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RECYCLE OF PRINTED E-WASTE AS BUSINESS TOOLBOX FOR SUSTAINABLE SOLUTION

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Abstract

The utilization of natural resources presents significant difficulty in contemporary culture. But an innovative concept of recycle has been established, by the new money-making theory, which views it as an avenue for profit. Given their rapid expansion, discarded material as e-wasted printed circuit boards, the most valuable component of Printed E-Waste (PEW), are of special relevance in this model.The current study assesses the hydrometallurgical techniques, applicable to Micro Small and Medium Enterprise (MSME). The standard approach is Discounted Revenue Flow (DRF), as well as the outcome of the economic metric is Final Present Worth (FPW). Toolbox offers a thorough rundown on how to set up an e-waste management. It also provides an overview of the numerous Indian laws, in addition to policy pertaining to environmental protection, including e-waste management. Entrepreneurs will find the toolbox useful in managing their trash in a manner that is mindful of the environment.

.***Keywords:*** *Printed E-waste (PEW), Business Toolbox, e-waste Management, Sustainability, Financial Sustainability.*

JEL Code : *L63, L65, 031 & 034*

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1. Introduction

Worldwide e-waste production was estimated at 50 million tons in 2018 and this amount has been predicted to increase soon. Ninety-five percent of the nation's e-waste is thrown away in an unsafe manner in the unofficial sector. According to an assessment, published by the World Economic Forum, India is ranked within the worst five nations on the Environmental Performance Index 2020 and 168^{th}, out of 180 nations worldwide. About forty million tons of PEW is discarded, illegally sold or handled in an unsound way each year because only twenty percent of the world's e-waste is repurposed. PEWis growing at a pace of five to ten percent annually in India. Regarding it, an e-waste recycling center is a commercial entity that needs permission from various government agencies to be established. Since they aid in the management of contamination of the environment, regulatory approvals are the most important of the different types of permits. The establishment of fresh reprocessing as well as tearing down operations, within the organized sector, will be aided by this business toolbox. Further, it is necessary to modernize or integrate the current informal sector operations to serve as an administrative structure for the combined arrangement. Ensuring sustainable development, along with integrating nongovernmental organizations into the general framework of PEW management efforts, will be made possible by this. In order to help entrepreneurs to establish top-notch formal PEW recycling facilities in India, these criteria were created for the establishment and operation of such a facility, with guidelines on the general procedures and regulatory requirements. Nonetheless, the particular specifications must match those stated by the State Government where the unit is situated (**Abdelbasir et al., 2018**).

Recovering materials from trash constitutes some of the most sustainable uses for them. PEW is one of the greatest major trash streams generated by mankind, with regard to its combined size as well as development. Estimating the total amount of PEW produced in a nation is generally easy, particularly when recovery mechanisms are either nonexistent, especially recently constructed, or when a sizable portion of Au-rich PEWs are being sold illegally. In the year 2024, the amount of PEW reached 54.9 million tonnes and the annual growth rate is 5 % to 9%. Lack of proper knowledge, along with present environment policy, is the main issue in recycling the PEWs. Transport cost of the e-waste is very high, if the e-waste were to be exported to other country for recycle (**Bi et al., 2010**).

Hydrometallurgical, pyro-metallurgical, and electrometallurgical techniques can be used to extract base and valuable metals from waste PEWs. Hydrometallurgical treatments have a number of benefits over pyro-metallurgical processes, including simpler management, better metal recovery, lesser environmental impact and cheaper capital costs. The three main phases of hydrometallurgical operations are metal recovery as a solid product, purification to separate metals through specific chemical reactions and leaching to dissolve metals. Mineral acids or compounds, based on cyanide, are used as the main lixiviants in traditional leaching techniques. Certain classic lixiviants, such as aqua regia and cyanide, are highly toxic. Thus, the use of eco-friendly lixiviants, such as thiosulfate, thiourea, and halides, for metal recovery, has gained more attention.

The present research proposes to apply the business toolbox, which involved hydrometallurgical approach towards Micro Small and Medium Enterprise (MSME), for enhancing our comprehension concerning the prerequisites for the development of novel PEWs processes for recycling. Usually, these varieties are divided among two categories, as seen in the **Figure 1**: Low Grade and High Grade.

Every group also looks at five different kinds of PEW. The substance composition of PEWs, are obtained via both the direct service centre or from government and nongovernment offices, for processes of PEW recuperation. Resource marketplace rates are known as genuine amounts in an effort to replicate fact as nearly as feasible. Toolbox offers a thorough rundown on how to set up an e-waste administration arrangement. It also provides an overview of the numerous Indian laws, in addition to policy pertaining to environmental protection, including PEW management. Entrepreneurs will find the toolbox useful in managing their trash in a manner that is mindful of the environment (**Chakraborty et al., 2022**).

2. Process of PEW Management

2.1 Specification of PEWs

A local resource recycling center, sold the PEW waste from a particular cell phone and another printed circuit board. The two sides of the specific waste PEW are shown in the Additional Sources. Upon receipt, the garbage PEWs measured around 12 by 6.2 to 28 by 32 centimeters and weighed between 20 and 90 grams. After being cleaned with dehydrated water, the discarded PEWs were submerged in isopropyl alcohol, using ultrasonic oscillation for 35 minutes, drying in the oven for 24 hours at 100°C and then divided into 10 to 40 fragments, each measuring around 3 × 2 cm. Copper, tin, calcium, and aluminum made up 56.9 weight percent, 5.1 weight percent, and 1.8 weight percent of the waste PEWs, while the remaining metals were all below 0.9 weight percent. Silver, gold, palladium, and platinum had contents of 518, 179, 159, and 36 parts per million respectively.

2.2 Process

Hydrometallurgy involves the use of aqueous chemistry, for the recovery of metals from ores, concentrates and recycled materials like e-waste. This method is preferred over pyro-metallurgy (which involves high-temperature smelting) because it is more energy-efficient, scalable and produces less toxic gas emissions. The hydrometallurgical technique, for gold extraction, typically involves three key stages: leaching, separation and recovery (**Chatterjee, 2012**). The first step in the hydrometallurgical process is pre-treatment. Printed circuit boards are manually or mechanically stripped of components and the gold-bearing materials are separated. These materials are then shredded or crushed into smaller pieces, to increase the surface area for chemical reactions. Pre-treatment also involves cleaning the pieces with detergents, to remove oil and dirt, ensuring better interaction with the leaching agents. The core of hydrometallurgical gold extraction is the leaching process, where chemicals are used to dissolve gold from the solid e-waste. One of the most commonly used leaching agents is aqua regia, a mixture of three parts hydrochloric acid (HCl) and one part nitric acid (HNO_3). Aqua regia effectively dissolves gold by forming chloroauric acid (HAuCl„). The crushed gold-containing materials are submerged in aqua regia in a glass container, where the reaction proceeds with bubbling and the solution turns a rich yellow or orange color, indicating the presence of dissolved gold (**Cucchiella et al., 2015**).

Once the gold is dissolved, the mixture undergoes filtration, to separate the undissolved materials, such as base metals and non-metallic components. The filtrate contains gold ions in solution. To recover gold from this solution, a reducing agent such as sodium metabisulfite (Na, S, O...), ferrous sulfate, or oxalic acid is added. This chemical reduction process causes the gold ions to precipitate out of the solution as a fine brown powder. The precipitated gold is then filtered, washed with distilled water to remove any residual chemicals and dried, as seen in the **Figure 2**. The final step involves melting the gold powder, using a furnace or gas torch to produce solid gold, which can be reused in electronic components or sold as a valuable raw material. The hydrometallurgical method offers numerous advantages (**Ghosh et al., 2015**). It is highly selective and effective for gold recovery, uses relatively low temperatures, and allows for the recovery of other metals like copper, silver, and palladium, if designed properly.

Moreover, it generates less air pollution compared to high-temperature methods. However, it is crucial to handle the process with care, due to the use of hazardous acids and the need for proper waste disposal systems, to avoid environmental contamination. The hydrometallurgical extraction of gold from printed e-waste is a promising and sustainable solution to the growing challenge of electronic waste. As technology continues to evolve and the demand for precious metals increases, efficient recycling methods such as this, will play a pivotal role in reducing resource depletion, minimizing environmental harm and contributing to the circular economy.

2.3 Economic Framework

Various methodologies exist for assessing the techno-economic feasibility of recycling processes. Among these, the Input-Output Technique, Life Cycle Valuation, plus Budget Value Scrutiny, are prominent. Life Cycle Costing is the most widely utilized approach (**Guo et al., 2021**). This method involves two primary cost categories: internal and external costs. Internal costs refer to conventional or direct costs, as well as indirect costs, which include hidden and less tangible costs. External costs arise from functioning indoors under a professional atmosphere as well as from encomposing expenses such as carbon taxes, environmental taxes, licensing fees and charges for emissions and effluent discharge. These costs are not directly derived from business operations and they are typically accounted for as indirect costs while calculating operating expenditures. The economic viability of e-waste recycling is contingent upon the efficient segregation and concentration of constituent materials prior to further processing. The most significant cost factors in e-waste recycling are associated with collection, storage and handling, dismantling, pre-treatment and the segregation of hazardous components.

Discounted Revenue Flow (DRF) is an old-style method, employed for assessing the financial practicability of a venture, predicated on projections of forthcoming currency inflows plus outflows, using an incremental approach. Two critical macroeconomic factors in this assessment are the appropriate lifespan of the venture as well as the accurate prospect budget of principal. The principal metric, Final Present Worth (FPW) is determined as the aggregate of the contemporary principles of distinct currency movements. The adaptation of left-over substantial hooked on different substantial, can result in probable revenue generation. This study examined the role of three precious metals (Ag, Au, and Pd) and five common metals: Al, Cu, Fe, Sn, and Zn. Concurrently, investment and operational costs were considered, encompassing the procurement of PEWs, conferred resources, discarding ingredients, electrical energy, coverage, employment and preservation plus reactant material (**Golev et al., 2019**).

2.3.1 Final Present Worth (FPW)

The FPW is the outcome of the income generated from the PEWs processes by the hydrometallurgical process, where the gold recovery will be 170 g per one tonne, and the recovery approximately will be 94%. The cost of power consumption will be Rs. 5902.00 where the cost of chemical will be Rs. 53784.00 and the cost of 1t PEWs is Rs. 55000.00 approx. Now the gold amount is Rs. 9573.00 per one g and therefore, the total amount of the gold will be 170g at 16,27,410.00, which is the high return on the investment as 1420% (more/less) approximately.

The scientific framework is denoted as:

Ag = ₳, Au =₦, Pd =₱, Al=₩, Cu =₵, Fe = ₣, Sn =₷, Zn =₲.:

Final Present worth (FPW) can be expressed as:

FPW = ¦∲ = 0 {€inv ÷ £d} + {{€inv_€lcs, ∲ } x ∑d} ÷ { 1 + ∑ }∲

+¦∲ = 1{Q₦ x P₦, ∲ x l₦ + Q₱ x P₱, ∲ x l₱

+ Q₳ x P₳, ∲ x l₳ + Q₵ x P₵, ∲ x l₵

+ Q₩ x P₩, ∲ x l₩ + Q₣ x P₣, ∲ x l₣

+ Q₷ x P₷, ∲ x l₷ + Q₲ x P₲, ∲ x l₲} ÷ { 1 + ∑ }∲

+¦ ∲ = 1{€p, ∲x Qk + €i, ∲x £I + €d, ∲

× {Qφ + Qφ₥} + €c, ∲X {Qπ + Qµ}

+ €π, ∲x{πs x Qk + πr x Qbr}

+pi x €inv+p₥s x €inv x ₴s+p₥r x ₴r+€r, ∲x Q∝r + p∲x π∝∲} ÷ {1 + ∑ }∲ **(1)**

€∲+1=€∲ x {1=in∲∲} ≈ ∲=1.....n **(2)**

Two critical macroeconomic factors in this assessment are the appropriate lifespan of the venture as well as the accurate prospect budget of the principal.

2.4 Business Toolbox

To establish a printed e-waste recycling unit, under the MSME category in India, it is essential to follow the environmental regulations laid down by the Central Pollution Control Board and the respective State Pollution Control Boards. The unit must be situated in an area, designated for industrial activity and should have adequate space, depending on the scale of operations. For a micro or small-scale unit, a minimum area of around 300 to 500 square meters is typically required. This space should accommodate separate zones for dismantling, segregation, temporary storage and basic mechanical processing like shredding or crushing. The premises must be secure, well-ventilated and designed to prevent any environmental contamination. Before starting the unit, the entrepreneur must obtain authorization from the State Pollution Control Board. This involves applying for approval to establish and subsequently, Consent to Operate **(Hanumanthakari et al., 2023).** These consents ensure that these MSMEs comply with environmental safety standards. Along with this, GST registration and incorporation under the Ministry of Corporate Affairs or Udyam Registration, under the MSME portal, are also necessary. If the unit employs ten or more workers, a factory license is mandatory. The project must also follow the guidelines under the E-Waste (Management) Rules, 2022, particularly concerning the collection, storage, treatment and final disposal of waste, that cannot be recycled. The infrastructure must include separate covered areas, for receiving and storing e-waste, to prevent unauthorized access and potential hazards. Manual or semi-automatic dismantling stations should be set up, with appropriate tools and safety gear for workers. Dust control systems, air filtration units and personal protective equipment, must be provided to ensure a safe working environment. If any water-based processes are involved, provisions must be made for proper wastewater treatment, to prevent contamination of soil and water bodies.

It is essential to accurately document all materials entering and exiting the facility, including the quantity and type of printed circuit boards or components being recycled. These records must be submitted annually to the relevant pollution control board via the designated online platform. Partnering with producers, under the Extended Producer Responsibility Framework, is also advised, as it facilitates a consistent flow of materials and regulatory backing. For a small MSME unit, the necessary machinery includes basic shredders, conveyor belts, separators and fume extraction systems. Investing in dust collectors is crucial and any residues remaining after processing, should be disposed of through authorized treatment, storage and disposal facilities. The recycling unit should avoid open burning or chemical leaching without appropriate treatment systems. Workers should be trained in handling hazardous waste, safety protocols and equipment operation. Employing an environmental officer or consultant with expertise in pollution control and documentation, is advantageous for compliance. Financial planning should account for the cost of land, machinery, safety systems, and regulatory approvals. Depending on the scale, an initial investment, between ten to fifty lakhs rupees is anticipated, along with additional working capital for operational expenses. The government provides various schemes to support such initiatives under the MSME umbrella, including loans through SIDBI, subsidies under environmental protection programs and benefits through Startup India and Make in India schemes. By ensuring regulatory compliance and adopting sustainable practices, the recycling unit can function effectively while contributing to environmental protection and resource recovery, as illustrated in **Figure 3**.

3. Threat and its Solution

In the context of establishing a printed e-waste recycling unit within the MSME sector, several potential threats to operational efficacy and sustainability have been identified. The primary concern is environmental non-compliance, which could result in penalties, unit closure or loss of credibility. Further, improper handling of hazardous materials poses significant risks to worker health and environmental safety (**Jena, R. K. 2015)**. The irregular supply of e-waste and lack of awareness among suppliers or consumers, may further impact the availability of raw materials. Financial constraints, including initial investment and operational costs, may delay operations or reduce efficiency. Technological obsolescence is also a concern, as outdated equipment can lead to inefficient processing and low recovery rates. To mitigate these threats, meticulous planning and adherence to governmental regulations are imperative. Securing all necessary licenses and implementing pollution control mechanisms, would ensure legal compliance. Training workers in safety procedures and providing personal protective equipment, can mitigate health risks. Establishing partnerships with e-waste collection networks or producers under Extended Producer Responsibility Schemes, can ensure consistent supply of raw materials. Financial risks can be minimized through government subsidies, soft loans and phased investment plans. Regular technological upgrades and process optimization, will help maintain competitiveness and efficiency over time.

4. Outcome and Confab of the Study

The study has successfully demonstrated that printed e-waste can be recycled efficiently and profitably, using hydrometallurgical processes, with in the MSME framework. The developed business toolbox outlines the environmental, economic and legal frameworks, needed for setting up a sustainable recycling unit. Experimental processes like microwave pyrolysis, leaching with eco-friendly lixiviants, solvent extraction and oxidative precipitation, proved effective in recovering valuable metals such as gold, silver, copper and palladium from waste PCBs. The economic evaluation, using Discounted Revenue Flow (DRF) and Final Present Worth (FPW), established that the recycling model is viable when proper segregation and recovery methods are applied. The toolbox also addresses the practical aspects such as space requirements, pollution control measures and legal permits needed, to start such a business under Indian regulations. The model serves as a practical guide for entrepreneurs, aiming to enter the e-waste recycling sector, with a focus on environmental responsibility and financial sustainability (**Jamader et al., 2023**).

The study revealed that electronic waste, particularly printed electronic waste (PEWs), is becoming an increasing environmental issue, due to inadequate disposal practices and the fast pace of technological progress. Although recycling regulations are in place, waste processing in India is largely controlled by the informal sector, which frequently ignores safety standards. This research demonstrated environmental sustainability with business potential, by suggesting a well-organized and scientifically supported recycling model. Incorporating hydrometallurgical techniques provides a more efficient, environmentally friendly and cost-effective solution compared to conventional pyro-metallurgical methods. Additionally, categorizing PEW into low and high grades, allows for improved processing strategies, based on the materials' composition. By utilizing financial models and focusing on the use of safe, eco-friendly chemicals for metal recovery, the study would enhance both environmental protection and business opportunities **(Selvam, M. 2020)**. According to **Table 1,** FPW of gold recovery of 170 g per tonne and recovery of approximately 94%, was the result of the revenue, produced from the PEWs procedures by the hydrometallurgical process. Power usage will cost Rs. 5902.00, while chemical costs will be Rs. 53784.00 and 1t PEWs will cost around Rs. 55000.00. Since one gram of gold currently costs Rs. 9573.00, the total value of gold for 170 grams will be Rs. 16,27,410.00, representing a strong return on investment of about 1420% (more/less). Hence the research advocates the formalization of the recycling industry, by providing MSMEs with a comprehensive framework from sourcing and processing to compliance and cost evaluation. The inclusion of government policies, potential subsidies, and extended producer responsibility mechanisms, makes this business model more feasible and scalable. Ultimately, the research revealed that a technically robust, legally compliant and economically viable recycling unit for printed e-waste, can be a sustainable business endeavor, with lasting benefits for both the environment and the economy.

5. Conclusion

The research concludes that adopting a structured and scientifically informed approach to recycling printed electronic waste is both economically feasible and essential for environmental sustainability. By employing hydrometallurgical techniques and incorporating them into a clearly defined MSME business toolkit, the model offers a sustainable method for recovering valuable metals from printed circuit boards. This approach, which combines environmentally friendly chemical processes, legal adherence and financial planning, presents a viable solution to the escalating e-waste issue in India. It not only promotes environmental conservation but also fosters entrepreneurship, job creation and resource preservation. The toolkit developed in this study, could act as a comprehensive manual, for setting up a printed e-waste recycling facility, specifically designed for the MSME sector. It includes crucial elements such as government regulations, operational setup, economic assessment and risk management. The outcomes of the process experiments further validate the model's practicality and profitability, if executed correctly.

6. Data Source Statement

The data employed in this study, on the recovery of gold from PEW, was sourced from authoritative governmental entities like the Central Pollution Control Board (CPCB), Government of India, and the West Bengal Pollution Control Board (WBPCB). These organizations furnished essential insights into the composition of electronic waste, environmental regulations and the potential yield of precious metals, such as gold, from PEW recycling processes.

7. Future Scope

To broaden the scope of the study, automation and AI can be integrated for more effective e-waste sorting and recovery. Investigating eco-friendly, biodegradable chemicals for metal extraction, will boost environmental protection. Establishing decentralized recycling facilities can enhance access in rural regions. Enhancing government regulations, providing incentives and adopting circular economy strategies, will further promote the advancement of sustainable e-waste recycling within the MSME sector.

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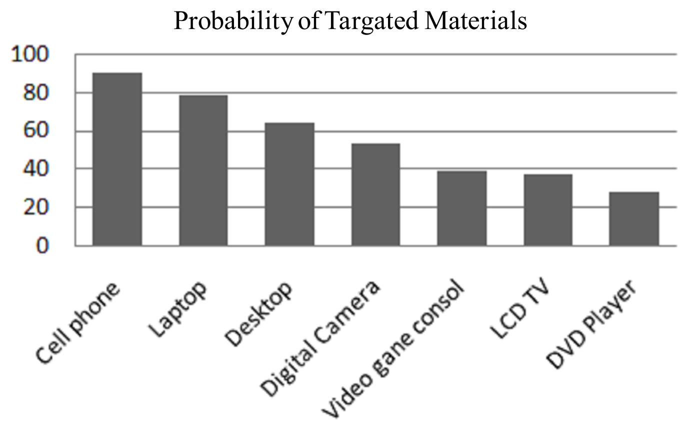
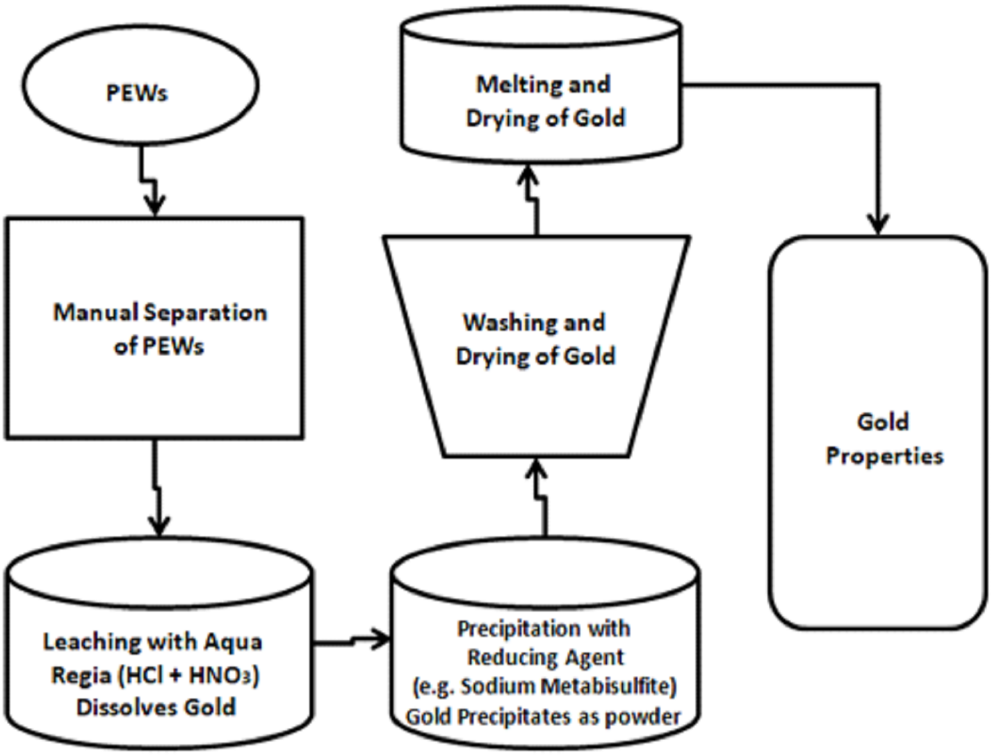
Figure-1 Category of PEWs as High and Low Grade



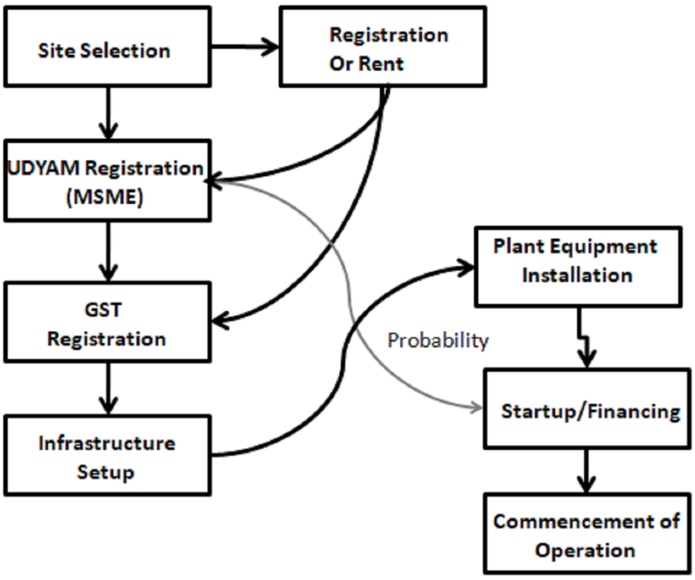
Source: Secondary data and collected from the website https://cpcb.nic.in/

Figure - 2 Recycle Process of PEWs



Source: Nie et al., (2023)

Figure-3: The Business model toolbox step by step



Source: Selvam et al., (2016)

Table-1 Expense and Profit Calculation

Sl.	Particulars	Expense as per 1t PEWs
1.	PEWs (1t)	Rs. 55000.00
2.	Power	Rs. 5902.00
3.	Chemical	Rs. 53784.00
	Total Expense	**Rs. 114686.00**
	Profit Calculation	
	1g Gold	Rs. 9573.00 as on May, 2025
	170g Gold	**Rs. 1627410.00 as on May, 2025**

Source: Secondary data and collected from the website https://www.goodreturns.in/gold-rates/kolkata.html