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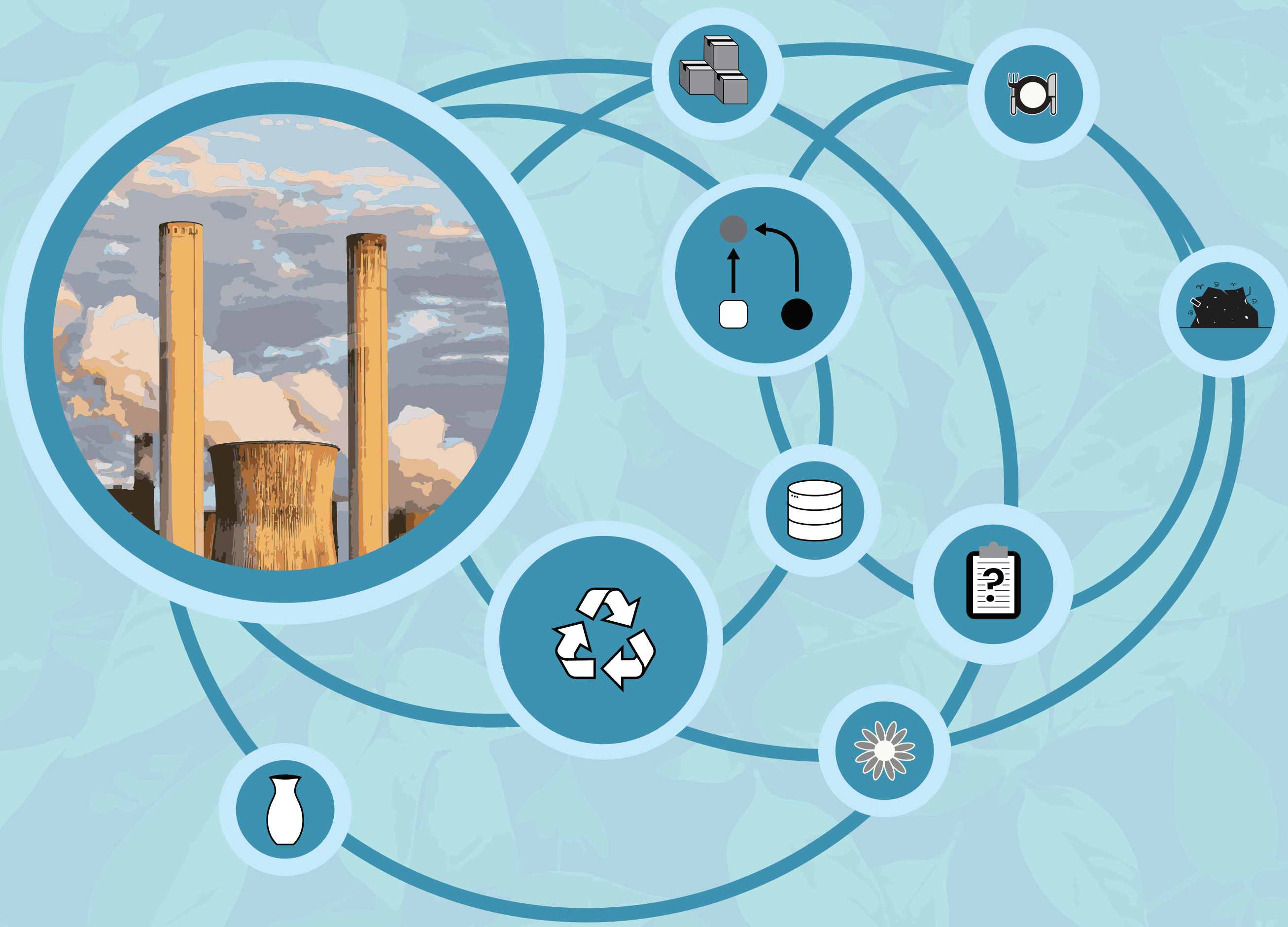
Anant Centre for Sustainability

Industrial Symbiosis in India – Challenge or Opportunity?

Learnings from a study of Naroda Industrial Estate, Gujarat



Gokulram A
Researcher and Project Manager,
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In collaboration with Dr. Abhishek Kumar,
Associate Professor, Anant National University

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Access the complete report by following the below link or scanning the QR code

Acknowledgement

We would like to thank the 65+ companies of Naroda Industrial Estate who agreed to be part of the field survey – their contributions helped us immensely to understand the challenges faced by industrial estates. Secondly, I would like to thank the Naroda Industries Association and Gujarat Cleaner Production Centre members for connecting us with key stakeholders. A special thanks to Dr Bharat Jain, Member Secretary of Gujarat Cleaner Production Centre and Shri Ajay D Patel, Hon. Secretary, Naroda Industries Association and Executive Committee Member of Gujarat Chamber of Commerce & Industry for sharing their extensive knowledge in industrial symbiosis, waste management and recycling.

The research on industrial symbiosis required numerous brainstorming with diverse field experts. A special thanks to Dr Miniya Chatterji, Director of Anant Centre for Sustainability, to foster and encourage us throughout the research. We are thankful to Dr Ashima Sood at Anant National University for supporting us through reading materials. We thank Dr Megha Shenoy, Industrial Ecologist, for providing the reading materials and knowledge. We are grateful to Joel Fernando for visualising and creating the informative infographics for the report. We also thank Abhishek Rathi and his team at Karma Online Ventures LLP for helping us conduct a specific phase of our field survey. Last but certainly not the least, we are grateful to Dr Anunaya Chaubey, Provost of Anant National University, who supported this research with resources and advice at every step.

About Anant Centre for Sustainability

We are a think-teach-do tank established within Anant National University that focuses on affordable housing, indigenous models of circular economy, and building sustainable education campuses in India. We publish research reports and multimedia products, create and teach relevant course work, and implement projects.

Preface

Dear Readers,

It is my great pleasure to bring to you this report titled 'Industrial Symbiosis in India - Challenge or Opportunity?' authored by Gokulram A., at the Anant Centre for Sustainability, Anant National University. This report is a result of 2 years of primary data gathering from field visits, expert inputs, and analysis, on a subject that is as yet rarely researched in India.

At a time when the world, especially India, is reeling under burden of disease, it is even more important to wake up to the need for greater sanitation and waste disposal. This report takes the case of the Naroda Industrial Estate in Gujarat, India, to map the material, information and monetary flows that lead to the lack of circularity in waste management at the Naroda Industrial Estate. The results are then extrapolated and analysed in the larger context of the state of industrial symbiosis in India. The conclusions of the analysis is solutions driven and offers a tool kit for companies located within any industrial estates in India to leverage industrial symbiosis in order to transform waste to wealth.

The findings and the conclusions of this report are supremely important, even if we plan ahead for the post-COVID world. The social and economic recovery will need all of us to be more prudent than ever before to maximise our available resources. As households and companies get financially squeezed, resource efficiency would need to be prioritised such that nothing that holds value should be thrown away. To move in this direction, I would urge all companies located within industrial estates to implement the toolkit proposed in this report.

This report is also important for piloting, testing, and establishing a sound research methodology to study industrial symbiosis at the level of a single industry unit or a cluster level of industrial estates in India. The materials flow analysis can be applied to such other cases. I hope that this would encourage more research to develop on this important subject. Industrial symbiosis in India has its own specific characteristics, patterns, challenges, and also opportunities. In Indian industrial estates, ee can not blindly follow methods for implementing industrial symbiosis as practiced in other countries. Yet the volumes of waste emanating from these estates is so high that its effects are either devastating or immensely opportune. Unless we conduct more research, we would not know how to create and implement effective ways to indeed transform the vast amounts of waste generating from industrial estates into wealth.

Finally, I would like to congratulate the author of the report, for his tireless commitment to the rigorous field work needed for this research. Gokulram A. has spent several weeks living within the premises of the Naroda Industrial Estate and other industrial zones, to conduct surveys and interviews with 60+ companies, which often required several meetings and interactions. His field research also focused on the role of various stakeholders such as industry associations and recycling companies besides a thorough study of the fascinating informal economy that is engaged in waste management within Indian industrial estates. He followed money transactions, as well as traced material and social networks, to derive his conclusions.

I hope this is report is useful to you and serves as an important milestone in helping companies embed greater circularity within their operations.

Keep safe,

Dr. Miniya Chatterji
CEO, Sustain Labs & Director, Anant Centre for Sustainability

Abbreviations

AMC	Ahmedabad Municipal Corporation
GHG	Greenhouse gas
GIDC	Gujarat Industrial Development Corporation
HDPE	High Density Polyethylene
ICT	Information and Communication Technology
IS	Industrial Symbiosis
LD	Low Density
LDPE	Low Density Polyethylene
MFA	Material Flow Analysis
MLD	Million Litres per Day
NHW	Non Hazardous Waste
NIA	Naroda Industries Association
NIE	Naroda Industrial Estate
PET	Polyethylene terephthalate
PoP	Plaster of Paris
PVC	Polyvinyl Chloride
RDF	Refused Derived Fuel

Content

List of Tables

List of Figures

Definitions of key terms

Industrial ecology

The term 'industrial ecology' is a study of materials and energy flows through systems on a scale. The effect of these flows, resources utilisation and treatments are studied with respect to the environment and their influence on the social, economic and regulatory factors among stakeholders.

Industrial symbiosis

Industrial symbiosis is a subset of industrial ecology that analyse the collaborative efforts among manufacturing companies over spatial proximity to exchange materials and energy for a competitive advantage. The cooperative efforts between companies reduce the negative effects of industrial waste disposal activities in an efficient and effective manner.

Industrial residue

The industrial residue is a by-product of a manufacturing process that could be technically matched as a raw material for another industrial process benefitting the environment.

Waste management

Waste management strategies is an important part of minimising the impacts of waste on the environment and human health in consideration of the affordability, effectiveness and social practices of the process.

Informal sectors

The definition used in India - The First Indian National Commission on Labour (1966-69) defined, unorganised sector workforce as –"those workers who have not been able to organize themselves in pursuit of their common interest due to certain constraints like casual nature of employment, ignorance and illiteracy, small and scattered size of establishments".

Closing loop

Closing loop or cycles is a set of strategies for preventing and reducing the waste materials within a system to attain zero emissions.

Abstract

The development of industrial ecosystems is dependent on the availability of adequate supply of raw materials and its sustainable use. The rapid growth of industrial estates and the flow (or lack of it) of materials within these estates raises important questions around resource efficiency. Indeed, companies within Indian industrial estates violating waste management rules is a perennial problem. Further it is much more challenging to attain a closed-loop system of material exchange within an industrial estate in India. However, our research also found early attempts of industrial symbiosis in some cases and a well-entrenched informal waste management system that currently overrides all formal material exchanges.

The study finds that the biggest challenge for successful industrial symbiosis within industrial estates to be the lack of trust and cooperation among companies to network, communicate, and exchange materials. On the other hand, we found that there were interactions amongst several company managers on issues related to the environment, water pollution, waste management, infrastructure and management of the industrial estate, which could lead to an environmentally favourable decision on exchanging waste materials for utilisation. There were also several informal interactions during commuting, events and casual engagements amongst company managers.

We also found that collaborations with local waste dealers were important for any existing forms of industrial symbiosis activities as in the case of Naroda industrail estate local waste dealers capture 78% of the waste materials from manufacturing companies within the estate. The study finds a necessity for local partnerships with informal waste markets in and around the industrial estates that foster economic and environmental benefit for disadvantaged communities.

If industrial symbiosis were to be further developed in India, it would contribute to greater resource efficiency, profitability, environmental protection, improved public health, besides contributing to the Sustainable Development Goals 8 (Decent work and economic growth) – Target 8.2, 8.3, 8.4; Sustainable Development Goals 9 (Industry, innovation and infrastructure) – Target 9.4; and Sustainable Development Goals 12 (Responsible production and consumption) – Target 12.4, 12.5, 12.6. The correlation between industrial symbiosis and Sustainable Development Goals is reflected in several cases of industrial symbiosis in India and the world.

Industrial Symbiosis in India – Challenge or Opportunity?

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1. Introduction

The incentives from the government of India to promote micro, small and medium scale enterprises have come in many ways, one of which is by setting up large industrial estates in the country. In these estates, enterprises can share facilities and other resources to optimise collective efforts, resources and expenditure.

The physical proximity between a large number of manufacturing entities offers several other opportunities. One of them is the potential to exchange industrial waste such that the waste generated by one may serve as a raw material for another. Here, therefore, lies the opportunity for industrial symbiosis (IS).

IS is an emerging field of industrial ecology that makes resource utilisation a collaborative event by physically exchanging waste among companies located within proximity.

This report takes up the Naroda Industrial estate (NIE) as a case in point for an empirical study of IS to evaluate if IS is a challenge or an opportunity in contemporary India.

1.1. Cases of IS in India

IS in India is discussed in detail in the studies conducted by 2 industrial ecologists. Ramesh Ramaswamy and Suren Erkman completed 4 industrial metabolism case studies on different industrial systems in India.[1] The first case study include a cotton clothing production Centre in Tirupur, Tamil Nadu. In this Centre, the potential use of wastewater was leveraged by a recycling system to reuse the enormous amount of water waste 90 million litres per day (MLD) in the dyeing process. The second industrial metabolism study was conducted on the foundry industries in Haora, that use coke as a fuel for boilers. The emitted coke oven gas is also a primary cause of pollution in the region. This study concluded that by adopting new technology, the underutilised coke oven gases might be used as a fuel to cut costs and reduce pollution. The third industrial metabolism study was conducted on leather industries in Tamil Nadu, that use a large quantity of freshwater (50,000 litres of water per ton of leather hide/skin) for tanning purposes. This study recommended relocation of these units to coastal regions so that they may withdraw seawater for the purpose. It made additional recommendations on using heat generated by the nearby thermal power plant for the desalination process. The fourth industrial metabolism study was conducted on a paper mill industry, that reuses the waste bagasse generated by sugar mills, as raw material for paper making. They also used molasses, another waste from sugar mills for the production of ethyl alcohol. To ensure a continuous supply of bagasse and molasses, the company had an agreement with the local farmers. The company also used bagasse pit and combustible agriculture waste as an energy source. This could be considered an example of Agro-industrial eco-system.

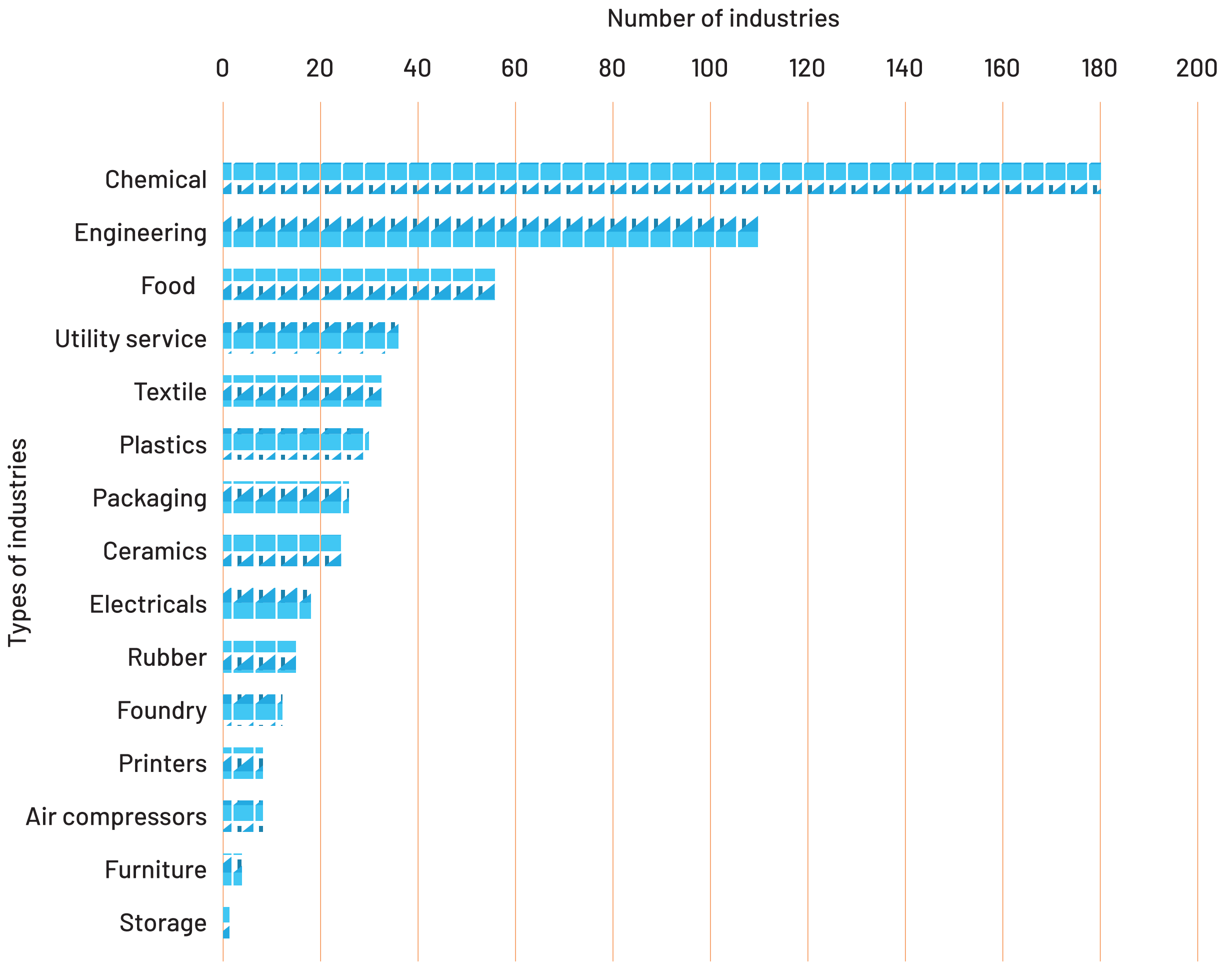
1 Suren Erkman, & Ramesh Ramaswamy (September 2000). Cleaner production at the system level: Industrial ecology as a tool for development planning (Case studies in India), UNEP's 6th International High-level Seminar on Cleaner Production

1.2. Introduction to the case of IS in the NIE

NIE is located in the city of Ahmedabad, India. To give a fillip to industrial development in the state, NIE was established in 1964. It was created by the Gujarat Industrial Development Corporation (GIDC), and today there are nearly 1200 companies belonging to various industries that employ about 50,000 people.[2]

NIE has companies that represent various industries like chemicals, engineering, textile, plastics, packaging, ceramics and other manufacturing industries (Figure 1).

Figure 1: Types of industries in the Naroda Industrial Estate



Source: Naroda Industrial Association annual handbook

An industrial ecology networking project initiative was performed at NIE, seeking a cooperative approach to achieve environmental concepts such as waste material management and energy conservation. Dr Michael Von Hauff and Martin Wilderer's research identified waste to wealth as the focus area on 4 different types of industrial waste.[3] The subjects of the first 4 projects were

2 Analyses of secondary data collected by the ACfS researcher Gokulram

3 Michael von Hauff, & Martin Z. Wilderer., (2000). Eco Industrial Networking: A practicable approach for sustainable development in developing countries, Helsinki Symposium on Industrial Ecology and Material Flows

recycling spent acid, recycling of chemical gypsum, recycling of chemical iron sludge and reuse/ recycling of biodegradable waste. However, only the common effluent treatment plant and waste exchange bank are currently in practice.

IS of non-hazardous waste (NHW) at NIE is rendered difficult as a large fraction of it either goes to the landfill when aggregated (24,514 metric tons per annum approximately) or is disposed of through informal channels (35,053 metric tons per annum approximately). On the other hand, the presence of more than 1,000 companies located within NIE makes waste-material exchange for collective commercial gain a possibility.[4]

1.3. Research questions

This study seeks to quantify and examine the opportunity of IS in NIE. To achieve its purpose, the study has set for itself the task of conducting material flow analysis, network behaviour analysis and monetary flow analysis to answer the following 3 research questions:

1. What is the current and potential scenario of non-hazardous waste disposal at NIE?
2. Are the firms sufficiently networked to create conditions for IS?
3. What kind of policy, process and institutional framework is needed to make IS a reality?

2. Research Methodology

First, the study analysed the secondary data available in published academic research articles and industrial estate brochures. This study then used both qualitative and quantitative methods for primary data collection. The qualitative methods used were two-fold - semi-structured interviews and focused group discussions. The quantitative method used was a survey questionnaire.[5]

A stratified random sampling method was used to identify companies that represent various industries that contribute to non-hazardous waste in the NIE. As industrial units located in NIE belong to 18 categories, a sample selection that proportionately covered the 18 categories was curated, leading to the selection of 65 industrial units.[6]

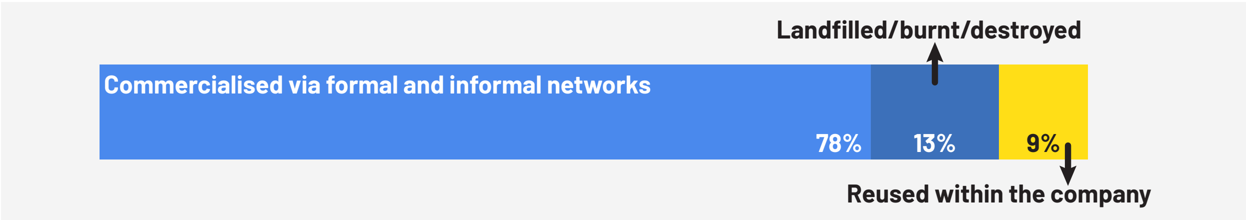
The waste generated at NIE from the stratified sample size of 65 companies is 11,904 metric tons per annum (approximately). The waste generated individually or at an aggregated level is treated or disposed of according to the available technology, methods and manner convenient to the industry. The total non-hazardous waste generated at NIE is 1,82,520 metric tons per annum.[7]

4 Analysis of primary data collected by the ACfS researcher Gokulram
5 The survey questionnaire is included in the annexe of this report
6 The stratified sample size is included in the annexe of this report
7 The quantification of industrial residues generated at NIE is provided in the annexe of this report

3. Current Scenario of Waste Management at NIE

The research sample of 65 companies undertaken in NIE generates 11,899 metric tons of non-hazardous waste annually.[8] Out of the total annual waste generation, 9,218 metric tons or 78% of the waste materials exited the companies are commercialised through formal and informal networks. Of the generated annual waste materials, a quantum of materials stored or reused onsite is 1,087 metric tons or 9%. A quantum of materials that is landfilled or burnt or destroyed in an open field is 1,594 metric tons or 13% of total waste (Figure 2).

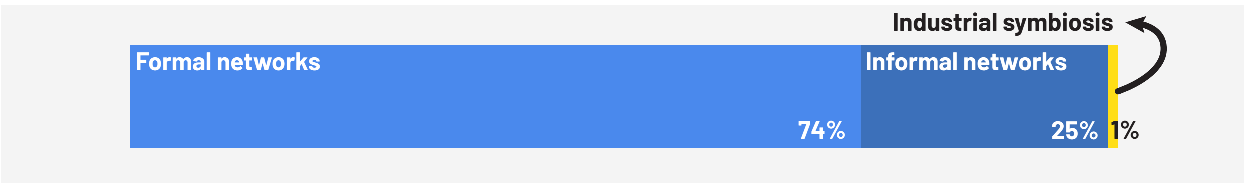
Figure 2: Management of the non-hazardous waste produced through the 65 sample companies per annum



Source: Analysis of primary data collected by the author

Further on the analysis of commercialised waste materials, we found that 6,842 metric tons or 74% of the materials are recycled or reused through formal networks and 2,279 metric tons or 25% of the materials is recycled or reused through informal waste dealers market. The sample companies directly transfer 97 metric tons or 1% of the total waste materials to the neighbouring industry as a primary resource from the fraction of waste materials sent offsite.[6] This 1% IS activity is formed on the basis of trust and cooperation factor between the company managers, who are located within the geographic proximity (Figure 3).

Figure 3: Commercialised non-hazardous waste through the 65 sample companies per annum



Source: Analysis of primary data collected by the author

4. Waste disposal methods - non-hazardous waste materials

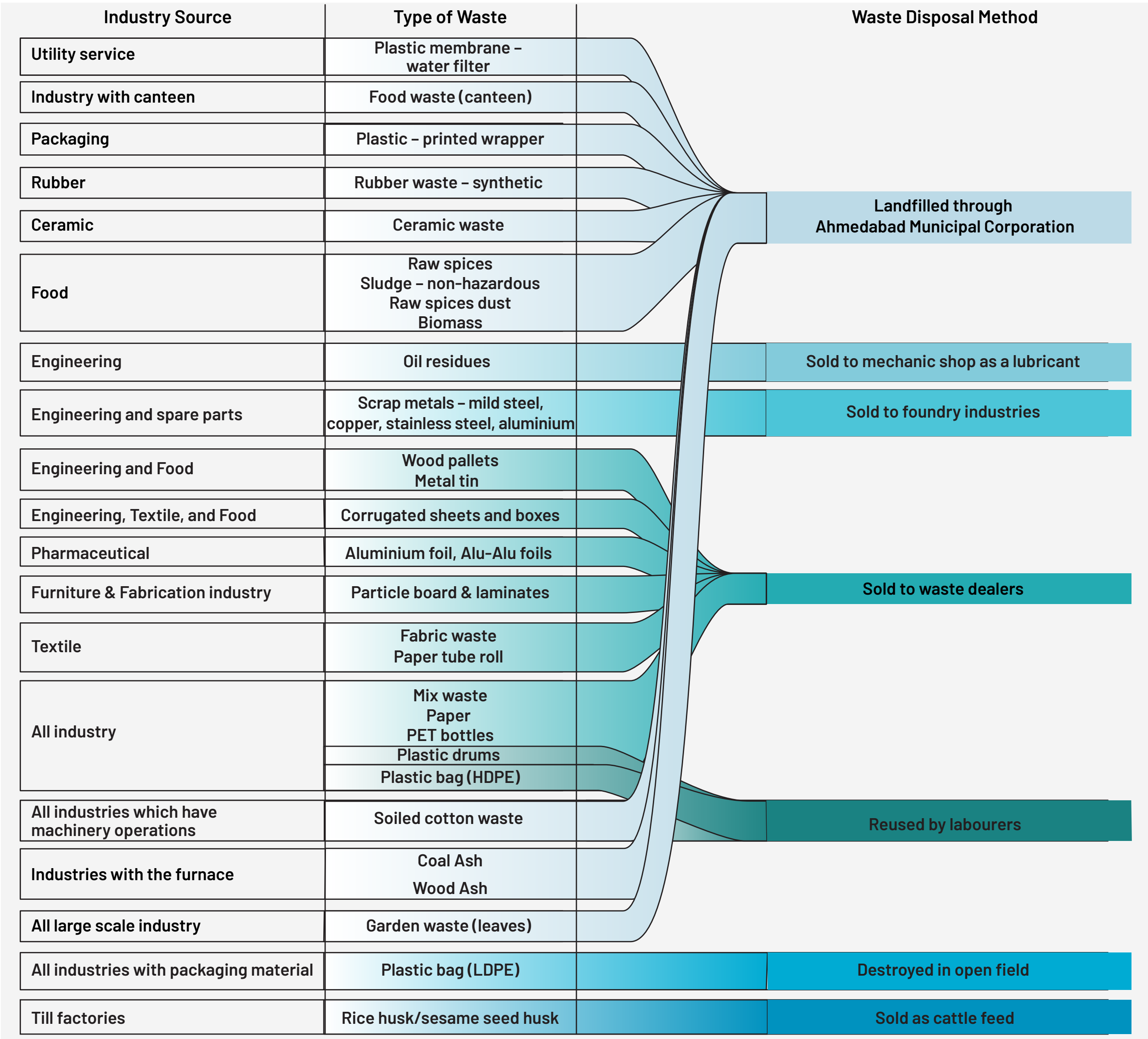
The study categorised several waste disposal methods based on the type of treatment used to dispose the NHW. For each waste disposal activity, the materials are accumulated within the company's premise at a designated place. Mostly the materials are collected door to door by known and unknown waste dealers for commercialisation purpose. The known waste dealers have an established firm, which is often listed under Gujarat Pollution Control Board (GPCB) as certified recycling vendors.

8 The quantification on waste materials is specified for the 65 sample companies; data are collected & analysed through survey questionnaire.

4.1. Management of NHW by the 65 sample companies

The waste that is recovered at NIE for sending to recyclers is accumulated at a designated place within each company's industrial premises. It is then collected door to door by the Naroda Industries Association (NIA) to be deposited at a common site within NIE.

Figure 4: Waste disposal methods at Naroda Industrial Estate



Source: Analysis of primary data collected by the author

Ahmedabad Municipal Corporation (AMC) trucks then collect all the waste from the common waste dumping site, and the waste is then landfilled at Pirana dump sites.[9] These dumpsites are frequented by rag pickers who collect items of value and sell them.

The 78% of the waste recycled at NIE (Figure 2), is primarily a result of commercialisation interest, which is sold to formal or informal markets (Figure 4). The waste recycling and reuse activities only

9 Pirana Landfill site is an open waste dumping area, owned and operated by the Ahmedabad Municipal Corportation

occur on particular NHW for the following three broad category of reasons:

4.1.1. Reused within the industry for energy and storage purpose

The sample companies within NIE reported that the reuse of waste materials within the industry are primarily for storage and energy conversion activity. More than half of the packaging materials are recovered and reused for storing the by-products; the plastic drums are restored, cleaned and utilised for storage purposes.[10] Among the sample companies, the underused textile, paper and wood wastes are converted into energy by the industrial boiler, which is commonly observed in the manufacturing industry. In a confectionery industry, the electric heater is used to convert 600 litres of grey water into steam, which is evaporated in the open field – the aggregated steam could be potentially used in the textile industry for the fabric manufacturing process. In larger enterprises, the horticulture waste is composted onsite to manufacture organic fertilisers, used in the facility. However, an estimated mass of 360 metric tons of horticulture waste is generated annually from the sample industries in NIE, and a significant amount of waste, i.e., 83% of the total horticulture waste, is either landfilled or destroyed in an open field.[11]

Among the sample companies, the manufacturing industry has installed onsite boilers, which generates the required heat and steam to the production process. Depending on the commercial flexibility, the companies install coal or wood boilers, which in return produces non-hazardous ash. An overall estimated mass of non-hazardous ash generated in the sample companies is 1,780 metric tons. A fraction of sample companies reported that non-hazardous ash from boilers is being recovered and transferred to the brick manufacturers, referring to it as a recycling activity. However, further records on brick manufacturers were not available with the reporting companies for verification. Therefore, cross verification of waste materials movement from the sample companies to waste recyclers was not possible.

4.1.2. Transferred or sold to potential recyclers (9,218 t or 77% of the waste materials are utilised through formal and informal recycling sectors)

The waste generating industries in the sample studied for this research were found to collect and sell their waste to the recycling sector through formal or informal ways. An estimated amount of waste materials traded for commercial exploitation annually was found to be 9,218 metric tons or 77% of the total waste generation. The formal recyclers specialise in recycling selective waste materials and often have recycling equipment. Whereas the informal waste traders collect the waste from the waste generating facilities and segregate based on the waste's commercial value. The research revealed that most of the formal recycling companies are located within the industrial area, and they have a yearly mutual agreement with the waste generating facilities. The agreement deals with collecting waste material for monetary exchange inclusive of a partial or fully subsidised

10 The data is specified for the 65 sample companies.

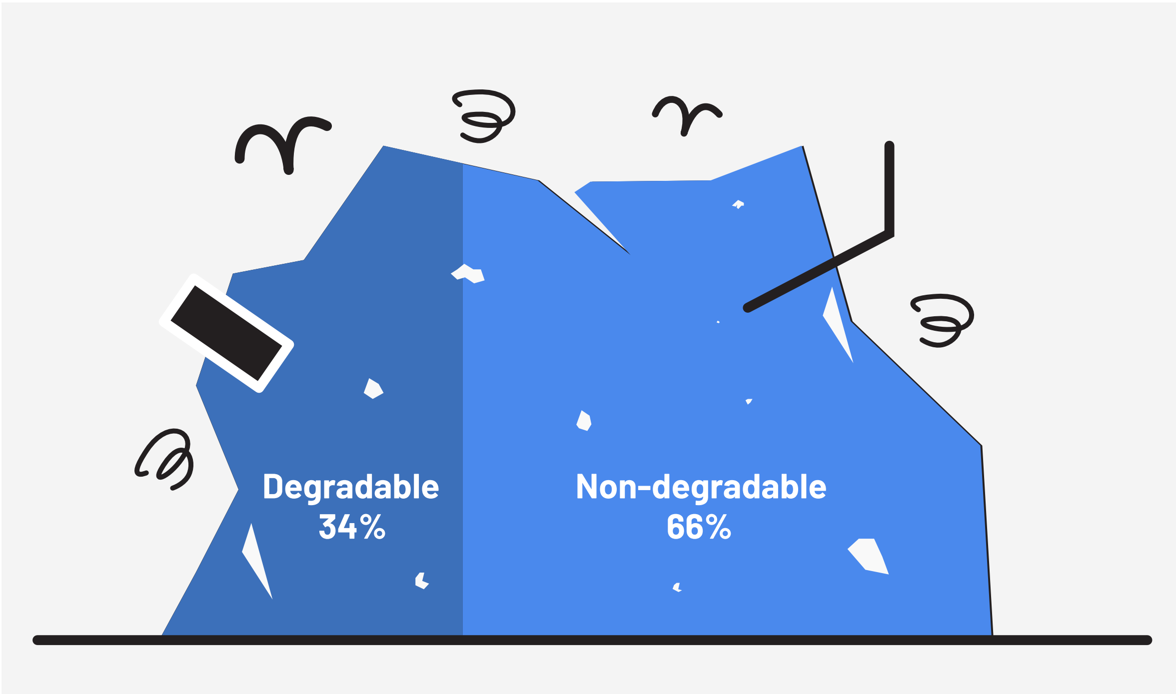
11 The quantification on waste materials is specified for the 65 sample companies; data are collected & analyzed through survey questionnaire.

transportation cost. However, waste materials are transported more than 20 kilometers (km) for recycling purpose, as appropriate facility is not available within NIE.
The industrial residues that travel more than 20 km from NIE are aluminium residues, soft plastic material – low density, hard plastic material – high density, PET plastic bottles, plastic packaging wrapper, aggregation of mixed/unsegregated residues (non-hazardous), soiled cotton waste, non-hazardous ash, paper residue, dust waste – food industry, food residue, and horticulture residue.

4.2. Landfilled waste (1,594 metric tons or 13% of the total waste generation per annum)

The sample companies generate a large quantity of NHW that is categorised as zero commercial value materials. Out of the total landfilled waste of 1,594 metric tons estimated from the sample industries annually, 1,050 metric tons or 66% of the waste materials are organic and 554 metric tons or 34% of the waste materials are inorganic in nature. We also observed that 439 metric tons or 28% of the total landfilled waste material are mixed and unsegregated with several industrial residues at the source, which provides a lesser opportunity to recycle or reuse further. The unsegregated waste is often disposed to landfill sites.[12] To prevent dumping of waste materials from open landfill sites, proper segregation could be emphasised, and the organic waste materials could be treated on the bio-gas plant of NIE.

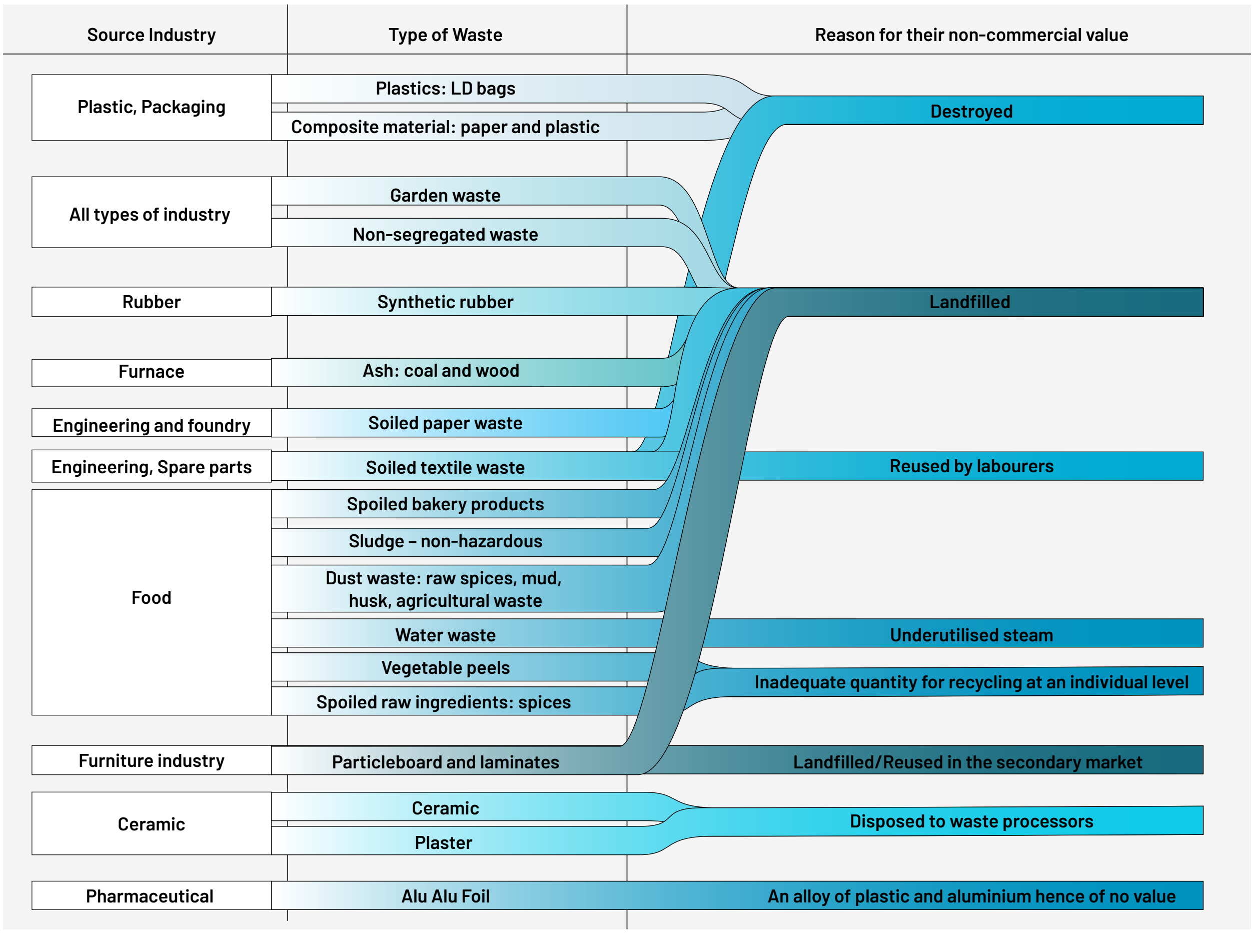
Figure 5: Composition of degradable and non-degradable waste materials disposed of in landfill



Source: Analysis of primary data collected by the author

12 The quantification on waste materials is specified for the 65 sample companies; data are collected & analyzed through survey questionnaire.

Figure 6: Industrial waste with zero commercial value



Source: Analysis of primary data collected by the author

5. The potential for IS

1. Commercial exploitation of industrial residues
2. Development of waste exchange platform among companies
3. Subsidised transportation and aggregation cost
4. Opportunities for waste recycling facilities
5. Prevention of environmental pollution

The utilisation of industrial residue within the NIE facilities presented the following opportunities: The waste generated at NIE that have the potential for commercial value are several and has been analysed by us below (Table 1). We also found that in many cases, the companies that can leverage value out of the waste also lie within NIE, thus further enhancing the potential of IS within NIE.

Table 1: Industrial waste with potential for IS

S. No	Types of Waste	Source Industry	Potential Use
1.	Metal tin	Engineering	Storage of secondary materials.
2.	Corrugated sheet	Engineering	Manufacturing of craft paper.
3.	Waste-paper	All types of industry	Processing of paper pulp.
4.	Scrap metals: mild steel, cast iron, aluminium, stainless steel,	Engineering and spare parts	Primary material in the foundry industry.
5.	Plastics: HDPE and LDPE	Packaging	HDPE – decontamination and reused for storage purpose. LDPE – converted as secondary granules.
6.	Wooden pallets	Engineering	Reused as wooden crates for storage and transportation purposes.
7.	Husk: rice, sesame seeds	Food	Reused as a cattle feed
8.	Fabric waste	Textile	Reused in the secondary market for making new threads, and other thread/rope-based elementary furniture
9.	Aluminium foil	Pharmaceutical	Reused for making tablet strips
10.	Paper tube roll	Textile, printers	Reused as raw material for the paper industry
11.	Plastic PET bottles	All types of industries	Converted into granules which are used as raw material for new plastic products

Source: Analysis of primary data conducted by the author

5.1. Extent of commercial exploitation possible through recycle and reuse

The information received through the interviews stated that currently, NIE is able to send 6,842 metric tons (58% of the total waste generated annually by 65 sample companies) of its non-hazardous waste to 8 recycling units. However, only 4 of these units are located within NIE. The waste material has to travel more than 15 km to other recycling units so that they can be gainfully used. Therefore, the potential of using a significant percentage of waste material by recycling plants can be increased if there are more reutilization facilities are provided within NIE.

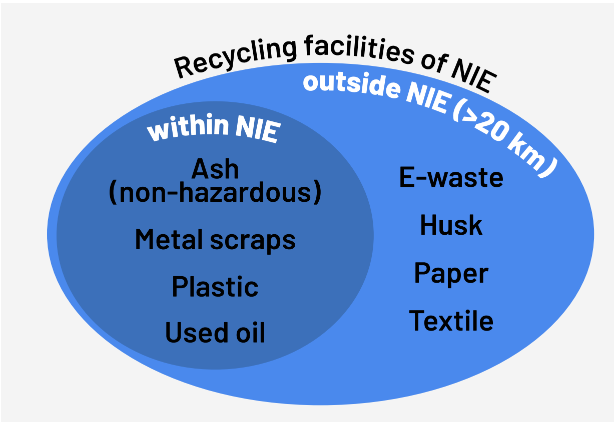
At the moment is a mere 1% or 97 metric tons of waste materials are utilised through IS activities among 65 sample companies. This symbiotic practice to convert waste of one company as a resource for another is observed among ceramic and plastic manufacturing industry. A possible solution to improve the IS activity could be to increase the percentage of information about the type and quantity of waste material among companies. More than 1000 units belong to different industries, and it is easily possible to increase this percentage by availability of information. The total waste handled by informal waste dealers among the sample companies is 2,279 metric tons (19% of the total waste per annum). It is difficult to track the treatment of waste due to the lack of records and the informal market's reluctant to provide interviews. If the informal waste dealers can be made a part of the supply chain, they will act as a facilitator to IS.

The study derived 13% of degradable waste (24,514 metric tons) from the total waste materials generated among the sample companies. The waste was largely horticultural (4,614 metric tons) and food waste (6,753 metric tons) disposed of in landfill. For example, a vegetable- based food processing industry produces 2.6 metric tons of vegetable peels annually. Due to a lack of facility to utilise the biodegradable waste, the materials are disposed of to landfill sites. If NIE were to have a biogas plant, this waste could have been utilised to generate gas and energy. The aggregation of waste could be subsided fully or partial by association members to facilitate this process effectively.

5.2. Possibility of establishing recycling firms for all waste types within NIE to leverage physical proximity of waste-generating companies

There is a vast opportunity observed for recycling companies within NIE. Currently, the information availed from 65 sample companies, there are 8 facilities accessible for recycling purposes. Out of them, 4 are located within NIE, and the rest are outside NIE. The 4 recycling facilities which are within NIE deals with non-hazardous ash (1,567 metric tons per annum), metal waste (1,866 metric tons per annum), used oil (36 kg per annum) and plastic waste (47 metric tons per annum). However, the waste types that are not processed within the NIE includes e-waste (3,112 metric tons per annum), husk waste (2.5 metric tons per annum), paper waste (1.2 metric tons per annum) and textile waste (245 metric tons per annum) that needs to travel nearly 15-20 km every day to be used commercially. If suitable recycling facilities were to be set up within NIE, this waste which is almost 3,361 metric tons generated from the 65 sample companies, could be utilised within NIE without incurring the transportation and handling cost while also saving on fossil fuels.

Figure 7: Access to recycling facilities



5.3. Increasing the scale and intensity of self-driven IS

Currently, self-driven IS is at a mere 1% at NIE. It can easily be observed that there are vast opportunities to use one's company waste as a resource for another company within NIE. The self-driven IS can happen only in the presence of trust, cooperation, geographic proximity and availability of relevant information. For example, a furniture company transfers the wood waste to neighbouring food industry to use as a fuel, and a plastic packaging company transfers the plastic waste as a feedstock to a plastic manufacturing company, which converts it into secondary plastic granules.

From the data collected at NIA, it was identified that there are 3 furniture companies and 57 companies belonging to the food industry that could potentially utilise wood waste as a fuel. Similarly, 25 plastic packaging companies and 30 plastic manufacturing companies could exchange plastic waste for the production of secondary plastic granules.

6. Continuous analyses of volume and types of waste and their possible usage

Just as production is continuous, waste generation is also a constant process. The technology adopted for manufacturing also changes at regular intervals because of which the composition and character of waste generated changes. It is therefore important to study the quantity, nature and quality of waste periodically, so that appropriate strategies may be formulated for their disposal and commercial exploitation. The study and database management should be supervised periodically by a statutory committee formed by industrial members.

Through the study of 65 companies, we observed the treatments adopted by the company managers depending on the nature of waste, commercialisation opportunities and quantity of generation. Based on the current treatment of waste materials, the ideal treatment of materials derived to improve IS activity.

Figure 8: Quantity of waste generated with their derived ideal treatment

Category		Waste or by-product	Quantity/month	Ideal treatment of waste
Metal Waste		Metal tin	200 tins/month	Waste material exchange with foundry industries
Metal Waste		Scrap metals	160 ton/month Mild Steel, Copper, Stainless Steel, Aluminium	melted and reused
Metal Waste		Aluminium foil, Alu-Alu foil	200 kg/month	Reutilization of aluminium scraps through shredding, thermal decoating and re-melting process
Plastic waste Ease of commercialisation	high	Plastic (Low-Density Polyethylene)	2.4 ton/month	sold to recycling facility/ create Refuse Derived Fuel manufacturing facility
	high	Plastic (HDPE) and Plastic Bags	550 kg/month, 800 to 1000 pieces/month	sold to recycling facility
	high	Plastic drums	50 kg/ month	Waste exchange through symbiosis network.
	high	Poly Vinyl Chloride (PVC)	3000 kg/month	To be found out
	high	Plastic covering: HDPE wrapping foil	200 + 200 kg per month	Segregated
	high	PET bottles	500 bottles/month	
	high	PP raffia waste	500 kg/month (1 ton/ two month)	
	low	Plastic membrane	25 to 30 piece per month Membrane weight 15 kg per piece	scraped and shredded into plastic granules. Further examinations
	low	Plastic pouches/wrapper	130 kg/month	Plastic waste could be made into RDF combining with textile.
	low	Plastic mix waste - polyethene (2,3 varieties, HDPE, LDPE, LLDPE, BAPP, CPP)	20 tons - Truck/15 days, 1600 kg/month	Waste processors at a low rate take mixed waste. A segregation facility/yard is to be implemented by the organization. The plastic waste could be traded/exchanged to other industries by IS network.
	low	Plastic: sticky material	25 kg (time duration is not specified)	
	low	Plastic laminates	5 kg/day (data collected from the furniture industry)	The furniture industry has non-segregated waste. The mixed waste requires being segregated to find maximum potential value.
	low	Plastic bits and shavings	Minimal quantity	Refuse Derived Fuel manufacturing process
	low	Carry bags (LD)	1000 bags	
Textile waste		Soiled cotton waste	3570 kg/month	
Textile waste		Textile waste from Ayurvedic medicine industry	Minimal quantity	
Textile waste		Fabric waste: Noyil, bonda, soft fabric, hard fabric, lycra yarn, soddy burr, rejected fabrics	8.5 ton/month	This waste must be sold to recycling units that convert it into ropes and threads
Ash waste		Coal ash	109 ton/month	Can be converted into bricks by a fly-ash brick-manufacturing unit.
Ash waste		Wood ash	17 ton/month	Quality of ash would determine whether fly-ash bricks can be manufactured from it. Else binders are used to make bricks from them.
Paper waste		Corrugated paper	40 ton/month	
Paper waste		Paper	2814 kg/month	To be converted into paper pulp for further processing.
Paper waste		Paper tube roll	12 roll - 1 kg per roll/day	
Food and kitchen waste		Food waste	220 kg/month	To be collected, sent and processed at a biogas plant.
Food and kitchen waste		Kitchen & Garden waste	Quantity is minimal in most industries (5 tractor/month)	To be collected, sent and processed at a compost pit.
Food and kitchen waste		Dust waste	4500 kg/month	The dust waste can be mixed with organic sludge to convert it into fertiliser.
Food and kitchen waste		Husk and husk-sludge	6500 kg/month	Conversion into fuel
Food and kitchen waste		Leftover spices	652 kg/month	
Wood waste		Wooden pallets	66 ton/month	Can be re-used as packaging material for relevant goods.
Wood waste		Leftover wood waste from the furniture industry	50 kg/month of scrap wood and 80 kg/month of small wooden pieces	Could be reused as fuel in the furnace.
Wood waste		Particle board & laminate	Substantial quantity	Particleboard could be reused in the construction of frames in different industries.
Biomass		Biomass	50 to 1000 kg/day	Due to its high calorific value, it can be mixed with relevant fuel (husk).
Other categories of industrial solid waste		Electronic waste	In-substantial quantity	MoU with e-waste dealers for recovery of useful parts and safe disposal of the rest.
Other categories of industrial solid waste		Ceramic & POP waste	4 to 5 ton/month	Not Applicable
Other categories of industrial solid waste		Used oil	322 litres/month	

Source: Analysis of primary data collected by the author

7. Gap Analysis

This study performs a gap analysis by comparing actual performance of the existing IS in NIE to the potential performance of IS achievable in NIE. The research tools used to conduct the exercise are as follows:

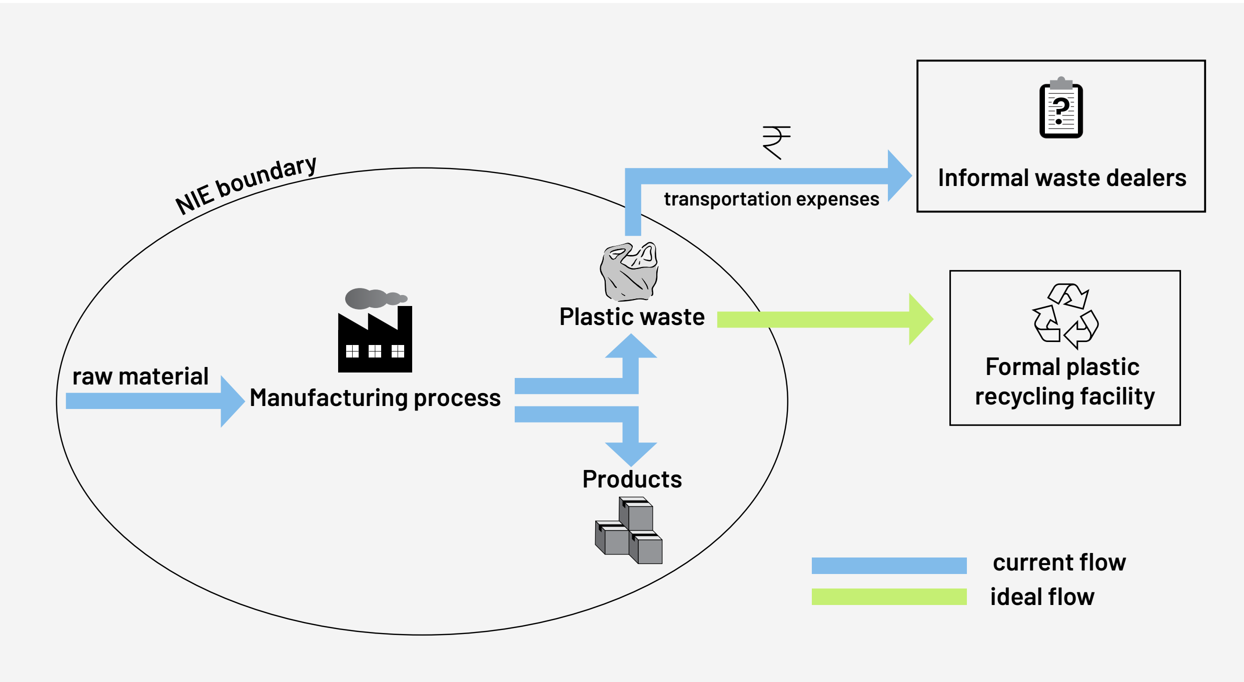
1. Material flow gap analysis
2. Information flow gap analysis
3. Monetary gap analysis

7.1. Material flow analysis

A material flow analysis (MFA) is used to study the physical flow of non-hazardous waste through industrial activities such as waste generation, recovery, and disposal. To balance the closed loop system, the waste materials could be reused either companies exchanging the waste materials as a source of raw materials to another or enabling access to information about waste and raw material requirement by various entities. Presently the waste material is either handed over to informal waste dealers or disposed of in a landfill. The MFA discovered that there is a physical movement of industrial residues to companies that use it as a raw material source. These self-organised IS activities are operated on the basis of trust and cooperation.

7.1.1. Material flow gap: Plastic waste

Figure 9: Plastic waste material flow in NIE

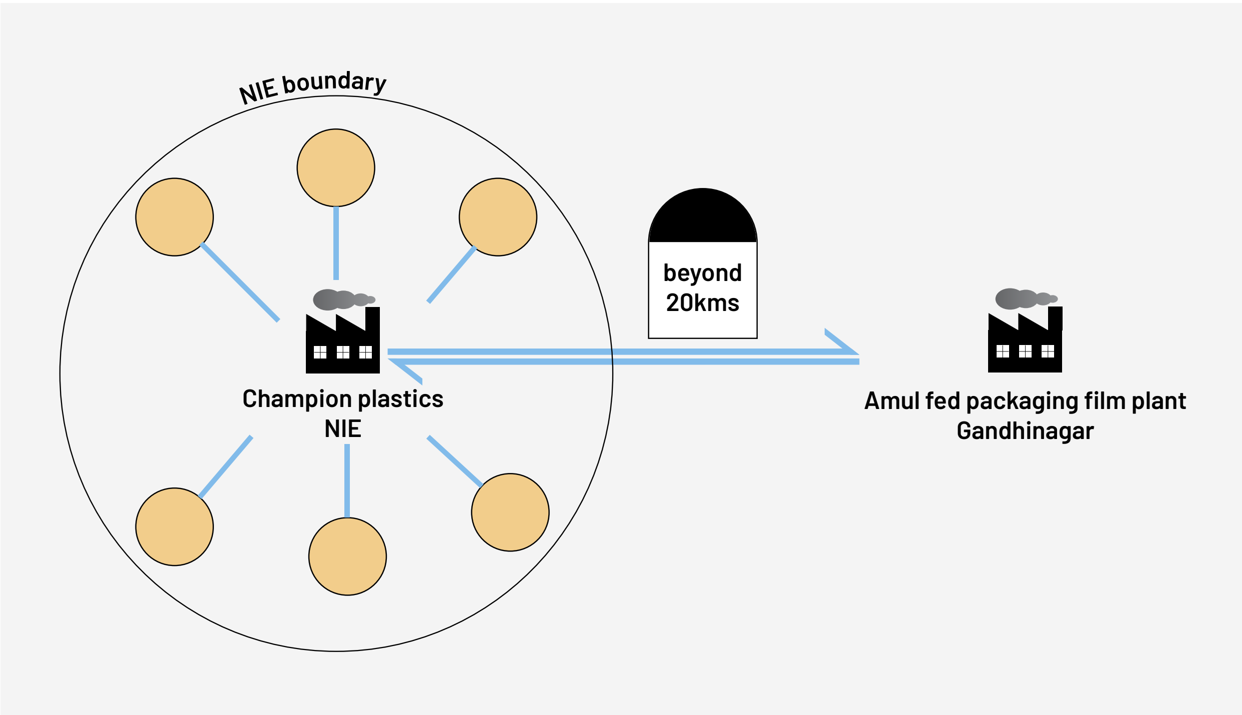


Source: Analysis of primary data collected by the author

Almost all the companies in NIE generate plastic waste of different variations. Their recycling opportunities have been understood from the responses to the survey with the sample companies where the informal waste dealers capitalise upon the waste recovery activities. Depending on the physical properties, the informal waste dealers segregate the plastics under 2 categories - soft plastics (low density plastics) and hard plastics (high density plastics). The informal sector fails to maintain a waste record or monitor the recycling activity, which may create toxic pollution. In a personal interview with Mr Aditya Shukla, founder and CEO of Saltech Design Labs Pvt. Ltd., a pioneering organisation specialised in converting unsegregated plastic waste along with other industrial residues into building blocks, described the necessity to eliminate particular plastic resins from recycling process to avoid the emission of toxic components. He further commented on avoiding recycling PVC materials as they emit dioxins due to rich chlorine content. The study also revealed that since the majority of plastic waste is collected by the informal sector, the NIE companies experience difficulties in obtaining plastic waste for intercompany usage.

7.1.2. Intercompany plastic reuse activity

Figure 10: Material flow of plastic waste for reutilisation activity outside the NIE



Source: Analysis of primary data collected by the author

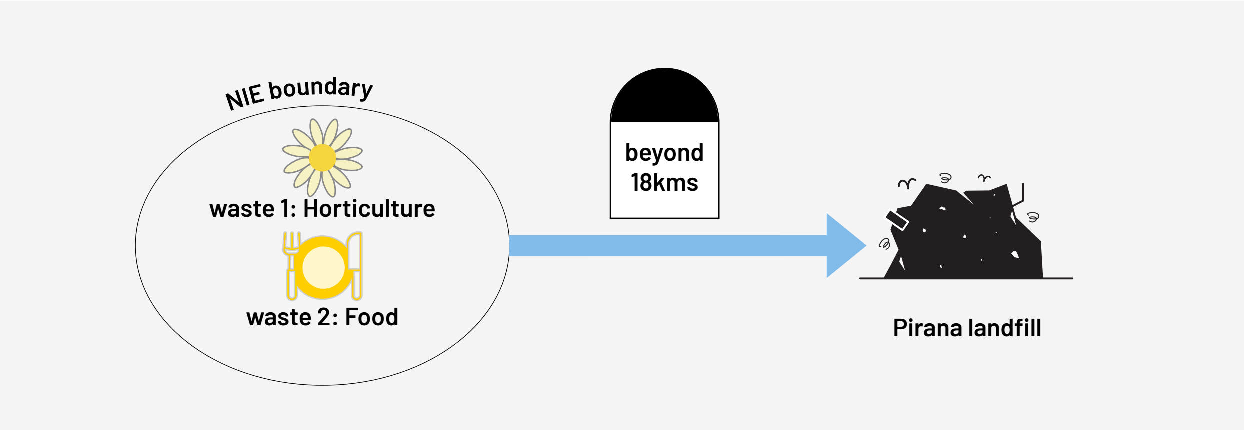
The companies believe that disposing plastic waste to the informal waste dealers result in a complete recycling activity. Data verification with the informal sectors is difficult, as they were hesitant to be part of interviews. The NIE has a fully operational secondary plastic recycling facility within its precincts which it imports plastic waste from a distant facility. For example, a plastic recycling firm, Champion plastics, recycles 50 metric tons of plastic waste which they receive from AmulFed packaging film plant, located at Gandhinagar which is more than 20 km away.[13] If the plastic waste generated within NIE can be aggregated and sold to Champion Plastics, not only will the long material flow be shortened substantially but the capacity utilisation of the recycling plant

13 Analysis of primary data collected by the ACfS research team

will also improve (Figure 10). Such advantages will occur in addition to besides the indirect reduction of transportation costs, greenhouse gas (GHG) emissions etc.

7.1.3. Material flow gap: Biodegradable waste

Figure 11: Biodegradable waste material flow at NIE

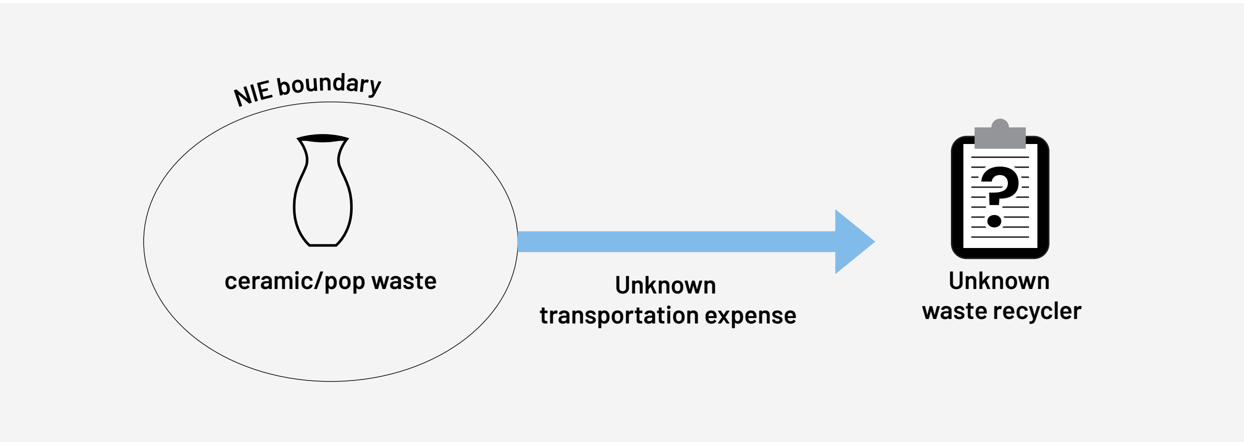


Source: Analysis of primary data collected by the author

The biodegradable waste produced within NIE is approximately 15,097 metric tons per annum. Biodegradable wastes are classified as food and horticulture waste. A large percentage of waste travels from Naroda waste collection site, located within NIE, to Pirana landfill that is nearly 18 km away (Figure 11). Such waste is an excellent raw material for rich organic compost and more than 46% of the landfilled waste generated within NIE can be reutilised. If an organic compost plant is established within NIE, it would get a regular supply of raw material and the compost manufactured could be used for commercial gains. This would also shorten the transportation cost, GHG emissions and increasing demand of landfill sites.

7.1.4. Material flow gap: Ceramic and Plaster of Paris (PoP) waste

Figure 12: Existing reusage of PoP/ceramic waste

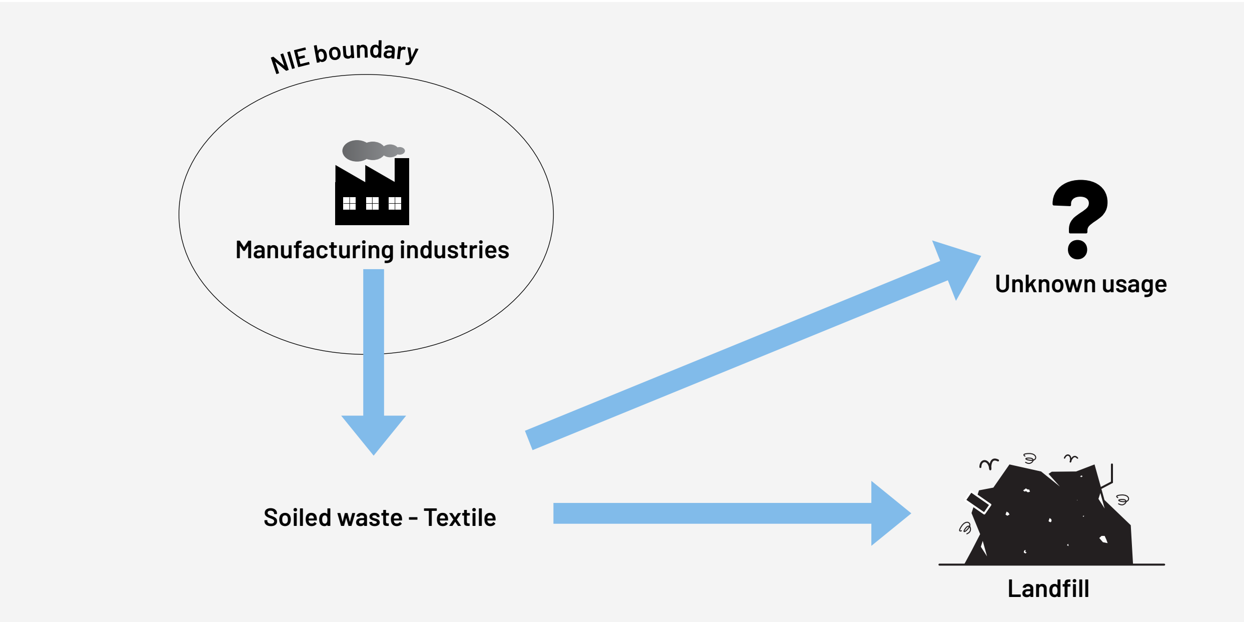


Source: Analysis of primary data collected by the author

The broken and uncooked ceramic and PoP residues generated from more than 80 companies amount to nearly 108 metric tons per month.[14] It is mostly transported for reuse to an unknown waste recycler. Due to its non-hazardous nature, it is often ignored and necessary efforts are not made to recover or recycle.

7.1.5. Material flow gap: soiled textile waste

Figure 13: Material flow of textile waste



Source: Analysis of primary data collected by the author

The manufacturing industries generate soiled textile waste to the order of 159 metric tons per annum. This is produced mainly from housekeeping, machinery priming and cleaning activities. Textile waste receives little or no attention. As the volume is minimal both at the level of an individual company or even when aggregated at the level of NIE, it is either landfilled or destroyed in the open field. However, it has a good calorific value and could find potential use as an industrial fuel. For example, companies reported that a portion of the disposed waste is used by the industrial workers as a fuel for household activities.

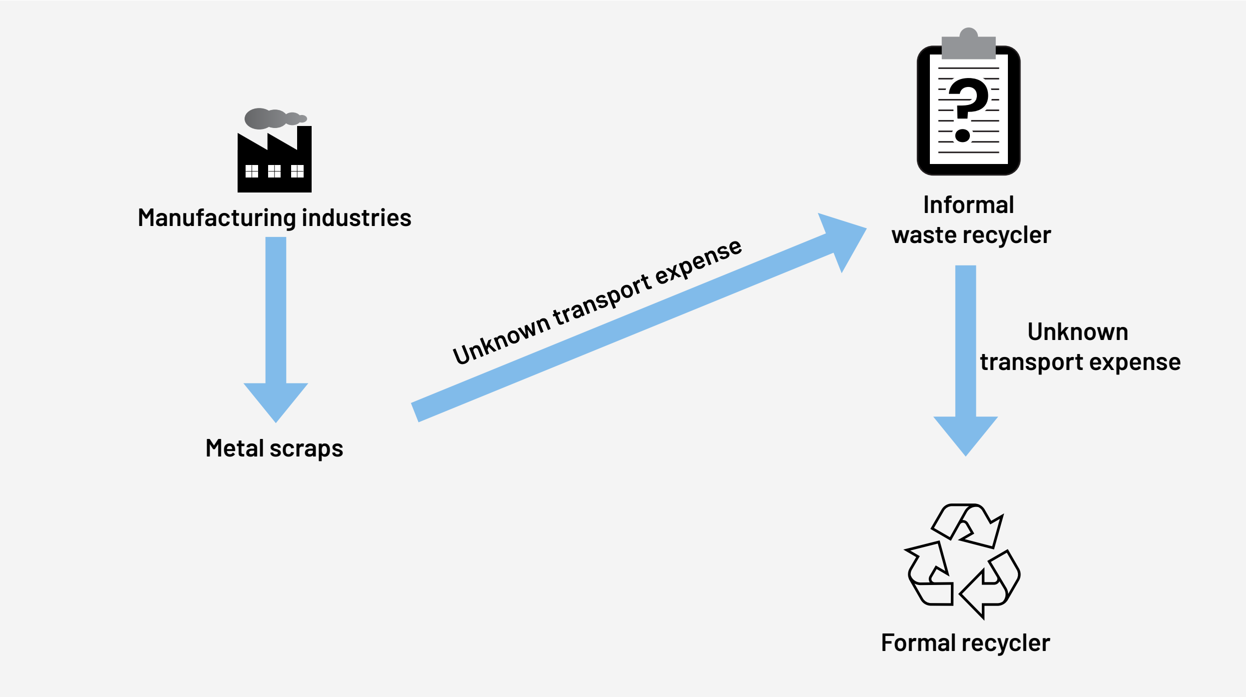
7.1.6. Material flow gap: Metal waste

The metal scraps are generated from industries manufacturing metal products and the metal residues from packaging items. The metal scraps include both ferrous and non-ferrous materials. An estimated quantity of 1,878 metric tons of metal waste is generated within NIE per annum and it flows through both informal waste dealers and remanufacturers (e.g., foundry industry). Data verification with the informal waste dealers is difficult to find the end result of the materials. An informal waste collector reported that most of the segregated metal is travelling more than 25 km away. However, the NIE has a rich settlement of foundry industry, which could be used. Directing

14 Analysis of primary data collected by the author

the materials to the foundry industries could save a significant amount of logistical expenses and provide a continuous source of raw materials.

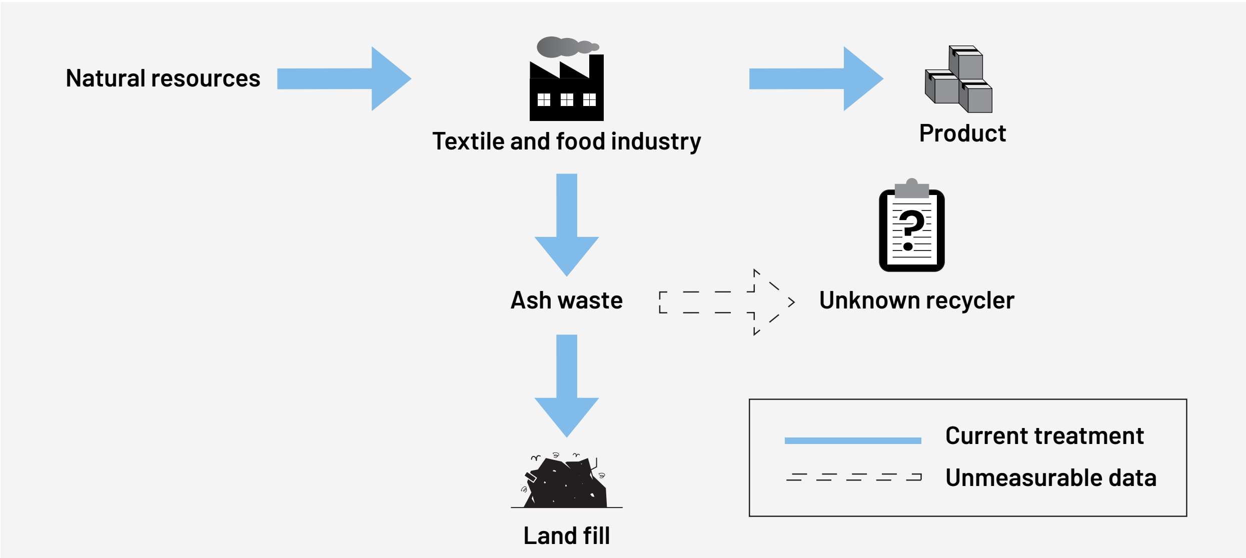
Figure 14: Material flow of metal waste



Source: Analysis of primary data collected by the author

7.1.7. Material flow gap: Ash waste

Figure 15: Material flow of ash (non-hazardous)

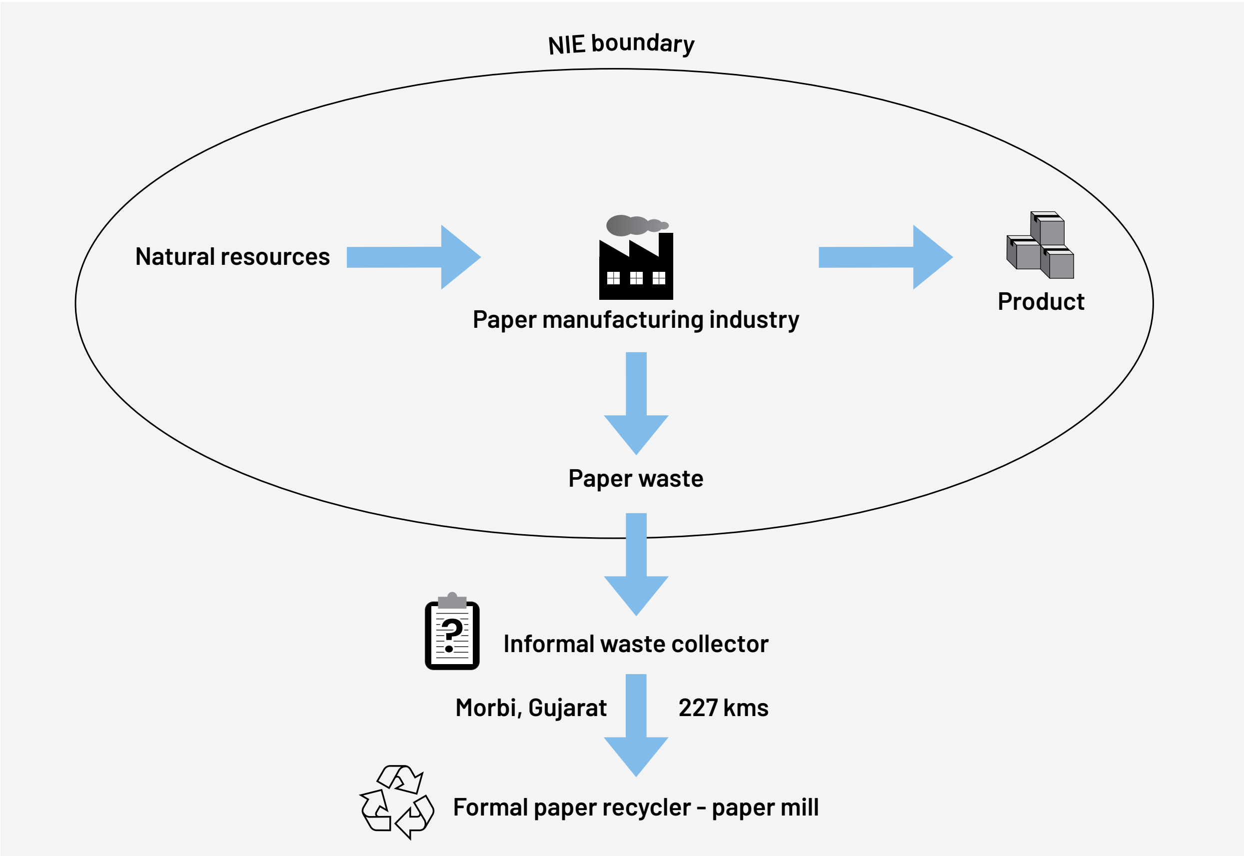


Source: Analysis of primary data collected by the author

The food and textile industries operate wood and coal furnace in large quantities. Non-hazardous ash is an underutilised residue disposed of at landfill sites. The study identified that the non-hazardous waste could be reused within NIE. Due to the waste characteristics, the companies deal with transportation and storage challenges. The ash is well-known for its usage in brick and cement manufacturing. Considering its possibilities of waste utilisation, the non-hazardous ash could be aggregated and reused.

7.1.8. Material flow gap: Paper waste

Figure 16: Material flow of paper waste

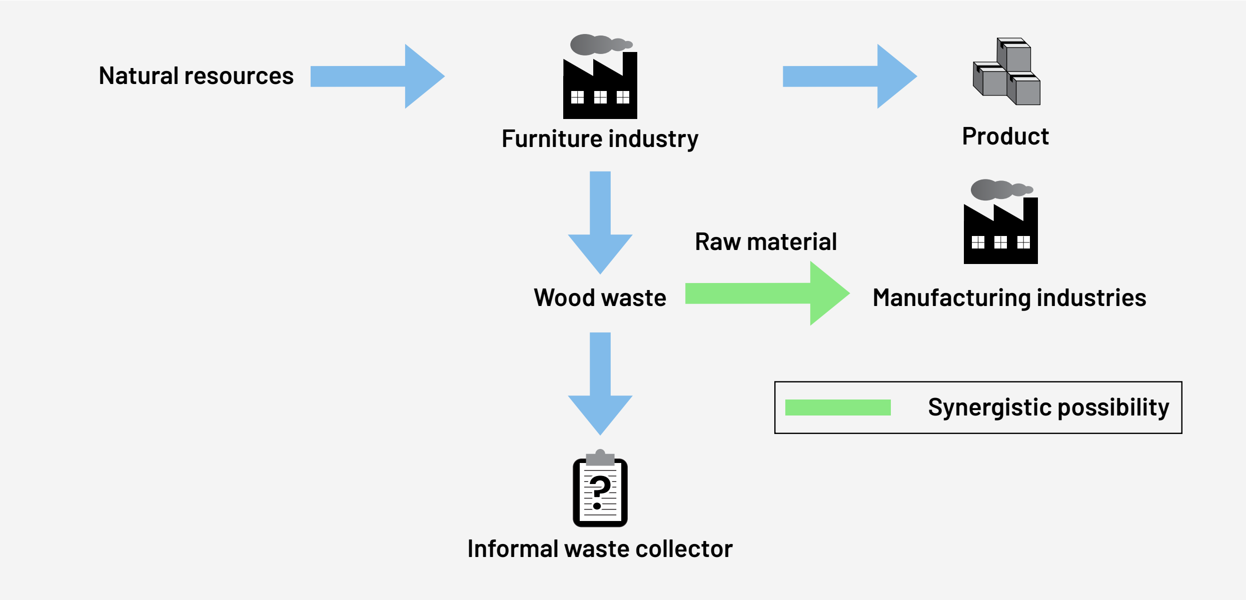


Source: Analysis of primary data collected by the author

The industries manufacturing paper based products generate waste in the form of paper scrap. Other paper waste such as paper tubes, corrugated paper and composite materials are generated from packaging materials. A majority of the paper waste is given away to the informal waste dealers (43%) and landfill sites (55%). Companies struggle with transportation and storage expenses, which forces them to dispose of the waste, which is cheaper than the cost incurred in recycling or waste exchange activity. The informal sectors transfer the waste to paper recycling plants in Morbi, Gujarat, which is 227 km away. However, there is good upcycling potential and the development of new technologies within NIE may put it to better use, reducing emissions from transportation activities.

7.1.9. Material flow gap: Wood waste

Figure 17: Material flow of wood waste



Source: Analysis of primary data collected by the author

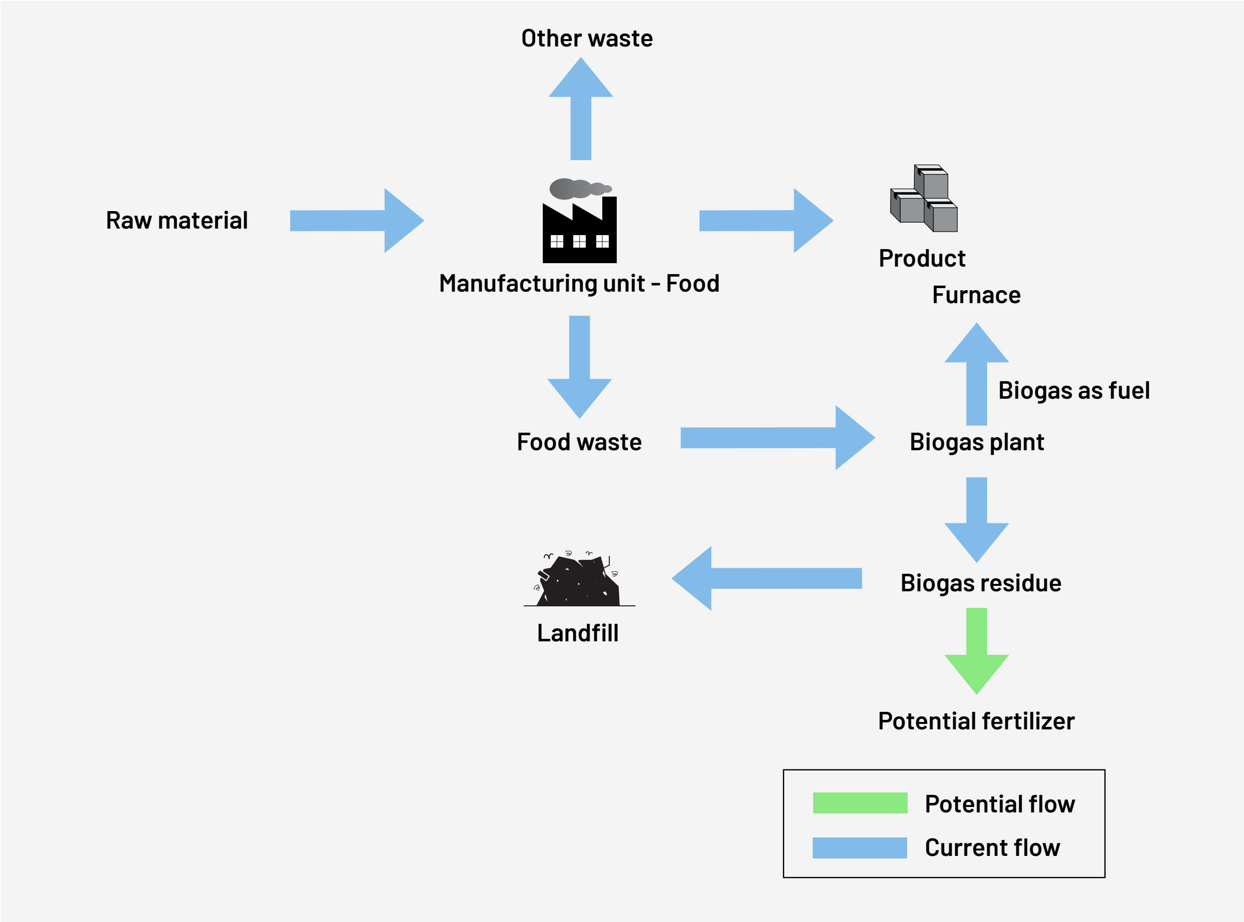
Turning wood waste into useful products has found many concrete examples in the recycling industry. In NIE, the industries are sourcing wood as a fuel for furnaces use. The furniture industry at NIE generates leftover wood scraps, plywood and wood dust. Storing the wood waste is discovered to be a challenge among several industrial stakeholders. For example, a furniture manufacturing company stores 3.8 metric tons of wood residues per month within its premises. The availability of information on the waste could enable the intercompany material usage promoting IS activity.

Currently, the informal waste dealers handle a significant amount (99%) of wood waste recovery that is segregated and traded to unknown recyclers. The leftover wood waste could be a source of fuel for the manufacturing companies at NIE.

7.1.10. Material flow gap: Biogas residue

The larger enterprises with established waste management facilities focus on recycling the waste within their premises. Most of the food companies reported that the organic residues generated from the biogas plant finds no commercial value or potential stakeholder within the NIE. For example, a food industry disposes of sludge waste (360 metric tons) to landfill generated from that biogas plant, which contains 2,000 calorific value and a moisture presence of 45% to 55%. This waste could be a rich source for the manufacturing of organic manure. The absence of a recycling facility has resulted in the organic waste being dumped in landfill sites.

Figure 18: Material flow of biogas residue



Source: Analysis of primary data collected by the author

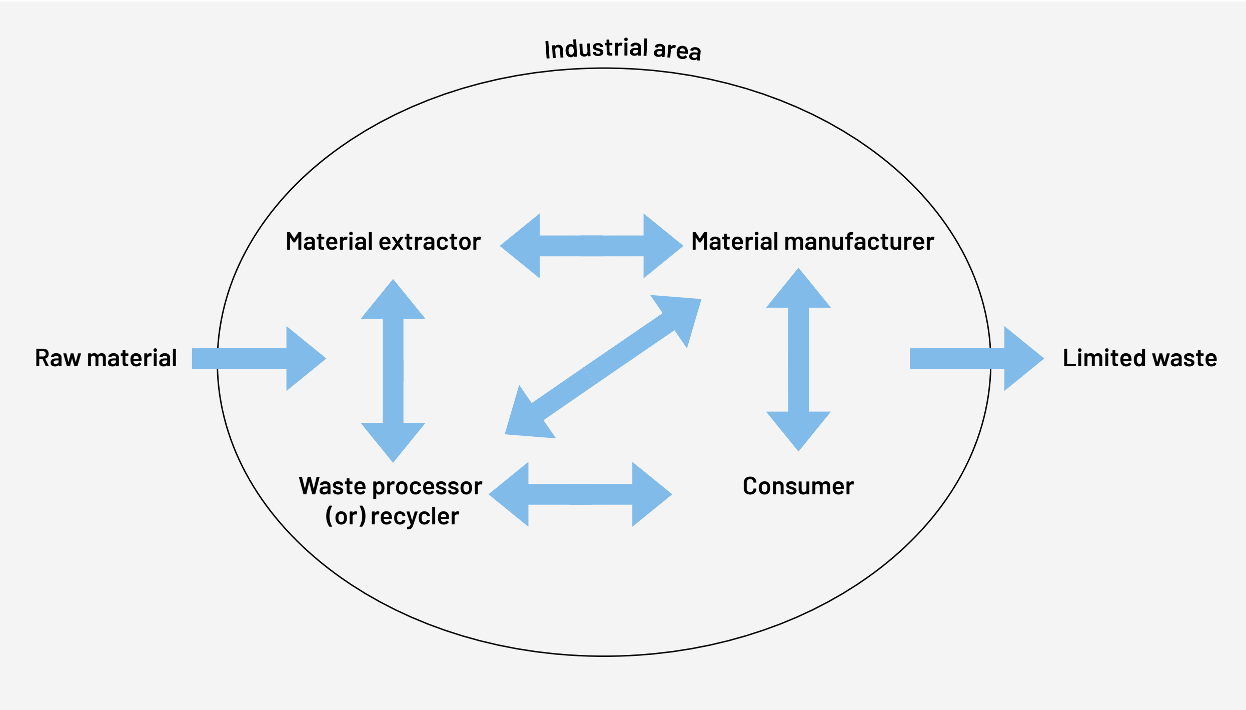
7.1.11. Closing the loop with the recycling facilities

The success of industrial symbiosis depends on 5 significant stakeholders: material extractor, waste generating companies, consumers, regulating authorities, and waste recyclers – both formal and informal actors. Each stakeholder forms a part of the ecosystem, and they play an essential role in closing the loop. In order to develop an effective closed loop material system, we may need to create relevant recycling and remanufacturing enterprises to bridge the missing waste-to-wealth loops.[15]

Waste recycling facilities enable residue recovery and material utilisation within the NIE but are not utilised due to the absence of input/output material flow data, presence of informal waste sectors, exceeding transportation expenses, and uncategorised waste types. Mostly the recycling facilities transports waste from companies which are over 20 km from NIE. The recycling companies established within NIE can reutilise wood waste, secondary plastics, non-hazardous ash, ceramic waste, ferrous and non-ferrous metal. Furthermore, establishment of recycling facilities to utilise the dumped waste generated within NIE could potentially close the material flow loop.

15 Robert A. Frosch, (February 1992). Industrial ecology: A philosophical introduction, Proceedings of the National Academy of Sciences of the United States of America, (pp. Vol. 89, pp. 800-803). USA

Figure 19: Industrial symbiosis ecosystem



Source: Jelinski, L. W., Graedel, T. E., Laudise, R. A., McCall, D. W., & Patel, C. K. (1992). Industrial ecology: concepts and approaches. Proceedings of the National Academy of Sciences of the United States of America, 89(3), 793–797

8. Information flow

8.1. Centralised information system

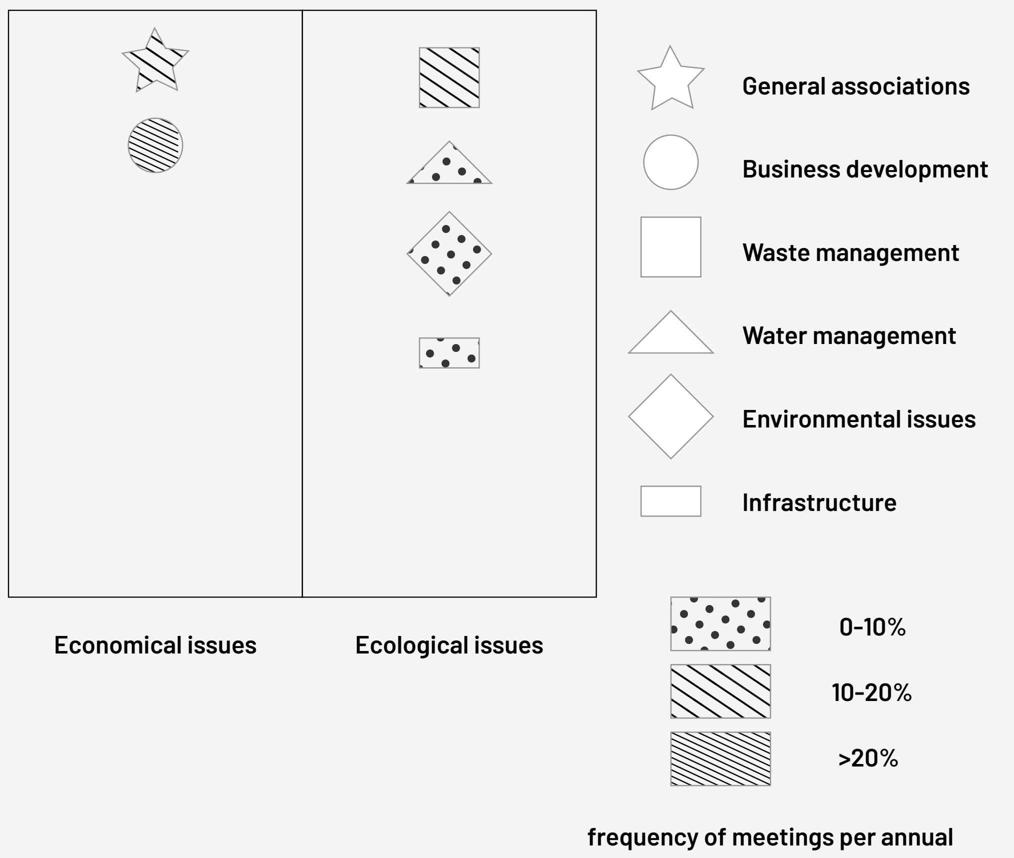
The owners of the companies located within NIE can avail membership with the Naroda Industries Association (NIA) and approximately 2/3rd of the companies are already members of the NIA. The NIA acts as a statutory authority in improvising the physical characteristics (infrastructure, services and environmental regulations) of the industrial area. It acts as a forum for questions relating to environmental performances and gathers vital information from the companies to learn several environmental approaches. The study observed that the information on NIA members (approximately 600 companies) is available with the NIA, but is not periodically updated. The information on the remaining NIE companies are not reported to NIA, which makes it difficult to map and devise environmental solutions. The study obtained information on recycling actors, input-output flow of companies, door-to-door waste collection activity and participation of informal waste dealers, which could be included in the NIA database. The availability of information on material flow, remanufacturers and waste traders helps the researchers and other statutory authorities in devising suitable waste recovery programmes.

8.2. Waste exchange platform

The material exchange at NIE from waste generating companies to the recyclers mainly occurs through the informal waste dealers. These actors in the informal markets are an invisible supply chain that play a vital role from the door-to-door waste collection service to the transportation of waste to manufacturers. The waste recyclers at NIE face challenges related to waste material transportation and market dominance from informal actors. The involvement of informal waste sectors in the material exchange platform could enable the closed loop system at NIE.

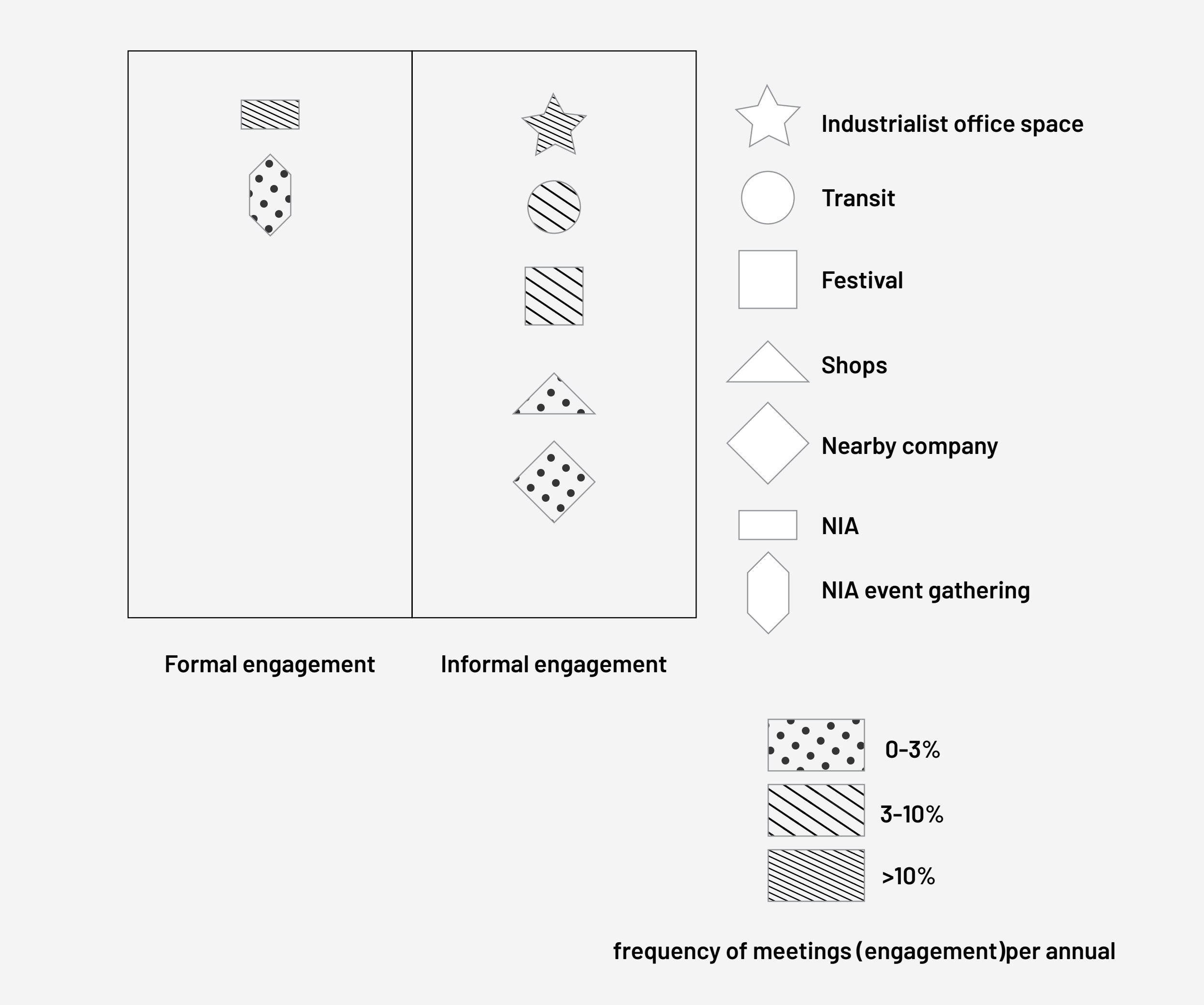
9. Social network analysis

Table 4: Social network representation – NIA



Source: Analysis of primary data collected by the author

Table 5: Frequency of formal and informal interactions



Source: Analysis of primary data collected by the author

Of its other functions, NIA also acts as a medium act of information flow for the industrial stakeholders and it has formed several committees to address the issues at NIE. The study surveyed the company managers and categorised the nature of discussion into 2 topics that include economic and ecological under the flow of information as formal or informal. According to the analysis, the attendance of the companies amongst all the discussions is found to be in high density (more than 20%) in the formal engagement (Table 5) discussing NIE's issues and economic status (Table 4). Under the ecological category, a medium density (10-20%) of engagement is observed in the waste management discussions, and a light density (0-10%) engagement is observed in the water management and infrastructure issues discussion. Under the economic category, a high density of engagement is observed in business development discussions and a medium density in general association meetings.

The stakeholder interest is more inclined towards the economic issues than the ecological concern. Companies reported that the action points discussed in the meeting at NIA regarding waste management, environment and infrastructure issues take longer to get implemented. NIA is however an effective change management platform to implement social, environmental and ecological matter. Development of IS dialogues will receive attention as it falls on the economic and ecological horizon. It is also observed that 10% of company managers (NIE) communicate with other industrial stakeholders during commuting, which develops trust and cooperation among managers.

Studies have showed that frequent communication and interpersonal trust enhances the ongoing interactions in an industrial ecosystem. For example, the Kalundborg industrial symbiosis waste exchange platform primarily developed as a result of the regular interactions of managers and staff of different organisations in several social forums such as the Rotary Club meetings.[16] Similarly at NIE, 1% of the self-organised industrial symbiosis occurred through inter-personal stakeholder trust.

10. Monetary gap analysis

The monetary analysis includes the value of waste in-terms of secondary market value, transportation cost, and infrastructure cost. The monetary analysis results help categorise the waste that is (i) industrial waste with commercial value and (ii) industrial waste that can be commercialised. These findings from the analysis will lead to a conceptual framework in understanding the economic value of handling waste materials.

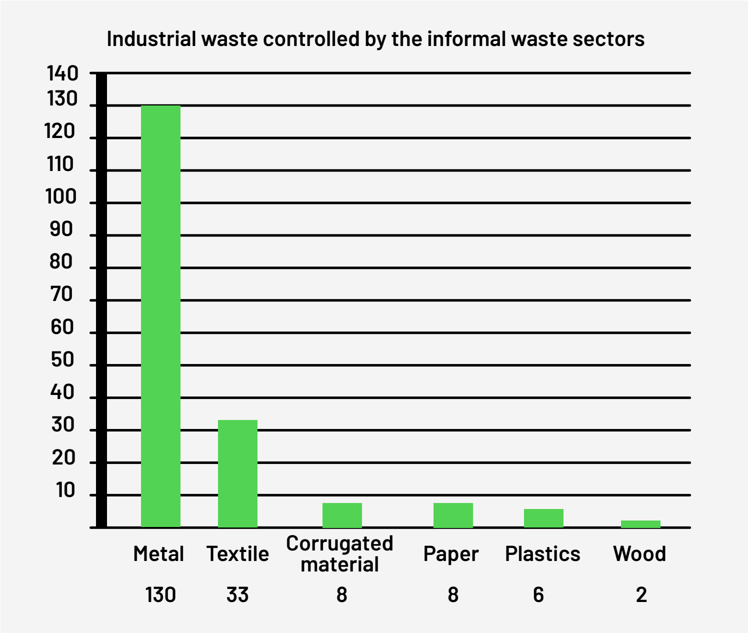
10.1. Industrial waste with commercial value

The waste generating facility segregates the waste, which could be exchanged for monetary benefits. The primary transaction occurs by the informal waste dealers and recycling facilities. The informal waste sector has formed a robust supply chain of door-to-door material collection against cash payment. Informal actors are leveraged to collect non-commercial value waste, which is disposed of by the companies. For small and medium scale enterprises, waste segregation and storage is often a challenging task for the companies, which involves expenditure of time and effort. This laborious task is compromised by the informal waste sectors, which makes the company managers to dispose of waste through informal markets.

The waste materials with highest demand among the informal sectors are: plastic, metal, corrugated material and paper waste. These waste are transported in bulk to the recycling industries to manufacture market ready products.

16 Kalundborg industrial symbiosis case study

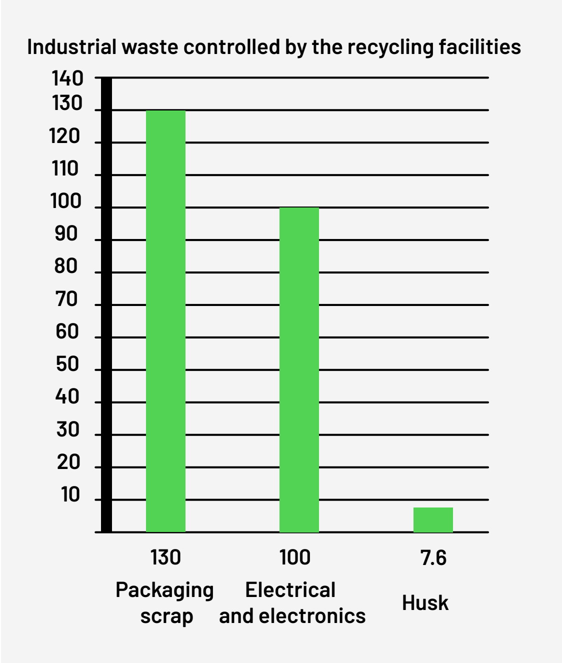
Figure 20: Quantification of industrial waste controlled by the informal waste sectors per month (kg)



Source: Primary survey data collected by the author on the informal waste markets operating at NIE

The formal recycling facilities struggle with the regular supply of raw materials as most of the waste is controlled by the informal waste markets. The waste materials captured by the informal markets are transported to other companies located beyond the industrial estate boundary. For example, a raise in metal scrap demand is observed in the foundry industry, which the waste generating companies trade to the informal markets - resulting the foundry industry in unproductive operation or temporary shutdown of the plant.

Figure 21: Quantification of industrial waste controlled by the recycling facilities per month (kg)



Source: Primary survey data collected by the author on the informal waste markets operating at NIE

10.2. Industrial waste that can be commercialised

Companies pay the price to landfill sites for dumping waste materials. This dumping of waste could be commercially exploited or reused within industrial activities. The lack of utilisation is due to the absence of material segregation or the expenses involved in the remanufacturing process.

Currently, the following waste materials are disposed of at landfill sites, but they can generate monetary returns by installing recycling facility or equipment within the industrial premise.

1. Ceramic waste – refractory industry
2. Horticulture waste – biogas plant
3. Used oil – secondary oil recycling facility
4. Soiled textile waste – Refuse derived fuel (RDF) plant
5. Organic waste – composting plant

The other aspect that affects the waste material utilisation process is the transportation cost. The effect of transportation cost depends upon the location of the donor company to the receiver. As industries are geographically concentrated, the transportation costs of materials are reduced. However, due to the absence of information and cooperation among companies to exchange waste as raw material, the transportation cost to dispose of waste in landfill sites or to find a recycler is expensive.

11. Network behaviour analysis

The networking analysis is applied in the industrial area; the results of which can identify the social embeddedness. This analysis is used to collect quantitative and qualitative data on social relationships and shared norms among the stratified sample area. The data in this study examines the trust factor, openness and communication pattern between the industrialist and the statutory body, which was further analysed to develop a conceptual framework.

The data is collected in relation to the stakeholder analysis, and it is further classified into the formal and informal network. The term formal network is defined to be the community gathering, which includes statutory personnel and the topics are mostly discussed for competitive advantage or an active discussion on industrial area development and planning. The NIA is considered to be a committee of members, who are the members of the industrial area that own or have been a reputed representative of the industrial unit. The informal network is the causal social relationship between 2 or many industrial members. The formal and informal relationship is examined based on their (i) nature and frequency of relationship, (ii) proximity or geographical location, and (iii) agenda. By literature review, it has been revealed that the co-located industrial units with proximity advantage make it an effortless process to optimise the economic and environmental benefits.

Figure 22: Formal engagement of stakeholders

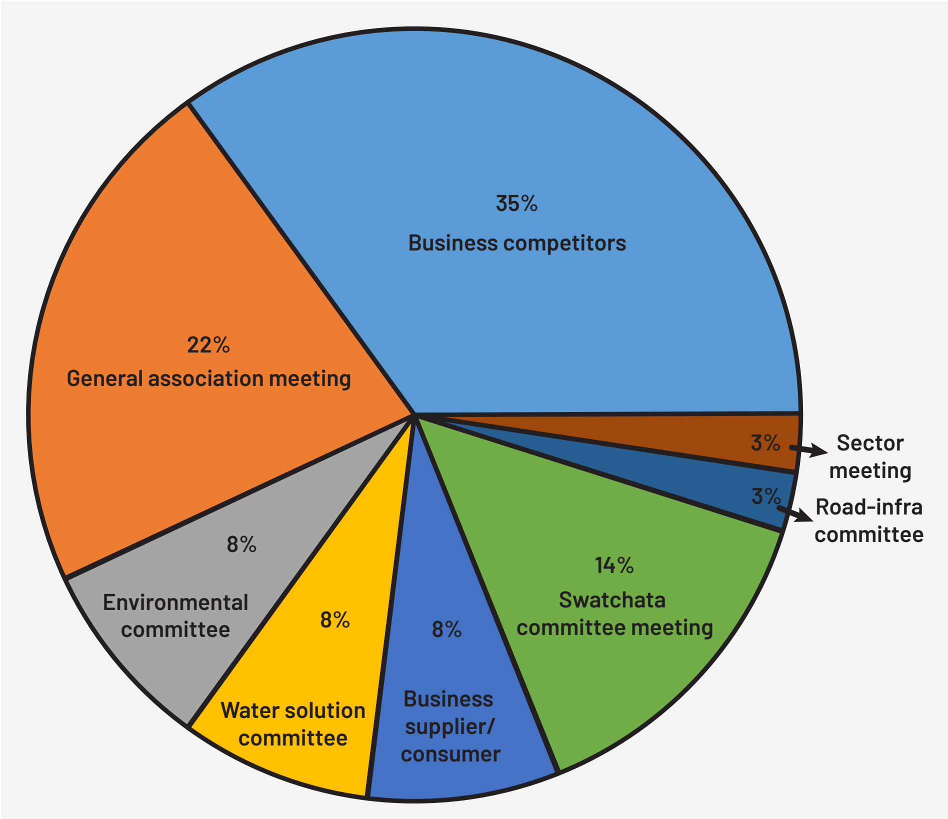
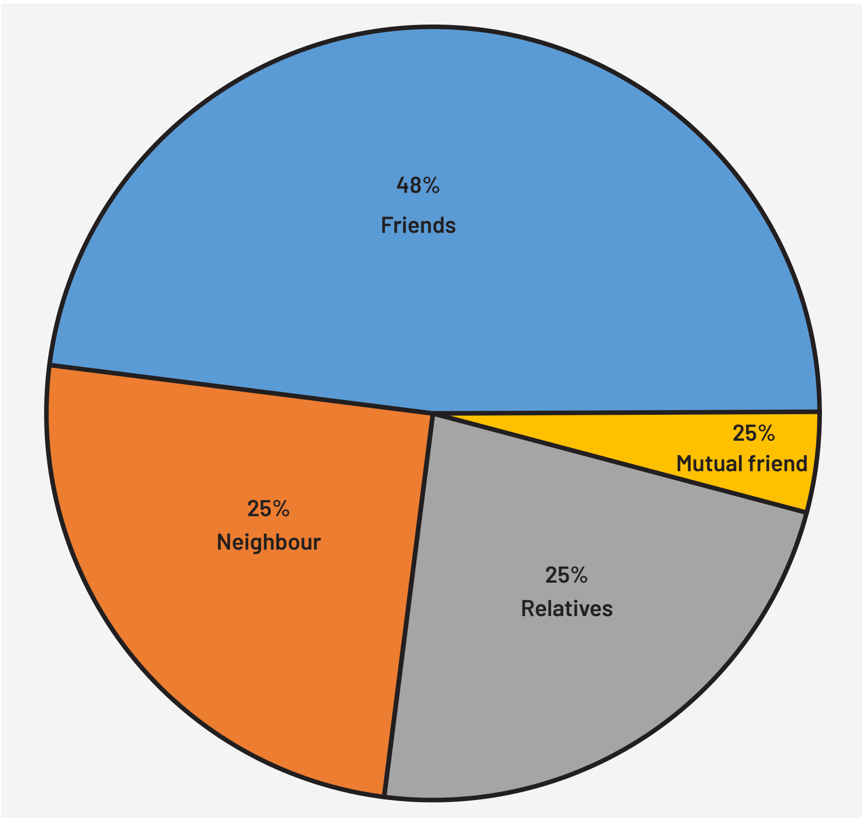


Figure 23: Informal engagement of stakeholders



Source: Analysis of primary data collected by the author

Figure 24: Spatial analysis of formal engagement

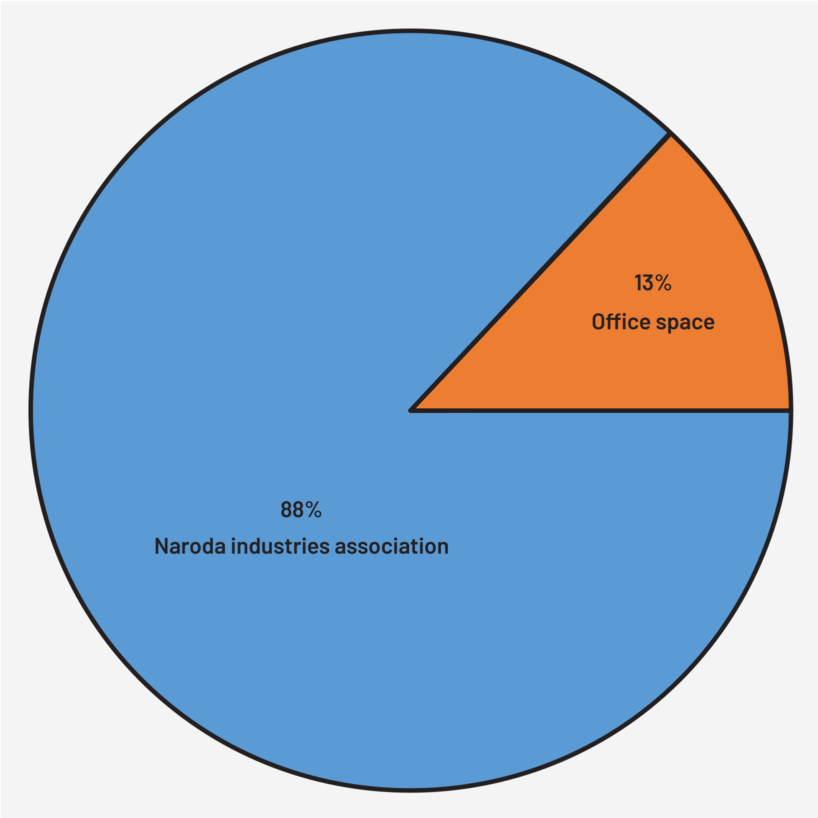
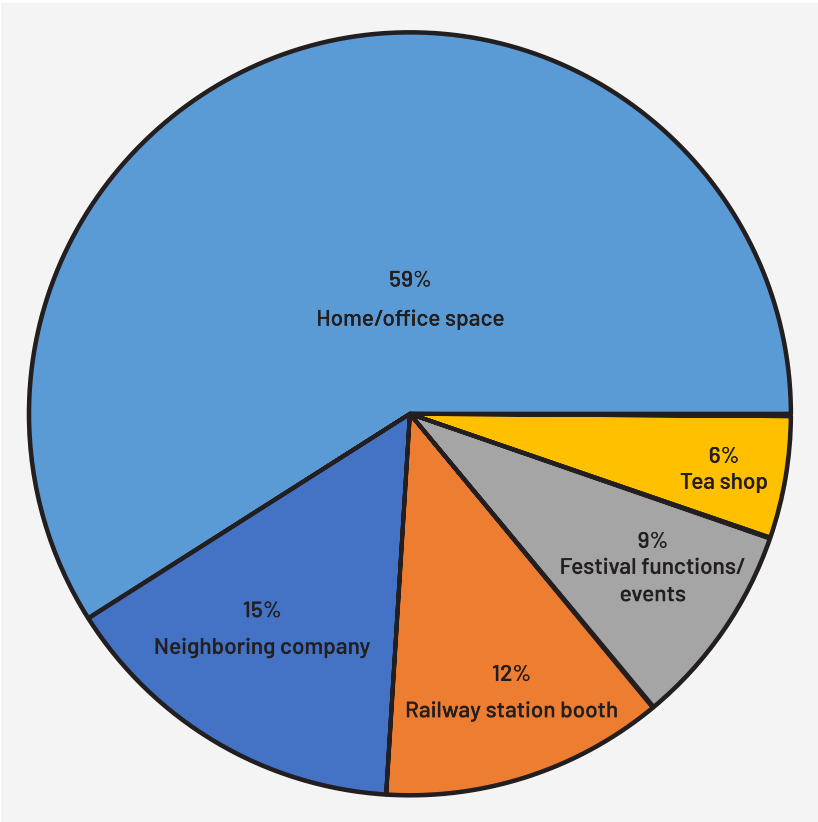


Figure 25: Spatial analysis of informal engagement



Source: Analysis of primary data collected by the author

12. Learnings from NIE case study for industrial symbiosis in India

The learnings from the NIE case study conducted by the Anant Centre for Sustainability helps to understand the IS problem in India in the following ways:

1. IS is adopted differently by several stakeholders. On the one hand, it is referred to as a technical linkage of production processes and the use of waste in those production processes. On the other hand, it is referred mainly to the cooperation, development and management of communities over geographical proximity. The current policies in India are to a great extent, aligned more towards developing technical conditions and cleaner production processes, whereas the social conditions of formal and informal collaborations as well as the technical knowledge of entrepreneurs in waste management in industrial estates are largely ignored.
2. IS is a collective approach to achieve competitive advantage through the exchange of materials amongst companies in close geographic proximity (Chertow, 2000). Therefore, the company manager's decisions concerning the material exchange often requires the involvement of the Board of Directors. However, often the headquarters of large production companies are located far away. This indicates that even if managers of a company are willing to exchange waste, they would still be required to convince the Board of Directors to approve collaborations for IS. Corporate policies of companies are not yet aligned towards facilitating collaboration to promote material circularity.
3. The industries association of every industrial estate in the country has the potential to act as a local hub to initiate collaboration among companies within the industrial estate. This has the potential to serve as a starting point for IS in India. For instance, from time to time, these associations typically invite stakeholders to discuss several environmental problems concerning the industrial estate which could serve as an excellent opportunity to share information and initiative towards industrial networking projects. However, developing commitment, trust and cooperation for a shared vision is a time-consuming process and might often require capacity building within the companies of industrial estates in India.
4. A strategic dialogue between bureaucrats, industrial owners and academia to build an eco-industrial system that is conducive to IS practices is crucial. Our study at the NIE observed self-organised interactions between plastic manufacturing companies to solve a waste utilisation problem. This points to the challenge faced by company managers who are trapped between strict environmental regulations and the high processing cost of waste materials. The current approach of eco-industrial parks is one that is top-down, such that offenders are penalised. However, IS is successful through cooperation.
5. Greater exchange of information related to waste management amongst companies is essential for any industrial estate to successfully roll out IS. Availability of information on waste

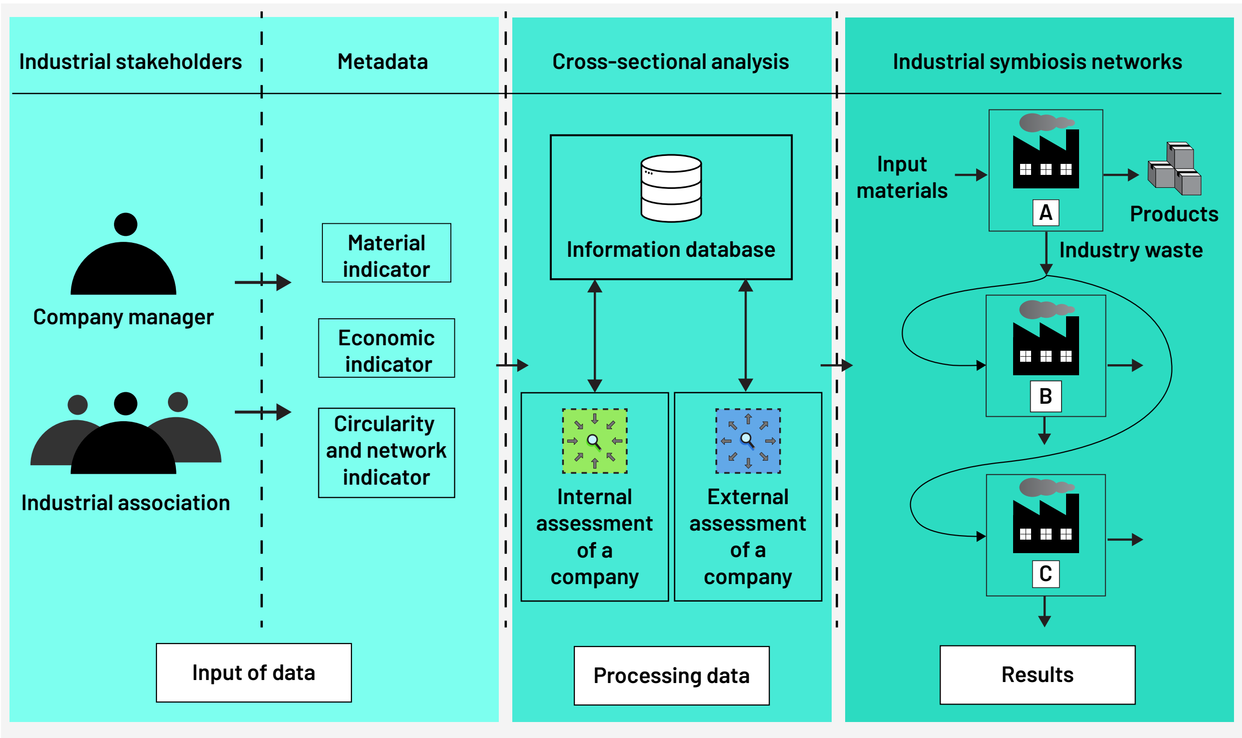
also supports researchers, corporate decision makers, and industry associations to resolve challenges together.

6. The waste economy in India is primarily an informal one - cash payments, no contracts, undocumented supply chain. This is especially prevalent in the waste recycling sector in the country. In Indian industrial estates, this activity is disproportionately dominated by unregistered informal waste dealers, which include cheap labour that move solid waste to recycling systems (Beukering, 1994). Due to the informal nature of this activity, it is difficult to set up systems for formally exchanging waste across companies for industrial symbiosis.

13. Framework for industrial symbiosis implementation in industrial unit and clusters

In order to establish IS within a closed loop system, the first step concerns the definition of a framework and its terminology. The IS framework is used to identify and develop the waste exchange platforms in an industrial estate (Figure 28). The framework consists of the following indicators: material indicator, economic indicator, circularity and network indicator. The IS framework is integrated into an Information and Communication Technology (ICT) Platform that will allow a cross-sectional analysis from different companies to enable various IS networks or waste exchange networks (Figure 26).

Figure 26: ICT Platform technological architecture



13.1. Material indicator

The material indicators guide the reporting organisation to track the data on material consumption, waste material generation and by-products production.

Subset 1: Material consumption indicator combines the data of consumption of both primary and secondary raw materials by the reporting organisation. The data on monthly consumptions expressed in metric ton.

Subset 2: Waste materials indicator collects the data of non-hazardous solid waste materials generated from the reporting organisation. It also involves the data gathering of the total amount of waste materials recycled, expressed in metric ton and percentage.

Subset 3: By-products indicator collects the data of materials generated and recycled. Generally, by-products are sold to nearby companies and this often leads to a symbiotic activity. This collection of data is necessary to track the end supply chain of materials and it additionally maps a materials exchange network of the reporting company.

Table 2: Material indicator

Material indicator		
Subsets of primary indicator	**Indicating**	
Material consumption	Raw materials	unit amount of primary and secondary raw materials in metric ton
Waste materials (non-hazardous)	Solid waste materials generated	unit amount in metric ton
	Waste materials recycled	unit amount in metric ton
	Percentage of waste materials recycled	unit expressed in %
By-products	By-products generated	unit amount in metric ton
	By-products recycled	unit amount in metric ton
	Percentage of by-products recycled	unit expressed in %

13.2. Economic indicator

The economic indicator focuses on the commercials of the reporting organisation. This indicator collects the information on product quantity, operational expenses and revenues from underused materials.

Subset 1: Products indicator is used in an industry to understand the utilisation capacity of a production process. This indicator could also estimate the capacity of materials exchange.

Subset 2: Operational expenses indicator is monitored on the costs of raw materials, waste disposal and waste materials storage. Information from this indicator shows the possible reduction of expenses through symbiotic activities.

Subset 3: Revenue streams from by-products and waste materials monitors the creation of monetary value through residue and waste materials. Furthermore, it leads to the discovery of potential revenue creation from symbiotic activities.

Table 3: Economic indicator

Economic indicator		
Subsets of primary indicator	**Indicating**	
Products	Product quantity	unit amount in metric ton
Operational expenses	Raw material cost	unit expressed in INR
	Waste disposal costs	unit expressed in INR
	Waste materials storage costs	unit expressed in INR
Revenues from by-products and waste materials	Revenues from by-product sales	unit expressed in INR
	Revenues from waste material sales	unit expressed in INR

13.3. Circularity and Network indicator

The circularity and network indicator focuses on promoting the IS activity. The indicators studied in this section are related to the symbiosis factor, quality of materials exchange, positioning of IS actors and operations of an industry.

Subset 1: Symbiosis factor of materials is derived from the treatment of by-products. It is the rate of by-products used within the reporting organisation by the by-products disposed of. The higher the internal usage of the materials and the lower the materials externally disposed of, the higher the symbiosis factor.

Subset 2: Utility - accounts the quality of the by-products/waste materials to analyses the IS activity. It is rated based on the ratio of material's lifetime to its function. The function of a material is assessed by an estimation of similar functions on the market.

Subset 3: Environmental cost effectiveness: evaluates and identifies the most cost efficient preference. This indicator examines the proximity of potential symbiotic networks and proximity of formal and informal IS actor. The least cost option in environmental and economic terms is be chosen.

Subset 4: Operations: evaluates the presence of organisational policies and materials record. This indicator improves the functions of the reporting organisation that could enable the waste exchange platform for IS activity.

Table 4: Circularity and Network indicator

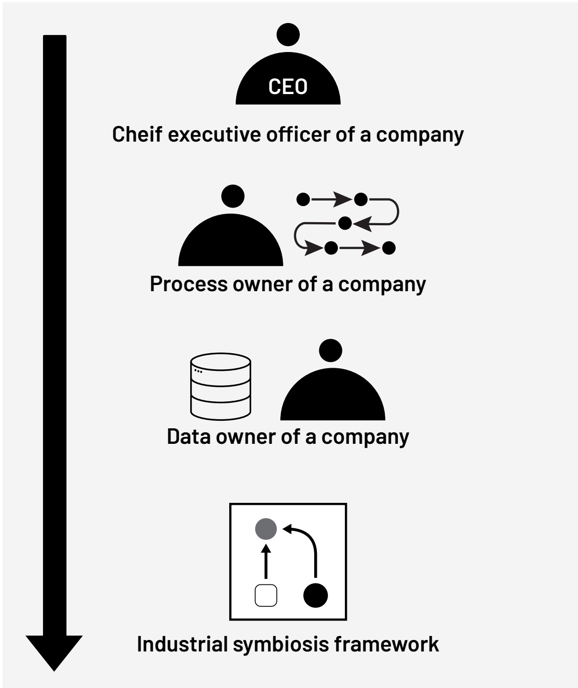
Circularity and Network indicator		
Subsets of primary indicator	**Indicating**	
Symbiosis factor of materials	Ratio of by-products used to the by-products disposed	unit expressed in %
Utility	By-product/waste materials quality	Ratio of product's lifetime/function
Environmental cost effectiveness	Proximity of potential symbiotic network	
	Proximity of formal and informal IS actor	
Operations	Presence of existing policy to enable IS activity	
	Record of waste materials and by-products	

14. Working model of the IS framework – within a company

The process of IS framework (Figure 27) within a company is as follows:

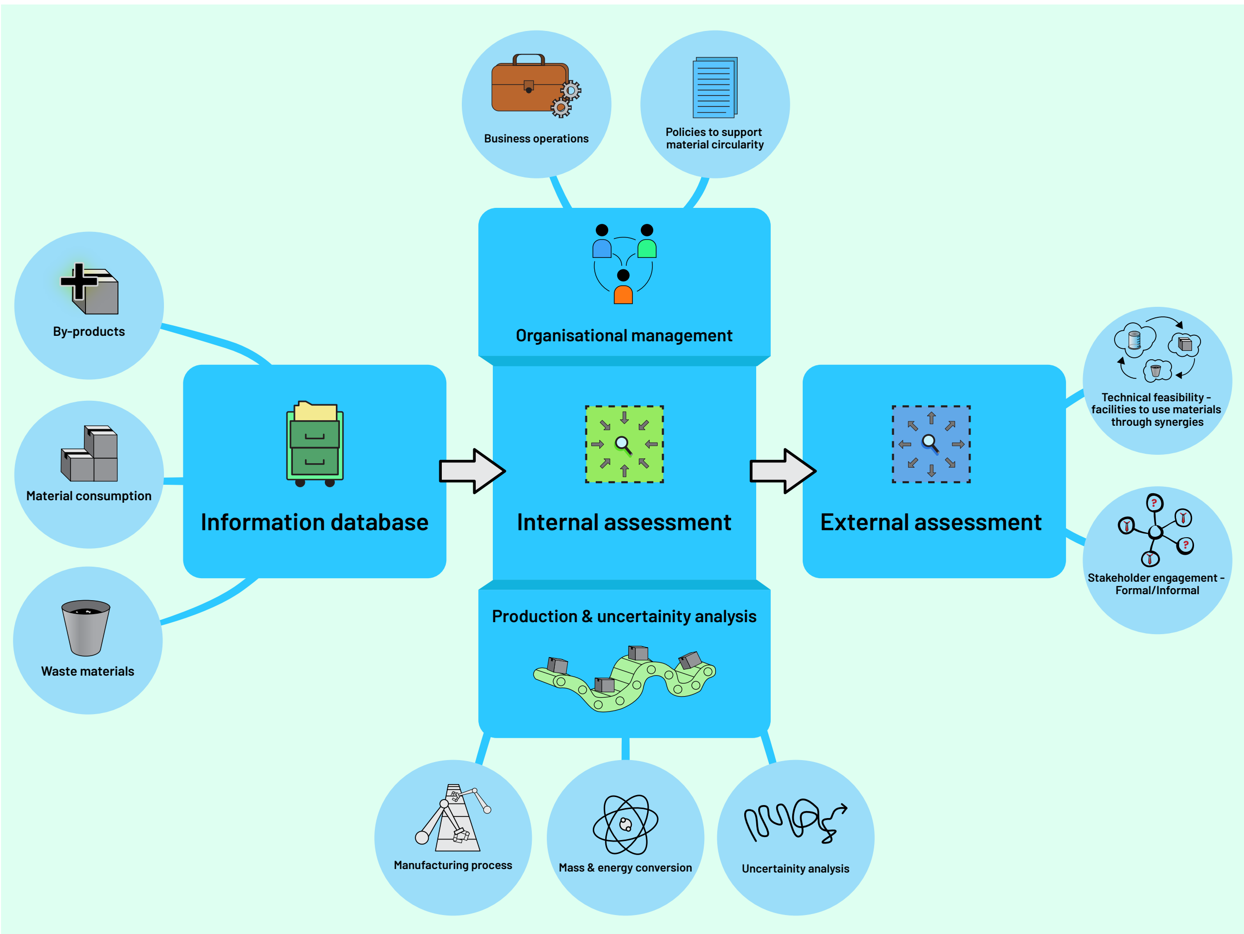
1. Preparation of an objective of the industrial symbiosis – the amount of wealth generated from the company's waste materials are set by the Chief executive officer (CEO) of the organisation and a process in-charge is appointed who will be handling the operations of the IS framework (Figure 28) within the company.
2. The process in-charge appointed by the CEO will search for data owners within the company to gather information about the IS framework.
3. The data owners assigned by the process in-charge will be gathering relevant information of the framework. The gathered information will be then forwarded to the process in-charge.
4. The process in-charge will conduct a primary evaluation, and the data will be shared to the CEO.
5. The CEO and process in-charge will be uploading the final data on an IS information database of the industrial estate.

Figure 27: Execution of IS framework in a manufacturing company



Source: Analysis of primary data collected by the author

Figure 28: Framework for industrial symbiosis implementation within a boundary

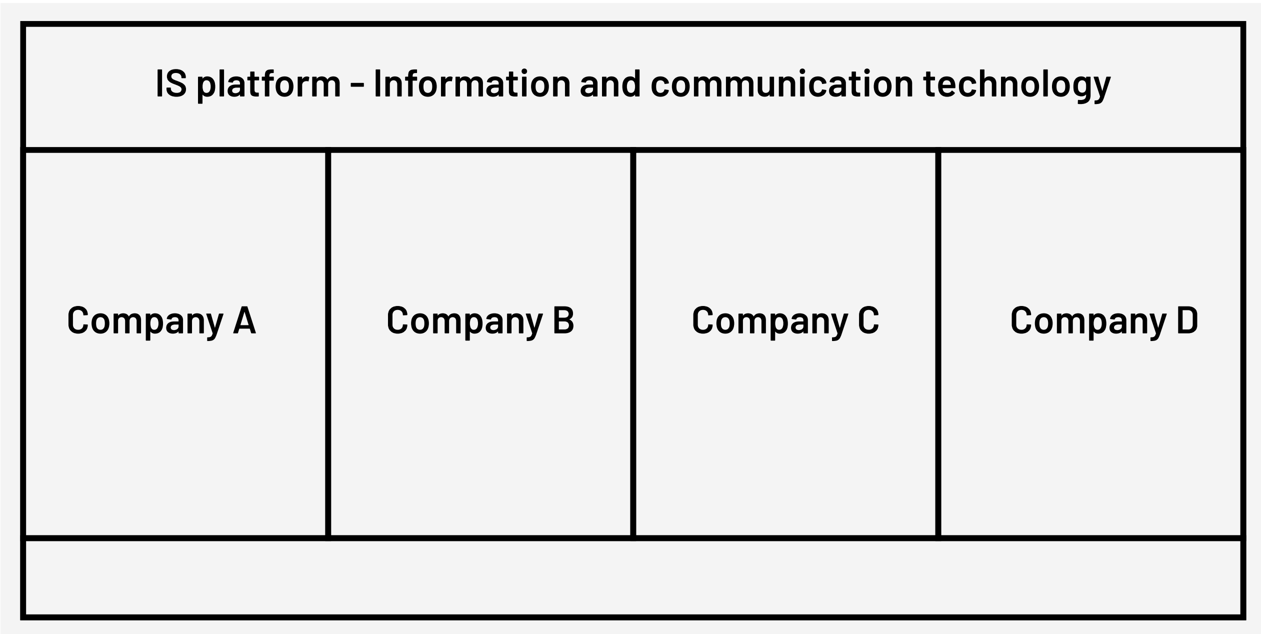


15. Working model of the IS framework – within an industrial estate

The process of IS model within an industrial estate is as follows:

1. The CEO and their process in-charge of each company will share the IS data of their company in an information database.
2. The information database is integrated into an IS software application that is managed by the NIA.
3. Action of the waste materials will be released from each donor in the IS application.
4. Potential formal and informal waste material buyer will be matched within the industrial estate through the IS application.
5. Upon the validation of quality of materials, the receiver will transfer the funds to the buyer. The transportation of materials will take place from the donor of the materials to the receiver.

Figure 29: Execution of IS application in an industrial estate



Annexe

Survey questionnaire

Industrial symbiosis

Questionnaire's focus area:

i. Types
ii. Volume – Weight (unit)
iii. Information on raw material, by-products/residues and output product
iv. Final stage of waste – disposed, treated, end of pipe treatment

Input – Raw material

The raw material would be useful to find the potential by-product cycle. Which primary products / raw material / auxiliary material does your company procure?

Name of primary raw material / auxiliary material procured	Quantity / month	Unit	Weight per unit in kg	Place of supplier

Output product

Product	Quantity/month	Unit	Per unit weight in kg

Output of by-product/residues

Type of by-product produced	Origin of process	Quantity / month	Hazardous (Y/N)	Type of treatment reuse / recycled / disposed	What happens to the by-product

Quantify the by-product/residues:

List of Material					
	Have	*Want*		*Have*	*Want*
Acids			Scrap		
Alkaline			Solid Waste		
Agricultural residue			Wood		
Ash			Batteries		
Barrels			Thermal Waste		
Bulk container			Transport		
Cardboard			Laboratories equipment		
Chemical residues			Production capacity		
Contaminated oil			Sludge waste		
Plastic Drums			Kitchen Waste		
Electric Waste			Vehicles (unused/waste)		
Electrical equipment (unused)			Material Handling		
Filters-air, oil & others			Warehouse waste		
Food wastes			Plasterboard		
Fuels			Office Furniture		
Glass			Process Equipment		
Metals			Aggregate(Concrete)		
Oil waste			Timber		
Paint			Glass		
Pallets			Textile residue		
Paper			Others		
Packaging Plastic					
Plastics-rigid (HDPE)					
Plastics-soft (LDPE)					
Process water					
Shot blast					
solvents					

Annexure 1: Stratified sample size

Type of industry	Total number of units in the industry	Sample size considered
Air compressor & spare parts	6	4
Ceramics	24	5
Chemicals & Pharmaceuticals	181	7
Electricals	17	4
Engineering	111	6
Food	57	11
Furnace & foundry	8	1
Furniture	3	1
General/ support/ utility service	37	1
Packaging	25	6
Plastics	30	7
Printers & stationers	6	2
Rubber	11	1
Scaffolding materials & accessories	1	1
Storage	2	1
Textile	33	7

Annexure 2: Quantification of industrial residues

Residual category	From Sample companies (in kg per month)	In NIE (tons per month)
Non-hazardous ash	1,48,325	2,281
Ceramic waste	7,000	108
Corrugated products	1,51,058	2,323
Dust waste	4,560	70
E-waste	2,59,400	3,990
Food waste	51,802	797
Horticulture waste	30,000	461
Metal waste	1,56,644	2,409
Oil waste	856	13
Paper waste	4,923	76
Plaster of Paris (PoP)	7,000	108
Plastic waste	19,797	304
Textile waste	47,314	728

Wood waste	66,299	1,020
Other waste category*	36,000	563

*The other waste category includes non-hazardous biomass, sludge and synthetic rubber waste.

Annexure 3: Overall recovery, reuse and recycling of residuals (in kg)

Residual category	Total mass of residuals per month (kg)	Reused within facility (kg)	Informal market recycling (kg)	IS (kg)	Formal recycling industry/ agency (kg)	Landfilled/ burnt/ destroyed (kg)
Non-hazardous ash	1,48,325	0	0	0	1,30,600	17,725
Ceramic waste	7,000	0	0	7,000	0	0
Corrugated products	1,51,058	85,040	66,010	0	0	8
Dust waste	4,560	0	0	0	0	4,560
E-waste	2,59,400	0	0	0	2,59,400	0
Food waste	51,802	0	15,000	0	210	36,592
Horticulture waste	30,000	5,000	0	0	0	25,000
Metal waste	1,56,644	0	944	0	1,55,533	167
Oil waste	856	0	853	0	3	0
Paper waste	4,923	3	2,106	0	100	2,714
Plaster of Paris (PoP)	7,000	0	0	0	0	7,000
Plastic waste	19,797	230	13,045	1,000	3,898	1,624
Textile waste	47,314	214	25,800	0	20,418	882
Wood waste	66,299	50	66,169	80	0	0
All other waste	36,600	50	0	0	0	36,550
Total	9,91,578	90,587	1,89,927	8,080	5,70,162	1,32,822

Footnotes

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