by-products ▶ Ethical and religious concerns

4.4 Availability of specific skills

The findings indicate that adopting circular practices in the sugar industry has no disruptive effect on the labour market with regard to skill needs. Respondents agreed that circular manufacturing operations involved both low- and high-skilled workers. According to one academic, the installation of ethanol production facilities will increase the demand for specialized skills in design and technology, thereby necessitating a large number of highly skilled workers. In contrast, increased reuse and recovery of filter cake and boiler ash will necessitate the hiring of new lower-skilled workers. It was also mentioned that, as sugar projects advance to operation, there will be greater demand for management and maintenance expertise. Cross-cutting skills and reskilling programmes will therefore be required in order to enable workers to adapt to the evolving labour market.

Participants in the study generally agreed that, while circular operations require enhanced skills, those skills do not necessarily differ significantly from those required in traditional industries. It was noted that general skills for industrial symbiosis-related tasks are widely available in the Tanzanian labour market and that only additional training and retraining is required to impart the new specialized skills. New skill training is especially important for designing, constructing and operating ethanol distilleries. Generally, respondents agreed that there was no scarcity of workers, such as graduate engineers, who could be trained or retrained to take on roles in circular operations.

4.5 Actions needed to promote positive employment effects

Tanzanian industry is complex, containing multiple stakeholders each with their own mandates and objectives. Broadly speaking, the Tanzanian sugar sector constitutes three broad categories of actors that play either operational or supporting roles:

- Producers, namely sugar farmers and mills operators, including corporate entities and small holders;
- Regulators, including the Government, which acts as a regulator through the Sugar Board of Tanzania and the Ministry of Agriculture;
- Supporting organizations, comprising social partners such as sugar grower and producer associations, as well as other relevant stakeholders such as the National Sugar Institute and other educational institutions.

The analysis reveals that these actors may be instrumental in addressing the Tanzanian sugar industry's transition to a circular economy while also promoting employment creation and adequate skills. According to the respondents, these actors could individually and collectively deploy a set of strategies aimed at creating opportunities and fostering a conducive environment with a view to steering the industry towards greater circularity and more positive employment outcomes. These strategies and interventions are outlined actor by actor in table 11. The discussion in the present study is focused on what the various actors should do, rather than how they should do it.

▶ **Table 11. Strategies for promoting positive employment effects**

Actor	Strategy/intervention
Producers	▶ Recognize the opportunities and threats of the sugar industry's transition to a circular economy. ▶ Integrate industrial symbiosis measures into their strategies for business growth and product development. ▶ Invest in larger, more efficient energy cogeneration plants so that more power can be sold to the national grid and stimulate the introduction of feed-in-tariffs. ▶ Provide supplementary training and retraining to develop the skills needed in circular operations.
Regulators	▶ Develop institutional structures, including legislative, regulatory and administrative frameworks that incentivize technological innovation, circular practices and employment creation. ▶ Integrate circular economy measures into sectoral development strategies, for example by conducting a sectoral strategic environmental assessment to strategically plan and manage the transition to a circular economy. ▶ Promote education and training policies for the circular transition within the sugar industry. ▶ Promote informational policies to raise awareness about the opportunities arising from the circular transition. ▶ Restructure the tax system to create fiscal incentives, such as tax exemptions and tax credits for capital investment in industrial symbiosis, and scale up bagasse cogeneration and ethanol production. ▶ Encourage the establishment of independent power companies, separate from sugar mill operators, thereby allowing for greater cogeneration capacity and flexibility.
Supporting organizations	▶ Continuously assess the sugar industry's training needs in order to establish relevant training programmes, and update human resource capabilities in order to boost circularity. ▶ Strengthen the ties between education and training institutions and sugar producers to improve skills development along sugar value chains and manage the drivers of work changes, including the transition to a circular economy. ▶ Conduct research relating to the circular economy in the sugar industry, including technologies and information systems that can facilitate the transition to circularity by providing more job opportunities. Work performance research is also needed, including standards for working conditions, occupational safety and job specifications, with the aim of optimizing circularity and productivity. It is also important to understand the efficacy and weaknesses of national and sectoral policies with regard to promoting the circular transition and positive employment effects, and to share global lessons. The findings should be used to raise awareness and understanding among the general public regarding the social, environmental and economic opportunities arising from the circular transition in order to increase public support and acceptance. ▶ Provide technical advice and consultancy services to sugar companies. ▶ Advocate for a conducive policy environment, including cogeneration feed-in tariffs and tax incentives for skills development and technological innovations. Advocate for explicit recognition of bagasse cogeneration as a strategy for encouraging and supporting local renewable energy within national environmental policy. ▶ Create broad forums for policy coordination and social dialogue, including task forces, with a view to incorporating policy and skills needs into industrial and environmental policies in order to reduce skill gaps and sustain positive environmental, economic and employment effects. ▶ Implement financing schemes targeting the adoption of circular technologies and practices, including bagasse energy cogeneration programmes.

5. Conclusions and recommendations

While the shift from linear manufacturing systems to a circular economy is widely recognized as having an effect on global labour markets, the employment effects are poorly understood. The current research has contributed to this discussion by showing how transitioning to a more circular, resource-efficient economy through industrial symbiosis in the Tanzanian sugar sector affects employment and the underlying contextual influences. We surveyed three case studies and interviewed several key informants to understand the subject thoroughly. The case of the Tanzanian sugar sector is informative because it demonstrates the potential for industrial symbiosis to promote economic growth and help alleviate high unemployment rates in poor countries. The analysis reported here offers a reasonable picture of the overall trend towards industrial symbiosis in the sector and the associated employment impacts.

Returning to the research questions posed at the outset, the results show that, while industrial symbiosis networks are still evolving, they are, overall, creating (fairly decent) jobs. Moreover, the employment figures provided here are conservative because they exclude indirect and induced jobs. Although the reality of a completely circular economy is a long way off, the findings are encouraging. As sugar firms grow, industrial symbiosis is becoming an important strategy to support business growth and employment creation. Although the bulk of employment appears to be of low quality, it may provide the intrinsic values that workers seek, especially for those with modest lifestyles in impoverished socio-economic settings. As such, the good practices seen in the three cases must be emulated by other sugar producers in Tanzania and worldwide.

Moreover, we have identified some overarching and sector-specific factors shaping the sector's circularity trajectory. Without a doubt, rising energy costs and a burgeoning ethanol market will continue to encourage sugar companies to pursue more circularity for the foreseeable future. Their ability to fully seize the opportunities that industrial symbiosis provides will depend on a greater understanding of the obstacles outlined here and on the provision of policy support to create a favourable sectoral and national context for industrial symbiosis to prosper. For example, consistent rules for power feed-in tariffs and fuel blending appear indispensable for scaling up bagasse cogeneration and encouraging investment in ethanol distilleries. An increase in investment in such facilities would therefore boost future employment creation. An important conclusion is that sugar producers, regulators and supporting organizations must work together on multiple fronts to create a more enabling environment. There are clear opportunities to boost industrial symbiosis in the sector.

Furthermore, labour input and skills requirements will continue to evolve as the scale and complexity of symbiotic networks expand, technologies mature and automation advances. The findings suggest that, as sugar companies adopt more complex circular business models, the demand for labour inputs will fall, and demand for multi-skilled workers will increase. A major challenge for creating more employment opportunities in the future is related to increased automation in the industry. These findings convey a clear message to decision-makers and policymakers – namely, that targeted training and education will become essential in matching skills demand and supply.

In conclusion, the transition to a circular economy in the sugar sector has had a positive effect on the labour market in terms of employment quality. Job prospects have grown, and individuals may now be in a better socio-economic position than they would have been without these jobs. There is little doubt that the sugar industry can serve as a model of the circular economy and that circularity and employment outcomes can be enhanced. This study complements previous research findings and adds sectoral perspectives to the discussion on the employment consequences of industrial symbiosis. There is a need for more research across different geographical and sectoral contexts to understand the topic more fully. It is hoped that this study will stimulate further research into the topic, in addition to policy action to scale up industrial symbiosis activities and propel higher levels of employment, while opening pathways for more sustainable economic development.

5.1 Recommendations

Clearly, many job prospects would have been lost if the industrial symbiosis activities described in the case studies had not occurred. Subsection 4.5 of this report summarizes the perspectives of several respondents on what actors in the sugar sector should do to encourage further industrial symbiosis and the associated job benefits. Here are some general recommendations to supplement those suggestions:

- The various actors in the sugar sector should collaborate to create stronger partnerships, including by raising awareness about their shared responsibilities in scaling up circular activities and continually improving working conditions.
- Researchers should conduct more research to demonstrate the feasibility and benefits of industrial symbiosis in the sugar industry.
- Social partners, such as the Tanzania Plantation and Agricultural Workers Union and the Tanzania Union of Industrial and Commercial Workers, should seek to improve working conditions in the sector, including by improving opportunities for social dialogue, gender inclusivity and job security.
- The Government should reform its energy policy to incentivize investment in bagasse cogeneration and the production of biofuels from sugar waste.
- The Sugar Board of Tanzania should develop a strategic plan for the sector and set strategic targets for circularity.

5.2 Study limitations and future research

The findings of the current study must be interpreted in the light of several limitations. First, we narrowed the scope of the analysis to focus only on direct jobs during the operational phase in order to produce more credible results. It should be noted that additional direct and indirect jobs are created during the planning, construction and installation phases. It is also important to acknowledge that the case study findings may not be generalizable to a larger population. Lastly, symbiotic networks are typically dynamic and evolutionary; and yet, the analysis presented here is based on data collected at a certain time. Consequently, important evolutionary features could not be captured. Therefore, further research focused on varied sectoral and geopolitical contexts is required to strengthen the qualitative and quantitative evidence on the topic, especially research that captures indirect and induced jobs and performs longitudinal analyses.

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Annex A: Survey questionnaire

Section A: Company background information and industrial symbiosis activities

1. Name and address of organization

....

2. Year operations started

....

3. What is your main product(s)? What are the annual production volumes?

....

4. What are the main unit processes and operations?

....
....

5. What are the main inputs/raw materials, including water, electricity, fuel and chemicals (quantity and price)?

....
....
....
....

6. What are your by-products (quantity and estimated cost)?

....
....
....

7. What types of wastes characterize your operations?

....
....
....
....
....
....

8. What are your waste streams (quantity/year)?

   Solid waste generated, tonnes/year

   ....

   Wastewater generated, volume/year

   ....

   Yearly cost of solid waste management

   ....

   Yearly cost of wastewater management

   ....

9. How do you manage the different waste streams?

Dispose

Reuse internally

Recycle internally

Energy recovery internally

Recycle externally

Other waste management measures (including transport)

10. Do you sell any of your waste streams/by-products to other companies?

Who buys your waste/by-products?

At what price do you sell your waste/by-products?

How are they used?

Who takes your waste for free?

11. Can you identify any company initiatives that have been implemented to reduce the environmental impacts of wastes and by-products?

Are there any plants/facilities that depend entirely or partially on waste streams or by-products?

....
....

12. Is there the possibility of selling/recycling/reusing/recovering any of the waste streams that are currently disposed of?

....
....

13. Do you receive any by-products or waste products from other companies that are then used as input in your production processes? If yes, please specify.

....
....

14. Could any of your raw materials be replaced with a by-product or waste product? If yes, please specify.

....
....

15. Which parameters are of importance when deciding whether or not a by-product can be used as an input in your production processes?

i. The content of heavy metals and other polluting substances

ii. Geographical and seasonal limitations

iii. Problems related to hygiene

iv. Regulations and fees

v. Problems of odour or aesthetics

vi. The environmental policy of your company

vii. Tradition

viii. Safe/stable and reliable delivery

ix. Technical limitations

Section B: General occupational categories associated with industrial symbiosis activity

1. Are there any existing occupations for which employment demand has increased as a result of industrial symbiosis activities, where the work and worker requirements of the occupation have not changed significantly and where the work context may have changed but the tasks have not? Please explain.

....
....

2. Are there any existing occupations where the work and worker requirements have changed significantly as a result of industrial symbiosis activity, resulting in an increase in employment demand for the occupation? Please explain.

....
....

3. Have industrial symbiosis activities resulted in the creation of any new occupations or the hiring of new employees because of the need for unique work and worker requirements? Please explain.

....
....

Section C: Specific occupations involved in industrial symbiosis facilities, processes, products and services

Occupational group (official title)	Task and duties performed	No. of jobs (2022)	Experience requirement	Educational requirement	Skills requirement	Women employed	Employment terms

Indicators to be derived for each occupation group:

- Share by gender (percentage);
- Share of total company employment (percentage).

Section D: Social welfare of workers involved in industrial symbiosis facilities, processes, products and services

Number of new enterprises created and formalized owing to industrial symbiosis activities	
Total number of jobs formtalized	
Average wage per month	
Working hour limits	
Workplace hazard protections in place	
Reported occupational health and safety incidents per day/week	
Unionization rate	
Social dialogue opportunities and activities (such as consultations, negotiations and workplace cooperation, including parties involved and frequency)	

Section E: Employment destroyed owing to industrial symbiosis activity

Number of enterprises or processes closed or discontinued	
Total number of jobs lost	
Number of female workers lost	

Section F: Skill level and skill specialization

Skill level	
Nature of work performed	
Level of formal education required	
Amount of informal on-the-job training and/or previous experience in related occupations required	
Skill specialization	
Knowledge required	
Tools and machinery used	
Materials worked on or with	
Kinds of goods and services produced	

Indicators to be derived:

- Skill level (level 1–4, according to the ILO International Standard Classification of Occupations);
- Number of occupational groups at each level.

Section G: Skill levels for different occupation groups

Occupation group (official title)	Skill level (1–4)

Annex B: Interview guide

1. **Background information on participant**

   1.1 What is your current position and role in the organization?

   1.2 Do you work in any activity related to industrial symbiosis, such as reuse, reprocessing, conditioning, recycling and energy, or recovery, and, if yes, in what way?

   1.3 In those resource recovery activities, who do you collaborate with?

   1.4 What is your primary motivation to work in the area in which you work?

2. **Personal perceptions**

   2.1 What is your understanding of industrial symbiosis or the circular economy?

   2.2 From your point of view, what are the factors of success that determine the positive employment impacts of industrial symbiosis, especially the qualitative effects concerning job formalization and employment for women? How do these factors facilitate employment?

   2.3 your point of view, what do you consider to be the main barriers to the achievement of positive employment results in industrial symbiosis (if any)? How do these barriers hamper employment?

   2.4 In your opinion, what actions can the private sector and national and local governments, respectively, take to further promote employment creation through industrial symbiosis and to improve job quality? Can you think of any other actor(s) who could contribute positively to this? What do you consider to be the main opportunities?

   2.5 In your opinion, what are the specific skills needed in jobs created through industrial symbiosis? Are such skills available in the local, regional or national labour market?

   2.6 In your opinion, are there any specific groups or organizations that could be advantaged/disadvantaged by industrial symbiosis activities in the sugar sector? Could you please elaborate?

3. **Additional information**

   3.1 Do you have any additional comments?

   3.2 Can you recommend other stakeholders who we could interview?

Annex C: List of interviewees

1. Academic, Ardhi University
2. Academic, University of Dodoma
3. Academic, University of Dar es Salaam
4. Academic, University of Dar es Salaam
5. Representative, East African Business Council
6. Representative, Confederation of Tanzania Industries
7. Human resource manager, sugar company
8. Human resource manager, sugar company
9. Engineer, sugar company
10. Representative, Sugar Board of Tanzania
11. Representative, Association of Tanzania Employees
12. Representative, Tanzania Sugar Producers Association
13. Representative, Export Processing Zones Authority, Ministry of Trade and Industry, Tanzania
14. Representative, Prime Minister's Office of Labour, Youth, Employment and Persons with Disability, Tanzania ....