Journal of Cleaner Production 525 (2025) 146552

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Toward successful industrial symbiosis implementation: An exploratory study on the UK sugar industry

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HIGHLIGHTS

- Industrial Symbiosis (IS) projects often fail due to high costs.
- This study explores factors leading to successful IS implementation.
- We present empirical evidence from eight IS cases from the UK sugar industry.
- Findings reveal strategies and processes that enhance IS successes.

ARTICLE INFO

Keywords:
Industrial symbiosis
Sustainable supply chain
Waste management
Sugar industry
Case study

ABSTRACT

To minimize the detrimental effect of finite resources on the environment while realizing the maximum economic benefits of industrial production, industrial symbiosis (IS) has become a new strategic approach for an industrial ecosystem where underutilized resources from one company become the inputs for another. However, IS, while designed to optimize resource flows, can often fail and lead to sizable operational costs which hinder growth and competitiveness. This paper examines the key factors and motivations for companies to engage in IS activities. Our findings, based on case studies of the UK sugar industry, focusing on two leading producers and six IS projects, identify a set of five key stages for establishing an IS relationship and fostering the widespread of IS: identifying, analyzing, system reconfiguration, functional networking, and market entry. We discuss a range of practical and theoretical implications, shedding more light on the underlying mechanism that guides decision-making processes for achieving higher level of productivity circularity and efficiency.

1. Introduction

Industrialization has been widely acknowledged to be a driver of fast economic growth and development. However, despite the huge benefits that industrialization brings, its negative externalities such as the issues of diminishing natural resources, environmental pollution, and ecological damages all may become a binding constraint on our ability to produce and may bring growth to a halt. To minimize these productive externalities, Frosch and Gallopoulos (1989) propose a systems-oriented concept, Industrial Symbiosis (IS), which stems from the view of an industrial ecosystem where energy and material consumption is optimized, and waste generation is minimized. To this effect, IS, a vital part of industrial ecosystems, has become a common approach to delivering environmental sustainability and competitive advantage because it promotes the exchange of materials, resources, energy, and by-products through business model innovations (Short et al., 2014) or a network of industries. The concepts of IS have evolved over the last two decades and IS has now been recognized as a promising approach toward the circular economy (Cao et al., 2025; Dong et al., 2024; European Commission, 2015).

In this study, we adopt the concept of IS, as proposed in the field of industrial ecology, which involves the physical exchange of by-products and materials, water, or energy between one or more “traditionally separate entities” or among several organizations or interdependent stakeholders (Chertow, 2000; Ehrenfeld and Chertow, 2002). The concept of IS or by-product synergy consists of turning the waste stream from one production process into consumable products. In the context of strategic partnerships, it is also known as cross-industry collaboration

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https://doi.org/10.1016/j.jclepro.2025.146552
Received 3 June 2025; Received in revised form 17 August 2025; Accepted 2 September 2025
Available online 6 September 2025

that enables a circular economy (Neves et al., 2020; Ratsimandresy and Miemczyk, 2025).

Indeed, applications of industrial ecology have been observed at both organizational and regional levels. For instance, British Sugar has systematically turned the waste streams and emissions from the production process into inputs for new product lines, thus offering a broad range of additional synergistic and profitable product lines (Short et al., 2014). At the regional level, a prime example of IS is the Kalundborg Eco-Industrial Park in Denmark where energy and materials are saved by waste sharing (Ehrenfeld and Chertow, 2002; Ehrenfeld and Gertler, 1997). The UK National Industrial Symbiosis Program (NISP) provides a business-led platform to support IS facilitated programs. Similarly, the US Business Council for Sustainable Development launches several regional by-product synergy programs. The European Commission recognizes that IS practices are important in supporting sustainable development (European Commission, 2015). Moreover, IS is highlighted by the Chinese government as a pillar of its sustainable industrial development plan to tackle the problems of intensive resource consumption and waste emission (Shi and Chertow, 2017).

Despite these benefits and initiatives, the IS transformation faces significant challenges that hamper its sustained operations. IS has been documented to be associated with the issues of uncertainty in the relationships among firms (Zhu et al., 2020), waste supply-demand mismatch (Yazan and Fraccascia, 2020), and ineffective governance models (Strom and Hermelin, 2025). In 2013, the UK government stopped funding NISP partly because IS had a cost-benefit ratio of between 32:1 and 53:1 (Cole, 2017). Several sugar manufacturers in China frequently fail to deploy IS due to the organizational ignorance of their own business models and market situation (Huang, 2020). Many studies have focused on assessing the issues of IS implementation across industries and eco-industrial parks (Rweyendela and Mwegoha, 2020) or by simulating model-based optimal contract, pricing and production strategies in IS projects (Cao et al., 2025; Dong et al., 2024; Fraccasica et al., 2020). However, the existing literature is relatively silent on the micro-level factors influencing waste reduction and IS operations (Tang et al., 2021). Details of understanding of the critical factors that influence IS successes, i.e. full integration and sustained operations that deliver both economic and environmental benefits, are essential considerations in the design of IS projects (Luo et al., 2022).

To fill this gap, this study seeks to answer the question: At an organizational level, *what factors can lead to a successful IS implementation?* Based on studies of two leading manufacturers from the UK sugar industry alongside six detailed IS projects, our findings discuss the key decision-stages for the design and development of IS and contribute to the theoretical awareness in sustaining IS. The empirical evidence can reveal various approaches, techniques, and strategies that have enhanced IS successes and those that have engendered failures. Thus, we make contributions to the literature of IS by discussing a range of practical and theoretical implications, shedding more light on the underlying mechanism that guides decision-making processes for achieving higher level of productivity circularity and efficiency.

2. Literature review

Past research has studied several industries and IS cases to understand various factors that could facilitate or hinder the establishment of symbiotic synergies among firms. Common IS enablers and barriers have been associated with information, knowledge, technology and process, cooperation and mutual trust, geographical proximity, symbiotic facilitators, and commitment to sustainable development, among others (Henriques et al., 2021; Liu et al., 2015; Neves et al., 2019). A number of recent papers have used various modelling and analytical methods to design waste-to-resource supply chains (Luo et al., 2022), to facilitate contract design between firms in IS under environmental tax policy (Cao et al., 2025), and to simulate optimal pricing and production strategies in IS (Dong et al., 2024; Fraccasica et al., 2020; Tang et al., 2021).

However, it is also argued that the efficacy of IS on firms' performances is unclear (Lombardi and Laybourn, 2012). As the traded waste is usually not the core business of the supplier and is not produced upon demand (Tang et al., 2021; Yazan and Fraccascia, 2020), different from traditional supply chain management, IS can experience difficulties in responding to shocks and economic uncertainty (Strom and Hermelin, 2025; Tang et al., 2021). In particular, the mismatch in waste supply and demand and uncertainties about waste availability play a major role in forming and consolidating IS relationships (Tang et al., 2021; Yazan and Fraccascia, 2020; Zhang et al., 2021). Specifically, the supply of waste is usually higher than the demand of waste utilizer, while the imbalance of supply and demand of wastes is also affected by the price sensitivity of the downstream market (see Tang et al., 2021; Yazan; Fraccasica et al., 2020; Zhang et al., 2021).

At the macro level, IS can also facilitate the formation of new business subsidiaries (Short et al., 2014). There are models to assist governments and NGOs to detect and assess IS opportunities (Cecelja et al., 2015) as well as to simulate IS scenarios in an eco-industrial park (Mantee, 2017; Rweyendela and Mwegoha, 2020). Studies also focus on how facilitators and consultants can assess the performance of an IS network. These include the IS maturity model (Litos et al., 2017) and IS performance indicators (Mantese, 2017; Fraccascia et al., 2021).

At the inter-organizational level, IS is often regarded as the cross-industry collaboration process designed to build a circular economy (Neves et al., 2020; Ratsimandresy and Miemczyk, 2025). From an industrial system perspective, Parida et al. (2019) categorize the process of IS as 1) readiness assessment, 2) ecosystem mechanism, and 3) outcomes. From an organizational perspective, Brown et al. (2021) propose three stages of IS: 1) identification of partners, 2) alignment of vision, and 3) development of value capture models, governance structures. More generally, the broader circular economy literature explores the practice of reduce, reuse, and recycle (Liu et al., 2024). Related processes also exist, which emphasize process improvement, product development, partner engagement, and relational development (Kohler et al., 2022; Liu et al., 2024). Much of the literature finds that one of the main barriers to IS is the lack of effective governance mechanisms to support the cross-sectoral collaboration (Strom and Hermelin, 2025).

At the organizational level, using an enterprise input-output model, Yazan and Fraccascia (2020) conduct a cost-benefit analysis on how companies share the total economic benefits from IS. Fraccascia et al. (2016) identify five business scenarios that may arise at inter-firm level among waste producers and users: 1) 'Internal exchange + input replacement'; 2) 'Internal exchange + co-products generation', also known as 'organizational boundary change' (Boons et al., 2016); 3) 'External exchange + input replacement', also known as 'self-organization' (Boons et al., 2016); 4) 'External exchange + co-product generation'; and 5) 'External exchange + new product generation'. In addition, infrastructure development, network design, product design, and process design are needed to implement IS projects (Babazadeh et al., 2017).

A number of papers are also related to the present paper with case studies from China and the UK. Guitang Group and Nanning Sugar Co. Ltd, two Chinese sugar companies, create subsidiaries to transform by-products into new products (Shi and Chertow, 2017), thus changing their traditional operational boundaries (Boons et al., 2016). Huang's (2020) study of IS-based projects shows that 53 % of businesses fail due to poor quality of products and high production costs. In contrast, the UK has been at the forefront of the implementation of various waste minimization programs and become the first to institute a national industrial symbiosis program (Laybourn and Lombardi, 2007). The IS case in Short et al. (2014)'s study reveals that, in light of evolving market conditions, IS is a necessity to maintain profitability and achieve growth (Bijon et al., 2022). However, this literature lacks an exploration of the organizational factors and processes that lead to a successful IS (Liu et al., 2015). Answering this question requires careful exploration of IS from the perspective of its operations – a gap addressed by this paper.

3. Research method

To answer the research question set out in Section 1, this study relies on the interpretation of firm-level IS operations. Accordingly, a qualitative case study method is adopted, as this is useful for exploring ongoing complex phenomena (Yin, 2009). Moreover, we use multiple case studies, as it helps to cross-examine the cases and identify patterns that could support the generalization of the theory development (Eisenhardt, 1989; Yin, 2009).

To explore this issue, we choose the UK sugar industry for our case study for two main reasons. First, the sugar industry demonstrates the opportunities of using by-products as raw materials for other processes to generate new revenue streams (Bijon et al., 2022). Similar case studies in various countries report mixed findings (see Bijon et al., 2022; Huang, 2020; Shi and Chertow, 2017; Short et al., 2014, among others). The study on this industry can reveal meaningful insights for theory development. Second, the UK has been a pioneer in IS implementation with facilitator programs from the government (Laybourn and Lombardi, 2007; Philips et al., 2006). Thus, findings can potentially be generalized to other regions and similar economies facing similar challenges.

We adopt the theoretical sampling method for case selection (Eisenhardt, 1989) following the criteria and our concept of IS set out in Section 1: 1) The company produces sugar as its core business; 2) The Waste Exchange Scheme is set up either inside the organization or with external partners; 3) Such an exchange creates co-products outside of its core business, which results in revenue generation; 4) The above practices have been conducted for more than five years; 5) There is good access to data derived from interviews and company archives. Our sampling criteria result in selecting of two companies, British Sugar (henceforth BS) and Tate & Lyle Sugars (henceforth TLS). We focus on the “project-level IS” as the unit of analysis, and investigate six case projects from the companies, as shown in Table 1. Cases 1–5 are the IS projects led by BS. Cases 6 is the IS project adopted by TLS.

Data collection involves conducting semi-structured interviews with senior practitioners associated with the IS operation. The interviewees included the managing director, technology manager, carbon manager, and continuous improvement manager, representing distinct yet interdependent functions as part of the projects (See Table 1). There were eight interviews conducted from March 2022 to October 2024, each lasting around 60 min producing a transcript of around 7000 to 8000 words. The interview covered the following topics: IS background at company level, by-product streams, waste utilization, waste business development process, existing and discontinued IS projects, motivation of each project, reasons for discontinuation, daily operations activities of the projects, and market of the IS co-products. The secondary data were collected from the company website, business reports and news release.

In the process of transcribing the interview data, we first map out the process flows of British Sugar (Fig. 1) and Tate & Lyle Sugars (Fig. 2), respectively, identifying their core products, by-products, and co-products. Then we adopt the thematic analysis approach in Braun and Clarke (2006) in six steps: familiarizing with the data; generating initial codes; searching for themes; reviewing themes; defining themes; and producing the report. This results in the categorization of four themes: 1) IS motivation; 2) IS business model; 3) IS implementation process; 4) Reasons for IS success (Table 2).

Table 1
Overview of the cases.

Company	Interviewee Position (No. of Interviews	Case: IS Project	IS Duration	Waste and By-product	IS Co-product
British Sugar	Chief Technology Officer (3 times), Carbon Manager (2 times)	Case 1	1996 -	Soil and stones in raw sugar beet	Aggregate and topsoil
		Case 2	1984 -	Sugar beet pulp	Dried animal feed
		Case 3	2017 -	Waste heat and CO_2	Medicinal Cannabis
		Case 4	2007 -	Sugar extract	Bioethanol
		Case 5	2016 -	Waste heat and CO_2	Renewable electricity
Tate & Lyle Sugars	Continuous Improvement Manager (2 times), Managing Director (1 time)	Case 6	2010 -	Calcium carbonate cake	Bricks

4. Case studies

This section describes the six cases shown in Table 1, Fig. 1 and 2.

4.1. Case 1: Production of topsoil and aggregate

The sugar beets delivered to BS from sugar beet growers usually contain soil and stones. BS founded a subsidiary, Topsoil, in 1996, to be a dedicated distributor of the soil recovered from the sugar beet and this has been a consistent source of revenue to the business group. The soil produced from BS’s four sites in the UK is sold to the construction, landscaping, sports, and amenity sectors. Furthermore, the company’s in-depth testing and analysis provide customers with the information to choose from a range of soil blends. This has been facilitated by the company’s dedicated soil scientists and collaboration with a university and a research institute that conduct independent scientific trials. BS can now recover 200,000 tonnes of soil and 4800 tonnes of stones from the sugar beet deliveries each year. The stones are marketed for civil engineering, roadbuilding and construction projects.

4.2. Case 2: Production of animal feed from beet Pulp

The sugar beets are cleaned, shredded and passed through a diffusion process during which sucrose is extracted from the sugar beets, leaving behind sugar beet pulp as a by-product. This pulp is pressed to generate over 500,000 tonnes of high-quality dried animal feed which has been branded and marketed as “Trident Sugar Beet Feed” since 1984. This business rapidly expanded through acquisition, technological expertise, nutritional innovation, and market development. Today, Trident market over 1.2 million tonnes of high-profile animal feed products that range from sugar beets and distiller feeds to liquids and protected fats. As for the environmental impact, Trident Feeds reduces not only the beet pulp waste disposal and landfill use but also farmers’ reliance on imported ingredients like soya beans by providing a lower-carbon, locally sourced feed option.

4.3. Case 3: Production of medicinal cannabis using waste heat and CO_2

In January 2017, BS started growing medicinal cannabis plants in glasshouses close to the sugar factory. The glasshouses are heated using the waste heat generated from sugar refining which is piped from the factory alongside CO_2 from the combined heat and power boiler. Prior to that, the glasshouses were used to grow tomatoes. However, BS had identified an opportunity in medicinal cannabis which is highly valuable. Motivated by economic benefits, the company reconfigured the process to produce cannabis, which contains an ingredient to treat rare, life-threatening forms of childhood-onset epilepsy. BS partners with Jazz Pharmaceutical Company which buys the plants from the glasshouses. Annually, BS produces enough of this ingredient to treat 40,000 children globally. BS also harvests rainwater from the glasshouse roof to water the plants, 110 million litres each year, meaning the site is 98 % self-sufficient for water.

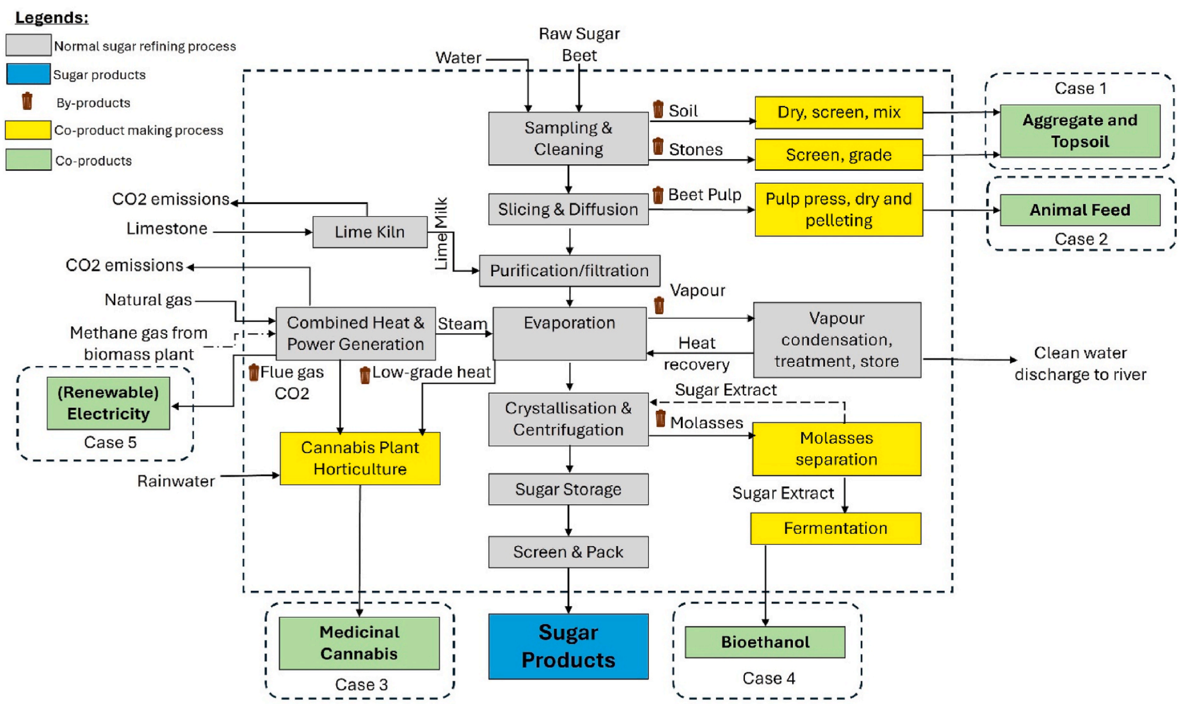

Fig. 1. Process flow at british sugar (Updated from Short et al., 2014).

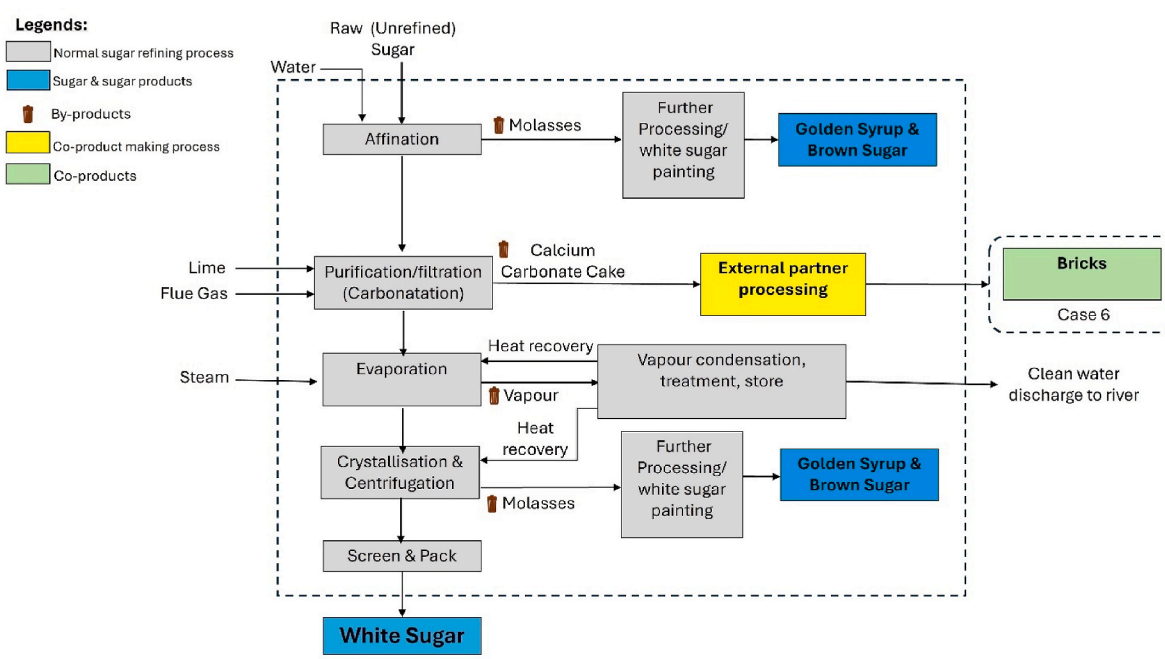

Fig. 2. Process flow at tate & lyle sugars.

4.4. *Case 4: Production of bioethanol from sugar extract*

BS originally considered making rum from the fermentation of the sugar extracted from the beet molasses or excess sugar produced. Realizing the competition in the alcohol market, it chose to produce bioethanol seeing that there was a huge market in the UK for sustainable petrol. The company commissioned a new bioethanol production facility in partnership with DuPont and British Petroleum. This led to the foundation of a separate bio-ethanol refinery Vivergo Fuels in 2007. It has since then produced up to 75 million litres of bioethanol annually. The company tracks the bioethanol to ensure it delivers environmental advantages. Currently, a blend of up to 5 % bioethanol can be used in any unleaded car on the road in the UK. There is potential for standard cars to use higher concentrations, meaning more business opportunity in the future.

4.5. *Case 5: Renewable electricity Production*

BS installed a power generation system, producing both steam and electricity, called Combined Heat and Power (CHP), which is recognized

Table 2
Summary of findings.

Case	Environmental Impact	Economic Benefit	Theme 1: Motivation	Theme 2: Business Model	Theme 3: Implementation Process	Theme 4: Reasons for Success
Case 1	Reusing waste; 200,000 tonnes of soil and 4800 tonnes of stones recovered annually	Estimated £4-£8 million in annual revenue (market price of £20-£40 per tonne)	Policy, Value capture from waste and diversification	Organization boundary change	Identify → Analyze → Reconfigure → Network → Market	Quality, Niche market
Case 2	Reducing waste disposal and landfill use; Reducing carbon footprint	Marketing 1.2 million + tonnes of animal feed products	Value capture from waste and diversification	Organization boundary change	Identify → Analyze → Reconfigure → Network → Market	Quality, Price
Case 3	Reducing carbon footprint; 12 MW low-grade heat and waste CO2 generated onsite; Save 110 million litres water annually	High-growth, high-margin sector; The medicinal cannabis treats 40,000 children annually	Value capture from waste and diversification	Organization boundary change	Identify → Analyze → Reconfigure → Network → Market	Niche market, Partnership, Quality
Case 4	Reducing and reusing waste; Tracing the full life cycle to ensure environmental benefits	Producing 75 million litres of bioethanol every year	Value capture from waste and diversification	Organization boundary change	Identify → Analyze → Reconfigure → Network → Market	Niche market, Partnership, Biggest industry player
Case 5	Reusing 97,500 tonnes of pressed sugar beet pulp each year; Reducing carbon footprint	CHP plant exporting electricity to power 180,000 homes	Value capture from waste and diversification	Organization boundary change	Identify → Analyze → Reconfigure → Network → Market	Internal use, Ready and niche market
Case 6	Reducing and reusing waste	Sales of 100,000 bricks annually	Value capture from waste	Self-organization	Identify → Analyze → Network → Market	Partnership, Quality

as one of the most fuel-efficient processes available. In 2016, the company invested £15 million in a new anaerobic digestion plant at the Bury St. Edmunds site. This plant breaks down the pressed sugar beet pulp into biodegradable material, with one of the end products being biogas. Methane generated from the biogas is fed into the CHP plant, generating green electricity. The plant is expected to use around 97,500 tonnes of pressed pulp each year and export 38GWh of electricity to the national grid, contributing to the UK's renewable energy targets under the Renewable Energy Directive. The CHP plant can export electricity to 180,000 homes.

4.6. Case 6: Production of bricks using calcium carbonate cake

As shown in Fig. 2, sugar product is the core business of TLS. During sugar refining, TLS produces around 11,000 tons annually of calcium carbonate cake (CCC), a by-product from the carbonation process involving lime and CO_2. Initially used to adjust soil pH, CCC was distributed to farmers for agricultural use. In 2010, York Handmade Bricks – a brick-making company in the UK – approached TLS for a partnership so they could use the CCC by-product as a raw material to make London Stock Bricks, as the calcium carbonate clay can give the bricks a particular yellow colour. The collaboration has created additional sales of about 100,000 bricks annually. TLS is working with other entities to see how the CCC can be used in sustainable architecture and landscape development.

5. Findings

Table 2 first summarizes the environmental impact and economic benefits from the case projects. It also highlights the four themes resulted from the thematic analysis.

5.1. Theme one: IS motivation

Data across all the cases shows that the main driver for IS in both companies is **value capture from waste and diversification strategy**. This is tightly connected with and often leads to the diversification of the firms away from sugar and sugar products. This pattern is seen across Cases 1–5. Cases 6 is slightly different because, even though the firm (Tate & Lyle Sugars) is keen on deriving economic value from its by-products, it tries to remain only in the sugar business.

Government policy is another factor motiving IS projects. Although BS already had the vision to turn wastes into revenue-generating streams, the emergence of TOPSOIL (Case 1) was facilitated by the government's waste legislation which prevented BS from distributing the waste soil across its sites or returning it to agricultural land. Indeed, Case 1 was formed partly in response to changes in waste management regulations. However, it demonstrated continued economic benefits. Thus, later, a joint motivation of value capture and policy helped the this IS project sustained for almost 30 years.

5.2. Theme two: IS business model

Cases 1–5 clearly show the '**organizational boundary change** (internal exchange + co-products generation)' model (Boons et al., 2016; Fraccascia et al., 2016). They involve internal exchanges where the company uses the by-products generated from its sugar refining operation to create co-products. These co-products are either sold directly to the end-users by the firm (e.g. aggregates), or through its subsidiaries or partnership with other firms with established market presence and a large customer base (e.g. bioethanol, animal feed). These operations depict some drift from the organization's initial business operation boundary (from sugar refining to other products) and have been a means of diversifying the company's business.

Case 6 however adopts the '**Self-Organization** (external exchange + input replacement)' business model (Boons et al., 2016; Fraccascia et al., 2016), in which the company identifies opportunities to gain economic benefit from its by-products and creates synergy with other firms to take its by-products. TLS partnered with a brick-making company that uses CCC in making London Stock Bricks. The company chose this IS business model because it has no interest in running a brick factory which is not in its expertise or market.

5.3. Theme three: IS implementation Process

The Cases demonstrate a process to implement IS, which can be visualized in Fig. 3 with five stages.

Stage 1 is to **identify** the IS opportunities. Both companies have a dedicated team responsible for exploring products that could be made using by-products. By-product and waste are constantly monitored and reviewed for which ideas are generated by R&D, production, and marketing departments through regular meetings led by the central management team.

Stage 2 is for the team to **analyze** the product at a strategic level, focusing on economic viability, risks, and feasibility. Specifically, economic viability focuses on the return on investment and the market of co-products. For risk assessment, the firm thoroughly reviews the co-product quality and price, market availability, existing competition, and potential partners. The feasibility analysis studies concern waste and by-product supply stability, technology, partnership, and market.

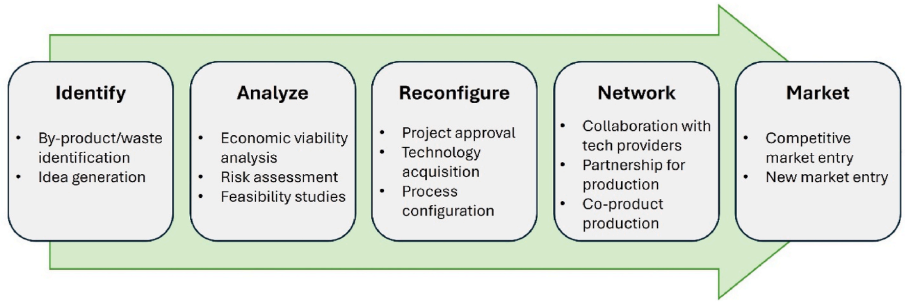

Fig. 3. IS implementation process.

Unlike the decisions for core business, IS co-creation often relies on companies' existing technology or partners, meaning low investment. Companies also try to avoid the competitive market for potential co-products. Moreover, as IS co-product sector is outside of the company's core supply chains, the amount of supply (e.g. waste) can be uncertain. Thus, a relatively stable supply is prioritized. For instance, BS once explored the opportunity of utilizing the stalks of wheat straw sourced from wheat farmers to generate green renewable electricity in a biomass power plant. However, the internal supply of wheat straw was unstable. Though the technology and market were ready, the company gave up the project.

Stage 3 is to **reconfigure** the systems. Following the analysis, the team presents the opportunities and analysis to the executive management who approves the project. Often, this requires the acquisition of technologies and reconfiguration of the manufacturing systems to implement the co-product production. While Cases 1–5 have successfully reconfigured the systems, Case 6 relies on existing systems based on which the partnership with a specialized company can fully take charge of the bricks production. As shown in Figs. 2–3, the co-existence of core business and IS co-product business shows the system reconfiguration, which is more complex than a traditional non-IS system.

The team is also responsible for identifying and establishing functional **networks** and partners to be able to take the products to the market and earn revenue from the business (Stage 4). This includes collaboration with technology and know-how providers, and partnership for co-production. This is followed by Stage 5 concerning **market** entry. In a saturated or highly competitive market, the team identifies and establishes network with well-established firms with a large customer base (e.g. BS partnering with British Petroleum and Du Pont for bioethanol marketing; partnering with reputable supermarkets for animal feed sales).

5.4. Theme four: Reasons for IS success

Competitive prices and better quality are among the factors that underpin the success of some of the IS businesses identified in our case studies. In Case 2, with supplies of sugar beet pulp internally from wastes, BS is able to produce animal feed at a lower price. In Case 3, the quality and traceability of the company's cannabis plant attracts the pharmaceutical company that buys the medicinal cannabis.

The Cases also demonstrate an **efficient central management and dedicated team.** Companies' one-management architecture oversees the IS activities, and this has enhanced an efficient decision-making process and a common focus on corporate goals. Companies' innovation team dedicated to the development of IS businesses helps in the facilitation of the processes. These teams adapt to market changes by executing dynamic capabilities where they continue to sense and seize new opportunities. For instance, in Case 3, BS transforms its tomato plant to growing medicinal cannabis, because of the significantly higher potential for growth and profitability in the pharmaceutical sector. This also demonstrates the team's flexibility to change, innovative co-product, and expansion opportunities.

Moreover, planning and **strategic analysis** is pivotal to the success of IS business in both companies. It forms the basis for the identification and selection of the best product, market, and partners to work with and helps the team to understand the market forces and the company's strengths and weaknesses to maximize the opportunities in the market. This is a comprehensive assessment of co-product quality and price, internal technology and resource, market availability, existing competition, and potential partners. In Case 3, the moving toward cannabis production aligns with the company's strategy to maximize returns on all assets.

Also, one of the benefits of the strategic analysis done by the IS innovation team is the ability to identify a **niche market.** This means that the IS products are in a sector where little competition exists, and there can be value provided to customers. For example, in Case 4, the company decides to produce bioethanol from molasses instead of rum. This is because rum is in a highly saturated sector in the UK alcoholic beverage market with several established players. In contract, the bioethanol market has little competition. Also, the company sees the growing demand for sustainable energy, thus, a great competitive advantage as BS has potential and access to a large customer base.

The cases also demonstrate that **functional partnership and alliance** with others, including universities, consultants, technology providers, can enhance IS success. Even though BS coordinates IS projects internally, it collaborates with universities and research institutes (Case 1) to conduct scientific trials, and partners with other companies (Cases 3–4) for product development. As for TLS, it focuses on the core business and utilizes external producers (Case 6) for co-product development and production. The partnership is built upon expertise and reputation of product quality.

6. Discussion

The existing literature has identified various factors such as technology, geographical proximity, policy, social and economic factors as the main enablers and barriers to the development of IS business (Henriques et al., 2021; Neves et al., 2020). Our study departs from previous studies and provides a micro-level project insight, involving in-depth knowledge of a project's progress, issues and outcome. This answers the call for more research on the operations and the development process of IS system (Tang et al., 2021; Ratsimandresy and Miemczyk, 2025).

Our findings first reveal that competitive prices and better quality of co-products are the key determinants of the success potentials. For instance, despite the tomato market saturation in the UK, British Sugar's tomatoes had a competitive advantage over the ones in the market due to the better quality and lower price. This can also explain reasons for the failure of IS in China's sugar industry where the co-products quality is poor (Huang, 2020). We highlight co-products quality as a new factor, in addition to the price factor (Dong et al., 2024; Fraccasica et al., 2020; Tang et al., 2021).

Efficient central management and dedicated team is an organizational factor that determines IS successes. This is different from the case of eco-industrial parks where there are many separate companies, with varying corporate objectives, which may lead to a struggle with interdependency on one another in a contractual way (Ehrenfeld and Chertow, 2002; Liu et al., 2015), as well as a mismatch in supply and demand (Tang et al., 2021; Yazan and Fraccascia, 2020). Indeed, focal firms need to have a management team with strong business development skills who should conduct thorough analysis of the firm's and intended co--product's strengths and weaknesses, and the external opportunities, threats, and risks. This would reveal the potential forces of competitors and enable the firms to determine the optimal IS business model (Fraccascia et al., 2016) and market entry strategy to follow such as direct market entry with developed co-products; by-product outsourcing; or partnership with other firms. An early realization of this factor through the audit of internal strengths and weaknesses could help the firm to decide the best strategy to adopt to increase success chances.

It is interesting to note that, while BS has integrated IS projects internally, TLS chooses to remain in the core business of making sugar and limit its exposure to competition by not diversifying into other sectors. Organizational culture plays a major role in this. At British Sugar, there is a culture emphasizing innovation, which regards IS as an innovation opportunity which can result in new products and formation of new subsidiaries (Short et al., 2014). IS is also strategically important to BS, as the integration of IS projects demonstrates long-term orientation. The continuous product development and process changes show evolving pathways toward the circular economy realization (Liu et al., 2024). TLS, on the other hand, leverages diversification related risks through collaboration with external producers in the by-product sector. It may be regarded as a short-term plan to reduce waste.

Size of business and rigid organisational structures may be another reason behind the different strategic choices. Traditional hierarchies can slow down decision-making, requiring multiple layers of approval before any investment in IS and co-production can be made. A smaller firm, on the other hand, may be more agile and responsive in capitalizing emerging collaborative opportunities in a timely manner. Thus, the comparison between the two cases demonstrates the dynamics and complexity of IS, where resource, existing network, product development capability, and process should all be considered to implement IS project (Babazadeh et al., 2017).

In addition, our findings highlight the effectiveness of well-established and consolidated relationships. This extends the view that a trusting relation between companies and sharing information is a key enabler of IS (Heriques et al., 2021). Trust can facilitate collaboration, in the form of knowledge sharing during IS implementation (Kohler et al., 2022). We argue that such relationships may rely on the expertise of the partners, which are not necessarily located in the same region or eco-parks (Kohler et al., 2022; Liu et al., 2015).

This research enriches the understanding of a micro-level IS business model. Our cases demonstrate a mechanism through 'internal exchange + co-products generation' (Fraccascia et al., 2016) or organization boundary change (Boons et al., 2016) where firms utilize by-products to produce a new product internally. We find that a dynamic process of five stages is embedded in such a business model, namely, (1) identifying IS opportunities, (2) analyzing the products, (3) reconfiguring the systems, (4) establishing functional networks, and (5) exploring market entry. (1) and (2) show some similarity to Prarida et al. (2019) 'readiness assessment', both emphasizing the external environment. However, different from an ecosystem, we argue that IS does not necessarily rely on an existing ecosystem, but that companies can establish an internal system (e.g. British Sugar) or form a new partnership (e.g. Tate & Lyle Sugars). Once the IS network is formed, the 'ecosystem mechanism' of Prarida et al. (2019) can be extended and refined as Stages (3) and (4). This requires changes to both the internal and inter-firm processes. Various functional networks can enable better governance mechanisms to support collaboration (Strom and Hermelin, 2025). (5) is similar to the 'development of value capture model' in Brown et al. (2021). Our findings expand the scope of existing inter-firm IS process (Prarida et al., 2019). It also indicates that IS can be effectively formed within an organization or between organizations, regardless of geographic proximity (Brown et al., 2021).

There are a number of possible avenues for future research. First, the case study could be enriched by considering a wider range of organizations, addressing sector-specific challenges. Luo et al. (2022) study such a case for the construction industry, while others such as Hu et al. (2025) investigate the steel industry. Given the significant presence of carbon emission in developing countries, the benefits of industry ecosystems could be felt more by the energy-intensive sectors. Second, the organizational factors, influenced by organizational culture and structures, remain underexplored in the literature of IS. Thus, the benchmark analysis can be extended to investigate the impact of culture and policy on IS organizational performances on a cross-country or cross-sectional basis. Third, another issue that certainly deserves further attention is digitalization. Incorporating a digital platform should stylize the nature of operations and supply chains in these ecosystems and help assess the performance of the system. Notable studies such as Liu et al. (2024), Mollica et al. (2025) and Yan et al. (2025) delve into the design and source of these digital networks.

7. Conclusion

We identified and studied several industrial symbiosis projects conducted by two major sugar producers in the UK. In this research, we discussed a number of key factors influencing IS motivation and success from a micro level. There are marked differences between the operations of the two firms suggesting that organizational structures and culture would play a significant role in affecting the dynamics and performances of IS. Our main findings also suggest a process of IS implementation in five stages and discuss the business models to be adopted.

As for the practical implication, this research has presented success-strategies to be adopted when developing waste businesses and has created more awareness of the often-neglected factors, especially business development strategies that firms need to imbibe to increase the chances of developing a successful waste-to-product business. Our findings imply that firms should look beyond the conventional barriers (such as technology, geographical proximity, economic viability, etc.) that have been commonly associated with IS when developing their new IS businesses and eliminating their wastes. Hence, firms should endeavour to constitute (or outsource) a strong business development team who conducts in-depth analysis of the firms' competitive strengths and weakness, as well as the opportunities and threats in the market. These would help them to identify potential market forces, such as competition, and the firms' competitive advantage over other players. Furthermore, our structured approach enables firms to make better-informed decisions about co-product development, partnerships, quality, business models, and market entry strategy.

CRediT authorship contribution statement

Chukwuebuka Jude Obetta: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zheng Liu:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yongjiang Shi:** Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bo Yang:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Research ethics

This research has been approved by the Institute for Manufacturing (University of Cambridge) Research Ethics Committee.

Funding

This work is supported by the Greenwich Research and Innovation Knowledge Exchange for Impact Fund (University of Greenwich).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We would like to acknowledge all interviewees for sharing their insights. Earlier versions of this paper were presented at Advances in Management and Innovation Conference (Cardiff Metropolitan University), EurOMA Conference, and Networks and Urban Systems Centre Research Seminar (University of Greenwich), during which we received helpful feedback to improve the paper. We acknowledge financial support for this research from the Greenwich Research and Innovation Knowledge Exchange for Impact Fund (University of Greenwich).

Data availability

Data will be made available on request.

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