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Systemic Economic Viability of Informal Sectors: E-Waste Management

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ABSTRACT

The informal sector has been at India's core of recycling WEEE for the last few decades. They do not have the scientific knowledge of processing e-waste and use acid baths and heat treatment to extract precious metals. The existing processes used by informal actors lead to a serious impact on their health as well as the environment. The introduction of advanced recycling technology for mitigating the hazardous effects on the environment and human health is as important as the development of technology for new-age electronic products. The social, economic, and environmental benefits to the informal sector can ensure formalized livelihoods in e-waste recycling by ensuring access to technology. The paper highlights how setting up a recycling facility and capacity building of the informal sector solves the problem of informality and its associated social, economic, and environmental evils, which will benefit the sector as a whole.

INTRODUCTION

E-Waste Management

The e-waste management structure worldwide is a complex system with different stakeholders. However, even in the most advanced countries, there are leakages into the informal sector. Laws in most countries now make it mandatory for producers to manage e-waste environmentally soundly under Extended Producers Responsibility (EPR) (Baldé et al. 2015).

The United Nations (UN), in the World Economic Forum on January 24, 2019, stated that in India, approximately 95 percent of e-waste is handled by the informal sector. The UN also mentioned that e-waste generated was 48.5 MT in 2018 and is likely to increase at 30 percent CAGR annually. The UN report specifies that only 20 percent of global e-waste is recycled. The report indicates that due to poor extraction techniques, the recovery rate of cobalt is just 30% (Lahiry 2019).

E-waste is hazardous; it requires proper segregation, collection, transportation and handling, treatment and recovery, and final disposal. The entire electronics cycle, from manufacturing to final disposal, requires the management of e-waste (UNEP 2007).

Recent data from 2017 states that national e-waste management laws cover 66% of the world's population; it's a rise from 44% that had framed a law in 2014. The large increase was mainly credited to India, where the legislation was revised in 2016. In Asia, most countries have e-waste rules, although, in Africa, very few have legislated e-waste-specific policies and regulations. Though, it is also noticed that even after national e-waste management laws, not all countries have been able to enforce the same. Many countries do not follow the collection and recycling mechanisms mentioned in their policies (Baldé et al. 2017).

Across the world, e-waste is mostly managed by the informal sector. The work of the informal sector is particularly hazardous for women and children as dioxins and furans are emitted on the burning of some components of e-waste. Formalizing the informal sector is the need of the hour, and systemic changes need to be brought in to ensure their integration. The formalization will have a positive impact on their health. It'll also ensure that they have sustainable livelihoods as the e-waste regulation becomes stringent through implementation over a period of time. (Chaturvedi et al. 2010).

Current Scenarios of E-Waste Management in India

- Extended Producer Responsibility (EPR) prolongs the duty of producers across the life cycle of their products, especially during the post-consumer period when products reach the end of life and are ready to be

disposed of, thereby categorizing them as e-waste. EPR is presumed to enhance waste collection, recycling, and treatment. The most important part of EPR is developing a closed loop of responsibility which comprises the product's entire life cycle, enabling waste materials to be used as raw materials in producing new products. By extending producer responsibility to the post-consumer stage, EPR creates a link between the end-of-life of products and product design, considering the Restriction of Hazardous Substances (RoHS) (Hemkhaus et al. 2018).

- EPR, introduced in the e-waste management and handling rules in 2012, proposed that it would be the producers' responsibility to complete the life cycle of an electronic product in an environmentally sound manner. Though stakeholders made no significant achievements regarding the collection of e-waste via EPR, some companies tried to set up collection mechanisms in the Indian context. In 2016 the revised e-waste management rules introduced target-based extended producers' responsibility (EPR) which keeps increasing over a period of time to close the loop. Rules also suggested financial mechanisms, including Deposit Refund Scheme, Advance recycling fee, etc., to implement EPR (MoEF & CC 2016).
- If producers have to meet their EPR targets, they must collect e-waste. The producers are completing their targets by getting associated with not one but multiple PROs. The PROs are very well aware that e-waste is mainly accessible from the informal sector. Hence, the PROs try to collect e-waste from the informal sector by working directly with different collectives of waste pickers or indirectly via collection agencies, aggregators, and recyclers. PROs can motivate or support the informal sector to increase its capacities through formalization. PROs can provide incentives like identity cards, social benefits, educational services, advocacy of workers' rights, etc. PROs can provide awareness-raising activities focusing on sound collection practices, inventorisation, following health and environmental practices, and dismantling and recycling e-waste using scientific means and technologies. Through proper implementation of EPR, recyclers can now access higher amounts of e-waste as producers focus on completing their EPR targets. The availability of more materials will motivate recyclers to adopt advanced technologies to recycle all materials of e-waste within the country, which will lead to social, economic, and environmental benefits. Research work has been done, and information was collected from the producers. A crosstab analysis has been done to find the connection between at least two variables which is given below in the observation.
- The new rules of e-waste 2016 have now provided guidelines on implementing EPR for producers. This has been linked to a certain set of targets that need to be fulfilled by producers, which would help them meet their EPR compliance within the ambit of the rules. Furthermore, these targets are mandatory and linked to producers' business goals.

Context of the Research Paper

India has a severe waste crisis on hand which is impacted further because of the lack of capacities of stakeholders. The huge population of the country and the rural-urban divide present waste management as the ideal livelihood opportunity with no investments and a sustainable income. This makes the informal sector a key player in waste, as the informal sector is where unregistered businesses work, avoiding paying taxes. Different material wastes create different flows and value chains, creating a multitude of stakeholders in the informal sector. Informal actors accumulate aggregate, dismantle and recycle e-waste. Few of the activities involved in dismantling present little or no hazards to human health and the environment. Though informal sector recycling practice is dangerous due to the material composition of e-waste, which has lead, chromium, cadmium, and mercury, the utilization of which is presently covered under RoHS guidelines of the e-waste management rules, 2016. Informal actors recycle e-waste either at home or in open spaces without using appropriate recycling technology, leading to pollution of the environment around them.

In India, the informal sector has a widespread network, making accessing materials easier. The material collection takes place through door-to-door collection, auctions, etc. Moreover, the low cost of the collection increases the value of waste, which is a deterrent for waste flow in the formal sector (Henzler et al. 2018). This paper is in the background of the resistance to formalization, as the informal sector operates on huge profits compared to the formal recyclers, as associated operational costs are minimal. Furthermore, no technology investments reduce capital costs, making them competitive in the face of expensive recycling technologies that formal players put up. Key steps which can lead to the formalization of the informal sector are the provision of advanced technology, Capacity building, and access to finance, which will lead to safe e-waste disposal. These steps will reduce system failures in this sector and allow different stakeholders to co-exist, ensure sustainability, and enhance resource efficiency, leading to a circular economy.

MATERIALS AND METHODS

In India, approximately 95% of total e-waste management is handled by informal/ unorganized sector. Different methods were used to collect primary and secondary information, including key informant interviews, questionnaires, e-mail communication, direct observation, and a site visit to collection centers, recycling plants, and Informal sectors.

Information was collected from 21 informal sector e-waste recyclers in Shastri Park, Mustafabad, Mandoli, Old Seelampur, Jamalu Ka Bag, Mayapuri Industrial Area, and Seelampur. This study has been carried out to assess the e-waste generated and the quantity handled in the informal sector.

20 producers were also questioned about all the necessary rules & regulations mentioned in the 2016 Notification. The interviews were held using a questionnaire prepared for Producers. A thorough discussion of the manufacturing and e-waste rules was done to understand the perception of producers regarding e-waste. Documentary proofs were also collected during the meetings. They were examined regarding the way of the take-back system, RoHS Certificate, collection of e-waste, Awareness program, information to customers regarding hazardous constituents, Recycling facility, Green Products, etc. Data was gathered from questionnaires, site visits, and interactions with people channeling e-waste.

OBSERVATIONS

Producers are institutions selling electrical and electronic equipment, their components or consumables, or parts or spares under their own brand. The regulatory framework is based on Extended Producer Responsibility (EPR), where the producer or manufacturer manages the products' end-of-life. The information was sought from 20 producers, which are private enterprises located in different states which cover the length and breadth of India. The cross tab was carried out for analysis along with the relevant questions mentioned in the questionnaires prepared for stakeholders, which are given below.

Crosstab of Internal E-waste Disposal Versus EPR

1. Are you aware of the e-waste (Management & Handling) Rules, 2011? (e-waste rules)?
2. Do you have an internal e-waste disposal/management policy for the organization?

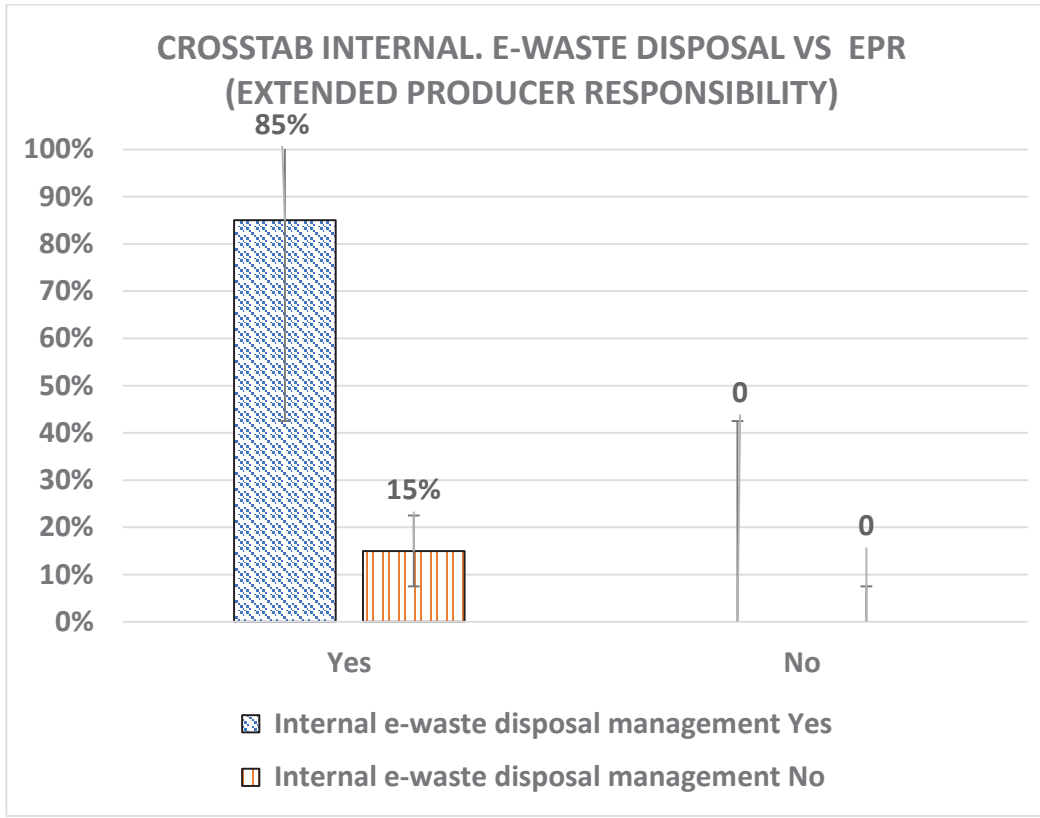

Fig. 1: Internal E-waste disposal versus EPR (Extended Producer Responsibility).

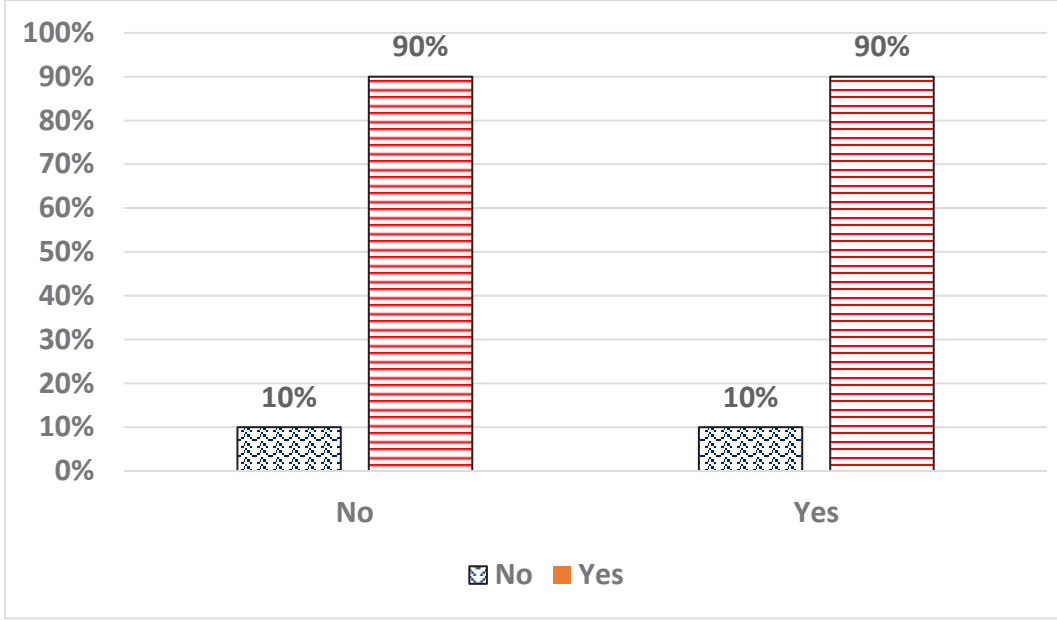

Fig. 2: Authorized Collection Centre versus EPR.

Producers mandated to seek authorization under EPR were asked if they also have an internal policy on e-waste. Fig. 1 shows 85 percent stated that they had an internal policy on e-waste, while the remaining 15 percent did not.

The Crosstab of Authorized Collection Centre Versus EPR

1. Are you in compliance with 'Extended Producer Responsibility (EPR) of electrical or electronic equipment to ensure that such e-waste is channelized to a registered dismantler or recycler?
2. Do you have an authorized collection center?

Producers were asked if they had fulfilled the EPR obligations and established collection centers. Fig. 2 shows 90 percent of the producers who have fulfilled the EPR authorization have chosen the PRO model to establish collection centers. There is a significant push towards collective producers' responsibility rather than individual producers' responsibility.

A Crosstab of the Service Center To Refurbish Products Versus EPR

1. Are you complying with the 'Extended Producer Responsibility (EPR) of electrical or electronic equipment to ensure that such e-waste is channeled to a registered dismantler or recycler?
2. Is your service center facilitating the refurbishment of the used product?

Fig. 3 shows only 10 percent of the producers who have EPR (Extended Producer Responsibility) authorization have asked for permission to develop refurbishment facilities so that they can channel their products into the repair market, thereby enhancing the life of the product. Not only does this encourage resource efficiency, but it also allows for reduced e-waste generation and is good for the environment.

The Crosstab of Information Regarding Hazards of Improper Handling, Accidental Breakage, Damage, or Improper Recycling of E-Waste Products Versus EPR

1. Are you complying with the 'Extended Producer Responsibility (EPR) of electrical or electronic equipment to ensure that such e-waste is channeled to a registered dismantler or recycler?
2. Are you informed of the hazards of improper handling, accidental breakage, Damage, or improper recycling of e-waste?

The new e-waste management rules, of 2016 have also helped to change the behavior of the producers in ensuring that proper precaution is taken while handling e-waste and transporting it across to registered recyclers and dismantlers. Fig. 4 shows 94 percent of producers now have the means to inform stakeholders on how to handle material that has hazardous content so that the same does not cause damage to human health or the environment.

The Crosstab of Enlisting the Hazardous Constituents Present in the Equipment Versus EPR

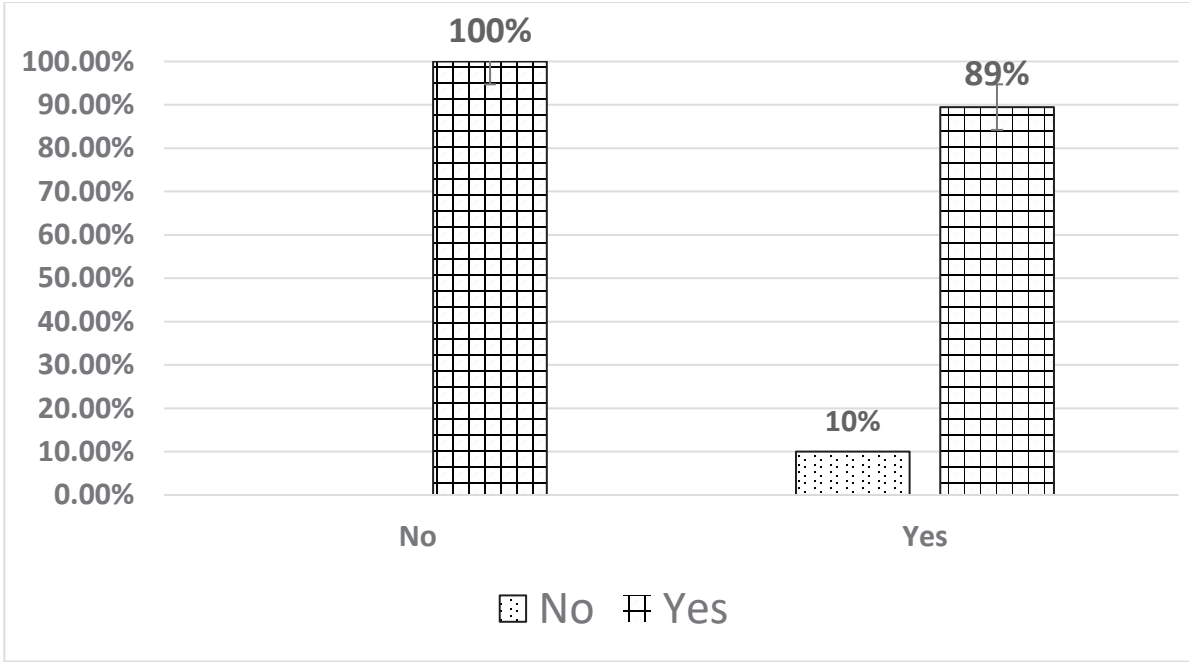

Fig. 3: Service center to refurbish products versus EPR.

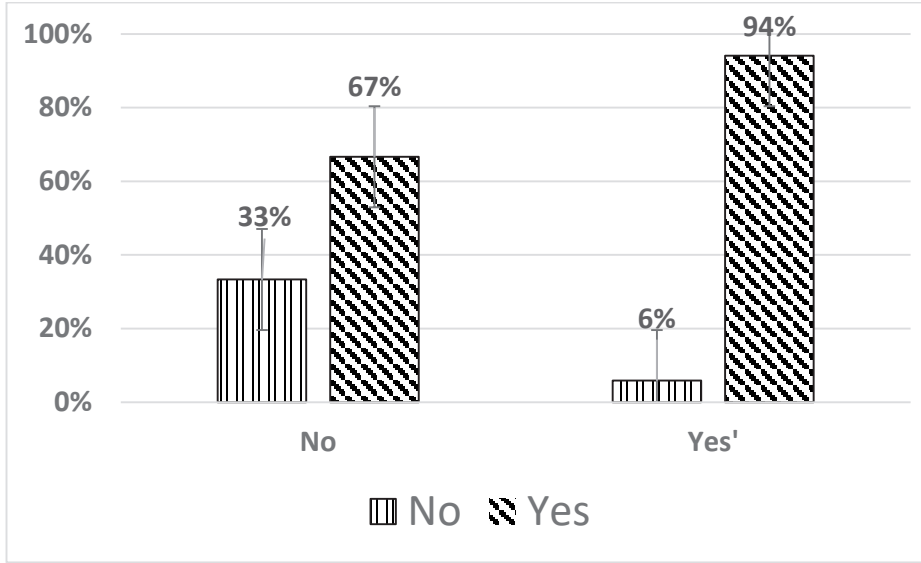

Fig. 4: Improper handling of e-waste products versus EPR.

1. Do you comply with 'Extended Producer Responsibility (EPR) of electrical or electronic equipment to ensure that such e-waste is channelized to a registered dismantler or recycler?
2. Are you enlisting the hazardous constituents present in the equipment?

The RoHS guidelines have allowed producers to publish hazardous content in the equipment sold. Fig. 5 shows 93 percent of the producers now publish such content on the packaging of their products sold, which complies with the e-waste management rules of 2016.

Key System Failures in Producers

- All producers need to be part of the EPR system by seeking authorization.

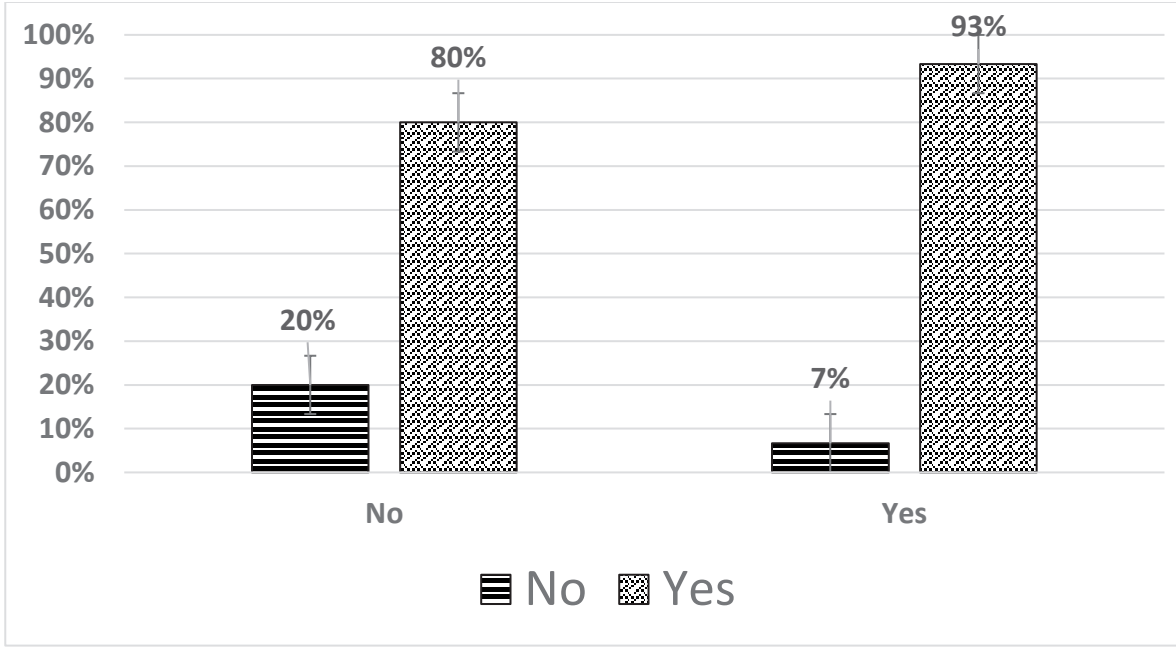

Fig. 5: Hazardous Constituents Present in the Equipment versus EPR.

- All producers need to set up collection systems and stop paper trading.
- All producers need to help channel materials to authorized recyclers and dismantlers.
- The law has helped to address a lot of concerns in the management of e-waste. However, compliance must be enhanced to ensure producers follow the law in its application and practice.

Informal Sector

In India, approximately 95% of total e-waste management is handled by informal/ unorganized sector. Information was collected from the informal e-waste recyclers in Shastri Park, Mustafabad, Mandoli, Old Seelampur, Jamalu Ka Bag, Mayapuri Industrial Area, and Seelampur. This study has been carried out to assess the e-waste generated and the quantity handled in the informal sector. The collected information for the same is given below.

The activity involves dismantling and recycling e-waste. The dismantled parts are recycled to obtain precious and other valuable metals. During dismantling, informal recyclers are exposed to acid fumes and chemical solvents as they do not use personal protection equipments. High and prolonged exposure to such chemicals/ pollutants emitted during e-waste recycling may lead to health consequences causing irreversible damage.

Dismantling Activities by the Informal Sector

All the steps are necessary for dismantling activities. We can extract valuable resources while dismantling electronic waste. We can properly segregate the parts by using hand tools to recycle devices. After segregation, we can properly treat the recovered parts for reuse and recycling. Data given in **Fig. 6** shows that 38% informal sector transfers electronic waste for further processing, and 19% dismantle their devices using hand tools to recycle devices or parts.

Ways of Recycling Operation by Informal Sector

The informal sector recycling involves a huge concern about human and environmental risks. It contributes to emissions of dioxins, heavy metals such as lead, cadmium, mercury, etc., in the environment, and the workers are exposed to these metals, potentially threatening human life. In addition, the laborers in the informal sector also face problems due to physical injuries, respiratory disorders, asthma, malnutrition, skin diseases, eye irritations, etc. Informal recyclers have expertise in extracting precious metals from PCB by an acid bath. The survey in Fig. 7 shows that 52% is operating manually, followed by 29% semi-manual.

Crosstab of Monthly Income Vs. Different Activities of the Informal Sector

- The income of the informal sector depends upon the kind of activity which it pursues.
- Dismantling and recycling in the informal sector require that a small infrastructure be set up so that they can

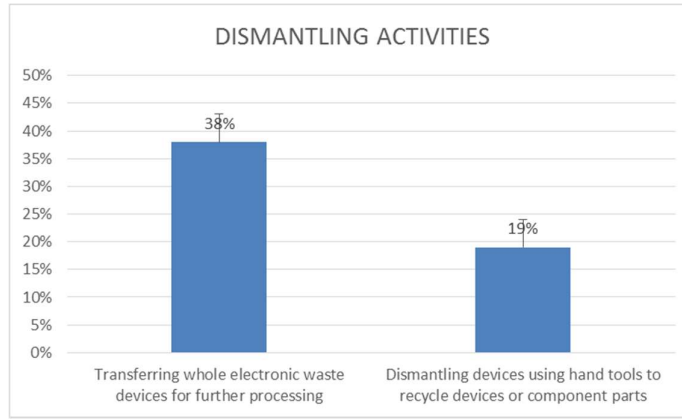

Fig. 6: Dismantling activities by informal sector.

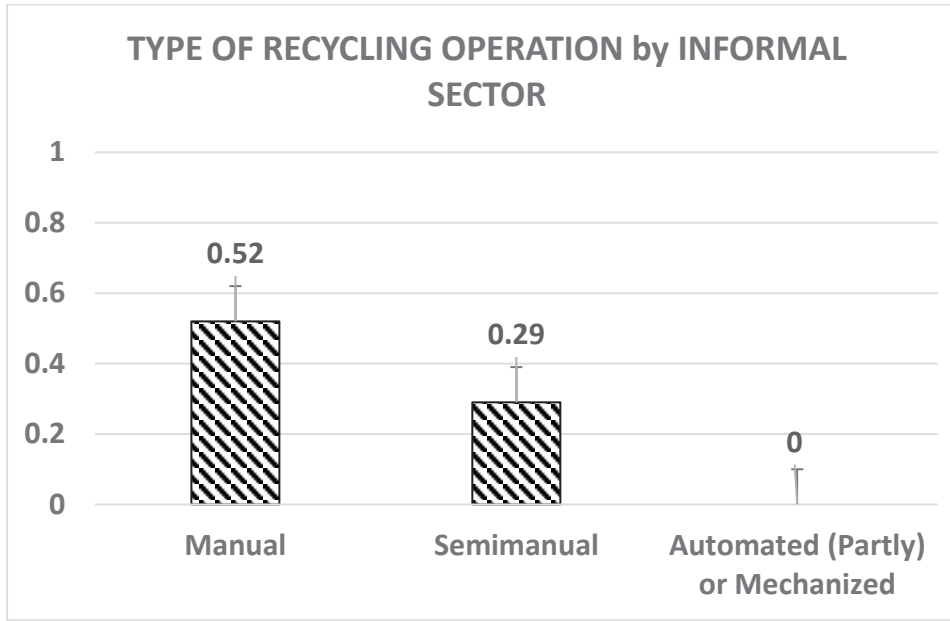

Fig. 7: Type of recycling operation.

handle a sufficient quantity of material to justify the input cost.

- Fig. 8 shows that overall, in Haryana, the income indicated is higher than the other areas because Gurgaon, Manesar, and other areas of Delhi NCR are one of the largest generators of e-waste in India and access to the same at a very low logistics cost leading to higher profits for them.
- Traders in the informal sector have a high monthly income compared to the costs they incur. Traders are not liable for expenses such as rent and legitimate wages; do not invest in modern technology; follow unscientific processes for recycling and extraction; and are not bound by any laws and regulations.

Available Space of Informal Sector Vs. Collected Waste

The collected data in Fig. 9 shows that all the traders have less space to be permitted to continue their operations.

Dismantling and Recycling Process by Informal Sector

The survey shows in Fig. 10 that 38% of the informal sector transfers electronic waste for further processing, and 19% dismantle their devices using hand tools to recycle devices or parts.

Survey shown in Fig. 11 shows that (52 %) is operating manually, followed by 29% semi-manual.

System Failure for Informal Sector

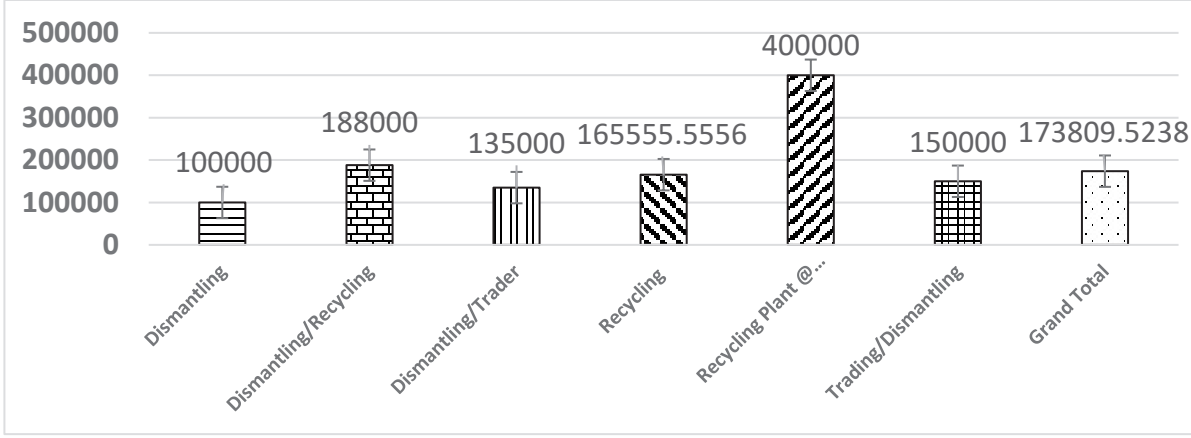

Fig. 8: Activities by informal sector.

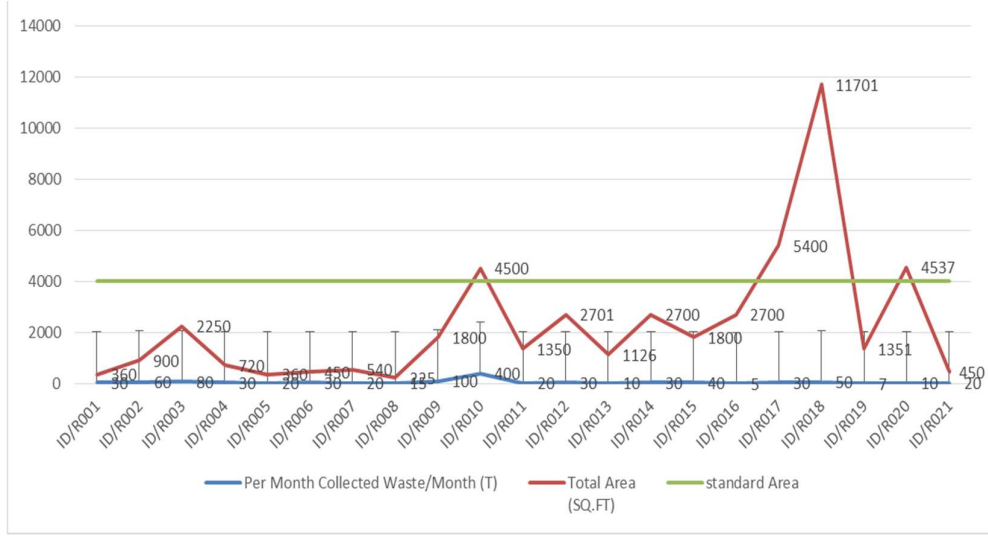

Fig. 9: Available Space of Informal Sector.

- Access to material without any authority under the e-waste management rules, 2016.
- Dismantling and recycling without authorization.
- No capacity for understanding the environmental and health hazards of managing e-waste improperly.
- No access to technology and other resources despite having access to finance.

Valuable Materials in E-Waste

The electrical and electronic products which have reached their end of life are considered electronic waste or e-waste. According to the site survey and reports, e-waste contains more than 1000 substances categorized as "hazardous" and "non-hazardous." It comprises ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete, ceramics, rubber, and other items (Rajya Sabha Secretariat Research Unit 2011).

It has been estimated that about 50% of the e-waste is made up of Iron and steel constituents, followed by plastics (21%), non-ferrous metals (13%), and others (16%). Non-ferrous metals comprise copper, aluminum, and precious metals such as silver, gold, platinum, palladium, etc. The presence of elements like lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants beyond threshold quantities in e-waste renders it hazardous waste (Rajya Sabha Secretariat Research Unit 2011).

As stated above, the data collected during the survey of the informal recyclers shared about the recycling of materials from the printers and CPU, which is mentioned below in Table 1. The objective behind collecting the data is to look

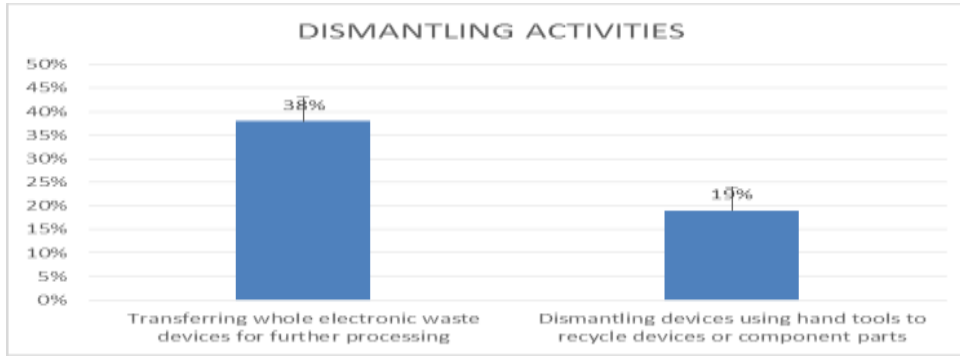

Fig. 10: Dismantling process by informal sector.

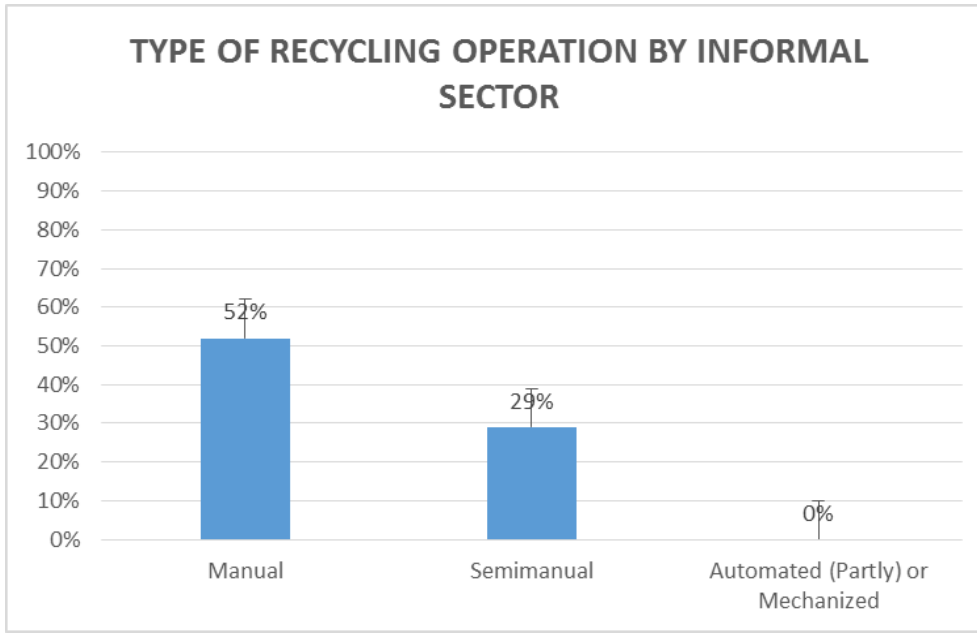

Fig. 11: Recycling process by informal sector.

at the operation and systemic changes that can be brought about through government and private sector mediation, which will lead to environmentally sound management of e-waste. This will enhance resource security and also lead to the success of key Government of India missions like Make in India, Skill India, Digital India, and Clean India (Swacch Bharat) (Niti Aayog 2018).

The informal recyclers share that from 100 kg mother board efficiency of recovery of materials is a minimum of 30%. We asked to recover materials from the PC motherboard and scrap mobile phones. The data shared by the informal recyclers are described below:

Gold recovery from PC motherboard: IC chips are the main source of gold in the motherboard of scrap computers. The informal recyclers use the hot air gun to separate the IC chips from the motherboard of scrap computers. Approx. 15-20 IC chips remain available on the main board of computers. As per the informal recyclers, they use the chemicals like sulphuric acid 4 times the IC chips temperature of 80-100^{0}C to dissolve the components. Use of nitric acid and others. Finally, they extract Gold wire and chips, and at least one mainboard generates approximately-rox—0.0123 g of gold. The recovered material details are given in Table 2.

Gold recovery from scrap cellphones: In mobile phones, gold remains embedded in many places like PCB, circuit boards, CCD cameras, and connectors. Gold wires remain attached to electrical circuit connections and other semiconductor devices. They separate all the gold-plated parts with the help of a hot air gun like a PCB board, CCD

Table 1: Quantity of Extracted Materials from Printers/CPU.

Name of Extracted Material	Quantity
iron,	5 kg
Plastic in printer/CPU	1.5- 2.5 kg
motor	0.5-1kg
useless plastic	0.5 kg
motherboard	1kg
glass	8kg from a total of 14 kg CPU
plastic	2.5 kg in computer
copper	0.5kg

Source: Site Survey by Author

Table 2: Recovery of materials from PC mother board.

Name of Extracted Material	Quantity
Gold	0.0123 gm from One Main Board from the CPU

Source: Site Survey by Author

camera, IC chips, Gold plated pins. They shared the amount of gold-plated parts mentioned in Table 3.

They also shared the chemicals used while extracting the gold from scrap mobile phones, like sulphuric acid @ temp 80-90^{0}C. Use nitric acid, cyanide, gold stripping chemical, Potassium hydroxide, zinc powder, hydrochloric acid, and nitric acid: Aqua regia, sodium meta bisulfate to make gold precipitate, and Borax.

Extracted from CRT monitor: The materials extracted from the CRT monitor, e.g., in 14 inches CRT monitor, the quantity of extracted materials are glass, plastic, copper, lead, PCB, etc. The name and quantity of materials extracted from LCD are also mentioned below in Tables 4 and 5.

Comparison Between Formal and Informal Recyclers

During the survey, queries were raised to formal and informal recyclers to understand the competitiveness in price available for the informal sector vis-à-vis the formal sectors. Based on responses from questionnaires, the information was gathered

Table 3: Recovery of materials from scrap cell phone.

Gold Plated Parts	Amount of Precious Metal
Accelerated Graphics Port (AGP) slot	482 g
RAM slot	209 g
IDE slot pins	689 g
VGA/COM Ports	318 g
Total gold extracted from the motherboard	3082 g
700 gm of mobile phones circuit boards	1.1 g of gold

Source: Site Survey by Author

Table 4: Recovered materials and quantity from CRT monitor

Recovered Materials	Quantity
Glass	4k g
Plastics	900 g
Copper	50-60 g copper in (Degaussing wire & yoke only)
Rest PCB	-

Source: Site Survey by Author

Table 5: Recovered materials and quantity from LCD (Liquid Crystal Display)/TFT (Thin Film Transistor) (17 ″).

Recovered Materials	Quantity
Plastic	700-800 g
LCD/Picture tube	1-2 kg
2Cart (SMPL, circuit)	10-20 g

Source: Site Survey by Author

from formal and informal recyclers. The sample collected during the survey is a computer, laptop, and Mobile PCB. The data in Table 6 shows the serious drawbacks formal actors face regarding the high acquisition cost of e-waste in India.

As per the information collected from the formal recyclers while doing the survey, they shared the Recovered metals per 1,000 kg of PCBs. The details of recovered metals from PCBs are also given in Table 7, and the recovered metals from the Informal Sector are also given in Table 8

Data collected from the survey indicates that the informal sector can pay a higher price for e-waste from different sources than formal recyclers. Formal recycling allows for better extraction of precious metals embedded in PCB's upto the extent of 90-95%, while informal recycling extracts only a few precious metals like Gold, Silver, Copper, and Platinum up to 20-30%. Methods adopted by informal recyclers adversely impact their health and reduce income potential because of the low efficiency of extracting valuable materials from e-waste.

Key Issues in the Regulation of the Informal Sector

The main challenges with the Informal sector in India are mentioned below:

1. The informal sector needs to improve the living conditions and proper disposal methods used for waste. Outreach and advocacy with waste disposers can be improved by building capacities and ensuring awareness programs representing hazards of improper disposal to human health and the environment.
2. As per the survey conducted during research, it was found that informal sectors have developed abundant knowledge of handling and managing e-waste;

Table 6: Informal and formal recyclers activities.

Activities	Informal Recyclers	Formal Recyclers
Computer/Laptop PCB Price	400 INR/kg Double chip (Original) 150-250 INR/kg single chip (pirated)	Computer and laptop PCB -200-250 INR/kg Depending on the grade of the PCB; For low-grade INR 30 /kg, medium-grade INR 80/kg, and high-grade INR 250/kg.
Mobile PCB Price	4000 INR/kg for brands like Sony, Samsung Branded manual keyboard mobile = 1600 INR/kg Non-branded Mobile = 400-800 INR/kg	Mobile PCB 1800 INR/kg
Amount of Extracted Precious Metals (PM)		High-grade PCB will have gold and silver as precious metal Medium grade has more copper, zinc, and traces or plating of gold. Additionally, nickel, chromium, cadmium, and lead are also found. Gold from high-grade PCB is in the range of 0.2 % Mobile PCB tops in grade, followed by laptop and computer RAM and processor have the highest gold quantity. Overall, iron is 60 %, plastic 30-35 %, and the rest other PM It is from a whole product like PC or laptop etc. About 90% of precious metals are extracted from what e-waste contains
What to do with extracted plastic from PCB	Sent to Plastic recycler.	Plastic, upon segregation, can be recycled or sent to a plastic recycler
Materials recovered from e-waste	Mainly gold, silver, copper	All precious metals
The efficiency of recovery of materials	20-30 %	90-95%
Capital costs involved	5-8 Lakh for chemicals, other supporting machines	25-50 Crore
Operational costs	-	20 INR/kg, including transportation and operational cost.

Source: Site Survey by Author

Table 7: Recovered metals per 1,000 kg of PCBs (from the formal sector)

S. No.	Recovered metal	Weight	Market Value	The value of Metal recovered
1.	Gold	279.93 g	36,000/10 g	Rs. 10,07,748
2.	Precious metals (Pt, Pd, In)	93.31 g	40,000/10 g	Rs.3,73,240
3.	Copper	190.512 kg	0.4/g	Rs.76,205
4.	Aluminium	145.152 kg	0.12/g	Rs.17,418
5.	Lead and tin (Pb/Sn)	30.844 kg	0.15/g	Rs.4,627
6.	Silver	450 g	400/10g	Rs.18,000

Source: (Chatterjee & Kumar 2009)

Table 8: Recovered metals per 1 Ton/1000 kg PCBs (From the Informal Sector)

S. No.	Recovered metal	Weight	Market Value	The value of Metal recovered
1.	Gold (1 Ton PCB)	10-100 g (Depends on PCB Grade)	36,000/10 g	Rs. 3,60,000

(Source: Site Survey by Author)

however, they are adopting either obsolete or inefficient technology. It was found that they are considered small-scale units, including easily available labor from their family members, small space, and no rules and regulations (Tiwari et al. 2019).

3. The survey says that Informal sector competencies can be improved by the availability of land, access to technology, and finances, which can change their lifestyle to be more resource efficient and environmentally sound. The work clusters can be made

away from residential areas so that people, especially children, are not exposed to environmental hazards (Hemkhaus et al. 2018).

RESULTS AND DISCUSSION

Capacity building and advocacy with the informal sector are serious bottlenecks encountered in the path toward formalization. The benefits of formalization, which can be accessed through a combination of multiple strategies and policy mix to deliver desired results:

1. Using advanced technology in India will increase opportunities in the recycling sector and its development. It will enhance the livelihood. Access to such technology for the informal sector will set the tone for formalization.
2. The introduction of advanced technology can improve living conditions and proper disposal methods for waste. This will ensure better health and the environment in places where the informal sector is working presently.
3. Capacity building of the informal sector will allow for efficiencies in their livelihoods, leading to higher income. It also allowed for compliance monitoring from the end of the SPCBs.
4. Formalization of the informal sector will result in the successful implementation of key Government of India missions like Make in India, Skill India, and Clean India. It also allowed multiple livelihood opportunities for skilled labour in the country (Niti Aayog 2018).
5. Safe e-waste disposal in an environmentally friendly manner will provide a fillip to the Swacch Bharat Mission.

- It is also important to understand that in a large number of cases, the request for formalization is coming from the informal sector. This is primarily because of 2 reasons:

1. The informal sector understands that the work that they are doing is not conducive to their health as well as the environment, which is why they want access to technology and other inter-alia items
2. The informal sector has been able to continue because of corruption since its margins were high. Higher levels of corruption have reduced their margins to levels where they now believe that it is better to formalize than stay informal because, in both cases, income will not differ much.

The informal sector may still stay in really small pockets, but a major chunk of materials will start to move into the formal domain.

In India, material fractions for which technology is not available for recycling are exported. Many formal recyclers have not invested in such technologies, either due to a lack of resources or access to materials because of the presence of the informal sector. The new rules, which promote Extended Producers' Responsibility, aim to ensure the producers are responsible for collecting e-waste such that the same can be channelized to formal recyclers.

To make the system effective, activity plans must be recognized alongside all the related players who will guarantee time-bound usage of techniques with distinguished stakeholders. As mentioned, the proposed pathways to formalize the informal sector are diagrammatically introduced in Fig. 12 (Tiwari et al. 2019).

For a positive implementation of the above-mentioned strategy, it's essential to involve all the stakeholders together as well as to understand their actual requirements or need to motivate them to get formalized. The proposed flow is given above in Fig. 12. For the last few decades. Many players are engaged in managing e-waste where producers are answerable for confirming the collection of end-of-life material, and the informal players are the one who collects and handle the e-waste through their network. Proper registration of the informal units is required so that the disposers of e-waste, both individuals and bulk consumers, can also reach out to these informal players. To make the strategy successful, it's required that action agendas be identified along with all the associated players who will ensure time-bound implementation of strategies with identified stakeholders.

The informal sector has been India's overall core of recycling WEEE for the last two decades. This sector doesn't have the chemistry knowledge in depth besides the simple knowledge about acid baths and heat treatment to extract precious metals. The existing technology used by the informal sector creates a serious impact on their health as well as the environment. Introducing advanced recycling technology for mitigating hazardous environmental and human health effects is as important as developing new electronic products. All these social and environmental benefits to the informal sector can ensure formalized livelihoods in e-waste recycling by using technology (Tiwari et al. 2019).

The informal sector players are responsible for reusing e-waste or are the backbone of waste collection and resource recovery. As referenced above, the absence of infrastructure and accessibility of advanced technology brings about low creation of sources yet the production of progressively waste. As per our research, we tried to find out the cost estimation details for setting up a material recycling facility, described below.

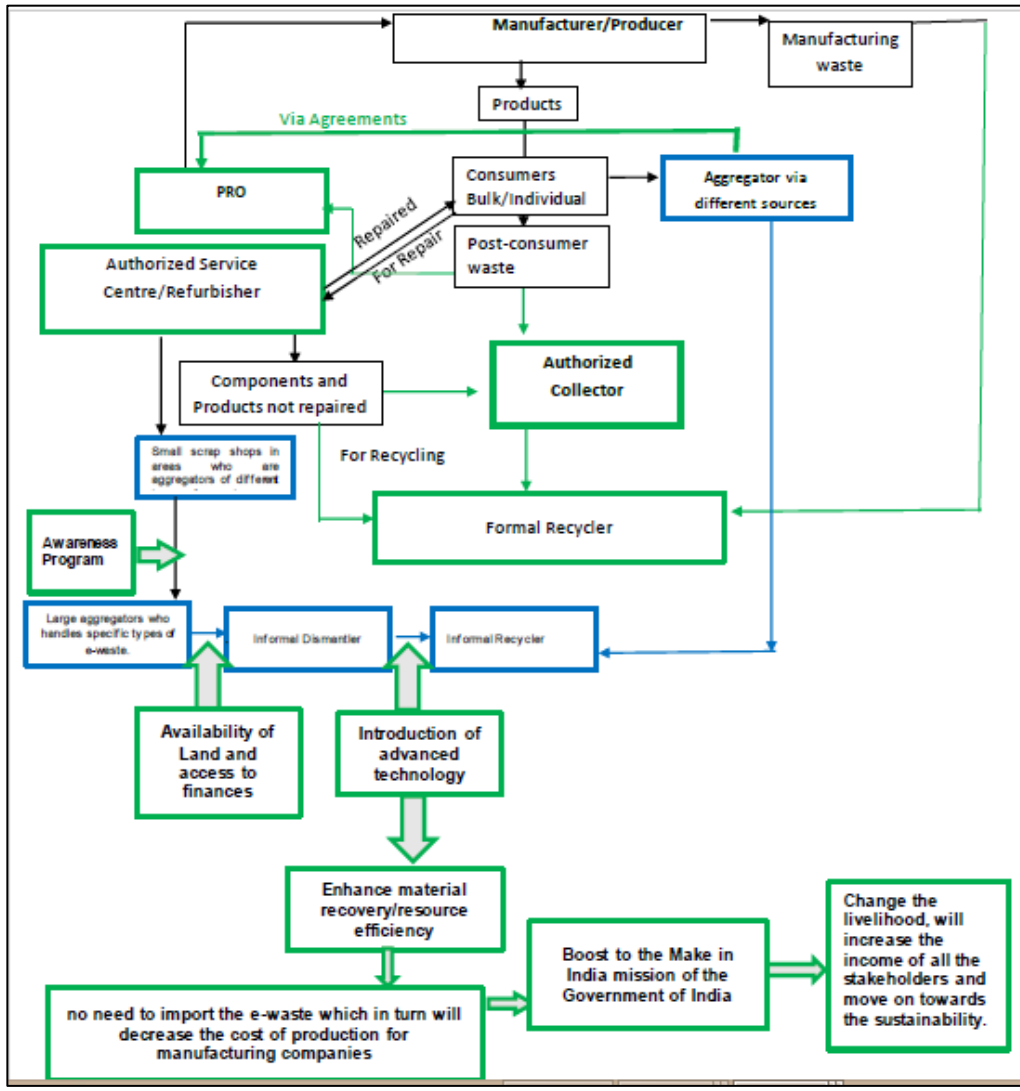

Fig. 12: Process reengineering for formalizing informal sector.

Cost Estimation for Setting up of Material Dismantling/Recycling Facility

Setting up a recycling facility close to areas that are bulk generators of e-waste has been considered an option to minimize the logistics cost of transportation of e-waste. This has been done based on the assumption that the PROs collecting on behalf of the producers would like to minimize costs so that they can churn out a profit for themselves from the activities they are pursuing. The same is given in Table 9.

In the case of an investment by the informal sector, the scale of operations becomes large, which could be difficult in case little finance is available.

In the case of a dismantling facility, the scale is smaller and more profitable, which allows for higher profits at low capital expenditure.

Centralized facilities for recycling and decentralized facilities for dismantling by formalizing the informal sector are the way forward to avoid system failures in the e-waste management system.

The financial mechanism, which is developed as an output of the business numbers which have been shared, goes on to depict that just formalizing and providing technology is not the solution. Capacity building, advocacy and outreach, and training are important, along with finance, land, and technology, so these actors and other stakeholders

Table 9: Setting up of a dismantling/recycling facility.

S. No.	Description	Cost
1.	Land for setting up of dismantling/recycling facility	30,00,000 for purchase/lease or INR 1,00,000 as rent for the facility.
2.	Set-up costs	5, 00,000 for ensuring proper insulation is completed within the shed so that dust does not go out.
3.	Dismantling tables	2, 50,000 for 5 dismantling tables with a capacity to process 1.5 tonnes a day.
4.	Storage bins and other inventorization infrastructure	1 00,000 for bins for different metals and materials and racks for inventorization.
5.	Rolling stock	20,00,000 per month for 3 months to be able to buy and sell and maintain cash flow
6.	Dust collection and other infrastructure	10,00,000
7.	Authorization and other costs	2,00,000
Operations cost		
1.	Human resource	3,00,000 per month
2.	Logistics cost	1,50,000 per month
3.	Electricity cost	1,00,000 per month
4.	Storage and other costs	50,000 per month
5.	Miscellaneous	50,000 per month

can be aligned as per the rules, which will benefit both the environment and human health.

Capacity building of the informal sector can allow them to uptake technology, leading to enhanced capacities in the country. It will also solve the problem of formalization of the informal sector, which will benefit human health and the environment.

CONCLUSION

The informal sector is a part of the system failure that the Indian e-waste sector has been experiencing for the past several years. The informal sector has access to materials because of the network created due to socio-economic issues faced by a section of the society in India. Large-scale urban migration leads to serious job crunch for unskilled workers. Waste collection is the easiest livelihood since there are no barriers to entry. This has led to networks channeling materials away from proper recycling. It has also created issues with recognizing these actors in the rules since it is difficult to identify them. They are neither part of the tax net nor are their businesses registered with the relevant authorities.

Analysis across the informal sector helps to understand that the socio-economic divide that has pushed a generation into waste picking and informal recycling has given way to aspirations for educating their children. This thought propels them to organize and formalize so they can move to work within the ambit of the law.

Analysis across these stakeholders allows us to understand the key issues which lead to system failure in the e-waste sector. Certain key reasons for the same are:

1. Lack of outreach and advocacy on the e-waste rules has not helped develop and understand the responsibilities across different stakeholders.
2. Lack of forums for the informal sector to speak for themselves and express their key issues has prohibited them from formalization.
3. Lack of recycling infrastructure in the country in the formal domain has not allowed all the material to flow into the formal sector.
4. Lack of compliance with regulation enforcement by authorities has led to slackness in implementing the rules.

Interviews with informal actors and other key actors helped shed light on these actors' key asks. These include the following:

1. Access to land: This will allow them to formalize and practice their livelihood, which they have pursued for the past few years. Furthermore, it will help build capacity within the formal domain so that more material can be recycled in an environmentally sound manner
2. Access to technology: This will allow them to ensure that the work that they do involves scientific processes so that it is environmentally sound and poses no hazards to human health

3. Access to finance: These actors who now formalize must be able to access finance at lower interest rates. This will allow them to invest in technology and land, which is part of the key steps to formalization.

Any system which acts in silos is likely to create unintended consequences. This happens because the cause and effect of the system are studied in tandem and not together. A study of the system, including all stakeholders, their actions, and their behavioral patterns, helps understand how one stakeholder will react to certain actions that could have unintended consequences. Guarding against unintended consequences helps build a stronger systemIt is important to note that certain key points from this study had nothing to do with the approaches taken by various stakeholders to solve the problems relating to effective e-waste management. Analysis of some of the programs which PROs have managed leads one to the following conclusions:

1. Awareness activities conducted by PROs have created a demand for formalization in the informal sector.
2. Over the last 3 years, informal actors have formalized to take the count of recyclers/dismantlers in India from 148 in 2016 to 312 in 2019.
3. Material flow to these formal actors has now helped producers to meet the target of 30 percent as provided for in the e-waste management rules, 2016 (revised guidelines of 2018).
4. PROs assist in formalizing informal actors into collection centers so that e-waste can be channelized for environmentally sound management.

The high-handed approach of compliance and regulatory authorities will likely lead to increasing illegal processes or livelihoods being waned away from the e-waste sector. On the other hand, an approach that looked to not attack the problem directly but indirectly led to demand for formalization within the system with consequences that favor properly implementing the e-waste management rules, 2016.

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