Origins and dynamics of industrial symbiosis networks in India

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Abstract

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Enrolment start: April 2017; Expected completion: March 2020
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Detailed abstract

A circular economy is a regenerative system of 'closing the loop', whereby materials and energy are recirculated to recover valuable materials and embedded energy for reuse and upcycle (EllenMacArthurFoundation, 2012). Industrial symbiosis (IS) through by-product exchange, sharing of utilities and common infrastructure among co-located firms in an industrial park is a circular economy approach (Mathews and Tan, 2011). Eco-industrial parks are well-established sources of innovation and collaboration. Institutional capacity building (ICB) has theoretical roots in urban governance where innovative projects embodied the purposeful stimulation of intrinsic network capabilities. Past research in Netherlands, Colombia and China found that institutional capacity of IS networks increased over time by mobilising capacity, relational links and knowledge resources between member and non-member actors of the network.

There is limited understanding of the evolution of IS through synergetic resource exchange in eco-industrial parks in India, a fast-growing nation where industrialisation through sector-specific clusters, government-owned and managed industrial estates, joint public-private industrial parks and special-purpose investment zones is prevalent. In contrast, circular economy is a national mandate in China through the creation of closed-loop supply chains; the ongoing transformation of industrial parks to eco-industrial parks and planned greenfield eco-industrial projects is a strategic and economic priority (Mathews, Tan, & Hu, 2018). This study conducted an exploratory investigation in India’s eco-industrial park landscape. IS networks rely on the ability, capacity and interest of multiple stakeholders in congregating to improve their material and energy footprint, reduce waste and accrue higher individual
and joint benefit, whether monetary or otherwise. Thus, the economic, ecological and social impact of an IS network is directly proportional to the ability of the network’s members to share, access and build-upon information and connections, utilising network benefits for embedded resource exchange.

The aim of the research was to identify key actors and to test the applicability of ICB theory to IS in diverse economic and cultural contexts. Knowledge resources, relational resources and mobilisation capacity are known sources of institutional capacity. The literature offers evidence that ICB kindles collaboration within and between governance actors to create impact, building upon extant networks to intensify dialogue and linkages (Healey, 1998). The following research questions were tackled by conducting interviews and field visits to two chemical manufacturing industrial parks, namely, Naroda and Nandesari, in India’s western state of Gujarat:

1. Is there evidence of industrial symbiosis in the chosen park? If yes, what are the drivers and inhibitors? Who are the key stakeholders responsible for creating/facilitating the symbiosis? Has the role of key actors changed over time?
2. How have i) Knowledge resources ii) Relational resources iii) Mobilisation capacity manifested in the operations of the industrial park? Has symbiotic resource exchange enriched Knowledge resources, Relational resources, and Mobilisation capacity of the network, over time?

Another knowledge gap addressed through the study was to identify the drivers of circular economy among Small and Medium Enterprises (SMEs). SMEs are integral to India’s manufacturing prowess and operate mostly within an industrial park setting. Using case study methodology, semi-structured interviews with park management authorities, firm managers, government departments and independent bodies revealed distinct motivations and barriers to implementing IS. While the existence of common infrastructure like roads, canteen, hospital and fire services, and shared utilities like water and power supply, waste recovery, treatment and reuse were a common paradigm, an unforeseen driver for IS networks was found in the ‘industry associations’. Weak regulatory presence in managing park progress often led to the formation of industry associations which comprise representatives from companies within the park. The results establish the industrial dynamics of a circular economy in India, where industry action is a driver for IS networks; policy and regulatory support bring supplemental benefit. This finding is in stark contrast to China, where a top-down approach with federal/state/regional directives translated into concrete action at the firm and industrial park levels.

Industry associations as internal actors that foster IS, with the ancillary role of local and regional governance institutions as ‘formal’ members of the network are noteworthy discoveries. The author argues that positive and negative feedback loops keep the network iterative and self-improvising, growing network dependence between active and passive actors. Specifically, for SMEs, the lack of technical knowledge, finance and technology to create a circular economy, industrial networks present opportunities for higher combined economic, social and ecological benefit. ICB theory is a meaningful foundation towards understanding the effectiveness of ongoing processes in improving IS network capabilities, as also identifying methods for strengthening network performance across temporal and spatial scales.

Early signs of industrial symbiosis are visible in India’s chemical, engineering and automotive manufacturing sectors. Industrial ecosystems as complex adaptive systems have ever-evolving, fast-paced, self-organising attributes, influenced largely by market demand and supply dynamics (Chertow, 2009). IS networks, thus, are advocated to be sources of ICB, with institutional capacity increasing through network activity over time. The test of ICB theory in industrial symbiosis across diverse cultural and economic settings is valuable in creating robust theoretical links. The examination of circular economy advancement through industrial symbiosis by the application of ICB theory adds to a deeper understanding of structural and institutional development of industrial clusters at the regional level.
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Abstract
A strategic balance between industrialisation and resources security is a dichotomy facing economies, especially nations like India, charted on a manufacturing growth path. Exemplars of industrial regions in Denmark, China and USA demonstrate industrial symbiosis as a means of progressing towards an eco-industrial future; evidence from India is sparse. This study conducted an exploratory investigation in India’s industrial park landscape, to create a deeper understanding of structural and institutional development of industrial symbiosis networks. Two case studies of Naroda and Nandesari chemical manufacturing estates in India’s western state of Gujarat revealed nine by-product loops and diverse actors engaged in the industrial symbiosis network. Past examination of institutional capacity building in industrial symbiosis networks discovered dynamic links between knowledge resources, relational resources, and mobilisation capacity. The study notes similar patterns in Naroda and Nandesari, and highlights the central role of industry associations as internal actors that foster industrial symbiosis, with the ancillary role of local and regional governance institutions as ‘formal’ members of the network. These results establish the industrial dynamics of a circular economy in India, where industry action is a driver for industrial symbiosis networks; policy and regulatory support bring supplemental benefit. This finding is in stark contrast to China, where a top-down approach with federal/state/regional directives translated into concrete action at the firm and industrial park levels.

Introduction and research background
A circular economy, in contrast to the virgin resource and waste intensive linear economy, entails judicious use of materials and energy through the creation of closed resource loops, enabling recovery, reuse, repurpose and the resultant reduction in waste to landfill. Industrial symbiosis, as a circular economy approach, is championed to be an economic tool for the advancement of equitable and sustainable development by means of reduction of virgin/primary material input, lower waste going to landfill, higher circulation of materials, water and energy in industrial activities and the advent of new industry sectors engaged in secondary material recovery, treatment, upcycle and use. The manufacturing sector in industrial parks, owing to high materials, energy and emissions
intensity, is best suited to participate in symbiotic by-product exchange. Referred to as *eco-industrial parks*, these sites are well-established sources of innovation and collaboration.

The Organisation for Economic Co-operation and Development (OECD) views industrial symbiosis as a means of achieving green growth (as cited in Lombardi and Laybourn, 2012); the momentum is reflected in the European Union circular economy package, and a variety of national and state policy frameworks. Circular economy is a national mandate in China through the creation of closed-loop supply chains; the ongoing transformation of industrial parks to eco-industrial parks and planned greenfield eco-industrial projects is a strategic and economic priority (Mathews, Tan, & Hu, 2018). The 2007 National Action Plan on Climate Change, the updated 2016 Solid Waste Management Rules, policy dialogues on resource efficiency and sector-specific initiatives outline India’s plans for ecologically sustainable growth.

India’s manufacturing output surged 159% during 2004–2013, second to China’s growth (344%) (UNCTAD, 2013). The manufacturing sector has a GDP contribution upwards of 16.5% and is projected to rise to 25% by 2025, creating 100 million new jobs by 2022 through mega investments and infrastructure projects like Make In India (MII) and Delhi Mumbai Industrial Corridor (DMIC). Optimistic growth prospects notwithstanding, directed efforts to embed industrial symbiosis in regional clusters or the circular economy are weak in India. Ashton and Shenoy (2015) criticised the ‘end-of-pipe’ pollution control and waste management measures perpetrated by Indian government agencies; these have resulted in industrial symbiosis unfolding in a disorganized manner, limiting the ability of robust networks to develop and improvise. The 2016 Solid Waste Management Rules specify targets for the segregation, recovery, treatment and scientific management of municipal solid waste, plastic, electronic waste, bio-medical waste and construction and demolition waste demonstrate India’s resolve to tackling waste and offering incentive for waste recovery and reuse.

Manufacturing as a driver for India’s economic growth

Extensive industrial reform, policy action, stable government, improvement in ease of doing business and foreign investments are indicators for a boost in India’s manufacturing prowess. The industrial sector comprises large, medium and small enterprises, with targeted government incentives and policy for the creation of a robust small and medium enterprise (SME) network. Make In India (MII), launched in 2015, is a core agenda of the current government to foster international investment, infrastructure upgrades and entrepreneurship in Indian manufacturing. Major industry incentives include subsidized power at fixed long-term rates, preferential land allotment, state
subsidies and tax breaks (Jai & Mukul, 2016). Similarly, Delhi Mumbai Industrial Corridor (DMIC), a massive 1483 km infrastructure project across seven Indian states, lays out 24 industrial regions, eight smart cities, two airports, five power projects, two mass rapid transit systems and two logistical hubs, with the likelihood of employing 3 million people (GOIEconomicSurvey, 2016).

Together, the states of Maharashtra, Gujarat, Tamil Nadu, Uttar Pradesh, Karnataka and Andhra Pradesh had 62.46% share of India’s manufacturing output (GOI, 2014). Referred as India’s Guangdong, the western state of Gujarat is one of India’s leading commercial centres and third-largest state economy, contributing 7.56% to the National Gross Domestic Product in 2015-16 (GoGSDP, 2017). Micro, Small and Medium Enterprises (MSMEs) constitute a large share of the state’s industrial landscape. Gujarat is one of India’s forerunners in chemical and petrochemical production; the state manufactures over 35% of India’s chemical output and fulfils 98% soda ash demand (GoG Compendium, 2012). Industrial clusters – groups of companies manufacturing identical and/or complementary products with a critical mass of 50 company units and located within a 10 kilometre radius, are visible throughout the state (Figure 1).

Figure 1. Product clusters in Gujarat, India

Gujarat’s chemical manufacturing sector comprises 13 formal chemical industrial estates (Table 1) all located in the eastern zone along the golden industrial corridor between Ahmedabad and Mumbai. Operational since 1965, Naroda industrial estate is located in the capital city of Ahmedabad with over 400 resident companies ranging from multi-nationals to MSMEs. Industry-specific clusters
include chemical and allied manufacturing, engineering, plastics, pharmaceuticals, metal. The second site, Nandesari industrial estate, comprises 250 units, majority of which are SMEs in the manufacture of chemicals. This estate is one of the oldest in Gujarat, and is highly saturated and constrained with unavailability of land for further expansion. Both case sites are categorised as retrofitting of industrial estates, akin to China’s eco-industrial park transformation approach.

Table 1.
Footprint of chemical manufacturing industrial estates in Gujarat

<table>
<thead>
<tr>
<th>Chemical industrial estate</th>
<th>Area (hectares)*</th>
<th>Chemical industrial estate</th>
<th>Area (hectares)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odhav</td>
<td>135</td>
<td>Ankleshwar</td>
<td>1200</td>
</tr>
<tr>
<td>Naroda</td>
<td>295</td>
<td>Panoli</td>
<td>1000</td>
</tr>
<tr>
<td>Vatva</td>
<td>690</td>
<td>Pandesara</td>
<td>218</td>
</tr>
<tr>
<td>Nandesari</td>
<td>270</td>
<td>Sachin</td>
<td>800</td>
</tr>
<tr>
<td>Dahej</td>
<td>4700</td>
<td>Sarigam</td>
<td>400</td>
</tr>
<tr>
<td>Vilayat</td>
<td>1000</td>
<td>Vapi</td>
<td>1100</td>
</tr>
<tr>
<td>Jhaghadia</td>
<td>1700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 100 hectares in one square kilometer; one hectare contains about 2.47 acres

Source: Gujarat Cleaner Production Centre (GCPC, 2018)

India’s material use trends

Conclusive evidence suggests that adversarial resources and environmental impact accompany aggressive industrialisation. From an ecological standpoint, the main resource- and energy-intensive industries in India are iron and steel, cement, fertilizers and refineries. Right from virgin mining and raw material procurement, unto final consumption and disposal of finished products, including logistics and transportation across supply chain networks, globally manufacturing is one of the most resource and emissions intensive sectors.

Material Flow Accounting and Analysis (MFA) is useful in determining economy-wide resource flows and decoupling, in order to ascertain longitudinal trends in material use and to enable comparative analyses. Direct Material Inputs (DMI, the sum of raw materials extracted and imports) and Domestic Material Consumption (DMC, the difference between DMI and exports) are important
metrics for nation-wide MFA (Eurostat, 2001; UN, 2016). India jumped to second place in 2015, superseding the USA in aggregate material demand, and a 81% increase since the year 2000. China has consistently witnessed the highest DMC among 168 countries, with the rate of increase levelling off to around 4% in the last few years (IRP, 2018).

India’s DMC has witnessed a rapid increase in the last decade, owing largely to increases in fossil fuels (74%) and non-metallic minerals (66%) (Figure 2). India’s current transition to solar and wind power sources notwithstanding, typical patterns to fast-growing economies emerged with the surge in fossil fuel use since 2007 comprised largely of coal-fired power; construction, industry and agriculture were dominant sectors for non-metallic mineral use.

In contrast to aggregate DMC, India’s per capita material demand tells a different story. While material consumption at 5.26 tonnes per capita in 2014 witnessed a steady rise over the last three decades, it still lags when compared to leading industrial nations. The USA recorded a staggering 21.03 tonnes, followed by China at 17.73 tonnes (Dittrich, 2014; IRP, 2018; OECD, 2016). At first glance, this poses optimistic prospects for India’s material performance, yet a closer look clearly shows a 35% increase in per capita consumption over a decade (IRP, 2018).
India is at the crossroads of deciding a development path that balances resources demand with its growth needs. Taking lessons from China’s recent strides in pursuing an equitable growth agenda, and its strategic national vision to pursue a circular economy, India now needs an inclusive plan with resource efficiency implementation at scale. The next section reviews recent literature on industrial symbiosis and theoretical development of institutional capacity building through industrial symbiosis networks. The research objectives, methodology and theoretical frameworks are outlined next, followed by the case description, key findings and discussion.

**Literature review**

*Industrial symbiosis networks as a means of achieving circular economy*

Industrial growth through the concentration of sector-specific clusters, government-owned and managed industrial estates, joint public-private industrial parks and special-purpose investment zones are not new in India’s development story. Regional agglomeration of specific industries has manifested successful examples, some of these are the result of accidental specialisation over time, but most are the fruits of a collaborative state-focused development plans. For example, the southern cities of Hyderabad and Vizag and the western city of Ankaleshwar are pharmaceutical manufacturing hubs, automobile production is centered in the states Maharashtra and Tamil Nadu, automotive parts manufacturers in the city of Vijayawada, cement manufacturing in the state of Rajasthan.

Industrial symbiosis (IS) through by-product exchange, sharing of utilities and common infrastructure among co-located firms in an industrial park is a circular economy approach (Mathews and Tan, 2011). A common understanding of the circular economy is a *purposefully designed regenerative business system, where material and energy processes form a closed-loop to enable reuse and recycling of resources and minimization of overall waste* (EllenMcArthurFoundation, 2013; Ghisellini et al., 2016; Mathews & Tan, 2011; Stahel, 2016; Webster, 2015; WorldEconomicForum, 2014). Industrial symbiosis network (ISN) refers to a network of firms among which industrial symbiosis relationships exist (Fichtner et al., 2005; Fraccascia, Giannoccaro, & Albino, 2017). Another perspective on ISNs refers to the actors involved in the creation of resilient networks; this view includes all actors that may be directly or indirectly involved in the formation of industrial symbiosis, signifying the interest of a multitude of stakeholder groups. The literature has identified eco-industrial parks as ideal settings to nurture industrial symbiosis with various cases of accomplishment and learnings.
Eco-industrial achievement is dispersed globally, noteworthy cases are evident in Japan (Kawasaki), China (TEDA & Suzhou), Korea (Ulsan), Australia (Kwinana & Gladstone), and multiple sites across the USA and Europe. Critical evaluation of diverse eco-industrial projects globally yielded rich understanding of patterns of symbiotic resource exchange among firms. Progressive innovation in the complex and diverse Kalundborg Symbiosis in Denmark has kept the network iterative and self-organising, with symbiotic linkages intensifying over time and experience (Valentine, 2016). The self-organising attributes and gradual evolution of inter-firm networks at Kalundborg, Denmark reflect the ‘practical’ and ‘monetary’ motivations for firms to initiate symbiotic exchange (Ehrenfeld & Gertler, 1997; Lowe & Evans, 1995; Mathews & Tan, 2011). In contrast, the quantifiable benefits of reducing resource intensity and improving waste utilization at Suzhou New District, China reinforced the application of closed loop ‘circular’ systems (Mathews and Tan, 2016). Evidence from India highlighted the significance of incorporating informal sector activities in fostering industrial symbiosis networks (Bain et al., 2010). In recent years, dynamics of eco-industrial development in India are limited in number and scope. There is little understanding of the origins and dynamics of industrial symbiosis networks in India. Furthermore, empirical evidence of circular economy drivers for SMEs in India is a research gap, both from academic and policy perspectives. The current study aims to address these knowledge gaps by presenting a critical appraisal of two major manufacturing estates in the industrially concentrated state of Gujarat.

In a bid to theorize the evolution of industrial ecosystems through the creation of resource sharing networks, Chertow and Ehrenfeld (2012) posit an evolving non-linear three-phase model: formative, intentional pursuit, formalisation. The most sophisticated ‘formalised’ phase has limited examples, Kalundborg in Denmark being the most prominent. Industrial ecosystems as self-organising networks influenced by dynamic market conditions were found to have lasting success in contrast to centrally managed or planned industrial symbiosis. Barring few cases of Chinese success with demonstration projects by the National Development and Reform Commission (NDRC), the pervasive failure of planned symbiosis is ascribed to the emphasis on by-product exchange over economic benefit, the latter being the most fundamental consideration for business. The path that India’s manufacturing growth agenda is seeking is still unclear, insights from the current study will be useful in determining the direction of industrialisation in India.

Healey et al. (2003) portrayed the role of administrative and government bodies in building institutional capacity for collective problem solving. As a consequence of network activities, ICB is hypothesised to kindle collaboration within and between governance actors to create impact, building
upon extant networks to intensify dialogue and linkages (Healey 1998, Healey et al. 2003). Boons et al. (2011) first examined the applicability of ICB theory in explaining industrial symbiosis network development, and found dynamic linkages amid the three main elements of institutional capacity building; namely, knowledge resources, relational resources, and mobilisation capacity. Drawing on theoretical roots of industrial symbiosis, knowledge resources include data repository for by-products and waste, technical information on recovery and reuse potential, best practice guides, skill enhancement programs. Relational resources refer to the communication and information links between actors and the resultant ‘trusting relationships’, which encourage data sharing (thus, strengthening knowledge resources), improve overall benefit and reduce costs of participating in the symbiosis. Mobilisation capacity is the ability of network actors to capitalise on extant resources, engage in industrial symbiosis, stimulate the depth and range of resource sharing and exchange; thereby, resulting in self-sustaining ‘formal’ networks. (Boons et al., 2011; Wang, Deutz, & Chen, 2017).

The underlying principles for the formation and eventual formalisation of industrial symbiosis networks are still emerging, this study aims to contribute to the discussion by presenting distinct socio-economic insights. The author explores specific drivers for industrial symbiosis in ‘manufacturing’ industrial parks, owing to the sector’s high material dependence and waste output, along with motivations and inhibitors for circular economy adoption by SMEs. Furthermore, patterns of network evolution and governance structures are still emerging, the author contributes to this scholarly literature by presenting novel cases of institutional capacity building.

**Research methodology**

This study conducted an exploratory investigation in India’s eco-industrial park landscape. Industrial symbiosis networks rely on the ability, capacity and interest of multiple stakeholders in congregating to improve their material and energy footprint, reduce waste and accrue higher individual and joint benefit, whether monetary or otherwise. Thus, the economic, ecological and social impact of an industrial symbiosis network is directly proportional to the ability of the network’s members to share, access and build-upon information and connections, utilising network benefits for embedded resource exchange.

The aim of the research was to identify key actors and to test the applicability of ICB theory to industrial symbiosis in diverse economic and cultural contexts. Knowledge resources, relational resources and mobilisation capacity are known sources of institutional capacity. The literature offers
evidence that ICB kindles collaboration within and between governance actors to create impact, building upon extant networks to intensify dialogue and linkages (Healey, 1998). The following research questions were tackled by conducting interviews and field visits to two chemical manufacturing industrial parks, namely, Naroda and Nandesari, in India’s western state of Gujarat -

1. Is there evidence of industrial symbiosis in the chosen park? If yes, what are the drivers and inhibitors? Who are the key stakeholders responsible for creating/facilitating the symbiosis? Has the role of key actors changed over time?

2. How have i) Knowledge resources ii) Relational resources iii) Mobilisation capacity manifested in the operations of the industrial park? Has symbiotic resource exchange enriched Knowledge resources, Relational resources, and Mobilisation capacity of the network, over time?

Case study methodology was found most appropriate as it gave an opportunity to analyse the phenomenon in deeper detail and enabled critical analysis based on existing events (Yin 2014). Extant research demonstrated some examples of industrial symbiotic networks; limited recent cases of circular economic implementation have been reported from India. Case study research is the predominant methodology to investigate the extent of eco-industrial park development, recently employed by Mathews and Tan (2011, 2016) and Mathews et al. (2018) to assess China’s eco-industrial progress using specific case sites and metrics such as resource intensity of Chinese industry. This approach served as an exemplar for data collection and analysis during the field study of manufacturing industrial parks in India.

Three main actors were met face-to-face to conduct semi-structured interviews, with the objective of gaining a deeper understanding of present policies, implementation challenges and future circular economic development. These actor groups play a mutually reinforcing role in the setup and implementation of industrial parks and their further evolution into eco-industrial parks. The main actor categories included:

i) Industrial Park Authorities: managers of industrial parks; aim was to understand set up of the industrial park and evolution of industrial symbioses

ii) Council/ State/ Federal government representatives: government departments and independent agencies involved in industrial policy and park development; this stakeholder category directly monitors and indirectly influences industrial symbiosis developments

iii) Firms located within industrial parks: senior management and sustainability experts; aim was to assess interest and barriers for participating in industrial symbiosis
Evidence from policy framework, macro (nation-level) resource patterns and empirical data from two chemical manufacturing industrial estates was sought to hypothesize patterns of the greening of industrial manufacturing in India. Using policy documents, publicly available reports, participant responses and additional data procured through field visits and interviews, the findings were linked to scholarly contributions to identify trends in resource efficient and cleaner production. Participant responses were grouped according to relevant themes in order to develop a deeper understanding of the industrial ecosystem, its origins, development and dynamics. The decision to interview multiple actors was crucial to arriving at a multi-stakeholder view of industrial symbiosis network evolution.

Case description

Two chemical manufacturing industrial parks were chosen; namely, Naroda and Nandesari, in the western state of Gujarat, India’s third-largest state economy. With 45 ports, 18 domestic airports and an international airport, Gujarat state is well-located on the country’s western border and boasts a 1600 kilometre coastline. As a petrochemicals hub with a total refining capacity of 101.9 Million Metric Tonne Per Annum (MMTPA), Gujarat accounts for 41.54% of the nation’s capacity. The cities of Ahmedabad, Ankleshwar and Vapi are home to industrial centres producing pharmaceuticals, agro-chemicals, specialty chemicals, dyes and pigments (GoG Compendium, 2012).

Gujarat’s Special Investment Regions Act of 2009, one of its kind in the country, is aimed at developing state-of-the-art industrial areas. In order to foster industrial ecosystems, multiple Special Investment Regions, Petroleum, Chemicals and Petrochemicals Investment Region, industrial parks and clusters are operational and in varied stages of planning. The state is a forerunner in eco-industrial development, it was one of the earliest states in the country to have adopted a formal industrial park development policy. This has now been updated to transform industrial parks into eco-industrial parks. There are 204 industrial estates, 83 product clusters, 60 Special Economic Zones and 12 Special Investment Regions, all ranging in size, core activity and sector specialisation. In addition to the setup and maintenance of multi-product estates, sector-specific industrial parks facilitate scale economies and supply chain efficiencies; for example, electronics estate in Gandhinagar, ceramics estates near Bhavnagar, chemical estates at Vapi, Ankleshwar, Panoli, Nandesari, Naroda.

Gujarat Industrial Development Corporation (GIDC) established under the Gujarat Industrial Development Act of 1962, operationalises the state government’s industrialisation agenda. The key
function of the GIDC is to develop land for the setup of industrial estates and associated infrastructure such as roads, power, water, drainage, effluent and waste management systems. Well-established estates also have low-cost housing, amenities and community services like banks, shopping complexes, schools, hospitals, telecommunications centres, police and fire stations. The scale of development positively impacts outlays for companies, cost of setup and manufacture within a GIDC estate is significantly lower than standalone operations.

Additionally, four implementation agencies function under the State Forests and Environment Department: Gujarat Pollution Control Board (GPCB), Gujarat Ecology Commission, Gujarat Institute of Desert Ecology and Gujarat Environmental Management Institute. Among these, GPCB has an advisory role on diverse areas of pollution and environmental management. Another nodal agency is the Gujarat Cleaner Production Centre (GCPC), which operates independently within the state’s industries department. Its functions include advisory services to GIDC for new and current industrial parks, industry dialogue and education programs for Resource Efficient and Cleaner Production (RECP), comprehensive RECP assessment, identification of waste flows and by-product recovery/industrial symbiosis opportunities, funding and financial assistance for the implementation of cleaner production technology.

**Case 1: Naroda Industrial Estate**

Operational since 1965, Naroda Industrial Estate is located in the capital city of Ahmedabad with over 400 resident companies ranging from multi-nationals to Micro, Small and Medium Enterprises (MSMEs). A community of member companies evolved to form the Naroda Industries Association (NIA) in 1967. Typical of other industrial estates in the state, Naroda was setup by the GIDC at a location once outside city limits. With rapid urbanisation, the estate has witnessed influx of residential and commercial activity and is a busy hub especially for SMEs. In 2006, the responsibility of infrastructure maintenance and shared utility services was taken over by NIA from the Ahmedabad Municipal Corporation (AMC) and GIDC.

The volume of effluent discharge for chemical industry which constitutes 30% of the estate, is very high and a constant pain for companies. In order to address these concerns and promote cleaner production, Naroda was the first industrial park in India to conduct an in-depth Resource Efficient and Cleaner Production (RECP) assessment where every major factory unit’s waste was quantified and characterised. 23 major waste categories were identified, of which 14 wastes had no commercial
value, 3 types like paper/wood had direct reuse potential, 5 waste types: spent acid, gypsum, fly ash, iron waste, food waste were found to have recovery and reuse potential.

**Industrial Symbiosis at Naroda Industrial Estate**

**Closed loop process for iron sludge**

Iron sludge, a by-product of dye and dye intermediate manufacturing processes, formerly sent to landfill due to restricted reuse within company operations owing to hazardous classification and low financial returns, is now being recovery for transfer to two industries – steel and pigment manufacturing. Received as input from dye manufacturers, iron sulphate (FeSO4) is separated in the steel manufacturing process to produce iron oxide (FeO) and sulphur trioxide (SO3). Iron oxide is used in steel making the separated sulphur trioxide is sent back to dye manufacturers as material input. Iron oxide is also used as input in pigment manufacturing, an example of vertical integration through symbiosis (Figure 3).

![Diagram of closed loop process for iron sludge](image)

**Figure 3.** Closed loop process for iron sludge at Naroda Industrial Estate, Gujarat, India

*Source: Author, based on GCPC (2018), field visits, interviews and secondary data

denotes by-products
**Spent acid recovery and reuse**

Spent acid, a by-product of chemical manufacture, is traditionally reused within company operations. For supply chain efficiency, a loop for spent acid transfer to textile manufacturers is established. In spite of this, excess spent acid was being disposed of. As a result of operational evaluation, recover and reuse potential of excess spent acid was identified and excess acid is now being treated to make gypsum which is a material input for cement industry. Due to limited volume at an estate level, scale economies were created by the setup of a common plant to treat spent acid/gypsum washery. Excess acid from 3 industrial parks (Naroda, Odhav, Vatwa) is now being transported at this shared facility for treatment before it can be sent to cement manufacturers (Figure 4). Similarly, colour pigments, fly ash, iron sludge are being recovered for reuse in brick manufacturing. Heat recovery and steam reuse are other common examples.

![Diagram of spent acid recovery and reuse](image)

**Figure 4.** Spent acid recovery and reuse at Naroda Industrial Estate, Gujarat, India

*Source: Author, based on GCPC (2018), field visits, interviews and secondary data*

~~~ denotes by-products
Bio methanation from organic waste

The Common Effluent Treatment Plant (CETP) used to receive up to 3 millions of litres per day (mld) of effluent, of which 0.4-0.5 mld was food industry effluent; segregation of effluent streams has enabled better treatment and recovery. For example, waste water from food manufacturers is directly sent to an anaerobic digester at the CETP, which recovers methane, diesel and clean water. 80% recovered methane is used to power the CETP, 20% diesel is sent back to the biogas plant. In addition, bio fertilizer produced at the biogas plant is used for agriculture (Figure 5). Energy efficiency is being implemented in water supply, whereby drainage pump running costs are optimised and leakages avoided. Reduced power consumption from an earlier average unit of 0.72 per kilolitre to 0.65 per kilolitre are achieved. Current plans aim to achieve world average levels of 0.55 per kilolitre.

Figure 5. Bio methanation from organic waste at Naroda Industrial Estate, Gujarat, India

Source: Author, based on GCPC (2018), field visits, interviews and secondary data

 denotes by-products
**Naroda waste action center**

To enable easy identification of symbiotic exchange opportunities, Naroda waste action center was instituted where characterised waste and by-product streams from member companies are on display. However, progress on this has slowed due to stringent pre-approval criteria as per Rule 9 of the 2016 Hazardous Waste Management Rules. Additional initiatives include the landfill beautification drive where a temple and community hall have been built above the landfill site. The industries association regularly engages with the Skill Development Center to address skill gaps based on industry demand. An onsite hospital equipped for primary treatment, fire hydrant systems on company premises and a shared fire station, community hall, training center are shared utility services accessible to companies located within the estate. An active industries association regularly conducts member meetings and workshops, facilitating knowledge transfer and informal networks among co-located companies.

**Case 2: Nandesari Industrial Estate**

Nandesari industrial estate comprises 250 units, majority of which manufacture chemicals. Home to mostly Small and Medium Enterprises (SMEs), the park is one of the oldest in Gujarat, highly saturated and constrained with unavailability of land for further expansion. Liquid effluent management is the key constraint for authorities and its disposal costs burden industry. An innovative solution by the industries association has become the benchmark for liquid effluent management across the country.

**Industrial Symbiosis at Nandesari Industrial Estate**

**Common Effluent Treatment Plant**

Providing local employment to 100 people, the Common Effluent Treatment Plant (CETP) is run by the Nandesari Industries Association and is a shared resource for research and development (R&D), effluent treatment, resource recovery and reuse, and safe disposal. There is no membership fee and any resident company can access services of the industries association. The CETP receives 1 million litres liquid discharge daily; a unique advance oxidation plant for effluent treatment, a global first, with 12 mld capacity is operational. The treated water is colourless and meets most international audit standards (Figure 6). Factory units pay the CETP based on volume of discharge; by charging USD 415 extra per million litres, the CETP generates revenue of USD 0.7 million annually.
The CETP at Nandesari Industrial Estate has received many accolades, including endorsement from industry partners and central and state government departments. The project has attained the status of being a national demonstration site for effective chemical effluent management, and the CETP technology is being replicated in other parks in Gujarat including upcoming petrochemicals park in Dahej; chemical clusters across the country are modelling their effluent management systems based on this plant. The R&D centre located onsite at the CETP is equipped with latest equipment and technical expertise, accessible to all member companies for waste/by-product characterisation and identification of reuse/exchange potential. In contrast to standard practice, effluent from individual company sites is transported to the CETP by tankers. Effluent transfer through underground pipelines has been consciously closed in this park to circumvent cases of illegal discharge, parallel discharge of untreated effluent, mixing of effluent streams and data misrepresentation. Although, evidence of such misdeeds is sparse, these risks threaten the steadiness of park-wide cleaner production attempts.

Cement manufacture co-processing

Sludge from the CETP, comprising 80% calcium oxide, is sent for cement manufacturing. Inorganic streams of calcium sulphate are used to make gypsum at a central facility which receives treated waste from multiple industrial estates. Co-processing at a common location helps maintain volumes and brings in cost efficiencies. Blended organic waste, collected separately from individual company units, is reused as fuel in cement-making (Figure 7). This by-product transfer has enabled the cement
industry to replace coal with organic waste and introduced supplementary revenue streams for cement-makers. Instead of purchasing coal for Rs. 6 per kilogram, cement companies now earn Rs. 4 per kilogram for receiving organic waste from chemical companies. For chemical companies, in addition to recovering value from waste, the cost of disposal of organic waste has significantly reduced: in the early phases of this by-product transfer, companies had to pay Rs. 15 per kilogram to cement-makers, this has now plummeted to Rs. 4 per kilogram owing to improved efficiency.

**Figure 7.** Cement manufacture co-processing at Nandesari Industrial Estate, Gujarat, India

*Source: Author, based on GCPC (2018), field visits, interviews and secondary data

- denotes by-products

*Plastic laminates from paper recycling used as fuel input in cement making*

Waste paper recycling is widespread by formal and informal recyclers. The technically-sound recyclers employ mechanical and automatic process to recover plastic laminates from waste paper; removal of plastic is essential when pulp is being made from waste paper, to be reused in newspaper printing or packaging. Earlier a challenge for paper recyclers to dispose of or reuse the recovered
plastic, the laminates are now being sent to cement manufacturers as fuel input owing to their high calorific value. In addition to waste recovery from manufacturing and recycling processes, secondary waste from treatment (liquid treated effluent converted to solid form), a.k.a. secondary sludge, which also has high calorific value, is currently being tested for co-processing.

**Potential symbioses**

Other industrial symbiosis initiatives include the study underway to ascertain reuse potential of surplus inorganic waste (after fulfilling demand in cement-making) to be sent for brick making. The remainder inorganic waste is currently being disposed of in a secured landfill. Technical feasibility to eliminate hazardous waste leakage, durability, market and cost implications for the ‘renewed’ product are presently under review and the product is in testing stages. Ammonium carbonate is another by-product in abundance, with no reuse synergies developed yet; possibilities to redesign manufacturing processes to reduce the volume of by-product and its reuse potential are being exploration. An overhead pipeline network for steam transfer is being installed which will be serviced by the shared boiler to reduce coal usage and facilitate the transfer of excess steam between factory units.

**Key findings**

*Drivers, inhibitors and key stakeholders for industrial symbiosis*

Features of industrial symbiosis are evident in India’s chemical, engineering and automotive manufacturing sectors. The strategy to retrofit existing industrial parks to enable industrial symbiosis and replicate eco-industrial features not only reduces exposure of industries from being dependent on particular by-product streams (which may change based on market dynamics) but also seeks innovative applications and partners for current by-product streams. Such an evolving nature of symbiotic networks has proven to be a lasting success globally (Mathews et al., 2018), as companies self-organise based on current demand/supply conditions. Eco-industrial parks which have invited companies based on their industrial symbiosis potential have met with limited success in the USA, EU and China. In addition to irregular demand and supply patterns for by-products, volumes and quality variations hinder elaborate industrial symbiosis networks.

While the existence of common infrastructure like roads, canteen, hospital and fire services, and shared utilities like water and power supply, waste recovery, treatment and reuse were a common paradigm in the cases of Naroda and Nandesari, an unforeseen driver for industrial symbiosis networks was found in the ‘industry associations’. Weak regulatory presence in managing park
progress often led to the formation of industry associations which comprise representatives from companies within the park. The results establish the industrial dynamics of a circular economy in India, where industry action is a driver for symbiotic networks; policy and regulatory support bring supplemental benefit. This finding is in stark contrast to China, where a top-down approach with federal/state/regional directives translated into concrete action at the firm and industrial park levels.

Mathews and Tan (2011) identified three broad stages of closed-loop economic activity:

i. **Cleaner Production** – undertaken by a single or set of companies to improve energy and resource efficiency

ii. **Industrial Cluster** – resource and energy flows are pooled and by-products are exchanged (industrial symbiosis)

iii. **Entire City or municipal area** – mainly found in China, waste reuse and recycling, resource exchange are encouraged through financial inducements and lack of compliance is penalised

The first two stages were noted at the chemical manufacturing estates in Naroda and Nandesari through company-specific resource efficient and cleaner production and material and energy loops between enterprises in the park. For example, Resource Efficient and Cleaner Production (RECP) assessment at Naroda Industrial Estate led to quantification and characterisation of 23 major waste categories, of which 5 waste types: spent acid, gypsum, fly ash, iron waste, food waste started employing recovery and reuse within- and inter- company processes. Similarly, the Common Effluent Treatment Plant at Nandesari Industrial Estate, transfers sludge comprising 80% calcium oxide, to be used as input in cement manufacturing.

In Gujarat, eco-industrial progress is being made at 3 levels:

- **Micro** – RECP assessments at company level in order to minimise waste generation at source (by identifying leakage points as also alternate uses for by-products); use of renewable energy, water conservation. Implementation – within an industrial estate (like Naroda), RECP is conducted at a representative company, after detailed assessment and analysis of waste/leakage points, solutions are offered. This information is disseminated to partner industries and is available for replication.

- **Macro** – shared infrastructure (continuous upgradation required) – roads, water supply, drainage, power supply, CETP, green belt, compound walls, research and development centre (Nandesari), skill upgradation centre, waste display centre (Naroda)
- Industrial symbiosis through by-products, energy and water exchange between co-located firms within the industrial park and transfer to external entities. This finding reinforces scholarly findings that symbiotic exchange is not always restricted to co-located boundaries, and in fact, goes beyond geographic boundaries.

**Institutional capacity building of industrial symbiosis networks**

Communication links, often spontaneous through informal or social connections, are the precursor to formal networks that promote symbiotic exchange. Collaboration starts with shared goals, problem solving and informal exchanges among participants. Positive and negative feedback loops keep the industrial symbiosis network iterative and self-improvising, growing network dependence between active and passive actors. Empirical evidence from India echoes this finding (Bain et al., 2010). Past research in Netherlands, Colombia and China found that institutional capacity of IS networks increased over time by mobilising capacity, relational links and knowledge resources between member and non-member actors of the network (Netherlands – Boons and Spekkink 2012, Spekkink 2013; Colombia – Van Hoof and Thiell 2015; China – Wang et al. 2017). Based on the results of the current study and evidence from literature, the central role of industry associations in advancing symbiosis has come to the fore. In order to contextualise the findings, prominent symbiotic activities and their links to known sources of institutional capacity building are categorised (Table 2a, 2b, 2c).

<table>
<thead>
<tr>
<th>Symbiotic behaviour</th>
<th>Main actors</th>
<th>Enablers for closed loop thinking</th>
<th>Example/ use case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informal networks – travel together, public transport, local housing, people changing jobs within same cluster/ region</td>
<td>Plant staff to mid-management levels</td>
<td>Knowledge spill over, best practice sharing, problem sharing, practical solutions</td>
<td>Nanjangud (Bain et al., 2010); Jawaharlal Nehru Pharma City (JNPC)**</td>
</tr>
<tr>
<td>Shared research and development</td>
<td>Industries Association, park management</td>
<td>Data banks of waste/by-product streams, Knowledge sharing, innovation, partner matching (if proactive in industrial symbiosis pursuits)</td>
<td>Naroda waste action center; Nandesari CETP R&amp;D Center; Jawaharlal Nehru Pharma City incubation laboratory</td>
</tr>
<tr>
<td>Skill enhancement programs, training, firefighting</td>
<td>Often initiated by industry associations and supported by municipal corporation, GIDC. Participants of these programs include low-mid level staff, new recruits and fresh graduates.</td>
<td>Knowledge transfer through informal networks, skilled manpower development, proactive action to create future-ready workforce and reduce</td>
<td>Naroda Industries Association tie-up with local Skill Development Center and government institutes for skill shortages and projected skill requirements</td>
</tr>
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worker migration outside industrial park

Common Effluent Treatment Plant
Industries Association, state pollution control boards, park management
Traditionally CETP was a passive ‘recipient’ of waste, an intermediary between waste generators and final disposal. Proactive estates view CETP as the center of research and development – depository of data on waste streams and effluent patterns, reduction of waste at source, scientific waste treatment methods, water and energy recovery and reuse
Nandesari CETP sludge recovery and reuse in cement manufacture (Figure 7)
Naroda CETP and biogas plant (Figure 6)
Monitor, control and report on firm-level environmental compliance to state pollution control boards

Table 2b. Evidence of relational resources creation and enrichment

<table>
<thead>
<tr>
<th>Symbiotic behaviour</th>
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<th>Example/ use case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared goals, problem solving – environmental targets, local ecology improvement, inefficiency of public governance, infrastructure development</td>
<td>Resident companies within industrial park are often the initiators, member representatives from company – human resources manager, senior management, owners</td>
<td>Success in implementing efficient environment management and closed-loop practices only when resident companies actively participate</td>
<td>Formation of industries association at Naroda, Nandesari industrial estates</td>
</tr>
<tr>
<td>Community events</td>
<td>Industries Association, member companies, local community/residents</td>
<td>Training and workshops, cultural exchange, community development among resident companies, local employment</td>
<td>World environment day at Naroda; fire safety and health programs; tree plantation drives; sports events</td>
</tr>
<tr>
<td>Specialised fora, professional associations, specific action groups – environment, supply chain</td>
<td>Respective specialists, senior management, plant managers</td>
<td>Best practice sharing, policy dialogue, supply chain partnerships/ efficiencies</td>
<td>JNPC – Bulk Drug Manufacturers Association; Pharm Excel</td>
</tr>
<tr>
<td>Shared utilities (transport, food canteens, hospitals, fire/post/police services)</td>
<td>Industries association, park management, local council</td>
<td>Informal exchange of knowledge resources, problem sharing, joint sense of community, local ecosystem development</td>
<td>Evident in most established industrial parks and estates; especially those having planned development and support of state industrial corporation</td>
</tr>
</tbody>
</table>
Peer-to-peer information channels as the foundation for industrial symbiosis network development were significant enablers in both case sites. Naroda Industries Association (NIA), a membership-based organisation, represents needs of industry to government and oversees compliance to environment rules and overall park standards. NIA conducts policy dialogue on key issues, intervenes when unfavourable standards are proposed, and helps address loopholes to maximise compliance. A company within NIA, Naroda Utility Services manages fresh water supply, roads, parking plots, storm water drainage, street lights, Common Effluent Treatment Plant (250 industries are members), domestic waste management/ collection, industrial waste collection and treatment, security and gate, green belt. Cost and resource efficiencies in energy and water management have cascaded to resident companies, yielding profits for the NIA.

Findings from the two case sites contribute to deeper understanding of ICB in industrial symbiosis. ICB theory is a meaningful foundation towards understanding the effectiveness of ongoing processes in improving industrial symbiosis network capabilities, as also identifying methods for strengthening network performance across temporal and spatial scales. Industrial symbiosis networks, thus, are advocated to be sources of ICB, with institutional capacity increasing through network activity over time. The test of ICB theory in industrial symbiosis across diverse cultural and economic settings is valuable in creating robust theoretical links. The examination of circular economy advancement
through industrial symbiosis by the application of ICB theory added to a deeper understanding of structural and institutional development of industrial clusters at the regional level.

**Circular economy for Small and Medium Enterprises**

A circular economy necessitates collaboration, either internal – within organisational departments and processes; between supply chain partners and customers; other firms within the industrial park, and in its most evolved form, with external firms. The pursuit of closing the loop cannot be attained in silos. The interviews revealed considerable interest by individual firms in pursuing a less materials- and waste- intensive, and more energy efficient future. Benefits would entail not only better environmental and social performance but more importantly, improved financial yields. Concern for local community development and the biological environment by SMEs should not be underestimated; in most instances, these firms have been operational for generations and have emotional ties to seek improvements to the neighbourhood.

Segregation and treatment of effluents at source will improve their potential for recovery and reuse. SMEs face financial and technical quandary to implement effective segregation and treatment onsite, mixed waste streams received by Common Effluent Treatment Plants increase cost and time delay and reduce reuse possibilities. Technology for waste characterisation, matching by-product streams (as is or value added – more likely) with prospective users, financial assessment for by-product exchange value are needed. Research and technical support to educate firms on the quality and value of their by-products and opportunity for monetary benefit by replacing virgin materials with recovered by-products, adoption of renewable energy, water recovery and reuse will improve demand and supply dynamics for a closed loop system.

Lastly, global cases have confirmed that monetary benefits for individual firms influence decision making: costs of waste treatment versus investment in resource efficient and cleaner production techniques, as also the costs of treating by-products for reuse versus costs of procuring virgin material. It was notable that second and third generation businessmen showed greater intent to pursue long term solutions via waste reduction, reuse and the willingness to invest in technology. As long as access to virgin resources is easy and cheap, there will be limited motivation for individual firms to seek symbiotic resource exchange. This is where the role of policy, removal of subsidy and harsh environmental targets for industry are vital. The absence of a clearly defined policy for industrial symbiosis development in India is a major failing, and poses a threat to sustainable industrialisation in the country. Global interest in the circular economy has sparked discussions
among Indian businesses, industry bodies, academia and think tanks; a comprehensive plan for structured infrastructure, industrial and urban development will have definitive bearing on the nation’s sustainable development goals.

**Discussion and future research**

The case study demonstrated not just successful examples of industrial symbiosis through resource exchange between collocated firms within the industrial park but also the evolution of institutional structures and support networks; these suggest early signs of embeddedness and a concerted effort to initiate resource efficient and cleaner production in Indian manufacturing. While the existence of infrastructure like roads, canteen, hospital and fire services, and shared utilities like water and power supply, waste recovery, treatment and reuse were a common paradigm, an unforeseen driver for industrial symbiosis was found in the ‘industry associations’. Industry associations as internal actors, with the ancillary role of local and regional governance institutions establish the industrial dynamics of a circular economy in India. Positive and negative feedback loops keep the network iterative and self-improvising, growing network dependence between active and passive actors.

The case for industrial symbiosis is strong in the two industrial estates of Naroda and Nandesari in Gujarat. While information on materials, energy and water exchange is fragmented and a focused pursuit of eco-industrial projects is warranted, optimistic headways are evident. Specifically, for SMEs, the lack of technical knowledge, finance and technology hinder circular economy progress; industrial symbiosis networks, thus, propose avenues for higher combined economic, social and ecological benefit. A revelation from the field study was the openness of industry to seek eco-environmental solutions, which positively impact not only their environmental performance but also accrue monetary benefits.

As is evident from the case of Nandesari, a concerted effort led by industry and academic insight has resulted in a demonstration site for cost-efficient and environmentally-effective CETP operations. What is then missing, is scale and knowledge-sharing. In order to scale the pace of adoption, local bodies can lead by disseminating this technology and knowledge to other industrial estates in the country. Governing bodies should play a bigger role in accumulating and disseminating knowledge/best practices, and in connecting technical experts with interested industry partners. Scattered roles and responsibilities across ministries and implementation agencies lead to ambiguity in cleaner production targets, implementation, monitoring and accountability.
The end-user also acts as a motivation for intentional pursuit of industrial symbiosis; for example, mandatory legal disclosures and global benchmarks for export-oriented units in pharmaceutical manufacturing require planned reduction in waste streams, by-product recovery and reuse, as well as scientific disposal of hazardous waste. Strict monitoring and control is maintained by international watchdogs, which makes these industries proactive participants in industrial symbiosis networks. Apart from industry actors, other important stakeholders are GCPC as independent assessor and cleaner production facilitator, GPCB as the chief regulator and educator and GIDC the agency responsible for industrial infrastructure development and land allotment. In addition, several state and federal government departments run financial assistance programs for individual factory units and park developers.

The success of resource efficient and cleaner production in India will depend on its implementation at scale, industrially concentrated regions like industrial parks being the perfect testing ground. Semi-structured interviews with park management authorities, firm managers, government departments and independent bodies revealed distinct motivations and barriers to implementing industrial symbiosis. Furthermore, challenges faced by SMEs in employing resource efficient and cleaner production were compared to past findings to assess similarities and differences across diverse geographic, economic, cultural and temporal scales. Revisiting the research methodology, an unexpected stakeholder category emerged through the field study, the significant role of industry associations merit modifying the third stakeholder category to ‘industry associations’, with firms forming a sub-category within this actor group.

Numerous barriers to smooth implementation of industrial symbiosis exist. The challenges for Small and Medium Enterprises (SMEs) to seek beneficial by-product exchange through industrial symbiosis are the lack of technical knowledge, finance and technology to implement resource recovery and treatment before reuse, along with the inherent challenges of identifying buyers and a steady market for the renewed resource. Reporting and access to data on material flows is the first and most important step to identifying the circular economy potential within an industrial park setting. Confidentiality and proprietary information exposure by sharing market-sensitive data are justifiable concerns for private firms, especially in highly advanced and competitive industries. A central data repository managed by a reliable party will accelerate the pace of knowledge creation and capacity mobilisation.
The author recognises the limited character of cases and the usefulness of seeking firm-level data in future to trace patterns of material use, by-products, waste and in order to identify potential for initiating symbiotic exchange. Quantifiable data on material flows will enable deeper analysis of savings and benefits of closed loop operations. At this stage, only mandatory disclosures to government departments like the Central and State Pollution Control Boards and voluntary information shared by participants were available for analysis. In future, if a structured program like the National Industrial Symbiosis Program in the United Kingdom is put forth, numerous possibilities will arise for in-depth evaluation of stakeholder motivations, barriers, benefits from industrial symbiosis. Such information will be invaluable for future scholarly output, in order to analyse the transition of industrial symbiosis networks, international comparison and theoretical development.

Acknowledgements
The author would like to thank Professor John A. Mathews for his continued guidance and support, his research and valuable feedback have enriched the quality of the paper. The author offers sincere gratitude to all the field study participants at GCPC, Naroda and Nandesari industrial estates, as well as the anonymous reviewers at DRUID Academy.

Note
Jawaharlal Nehru Pharma City (JNPC) located in the port city of Vizag (also known as Visakhapatnam) in southern India, is spread over 2500 acres and home to leading Indian and international bulk drug manufacturers. It is one of India’s early examples of a planned eco-industrial park and is operational under the public-private-partnership model. The case is part of the author’s PhD thesis; however, it has been excluded from this paper due to limitation in research scope, relevance and word count.

References


