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Sustainable waste management practices in the informal sector: Towards industrial symbiosis

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ABSTRACT

Industrial pollution is considered to be routed in the waste and byproducts of the production process. Traditional pollution control approaches try to eliminate and/or treat the pollutants which are often technically complicated and expensive. In this regard, industrial ecology and industrial symbiosis have emerged as effective strategy to eliminate industrial pollution. This principle requires the generated waste/by-products absorbed in the same or other industrial process cycles and thus the material cycle remains closed. Industrial pollution appears as a big problem in the global south countries, where industrialization is considered as the main thrust of economic development. Usually, in such countries formal pollution control approaches are primarily directed to the formal sectors (such as state owned and legally registered industries), informal sectors are often left behind. Although the role of informal sector is increasingly being recognized for sustainable development, their significance in pollution abatement is a less discussed topic. This article attempts to investigate the informal industrial sector in Dhaka, Bangladesh with empirical evidence. Adopting a qualitative approach with field investigation of the informal industries and detail interviews, this study identified that the informal industries are closely linked in clusters according to the manufacturing process and continue material/byproduct/waster exchange primarily from the need to minimize cost. The studied patterns of waste management practice indicate existence of industrial symbiosis without adequate academic/technical knowledge and designed efforts. This suggests that the informal sector can meaningfully contribute to sustainable development offering insights for the application of similar approaches in the formal sector.

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INTRODUCTION

Concern about the environment is ever increasing, and so is the concern for sustainability. Sustainable practices now receive the highest priority to save resources for the present and future generations [1–4]. Since the Brundtland Report to date, environmental protection, economic efficiency, and social equity are unquestionably considered the core objectives of sustainable development [2, 5–7]. Sustainable development is a well-recognized research domain with a great volume, and this study explores the environmental enclave. Within the vast literature in this field, there exists an assumption regarding the role of the state in regulating, controlling, and coordinating activities for sustainable development, focusing on the environment, through technological and non-technological means [5]. The role of the state is obvious, however, the path to sustainability is far from straightforward, and the participants are not always the known ones.

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Beyond the conventional formal stakeholders, the informal sector has also emerged as a significant player in this protracted journey [5, 8, 9]. Scholars consider that the informal sector often remains obscured in the mainstream sustainability discourse due to its unique characteristics such as nonstandard, illegal, hidden, shadowy, invisible, unobserved, irregular, and unofficial [10–14]. Though the question of administering the informal sector is still in the academic debate, their role is being widely accepted for inclusive sustainable development [8, 9]. Gradually the informal sector is being considered, sometimes, in the policy framework too. In some fields, such as waste management, recycling etc. the contribution of informal sector is well recognized [15–19]. While informal sector waste management and recycling is a recognized academic field, there is deficiency of scientific knowledge regarding the contribution of informal sector in pollution generation and abatement [20–24]. On the other hand, informality is often associated with many countries in the global south [25–27] where development is often prioritizes over environment and the drive is mostly towards growth at any cost being blind to the environmental burdens [28–31]. In addition, they often opt for traditional expensive ways of treating the generated waste [22, 32].

In such context, this research is focused towards the informal waste management from the perspective of industrial pollution control, which is often left outside the mainstream pollution control domain [22]. It attempts to study the informal industrial sector in relation to the concept of Industrial Symbiosis (IS) taking the examples from the city of Dhaka in Bangladesh, a country where more than 80% of the national employment is offered by informal sector and the rate varies between 60-90% in the urban areas [33]. Bangladesh shows typical pattern of development-environment dilemma where the environmental concern is recognized only since the 1990s [34] and the focus is to control environmental pollution caused by the industrial sector through treatment of the pollutants [35–37].

Informal small and scale industries contribute to a significant portion of the manufacturing sector in Bangladesh and they are often blamed for environmental pollution of varying extent [38, 39]. This study attempts to investigate the waste management practices in the informal industrial sector in Dhaka, in a qualitative manner, with the aim to look for sustainable practices that can reduce the environmental burden. This study aimed to get a clear understanding of.

- How the informal industries manage their waste.
- If the industries are consciously adopting any strategies to reduce waste.
- The state of material cycle within the industries or within the expanded boundary of the industrial unit incorporating other industries.

Due to the lack of scientific and/or national level databased on the informal manufacturing industries, this qualitative study was exercised with observation of the industries and semi structured interviews with the entrepreneurs. Data was analyzed with qualitative content analysis method to understand how these informal industries manage their waste or by-products and how the material cycles relate to the principles of Industrial Ecology (IE) and IS.

The scope of this study is restricted only the informal those industrial units that use new or used or both types of materials as raw material for their production process leaving the recycling activities out of the scope. Therefore, this study is distinguished from other studies that uncovers symbiotic activities in the formal industrial sectors that might include informal activities within the broader industrial enclave, for example the studies in Sitakunda-Bhatiary of Bangladesh [40] and Nanjagud in India [41].

The implication of the study is multifaceted. This study contributes to understanding the informal sector, particularly to the character of small-scale manufacturing industries regarding production, clustering, interconnectedness etc. This identifies that the informal industries exercise sustainable waste management practices and suggest that more of such examples await to be explored. A significant driver behind this sustainable practice is economic benefit, rather environmental concern. This suggests the policymaker about the adoption of IE/IS and CP principles for informal sector and the directives for the formal sector.

The Material Perspective for Pollution Abatement

Analysis of material flow in the industrial process makes it clear that industrial pollution is routed in the waste and by-products generated from the industrial process. Thus, to diminish industrial pollution, elimination of industrial waste is considered the best approach. The traditional End-of-Pipe (EOP) method of pollution control approach treats the wastes and recuses pollution, but does not necessarily eliminate the polluting wastes and increase the production cost [32, 42, 43]. Yet pollution control approaches are applied, and even sometimes enforced by regulations, for industrial waste management in most of the global south countries [22, 32]. The response to industrial pollution has been shifted from initial EOP towards the recent IE for a sustainable industrial development in terms of both resource consumption and waste management. The basic principle of IE is that output from one industrial process could be used as input for other industrial process/processes [44, 45]. Thus IE aims to optimize the material cycle from raw materials to final disposal, and ultimately striving for a zero-waste, non-polluting industrial system [43, 46–48]. With the growing concern of dealing with environmental issues, IE concept denotes a vital step and is believed to lead towards a society with sustainable production and consumption because it incorporates the technological perspective of Pollution Prevention (P2) Cleaner Production (CP) and Life Cycle Assessment (LCA) [49–51]. In this vein, IS is considered as a subset of IE enclave.

The notion of industrial symbiosis is derived from biological symbiotic relationships of species in the natural environment. It is the relationship among different industrial enterprises. This idea was initially recognized as the matrix of complex relationship among different entities to strive

for a collective benefit greater than the sum of individual benefits [52]. IS is usually developed within a specified place boundary like an (eco)industrial park [52–55]. However, studies also indicate that it is necessary to extend the geographical boundary beyond that specified formal park so that other industries in the wider area can be included in the material flow [56]. Also it is noted that outside the industrial parks, there are possibilities of meaningful benefits achieved from sharing of resources among the business in industrial districts [52, 57].

Industrial Symbiosis is usually developed either as designed or evolved from mutual understanding and benefits. IS in Kalundborg, Denmark is a classic example of mutual understanding [52, 57]. IS usually emerges as 'self-organized' business among willing firms with a common strategy to reduce the increasing cost of waste management stipulated by the legislative requirements [58]. Usually, such businesses are located in close geographical proximity, such as designated industrial areas. Such 'spontaneous co-location' of businesses in industrial districts can offer many public and private benefits including labor availability, access to capital, technological innovation, infrastructure efficiency etc. [59–61]. Such 'unplanned' development of IS may produce better result that planned developments, in new or underdeveloped eco-industrial parks [62]. It is also noted that 'anterior territorial agglomerations' is not always necessary for industrial symbiosis and entrepreneurial activities can lead to symbiotic relationship as well [40]. However, the modern literature generally overlooks environmental benefits of agglomeration through resource sharing [63] and there is a consensus that 'self-organized' symbiosis networks are insufficient and urge that delicate policy instruments, facilitatory environment and enabling framework are required to develop successful industrial ecosystem [53, 57]. The enabling framework for development of industrial symbiosis is influenced by social, informational, technological, economic and political factors [58]. Perhaps this is why IS is very often perceived as some designed and deliberate effort for the industrialized societies. Although, studies have identified examples of IS in the emerging and developing economies as well, such as Puerto Rico [64], China [54, 55, 65], Vietnam [66] etc., and there are also initiatives in some Latin American and African countries [67]. There have been also a few studies to identify spontaneous development of symbiotic activities in formalized industrial areas in the developing economies such as India [41], Bangladesh [40] etc. Studies in this field has grown sufficiently in the last decade and they suggest increasing concern about the IS principle and practice, however there are relatively few studies in the global south and extremely rare example in the informal sector, even though waste management in the informal sector is well recognized in such countries.

Waste Management in the Informal Sector

In the informality discourse, the core idea that the informal sector works outside the established legal/regulatory framework which restricts greater benefit is quite old fashioned [68]. Contemporary studies have identified the informal sector with organizing logic and a system of norms that governs the process of urban transformation itself [69–71]. For this study, the character of informality is perceived not on the illegality issue, but on the modality of informal activity. This signifies that informality is identified by what they lack, but by what they are [69].

Informality is a distinguished feature in the South and South-East Asian cities with a considerable share in employment generation [69, 72–75]. The significance of informal sector in the domain for material recycling and recovery is well established [41, 76–81]. The waste business operates in a 'grey market' outside the regulatory framework of concerned authorities [82]. It is quite difficult to keep track of materials in this multilayered waste business that involves several actors and run for both domestic and non-domestic waste. At the lower level, collectors gather waste door-to-door or scavenge from dumpsites. Some collectors purchase waste and old staff from households for cash or new products. Organized door-to-door waste collection and transportation to dumpsites are common [78, 83]. Collectors sort the waste and sell it to scrap dealers, who, in turn, contract collectors to obtain waste from diverse sources. These dealers often secure agreements to collect waste from non-domestic waste producers based on their capacity and social influence. Subsequently, the scrap dealers sort the waste and sell it to different clients, either directly or through intermediaries.

Informal Waste Management in Dhaka

Dhaka, the capital of Bangladesh is a densely populated city. The city has a waste production rate of approximately 1,950 tons/day for domestic source and 1,050 tons/day for non-domestic source including industries [84]. At best half of the waste is collected and a large portion of the waste handling is performed in the informal sector [76, 81, 84, 85].

The waste business involves various actors, including waste collectors and treaders operating at varying scale. Door-to-door waste collection is usually organized. Waste pickers, known locally as 'tokai', scavenge for waste, while 'feriwala' buy discarded items from households and businesses. These feriwalas then sell the collected items to scrap dealers, referred to as 'vangari', who play a central role in sorting, dismantling, and selling various types of waste to different user groups on demand. There is a dearth of academic research about this waste business related to informal industries, but it is perceived that the informal industries collect materials from the waste market [86].

In Dhaka the southern periphery is the house of scrap business as well as informal industries for a long time [19, 86, 87]. These industries are usually small scale and mostly termed as workshops in the local culture. Industries with similar production process are clustered together and they work on mutual understanding. Clustering of similar industries is a defining and historical characteristic of the older part of Dhaka resulting in specific areas becoming renowned for particular types of industries [39, 86, 87].

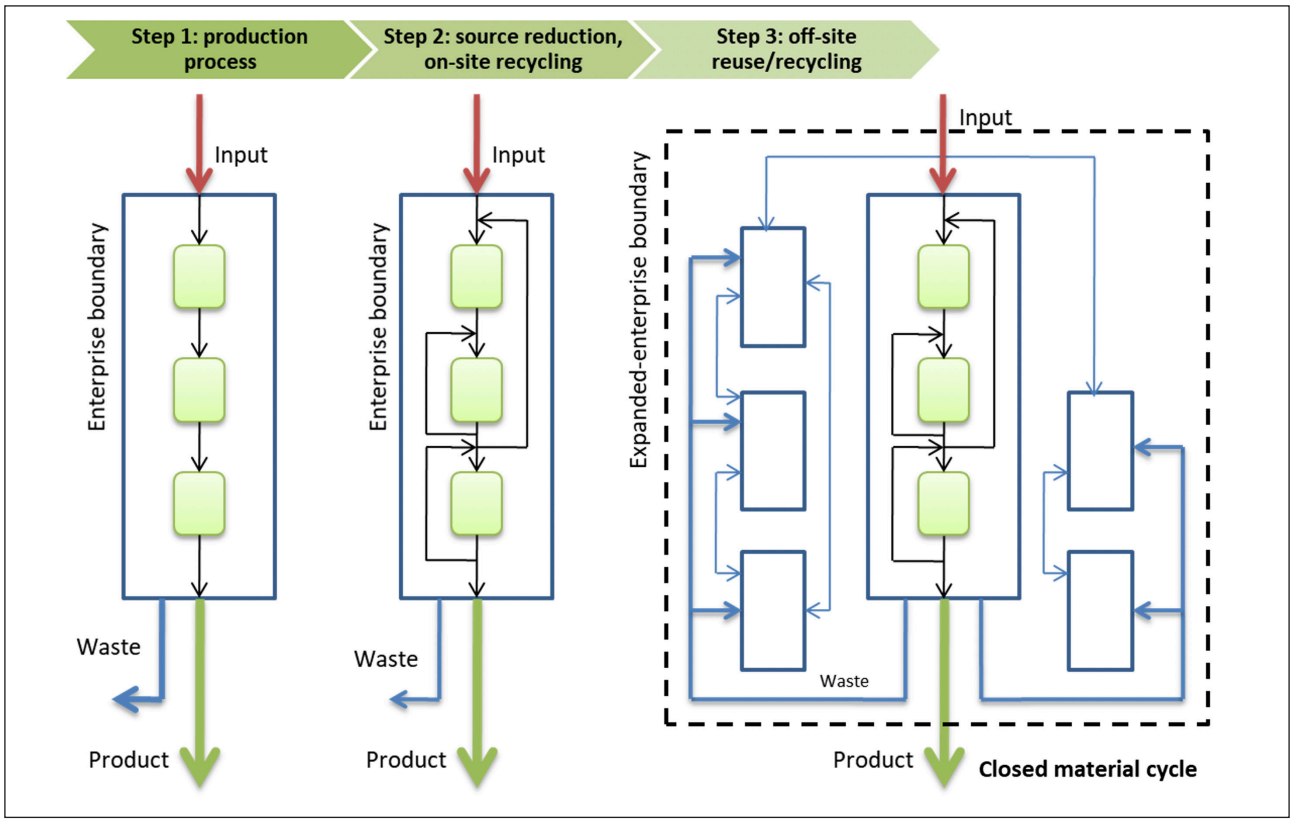

Figure 1. Conceptual framework to address the waste stream, based on [48].

METHODOLOGY

Conceptual Framework Regarding IEs

The concept of Industrial Ecology (IE) suggests that any residuals or by-products should be considered as potential inputs for other industrial units. It also requires the design of products for reuse, ensuring that the material cycle closes effectively. Following this principle, a three-step conceptual framework was developed for this study with the aim to analyze material flow and waste streams and as a guideline to close the material cycle. The framework, illustrated in the following figure, is based on a previous study [48] (Fig. 1).

Identification of Informal Industries

Academic research in Bangladesh typically consider the characteristics of activities to define informality [39, 75, 78, 85, 86, 88]. Accordingly, for this this research, industrial units were considered informal if they had one or more of certain characteristics: non-permanence and casualness, operation in open spaces or in space that is not assigned for that use by the concerned authority, operation in residence or backyard, remaining outside the scope of company law or factory act or trade license or any other government regulations, small scale with less capital investment and mostly relying on household labor [88, 89].

Selection of Study Area

No comprehensive database is available regarding the type of informal industrial clusters in Dhaka. The old part of Dhaka (including the southern periphery along the Buriganga river) is generally considered as the hub, nevertheless some studies have identified specific areas for industrial concentration, to name a few Dholaikhal, Lalbagh, Islambagh, Chawak Bazar, Imamganj, Postogola, Keraniganj, Kamrangir Char, etc. [19, 39, 86, 88, 90–92]. Following the available literature and field investigation, three areas of old Dhaka were selected for detail investigation, namely Dholaikhal, Imamganj and Kamalbagh (near Lalbagh and Islambagh).

Dholaikhal is well known for its concentration of metal works and iron business as well as specialized for repairing and remanufacturing services for the automobiles and light engineering works. At least one study indicated that the industries in this area have some connection regarding waste and material flow [86]. Imamganj is specialized for waste business for the entire Dhaka citys and connects with waste business outside the city. This area is dotted with industries that use recovered or recycled materials such as plastic, metal, paper etc. Kamalbagh is close to Lalbagh and Islambagh, well known for plastic manufacturing. Kamalbagh has a concentration of small industries that manufacture mainly cheap shoes/sandals and a variety of cheap trifle items.

Data Collection and Analysis

This research is carried out in a qualitative manner. Industrial units from different industrial process clusters of Dholaikhal, Imamgonj and Kamalbagh are selected following purposive and snowball sampling [93, 94]. First, based on field observation informal industries were identified, then

Figure 2. Product sample, molded metal section and foundry works (left to right).

Figure 3. Dice making, molded metal section and finished product (left to right).

industrial units were observed, and entrepreneur were interviewed. From this round of interview other interview contacts were obtained, and this snowballing was carried until the loop in the conceptual framework was (nearly) complete and collected information reached the saturation point. Some entrepreneurs refused to cooperate, and some loops were found open and/or did not comply with the conceptual framework; such cases were not considered in the final analysis.

Observation primarily focused on the production chain covering the issues of production process, input and output materials, flow of materials, waste/byproducts generation, recycling/reuse of materials/waste/byproducts, waste disposal/management, link with other industrial units/clusters etc. Interviews were informal in nature, this means notes were taken instead of recording and conducted with semi-structured questionnaire. Interviews aimed to know more about the industrial process and get deeper understanding of their reasoning behind their actions/decisions, environmental concern, knowledge about pollution and industrial ecology, support for pollution/waste reduction or technological improvement from public/other agencies etc. Alongside, field notes from observation were also considered for analyzing the total matrix. There were a few assistants for field data collection, for consistency assistants were assigned to the same group of industries.

All the collected information was analyzed, following qualitative content analysis though constant comparison with the conceptual framework and relevant literature [95–97]. The analysis aimed identify the flow of material in the production process and relate the industrial unit/cluster with relevant stage identified in the conceptual framework. It also attempted to identify if any relation existed among the clusters in the area or within a wider area.

A total of 44 industrial units were observed and interviewed in detail. 12 for lathe engineering works and 10 for old tire business making a total of 22 in Dholaikhal, 16 for metal works in Imamganj and 6 for plastic shoemaking in Kamalbagh. In addition, 3 more expert interviews were conducted with the concerned regulatory authorities in Bangladesh, namely the Ministry of Industries, Bangladesh Small and Cottage Industries Corporation (BSCIC) and SME Foundation, to know about the formal initiative regarding IE or any other concepts for environmental concern for the industrial sector. At least 4 examples of (nearly) closed material cycle loops were identified in the study area, counting 2 in Dholaikhal, 1 in Imamganj and 1 in Kamalbagh area.

RESULTS AND DISCUSSION

The investigation identified at least 4 patterns of closed loops. It was quite interesting that there were efforts of resource recycling, recovery, and reuse, clustering of similar industries, and interconnectedness of similar and related production. Such efforts from the entrepreneurs were not made with any consciousness for the IE concept or with any considerations to reduce environmental burden, or with any support or knowledge from the concerned authorities, but purely driven by economic constraints. All of the entrepreneurs confirmed that the connections developed predominantly with the aim of reducing resource consumption and starting new business with minimum investment while

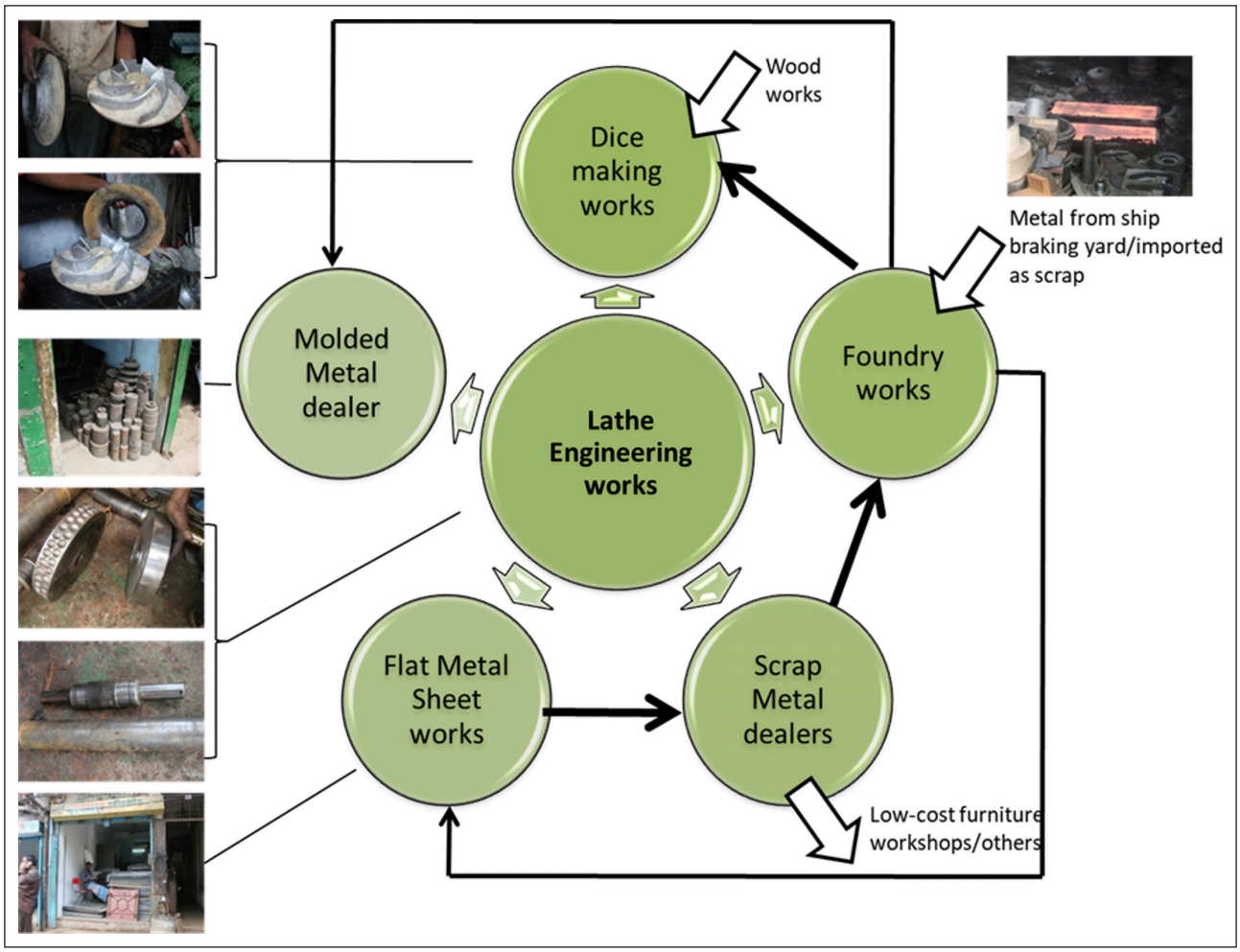

Figure 4. Material flow in Lathe engineering works in Dholaikhal.

they expanded by mimicking others doing the same. The identified cycles are described here.

Pattern 1: Lathe Engineering Works

Lathe engineering workshops in Dholaikhal typically received orders along with product samples. For simple products, the workshops collected metal sections from molded metal shops, usually found in Dholaikhal or nearby areas like Jatrabari, Demra, and Postogola. These shops sell metal sections in various forms and sizes, often casting them in small and large foundries. A significant portion of the metal used were recycled from scrap generated in Dholaikhal workshops, with some imported or collected from ship-breaking yards in Chittagong.

For more complex products, lathe works contacted dice-making workshops, mostly located in Bongram, to acquire molds for casting metal sections. Dice making often involves woodwork and cast-iron works. The sole responsibility of completing the mold fall on the dice maker. Woodwork was typically found in Badamtoli, and foundry works for cast iron sections in Dholaikhal and Bongram. Occasionally, lathe engineering works needed flat metal sheets, however flat metal sheet works normally function as separate business. Additional accessories are usually sourced from Nawabpur (Fig. 2).

Scrap dealers collected scrap metals from various workshops, sorted and sold them on demand. Shredded metals were recycled in foundries, while larger portions of flat metal sheet were sold to furniture-making workshops, commonly located in Jatrabari and Sayedabad. This network formed a closed flow of metal, connecting dispersed industries in different locations without significantly increasing production costs due to additional transport. The flow is presented graphically here (Fig. 3).

Pattern 2: Old Tire Retreading

This cluster of workshops were found to deal with old tires. All the parts of an old tire were either reused or used to manufacture variety of different products. This tire cluster comprised five main groups of workshops. The first group purchased old and rejected tires, sorted them, and sold to other workshops based on types and demand. The second group repaired less damaged tires for rural vehicles. The third group collected irreparable damaged tires, cut them into sections, and separated bead wires, which were sold to the fourth group producing springs and shock absorbers, located in Jinjira and Keraniganj on the other side of the river Buriganga. Cut tire sections were sold to different workshops (Fig. 4).

Figure 5. Tire retreading cluster, manual cutting, separated bead wires (left to right).

Figure 6. Different products made from old tires (left to right).

The fifth group produced diverse products from cut sections, including belts for various machines, hinge protectors, shock absorbers for engines and vehicle bodies, and components for machinery used in textiles, river digging, low-cost furniture, shoemaking, boat building, and bolt joining. Workers were observed to have a high level of manual cutting skill (Fig. 5).

Scrap dealers collected shredded tires from cutting workshops year-round for sale. Shredded tires served two purposes, oil production and fuel for brick kilns. In the oil production process, scrapped tires were burned to yield oil and carbon black. The oil was usually used as industrial fuel or further refined to diesel, while carbon black served as fuel or occasionally refined. Brick kilns used scrapped tires as fuel. In this, a closed material flow was observed with every part of an old tire as recovered or reused to manufacture new products. The bead wire workshops were the only cluster located away from Dholaikhal in this cycle. The cycle is represented graphically as follows (Fig. 6).

Pattern 3: Metal Products Manufacturing

At least 16 mall-scale industrial units, popularly referred to as workshops, that manufactured various trifle metal products in Imamganj were studied in detail. These workshops utilized both new and old/used input materials in their production processes. Typically, thin flat metal sheets were imported and stored in warehouses, locally called godown. Imamganj hosting the majority of such warehouses, served the entire city for bulk and retail. Some of the godowns were equipped with cutting machines for efficient business (Fig. 7).

Household items like mugs, measuring cups, cooking pans, buckets, and box trunks were generally manufactured in the Imamganj area. Metal handles for box trunks and buckets were not produced on-site; instead, old metal handles were purchased from vangari shops (scrap dealers) and reused. Containers for various purposes, like baking molds, oil cans, biscuit tins, kerosene containers, tar cans etc. were also crafted here. Container labeling was carried out in a different area across the Buriganga River. Leftover metal sections were sold to workshops producing very small containers, such as those for tobacco, betel nut, and spices (Fig. 8).

Additionally, some workshops in the area manufactured kerosene lamps with used metal cans, such as different types of aluminum beverage cans, spray cans etc. These slender, cylindrical cans were cut into two or three sections, depending on length, with the lamp's handle and bottom section made from the same can or leftover metal sections. Nozzles were crafted separately and affixed to the lamps. Cotton filaments, produced in unrelated industrial processes, were retailed to end-users in separate shops. Discarded lamps and other metal products were reintegrated into the waste recycling cycle (Fig. 9).

Lastly, scrap dealers collected scrap metals from the manufacturers multiple times a year, sorting and selling them to different users. Larger discarded metal sections were used for manufacturing rivet fasteners, low-cost furniture, kitchen tools, and for binding deformed bars in construction sites and steel mills. Shredded metals too small for reuse were recycled in foundry workshops. The remaining metal sections reached end-users through scrap dealers (Fig. 10).

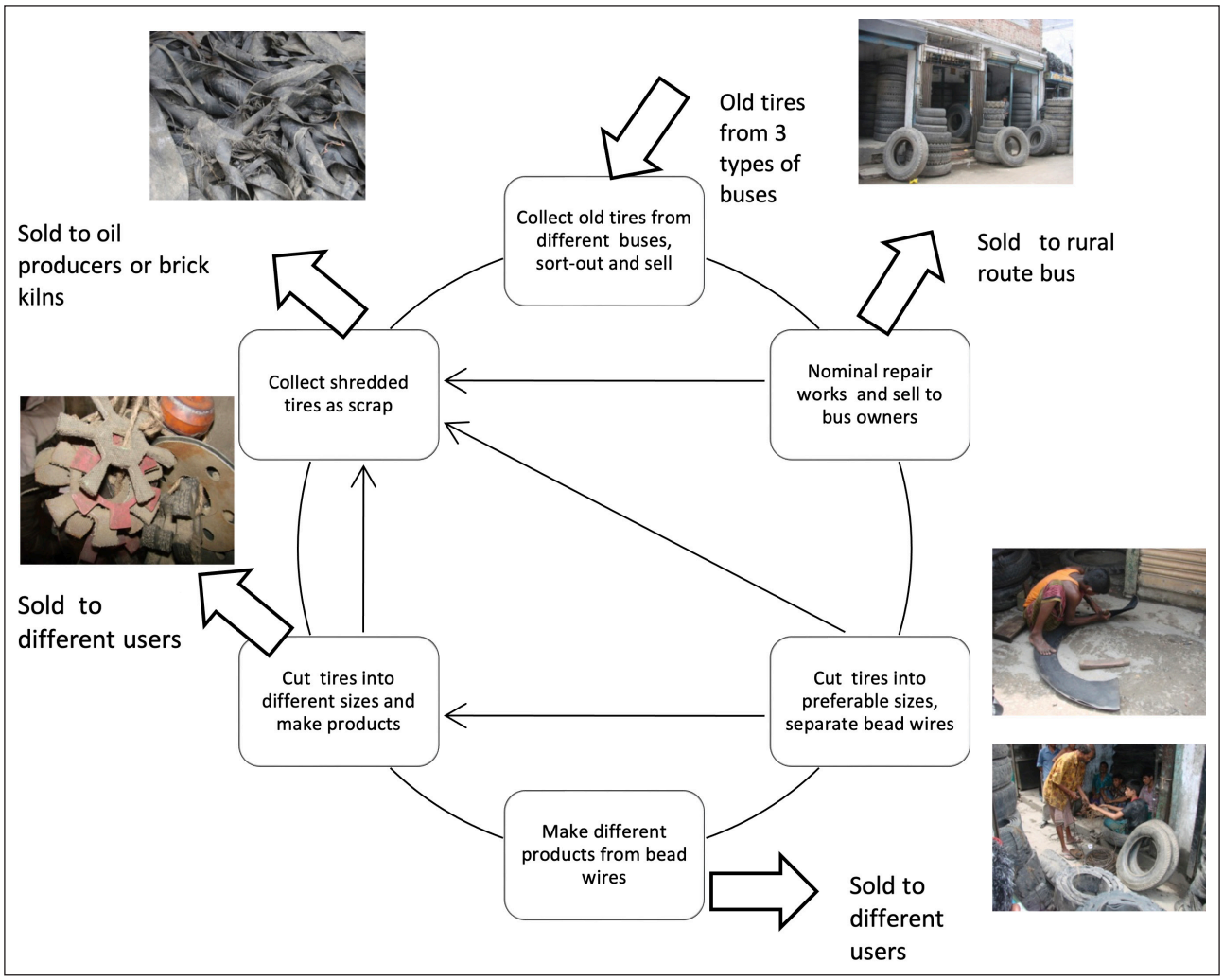

Figure 7. Material flow in the old tire retreading business in Dholaikhal.

Figure 8. New metal sheets, old and cut sections of metal sheets, metal handles of rejected buckets (left to right).

Figure 9. Manufacturing of box trunk, bucket, mug and cooking pan (left to right).

Figure 10. Manufacturing of metal containers and kerosene lamp (left to right).

Figure 11. Left over metal sections, rivet fasteners and washers, kitchen tools (grater) and shredded metals for recycling (left to right).

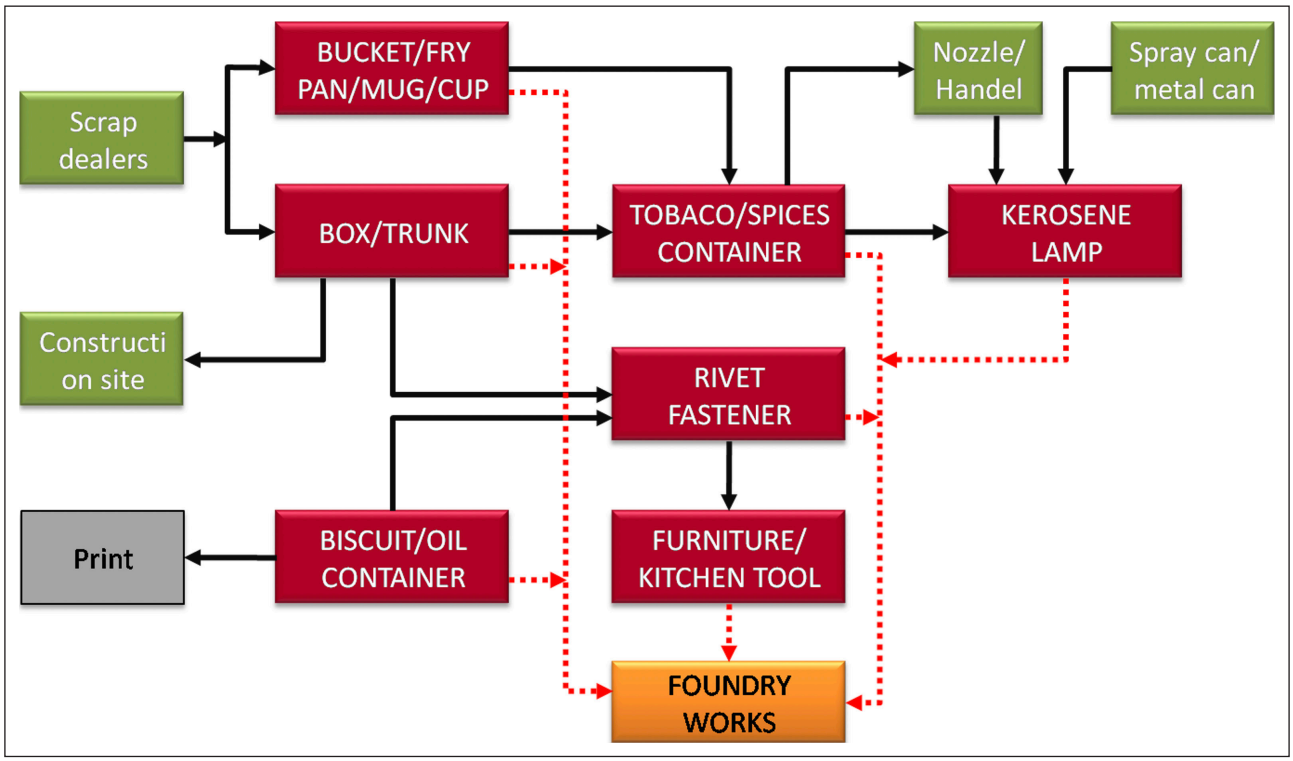

Figure 12. Flow of material in the metal products manufacturing clusters in Imamganj.

In this example, flow of metal was closed with nearly all industrial units located in Imamganj. The material cycle is graphically represented as follows (Fig. 11).

Pattern 4: Shoe Manufacturing

This was a cluster of industries in the Kamalbagh area that manufactured affordable plastic shoes, sandals, small toys and trifle items. The industries were popularly termed as factories. This study focused on shoemaking.

The factories primarily used Chlorinated Paraffin Wax (CPW) and Ethylene Vinyl Acetate (EVA) as raw materials, obtained locally or imported. CPW and EVA were used in the production of rubber and Polymerized Vinyl Chloride (PVC) in the shoe factories. Rubber formed the sole and lower part of the shoe, while PVC was used for the upper part. Rubber sheets were cut for soles, with leftover sheets recycled for reuse. PVC was molded into desired shapes for the upper parts, and any leftover PVC was recycled within the production cycle. Occasionally, minimal amount of waste PVC was sold to the nearby plastic factories that manufacture small toys and trifle items like tiffin box, container box, mug, watering can, soap case, pen stand etc (Fig. 12).

Figure 13. EVA raw material for producing rubber sheets, newly produced rubber sheets, dice for preparing shoe sole and newly produced PVC sandal straps (left to right).

Figure 14. First grade (newly produced) shoes, left over cuts of soles to be reused in the production (left to right).

Shoes produced from new raw materials were termed as first grade shoes. In addition to the standard production chain, waste and used plastic shoes were utilized as raw materials. Such items were collected from scrap dealers and various sources cleaned and different parts were crushed and incorporated into the production line. Recycling occurred at least twice resulting in second and third-grade shoes with diminishing quality. The color in recycled shoes had non uniform color and the blend had back or close to black hue. Recycled shoes were often painted black or another dark hue to mask their messy colors (Fig. 13, 14).

The quality of shoes decreased with each recycle, with third-grade shoes being the lowest in quality, but cheapest. Newly produced and recycled parts were sometimes mixed in the same shoe to reduce costs but at the expense of quality. Shredded plastic and rubber items that couldn't be reused were sold to scrap dealers and brick kilns, serving as fuel (Fig. 15).

This shoe cluster maintained a closed material cycle, with all residuals reused within the production line. Old and scrapped shoes underwent recycling up to three times in the same production line. Any remaining waste, if produced, was utilized in nearby plastic factories. This cycle closely resembled the conceptual framework of a closed material cycle, with onsite and offsite recycling, resulting in various types of new, recycled, and mixed-grade shoes. The material cycle is graphically presented below (Fig. 16).

The IE and IS concepts are often seen as designed approaches, hence, leading to a perception that their application are primarily confined to eco industrial parks [52–55]. Although there are examples of such relation that have evolved gradually, but again such examples are usually found within a specified place boundary like the Kalundborg [52, 57]. The studied examples in Dhaka are outside the scope of eco-industrial park or any other kind of formal approach of industrial area. Hence, the designed territorial approaches cannot be applied as verbatim, instead relevance with the core idea of IS is meaningful (Fig. 17).

In the industrial enclave, it is not uncommon to observe many types of exchanges among the industrial units, but this does not necessarily mean IS [98]. The development of symbiotic relation can be identified in different stages such as Sprouting, Uncovering and Embeddedness and Institutionalization [98]. Sprouting is the early stage where firms begin to exchange resources randomly. This initial exchange is considered as the kernels of IS which many or may not lead to further exchange activities [57]. Uncovering refers to the disclosure of exchange networks with environmental bene-

Figure 15. Old shoes for recycling, crushed chips of old shoes and recycled sheets (left to right).

Figure 16. Second grade shoes in black hue, third grade shoes in black hue, painted third grade shoes and mixed grade shoe soles where the pink part is new and the black part is recycled (left to right).

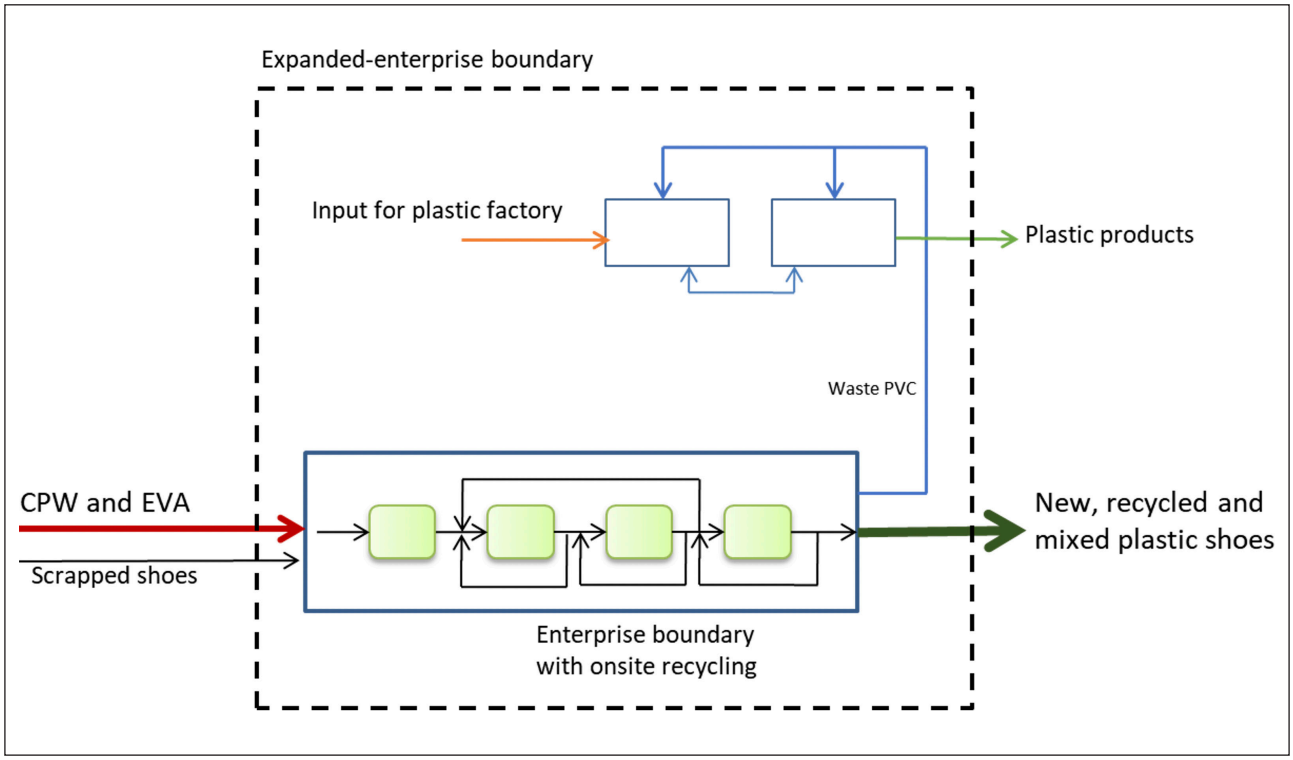

Figure 17. Flow of material in the plastic shoe manufacturing cluster in Kamalbagh area.

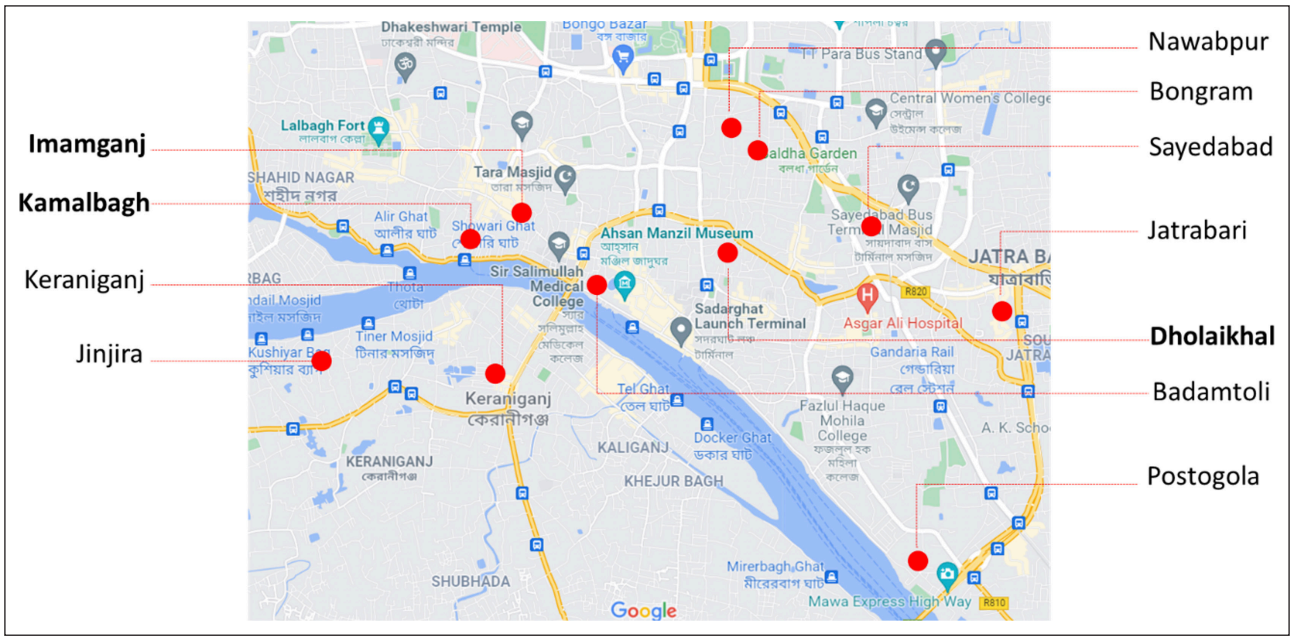

Figure 18. Geographical location of the industrial clusters, modified from Google Map view.

fits through observation, usually by an actor whose focus is beyond the private transactional network [57]. Usually in this stage, horizon and members of the networks increase. Further nourishment of such self-organizing developments leads to institutionalization of the entire system to support maneuvering and growth. 5 types of exchange networks are considered for eco-industrial parks [52]. They are

- Type 1: through waste exchanges
- Type 2: within a facility, firm, or organization
- Type 3: among firms co-located in a defined eco-industrial park
- Type 4: among local firms that are not co-located
- Type 5: among firms organized "virtually" across a broader region

In this typology, type 1 is the simplest category and the type 2 to type 5 are considered as true industrial symbiosis in the eco-industrial park model. Type 5 model depends more on the virtual linkage than the physical co-location although such virtual eco-industrial parks are of course place based. This model simply takes the advantage of increasing the number of participating firms by increasing the boundary.

The studied examples contain several types of industrial units or clusters of similar industrial units. Clustering, a common feature of old Dhaka, was observed in close proximity, if not in the same area, and occasionally sparsely scattered, such as on the other side of the river. Typically, the distance was always to be covered either by foot or with informal transport like handcart or pushcart, without contributing to the production cost substantially. Geographical location of the clusters is shown in Figure 18. Such arrangements of clusters were not designed or guided, rather evolved out of need. Thus, clusters were found place based and virtually linked, aligned with the argument for extending the boundary of industrial park for considering IS [56] and reveal that geographical proximity is not an absolute necessity for IS [99]. There was no mention of any support program related to IS or similar principles by any public or private agencies. Therefore, the studied examples clearly demonstrate a 'self-organizing' system. The examples also goes in line with the observation in the study of ship braking industries in Sitakunda-Bhatiary that entrepreneurial activities foster more than the territorial agglomeration for IS, at least in Bangladesh [40].

Considering the analysis of material flow, inside the enterprise boundary, outside the enterprise boundary, within the extended enterprise boundary, within the enterprise cluster boundary and inside/outside of related clusters of enterprises, this study identified sustainable waste management practices. These practices and the links among different industrial units/clusters clearly show the application of Industrial Symbiosis principles.

The studied loops identified more developed stages than the sprouting level and uncovered the existence of different exchange networks and sustainable practices of resource consumption, but not much beyond this. The clusters were geographically scattered and virtually linked, which resembles with the Type 5 exchange network. Metal industries and metal scrap dealing business are usually considered as Type 5 exchange [100]. The tire retreading cluster and shoe manufacturing clusters demonstrated the level of decent practice with almost all the residual waste reused in the production line within the cluster or with a little extended boundary of the cluster, particularly the shoe cluster additionally incorporated recycling of old and scrapped products in the production line. Thus, these clusters resemble the Type 2 exchange, which contains the true nature of IS.

During this study, the entrepreneurs were asked about the rationale for recycle, recover and reuse of material and

questioned about IE principles, CP technologies and environmental concerns. Their responses provide a simple and logical answer, to minimize the cost; there was no evidence of knowledge of IE or CP, nor any concern for environmental responsibility. This is a sharp contrast from the academic literature that put much emphasis in the environmental benefit. Theoretical conceptualization portrays environmental concern as a prominent driving force for IS [52, 57, 63, 98, 101–104], and literature about real-life examples, mostly in the Euro-American region and Eastern Asia, indeed demonstrate environmental benefit [54, 55, 65, 101, 103, 105–107]. However, it appears that the academic discourse has not dig deeper into the question if environmental benefit is the prime drive for IS, and significance of other drivers. This study clearly revealed that environmental benefit was not the prime consideration for waste exchange, suggesting sustainable resource consumption not necessarily stem solely from environmental concerns; economic benefit can dominate the drive. This realization can be helpful in pollution reduction strategies for developing economies. Beside formal legislative controls, emphasis on economic benefit and example form the informal sector may have positive impact for the organized industrial sector as well.

This study, covering only a few areas with concentration of informal industries in old Dhaka, identifies various economic activities driven by resource sharing and consumption minimization. The informal businesses, spanning manufacturing, recycling, and services, are observed to be closely interconnected and operated within the same or extended household oriented small enterprise. Such chains are difficult to separate and attempts to disrupt these interconnected chains may impact business flow. Beyond the 4 closed loops that were studied in detail, the initial exchange, which is the kernel of IS, were observed in many areas. This study suggests potential unexplored exchange networks that demand further research for comprehensive understanding.

CONCLUSION

This study recognizes sustainable waste management practices in some selected small scale informal industries in Dholaikhal, Imamganj and Kamalbagh areas of Dhaka. Considering material flow analysis, this study identifies industrial symbiosis in the study areas. It also suggests that more examples are likely to be recognized in other industrial clusters there. There is a clear indication that the entire informal manufacturing business sector practices waste recovery and recycling at various levels and there exist complicated and intricate symbiotic relations amongst the different types of industrial clusters. However, in identifying this, the study had some limitations, it only looked at the flow of material and the flow of energy or other components were out of the scope in this research. Moreover, the flow of material was studied qualitatively, it was not inclusive nor quantified.

Though the study does not provide quantifiable data, but it provides a generalized qualitative overview of the waste management practice in the informal sector manufacturing industries. This suggests that application of IE and CP principles has a great potential to be exercised in other industrial sectors, provided that a strong knowledge and human resource base is created, and necessary technologies are made available and supported. It may sound simple, but the task is not easy. Further investigations and in-depth studies are required to identify examples and the modality for transferring the concept. Formalization of the informal sector may not be the target, rather identification and promotion of best practices as well as incentives may be more helpful in the informal sector. Proper policy support, regulatory mechanism and an enabling framework can extend such practice in the formal industrial sector which can contribute considerably to pollution abatement.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not used.

ETHICS

There are no ethical issues with the publication of this manuscript.

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