Electronic waste recycling: A review of processes and technology options

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Contents

1. Introduction

Advances in the field of science and technology brought about industrial revolution in the 18th Century which marked a new era in human civilization. In the 20th Century, the information and communication revolution has brought enormous changes in the way we organize our lives, our economies, industries and institutions. These spectacular developments in modern times have undoubtedly enhanced the quality of our lives. At the same time, these have led to manifold problems including the problem of massive amount of hazardous waste and other wastes generated from electric products. These hazardous and other wastes pose a great threat to the human health and environment. The issue of proper management of wastes, therefore, is critical to the protection of livelihood, health and environment. It constitutes a serious challenge to the modern societies and requires coordinated efforts to address it for achieving sustainable development.

The electronics industry is the world's largest and fastest growing manufacturing industry. In the last few years, it has played a significant part in socio-economic and technological growth of societies. According to the Basel Convention, wastes are substances or objects, which are disposed of or are intended to be disposed of, or are required to be disposed of by the provisions of national laws. Additionally, wastes are such items which people are required to discard, for example by law because of their hazardous properties. Our daily activities give rise to a large variety of different wastes arising from different sources. Thus, municipal waste is waste generated by households and consists of paper, organic waste, metals, etc. The wastes generated by production processes, households and commercial activities are hazardous waste. Biomedical waste is waste generated by hospitals and other health providers and consists of discarded drugs, waste sharps, microbiology and biotechnology waste, human anatomical waste, animal waste, etc. Radioactive waste is any material that contains a concentration of radionuclides greater than those deemed safe by national authorities, and for which, no use is foreseen. Other sources of waste include end-of-life vehicles, packaging waste, tyres, agricultural waste, etc. These waste substances are in the long run hazardous in nature as they are ignitable, corrosive, reactive, toxic, explosive, poisonous or infectious. Hence, they pose substantial or potential threat to public health and the environment.

○ What has motivated us to work on this project?

E-waste management industries are growing rapidly in today's world. India is world's 5th largest generator of e-waste. We are now technologically capable enough so that we can make most out of the e-waste which can make a change in large scale in many ways for our country since we are still a developing country. When we see this project from a Metallurgist's perspective the rejected and outdated electronic devices provide a lot of scope in recovering precious metals from them by using various metallurgical processes.

So, this project brings in a lot of real-world problems and will help us learn a lot. This attracted us towards this project.

2. Objectives

- India is a very vast country and e-waste generation pattern fluctuates throughout geographically. Through this project we can study the e-waste generation pattern across the land.

- To find best possible alternative metallurgical process that can be used at a particular location. Since we cannot use the same processes to recover metal at every location, this software helps us to take decision which process best fits there.

  E-waste is increasing enormously in number because technology is developing so fast that devices become outdated in very short span of time. This is giving a lot of scope and exposure to e-waste management industries, so with the help of this project we can predict the best method to be applied in order to get maximum upshot.

- To help government in order to manage e-waste efficiently.

3. Literature review

3.1. Electronic waste

3.1.1. What is E-waste?

Like hazardous waste, the problem of e-waste has become an immediate and long-term concern as its unregulated accumulation and recycling can lead to major environmental problems endangering human health. The information technology has revolutionized the way we live, work and communicate bringing countless benefits and wealth to all its users. The creation of innovative and new technologies and the globalization of the economy have made a whole range of products available and affordable to the people changing their lifestyles significantly. New electronic products have become an integral part of our daily lives providing us with more comfort, security, easy and faster acquisition and exchange of information. But on the other hand, it has also led to unrestrained resource consumption and an alarming waste generation. Both developed countries and developing countries like India face the problem of e-waste management. The rapid growth of technology, upgradation of technical innovations and a high rate of obsolescence in the electronics industry have led to one of the fastest growing waste streams in the world which consist of end of life electrical and electronic equipment products. It comprises a whole range of electrical and electronic items such as refrigerators, washing machines, computers and printers, televisions, mobiles, I-pods, etc., many of which contain toxic materials. Many of the trends in consumption and production processes are unsustainable and pose serious challenge to environment and human health. Optimal and efficient use of natural resources, minimization of waste, development of cleaner products and environmentally sustainable recycling and disposal of waste are some of the issues which need to be addressed by all concerned while ensuring the economic growth and enhancing the quality of life. The countries of the European Union (EU) and other developed countries to an extent have addressed the issue of e-waste by taking policy initiatives and by adopting scientific methods of recycling and disposal of such waste. The EU defines this new waste stream as ‘Waste Electrical and Electronic Equipment’ (WEEE). As per its directive, the main features of the WEEE include definition of ‘EEE’, its classification into 10 categories and its extent as per voltage rating of 1000 volts for alternating current and 1500 volts for direct current. The EEE has been further classified into ‘components’, ‘sub-assemblies’ and ‘consumables’. Since there is no definition of the WEEE in the environmental regulations in India, it is simply called ‘e-waste’. E-waste or electronic waste, therefore, broadly describes loosely discarded, surplus, obsolete, broken, electrical or electronic devices.

3.1.2. Composition of e-waste

E-waste consists of all waste from electronic and electrical appliances which have reached their end- of- life period or are no longer fit for their original intended use and are destined for recovery, recycling or disposal. It includes computer and its accessories monitors, printers, keyboards, central processing units; typewriters, mobile phones and chargers, remotes, compact discs, headphones, batteries, LCD/Plasma TVs, air conditioners, refrigerators and other household appliances. The composition of e-waste is diverse and falls under 'hazardous' and 'non-hazardous' categories. Broadly, it consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete, ceramics, rubber and other items. Iron and steel constitute about 50% of the waste, followed by plastics (21%), non-ferrous metals (13%) and other constituents. Non-ferrous metals consist of metals like copper, aluminium and precious metals like silver, gold, platinum, palladium and so on. The presence of elements like lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants beyond threshold quantities make e-waste hazardous in nature. It contains over 1000 different substances, many of which are toxic, and creates serious pollution upon disposal. Obsolete computers pose the most significant environmental and health hazard among the e-wastes.

3.1.3. E-waste generation in India

In the list of e-waste generating nations India stands 3rd in the list after China and Japan.

There are 10 States that contribute to 70 per cent of the total e-waste generated in the country, while 65 cities generate more than 60 per cent of the total e-waste in India. Among the 10 largest e-waste generating States, Maharashtra ranks first followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab. Among the top ten cities generating e-waste, Mumbai ranks first followed by Delhi, Bengaluru, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat and Nagpur. The main sources of electronic waste in India are the government, public and private (industrial) sectors, which account for almost 70 per cent of total waste generation. The contribution of individual households is relatively small at about 15 per cent; the rest being contributed by manufacturers. Though individual households are not large contributors to waste generated by computers, they consume large quantities of consumer durables and are, therefore, potential creators of waste. Maharashtra contributes the largest e-waste contributing 19.8% but recycles only 47,810 TPA (Tonnes per annum) whereas its counterparts Tamil Nadu(13%) recycles about 52,427 TPA, Uttar Pradesh(10.1%) recycles about 86,130, West Bengal (9.8%),Delhi(9.5%), Karnataka(8.9%), Gujarat(8.8%) and Maharashtra(7.6%).

According to ASSOCHAM, an industrial body in India the, Compound Annual Growth Rate (CAGR) of electronic waste is 30%. With changing consumer behaviour and rapid economic growth, ASSOCHAM estimates that India will generate 5.2 million tonnes of e-waste by 2020.

While e-waste recycling is a source of income for many people in India, it also poses numerous health and environmental risks. More than 95% of India's e-waste is illegally recycled by informal waste pickers called *kabadiwalas* or *raddiwalas.* These workers operate independently, outside of any formal organization which makes enforcing e-waste regulations difficult-to-impossible. Recyclers often rely on rudimentary recycling techniques that can release toxic pollutants into the surrounding area. The release of toxic pollutants associated with crude e-waste recycling can have far reaching, irreversible consequences.

3.2. Electronic waste in Global context

E-waste is the fastest growing municipal waste across the world, and more than 50 MT of e-waste is generated globally every year. The developed western economies accounted for only 2 % of the total solid waste generated in developed countries by 2010. Developing countries with increasing consumer base and an anticipated rise in the sales of electronic products in these countries due to their heavy prospective demand would experience rapid economic and industrial growth along with the huge quantity of e-waste generation that will be of serious concern. Recent studies carried out by UN reports that e-waste from old computers would jump by 400 % in China and by 500 % in India on 2007 levels by 2020. Further, e-waste from discarded mobile phones would be about seven times higher in China and, 18 times higher in India than 2007 levels by 2020. Such predictions highlight the urgent need to address the problem of e-waste in developing countries like India where the collection and management of e-waste and the recycling process is yet to be properly regulated. According to the UNEP, China, India, Brazil, Mexico and others would face rising environmental damage and health problems if e-waste recycling were left to the informal sector. The EU (30%) and the U.S (28%) accounts for maximum e-waste generation during this current decade. As per the Inventory Assessment Manual, it is estimated that the total e-waste generated in the EU is about 14-15 kg per capita or about 5MT to 7MT per annum whereas India and China, contributes less than 1kg. In Europe, e-waste accounts for 6 million tons of solid waste per annum. The e-waste generation in the EU is expected to grow at a rate of 3 per cent to 5 per cent per year. A major reason for the rapid generation of e-waste and the resulting growth of the recycling market can be found in the high rate of obsolescence in the electronics market. Most electronic goods, especially in the West, have very short life span. Such goods are routinely replaced at least every two years, and then either simply discarded or exported to developing countries where there is still a demand for second hand merchandise.

3.3. E-waste in Indian context

3.3.1. E-Waste Management in India: Challenges and Opportunities

Growth in the IT and communication sectors has enhanced the usage of the electronic equipment exponentially. Faster upgradation of electronic product is forcing consumers to discard old electronic products very quickly which in turn**,** adds to e-waste to the solid waste stream. The growing problem of e-waste calls for greater emphasis on recycling e-waste and better e-waste management. Electronic waste or e-waste is generated when electronic and electrical equipment become unfit for their originally intended use or have crossed the expiry date. Computers, servers, mainframes, monitors, compact discs (CDs), printers, scanners, copiers, calculators, fax machines, battery cells, cellular phones, transceivers, TVs, iPods, medical apparatus, washing machines, refrigerators, and air conditioners are examples of e-waste (when unfit for use). These electronic equipments get fast replaced with newer models due to the rapid technology advancements and production of newer electronic equipment. This has led to an exponential increase in e-waste generation. People tend to switch over to the newer models and the life of products has also decreased.

E-waste typically consists of metals, plastics, cathode ray tubes (CRTs), printed circuit boards, cables, and so on. Valuable metals such as copper, silver, gold, and platinum could be recovered from e-wastes, if they are scientifically processed. The presence of toxic substances such as liquid crystal, lithium, mercury, nickel, polychlorinated biphenyls (PCBs), selenium, arsenic, barium, brominated flame retardants, cadmium, chrome, cobalt, copper, and lead, makes it very hazardous, if e-waste is dismantled and processed in a crude manner with rudimentary techniques. E-waste poses a huge risk to humans, animals, and the environment. The presence of heavy metals and highly toxic substances such as mercury, lead, beryllium, and cadmium pose a significant threat to the environment even in minute quantities.

Consumers are the key to better management of e-waste. Initiatives such as Extended Producer Responsibility (EPR); Design for Environment (DfE); Reduce, Reuse, Recycle(3Rs), technology platform for linking the market facilitating a circular economy aim to encourage consumers to correctly dispose their e-waste, with increased reuse and recycling rates, and adopt sustainable consumer habits. In developed countries, e-waste management is given high priority, while in developing countries it is exacerbated by completely adopting or replicating the e-waste management of developed countries and several related problems including, lack of investment and technically skilled human resources. In addition, there is lack of infrastructure and absence of appropriate legislations specifically dealing with e-waste. Also, there is inadequate description of the roles and responsibilities of stakeholders and institutions involved in e-waste management, etc. In 2016, the Ministry of Environment, Forest and Climate Change (MoEFCC) released the updated E-waste (Management) Rules, which came in supersession of the E-waste in India (GOI, 2016).

3.3.2. E-waste problem in India

India ranks 177 amongst 180 countries and is amongst the bottom five countries on the Environmental Performance Index 2018, as per a report released at the World Economic Forum 2018. This was linked to poor performance in the environment health policy and deaths due to air pollution categories. Also, India is ranked fifth in the world amongst top e-waste producing countries after the USA, China, Japan, and Germany and recycles less than 2 per cent of the total e-waste it produces annually formally. Since 2018, India generates more than two million tonnes of e-waste annually, and also imports huge amounts of e-waste from other countries around the world. Dumping in open dumpsites is a common sight which gives rise to issues such as groundwater contamination, poor health, and more. The Associated Chambers of Commerce and Industry of India (ASSOCHAM) and KPMG study, Electronic Waste Management in India identified that computer equipment account for almost 70 per cent of e-waste, followed by telecommunication equipment phones (12 per cent), electrical equipment (8 per cent), and medical equipment (7 per cent) with remaining from household e-waste.

E-waste collection, transportation, processing, and recycling is dominated by the informal sector. The sector is well networked and unregulated. Often, all the materials and value that could be potentially recovered is not recovered. In addition, there are serious issues regarding leakages of toxins into the environment and workers' safety and health.

Seelampur in Delhi is the largest e-waste dismantling centre of India. Adults as well as children spend 8–10 hours daily extracting reusable components and precious metals like copper, gold and various functional parts from the devices. E-waste recyclers use processes such as open incineration and acid-leeching. This situation could be improved by creating awareness and improving the infrastructure of recycling units along with the prevalent policies. The majority of the e-waste collected in India is managed by an unorganized sector.

Also, informal channels of recycling/reuse of electronics such as repair shops, used product dealers, e-commerce portal vendors collect a significant proportion of the discarded electronics for reuse and cannibalization of parts and components.

3.3.3. Opportunities of E-waste management in India

The Ministry of Environment, Forest and Climate Change rolled out the E-Waste (Management) Rules in 2016 to reduce e-waste production and increase recycling. Under these rules, the government introduced EPR which makes producers liable to collect 30 per cent to 70 per cent (over seven years) of the e-waste they produce, said the study.

The integration of the informal sector into a transparent recycling system is crucial for a better control on environmental and human health impacts. There have been some attempts towards integrating the existing informal sector in the emerging scenario. Organizations such as GIZ have developed alternative business models in guiding the informal sector association towards authorization. These business models promote a city-wide collection system feeding the manual dismantling facility and a strategy towards best available technology facilities to yield higher revenue from printed circuit boards. By replacing the traditional wet chemical leaching process for the recovery of gold with the export to integrated smelters and refineries, safer practices and a higher revenue per unit of e-waste collected are generated.

E-waste is a rich source of metals such as gold, silver, and copper, which can be recovered and brought back into the production cycle. There is significant economic potential in the efficient recovery of valuable materials in e-waste and can provide income-generating opportunities for both individuals and enterprises. The E-Waste Management Rules, 2016 were amended by the government in March 2018 to facilitate and effectively implement the environmentally sound management of e-waste in India. The amended Rules revise the collection targets under the provision of EPR with effect from October 1, 2017. By way of revised targets and monitoring under the Central Pollution Control Board (CPCB), effective and improved management of e-waste would be ensured.

3.3.4. Need of E-waste management

The most important reason to care about e-waste is reducing our environmental impact. It is far more energy intensive to mine new resources than to recycle our existing ones. These recycled metals produce raw materials that are introduced back into the product lifecycle.

From an environmental perspective, e-waste is an enormous source of pollution. When e-waste is tossed into the landfills, some of them contain chemicals that can leach out of the landfills and into their surroundings, thus contaminating our water supplies. Likewise, when e-waste is tossed into the incinerators, the act of burning them is known to create chemicals called dioxins. Made up of carbon, oxygen, hydrogen, and chlorine, said chemicals are known to contribute to the greenhouse effect behind man-made climate change. Furthermore, dioxins are known to have a horrible impact on human health, with common examples ranging from an increased chance of cancer to serious developmental and reproductive issues.

For every one million cell phones that are recycled, 35,274 pounds of copper, 772 pounds of silver, 75 pounds of gold and 33 pounds of palladium can be recovered. Over 1 billion cell phones were produces in 2015.Instead of destroying land to mine for new resources, we can simply reuse existing resources at a lower environmental cost. According to the EPA (Environmental Pollution Agency), only 15–20% of used electronics are recycled, the rest are incinerated or end up in landfills. This is a huge waste of resources. So it is important to recycle E-Waste.

Moreover it is growing rapidly, due to the world aiming to a “smarter” built environment. It can be extremely toxic, because electronics performances require particular materials and compounds. That’s why a lot of it end up in poor countries to be treated. It is precious, because among those particular materials there are some precious metals (gold, platinum, copper) and rare earths (cobalt, indium).

E-waste management helps to keep the e-waste out of landfills**.** Computers, mobile devices, televisions, sound systems, chargers and even household appliances are all recyclable, yet they can also be the most dangerous materials dumped inside a landfill, according to the Environmental Protection Agency. When improperly disposed of, the heavy metals, plastics and glass in e-waste can pollute the air or seep into waterways. Recycling e-waste can significantly decrease the demand for mining heavy metals and reduce the greenhouse gas emissions from manufacturing virgin materials.

4. Metallurgical Processes for the Extraction of Metals from E-Waste

The metal fractions separated from e-waste during preprocessing can be further processed using hydrometallurgical, pyrometallurgical, electrometallurgical, bio-metallurgical processes, and their combinations. The hydrometallurgical and pyrometallurgical processes are the major routes for processing of e-waste. These routes may be followed by electrometallurgical/electrochemical processes (for example electrorefining or electrowinning) for selected metal separation and recovery. Currently, there are only limited laboratory studies for e-waste processing through bio-metallurgical routes, e.g., bioleaching of metals from e-waste. Nevertheless, this route has a potential for further development.

- ## Hydrometallurgical Processes

Various investigators studied the extraction of PMs, copper, lead and zinc from e-waste using hydrometallurgical routes [11,37–41]. These routes are based on traditional hydrometallurgical technology of metals extractions from their primary ores. Similar steps of acid or caustic leaching are employed for selective dissolution of PMs from e-waste. The pregnant solution is separated and purified for the enrichment of metal content thereby impurities are removed as gangue materials. The isolation of metal of interest is conducted through solvent extraction, adsorption and ion exchange enrichment processes. Finally, metals are recovered from solution through electrorefining (electrometallurgy) or chemical reduction processes.

<u>Limitations of Hydrometallurgy Route</u>-

- Overall, hydrometallurgical routes are slow and time consuming and impact recycling economy. There are concerns regarding the economy of hydrometallurgical routes compared to pyrometallurgical processes for the extraction of PMs from e-waste.

- Mechanical processing of e-waste takes longer to reduce size for efficient dissolution. It is reported that 20% PM is lost by mechanical force during the liberation process that contributes to a significant loss in the overall revenue.

- Cyanide is a dangerous leachant and should therefore be used with high safety standards. It can cause contamination of rivers and seawater, especially near gold mines, which poses serious health risks to the inhabitants.

• Halide leaching is difficult to implement due to strong corrosive acids and oxidizing conditions. Specialized equipment made of stainless steel and rubbers is required for leaching of gold using halide agents from e-waste.

• The use of thiourea leachants is limited in gold extraction due to its high cost and consumption. Moreover, further developments are required to improve the current technology of thiourea-based gold leaching.

• Pyrometallurgical Processes

Pyrometallurgical processes for recovering metals from various waste materials have been used during the last two decades. Smelting in furnaces, incineration, combustion and pyrolysis are typical e-waste recycling processes. State-of-the-art smelters and refineries can extract valuable metals and isolate hazardous substances efficiently. Such recycling facilities can close the loop of valuable metals and reduce environmental impact arising from large quantities of e-waste. Currently, e-waste recycling is dominated by pyrometallurgical routes [57], whereas the steel industry embraces the ferrous fractions for the recovery of iron, and the secondary aluminium industry takes the aluminium fractions. Pyrometallurgical processes work with the steps of liberation, separation/upgrading and purification that are fundamentally similar to those of mechanical or hydrometallurgical routes. However, the liberation of valuable metals is not achieved by leaching, crushing or grinding but by smelting in furnaces at high temperatures. In these processes, metals are sorted by exploiting their chemical and metallurgical properties, e.g., PMs are segregated into a solvent metal phase (copper or lead). The metal fractions separated during the pre-processing of e-waste are composed of Fe, Al, Cu, Pb and PMs. After Fe and Al, Cu and Pb are the main constituents of a typical e-waste. Currently, copper and lead smelters work as e-waste recyclers for the recovery of Pb, Cu and PMs. In these pyrometallurgical processes, e-waste/copper/lead scrap is fed into a furnace, whereby metals are collected in a molten bath and oxides form a slag phase.

➢ Lead Smelting Route

Primary lead is produced from sulfide ores containing iron, zinc, copper, PMs, and other trace elements. The concentrated ore and e-waste is treated for the extraction of lead and PMs. The process consists of sintering (ores), reduction and refining stages. Sintering is carried out to reduce the sulfur contents of feed material that is composed of pyrite, lime rock, silica and high concentrated lead. The reduction process is conducted in blast furnaces with the help of coke where molten lead with about 85% purity is tapped from the bottom of the furnace. The plastics fraction of e-waste can partially replace coke as a reducing agent during the reduction stage, and the metals fraction ends up in the metal phase. In the refining stage, copper dross is skimmed off from the lead dross and is treated in a reverberatory furnace. The lead dross is processed by adding wood chips, fine coke and sulfur. The sulfur dross produced is separated and transferred to the reverberatory furnace. The heating of lead dross in the reverberatory furnace separates the lead bullion (rich in lead), matte (copper and other metals sulfides) and speiss (high in arsenic and antimony contents). Matte and speiss are treated in copper smelters for the extraction of copper and other associated metals. In the last stage of e-waste processing via the lead smelting route, PMs and other elements are separated from the lead bullion. PMs are separated by the Parkes process, in which zinc forms an insoluble intermetallic compound with gold and silver. Other impurities including antimony, tin, arsenic, bismuth, and trance elements are also separated during the refining stage. Final products of refining stage include metallurgical grade lead (99.99%).

➢ Copper Smelting Route

Primary and secondary copper smelting routes are adopted to recycle and extract PMs from e-waste. It is reported that copper smelting routes are more environmentally friendly compared to lead smelters that generate toxic fumes. Copper smelting facilities near populations will minimize the cost of e-waste transportation and therefore the recycling economy will be improved. These advantages allow copper smelters to be installed near cities where e-waste is generated. In these processes, PMs are recovered via a conventional electrorefining process where they are segregated in slimes. Commonly, copper smelting routes including matte and black copper are used for e-waste recycling. In the sulfur-based route (primary copper smelting), copper matte (40%) and blister copper (98.5%) are produced. Finally, blister copper is refined by fire refining to produce pure copper. In the black copper route (secondary copper smelting), crude copper is produced during a reduction process and is refined by oxidation in a converter. The black copper is an attractive route because it can receive high levels of impurities including Fe, Zn, Pb and Sn. The black copper smelting process consists of reduction and oxidation cycles. Impurities are mostly segregated into the vapor phase and are discharged in the off gas.

Limitations of Pyrometallurgy route-

- Recovery of plastics is not possible because plastics replace coke as a source of energy.
- Iron and aluminium recovery is not easy as they end up in the slag phase as oxides
- Hazardous emissions such as dioxins are generated during smelting of feed materials containing halogenated flame retardants. Therefore, special installations are required to minimize environmental pollution.
- A large investment is required for installing integrated e-waste recycling plants that maximize the recovery of valuable metals and also protect the environment by controlling hazardous gas emissions.
- Instant burning of fine dust of organic materials (e.g., non-metallic fractions of e-waste) can occur before reaching the metal bath. In such cases, agglomeration may be required to effectively harness the energy content and also to minimize the health risk posed by fine dust particles.
- Ceramic components in feed material can increase the volume of slag generated in the blast furnaces, which thereby increases the risk of losing PMs from BMs.

5. SuperDecision Software

5.1. Introduction

Super Decisions is decision-making software which works based on two multi-criteria decision-making methods.

Super Decisions implements the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). It has been used in many research and practical fields such as manufacturing, environmental management, aviation, small hydropower plants and agriculture.[1]

5.1.1. Analytic hierarchy process (AHP)

The AHP, which is a MCDM technique, is regularly used to evaluate several conflicting criteria during complex decision-making process (Atmaca and Basar, 2012). AHP which is based on mathematics and judgement, serves to set priorities among the various criteria concerned, and eventually helps in making the most appropriate decision. The general idea of the AHP technique consists of breaking down a complex decision or goal into a set of hierarchical levels of criteria and alternatives. The set of selected alternatives are then assessed with regards to a set of pre-defined evaluation criteria. The best option is the one achieving the most acceptable trade-off among the criteria being considered as shown in Fig. 1.

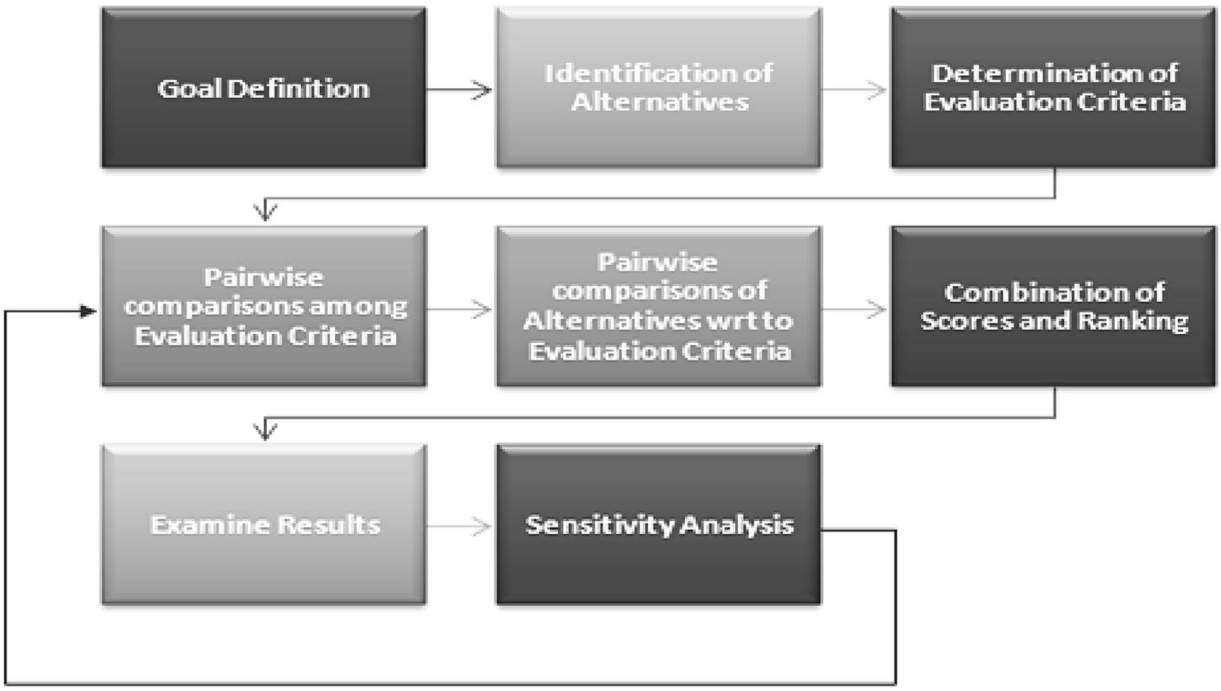

Fig. 1. Steps for the analytical hierarchy process.

5.1.2. Analytic Network Process (ANP)

The **analytic network process** (**ANP**) is a more general form of the analytic hierarchy process (AHP) used in multi-criteria decision analysis.

AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while the ANP structures it as a network. Both then use a system of pairwise comparisons to measure the weights of the components of the structure, and finally to rank the alternatives in the decision.

5.2. Role of the software

In this project we have taken the city of Bhopal and tried to find the most suitable way that can be implemented to recover the desired metals from the rejected electronic devices. When the situation becomes complex and there is lack of clarity in finding the most suitable way economically as well as taking care of feasibility then this software comes into help and can be used to predict the process that should be used for better results.

5.3. Implementation

We have to find appropriate data in order to feed the software to get desired results. Here since we have selected Bhopal city in Madhya Pradesh Open SuperDecisions software, start by saving the title for the file, then we need to create clusters (containers of nodes).Generally we create 3 clusters namely: 1)GOAL 2)CRITERIA and 3)ALTERNATIVES as shown in the Fig. 2.[2]

Fig. 2.

Now we have 3 clusters arrange them in a way that we can see all of them. Now we need to create nodes in each of the clusters to represent components and here in this project, the goal nodes, the criteria nodes and alternatives nodes are as shown in the Fig. 3.

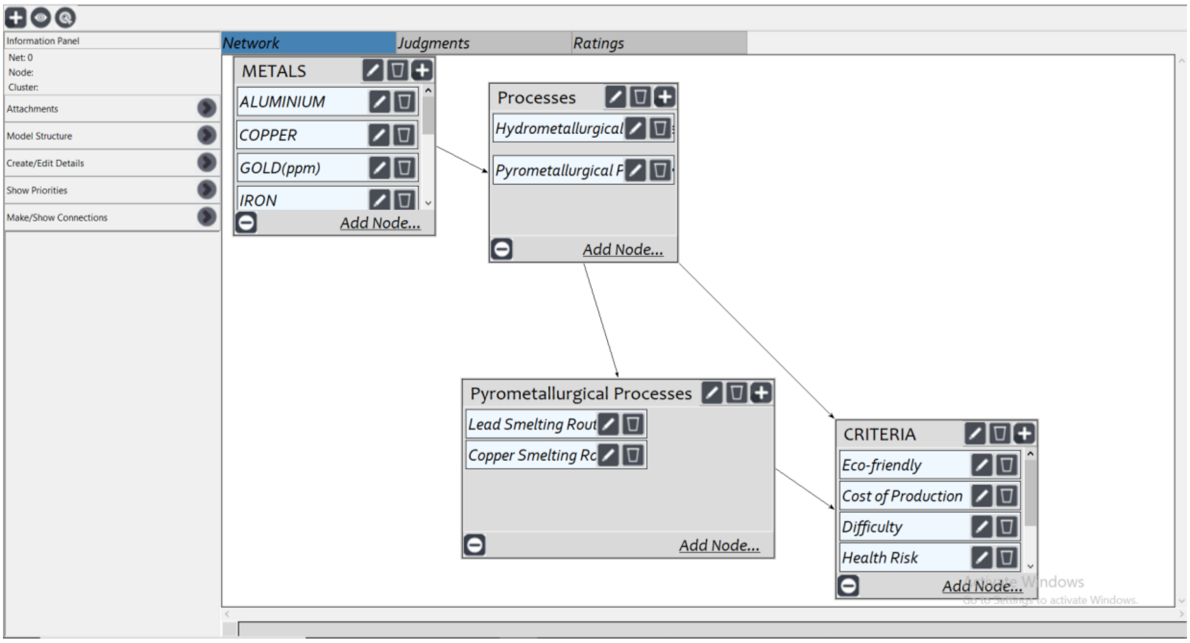

Fig. 3. Representing Nodes

where pyrometallurgical process is a sub-cluster under the criteria cluster processes. Next we need to connect all the nodes in all the clusters, for this

we need to click on the right most bottom position "Make/Show connections" and then give the required connections to the remaining cluster, we repeat this process for all the nodes so that all the nodes are correctly connected. Then the software would look like, as shown in the Fig. 3. To check this, click on the top most 3rd icon and select on the node, then all the other nodes it is connected will be shown in red border as shown in the Fig. 4

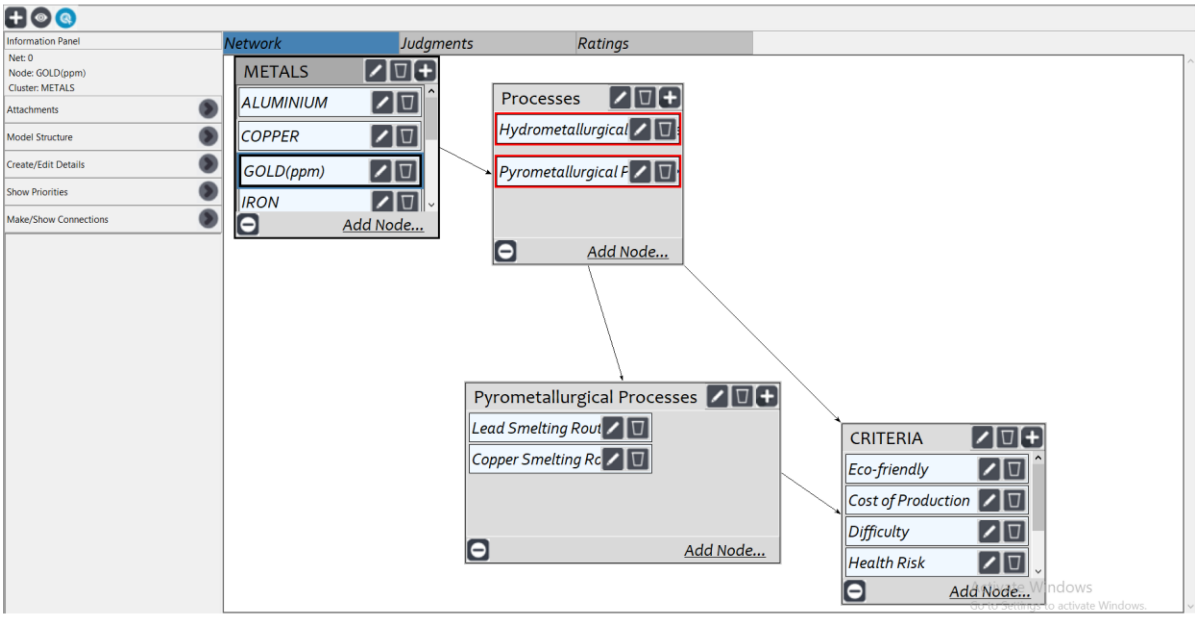

Fig. 4.

Now we can use the computations → Unweighted Supermatrix → Graphical

to check the supermatrix that all the weights inside the cluster are equally distributed and now the next step would be to make the judgements by pairwise comparisions, to do this we have to move to the judgment section then we need to select the node and start from the goal cluster node to compare all the criteria with respect to goal cluster. There are 5 different modes to do judgement, "Questionnaire" is the default mode. The judgements range from 1 to 9 as shown in the Fig. 5. Be careful while making the pairwise comparisions. To enter judgements directly, we can use graphical mode where we choose which of the components we are entering the values for, and then we move the graph inorder to decide and in verbal we drag up and down to find out the preference and the direct mode allows us to put tangables when we have direct values and finally the matrix mode allows us to enter judgements directly as numbers. We

have done our project in Questionaire mode as shown in the Fig. 5.

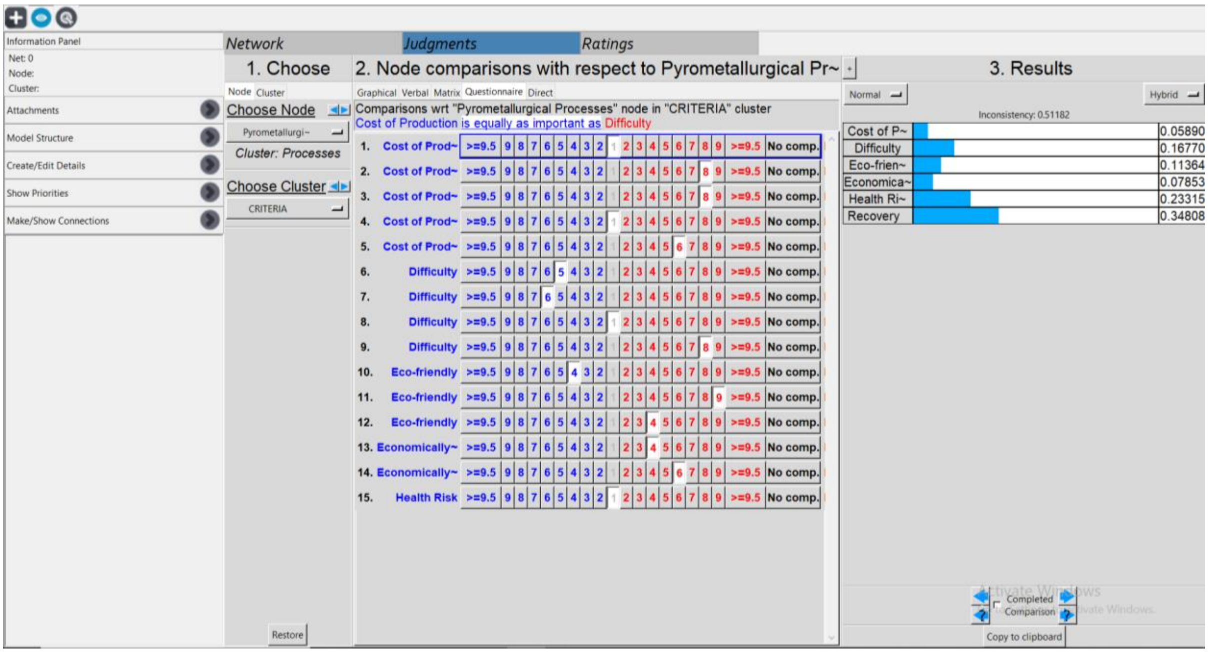

Fig. 5. Node comparision with respect to Pryometallugical process

6. Result & Discussion

As we see from above outcomes theoritically Pyrolysis is the most preferable process to extract electronic waste from the Bhopal Industries. But from the above results we cannot completely come to a conclusion since the inconsistency is high(~0.5) in the pairwise comparision of Pyrometallurgical process, because the data that is used in this project is not completely accurate but was slightly assumed. We need to minimise the inconsistency to make sure that the results obtained are perfect for use for that location as well as economical.

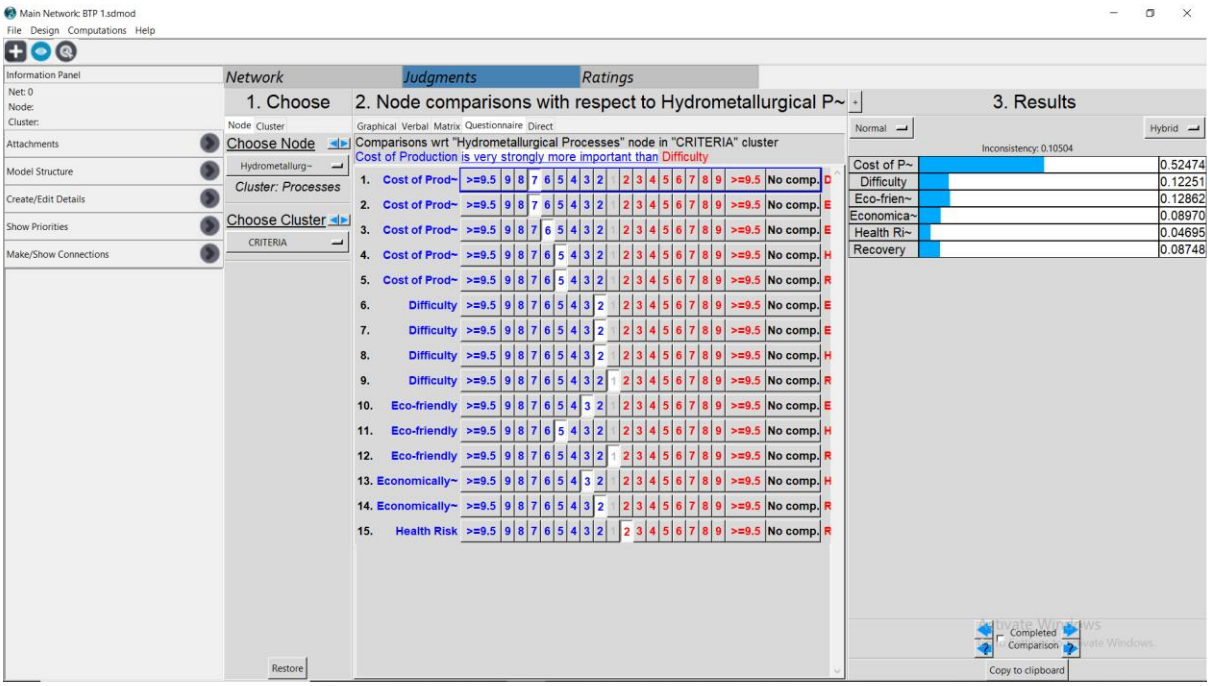

Fig. 6. *Pairwise Comparision in Hydrometallurgical Process.*

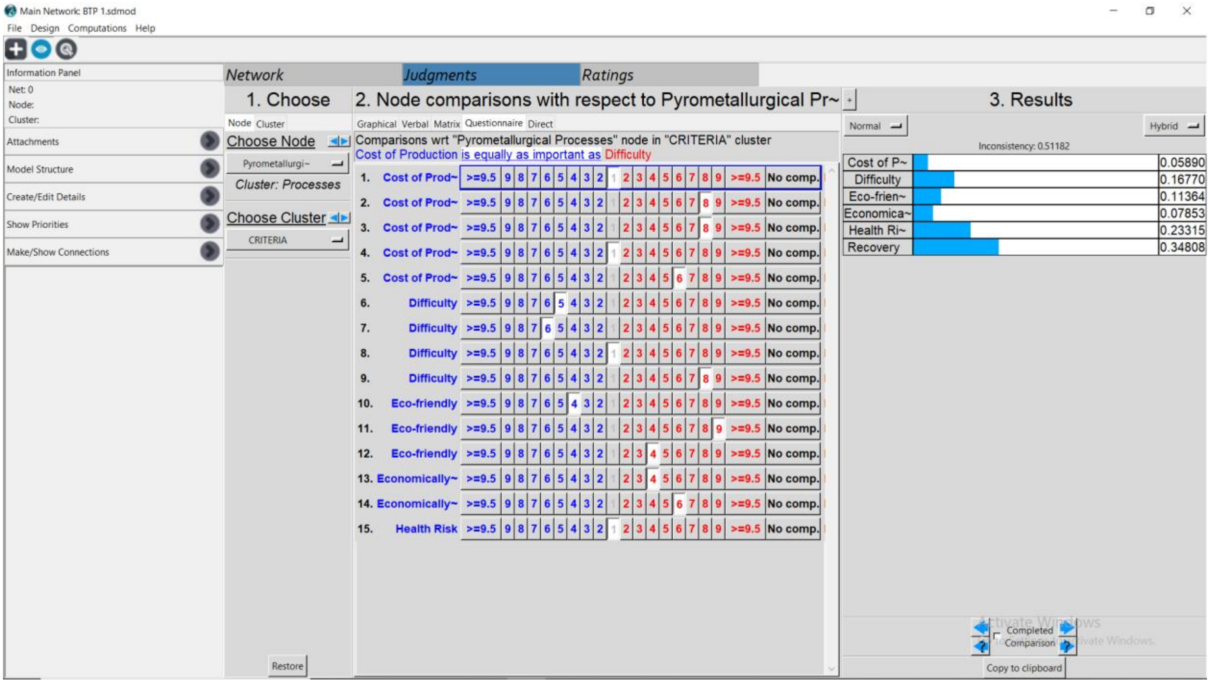

Fig. 7. Pairwise Comparision in Pyrometallurgical Process.

CLUSTERS	NODES	HYDROMETALLURGICAL PROCESSES	PYROMETALLURGICAL PROCESSES
CRITERIA	Cost of production	0.524745	0.058897
	Difficulty	0.122509	0.167699
	Eco-friendly	0.128619	0.113644
	Economically efficient	0.089700	0.078528
	Health risk	0.046949	0.233152
	Recovery	0.087479	0.348081

Fig. 8. Unweighted super Matrix

7. Conclusion

In this project of "**Electronic waste recycling: A review of processes and technology options",** we used a decision-making software called SuperDecisions and tried to obtain the best possible alternative for recovering metals from e-waste. Also, we tried to understand the e-waste generation pattern in various places. Here for this project we extracted data from MP government[3] and used it for obtaining the best possible process for a particular location i.e., Bhopal which could be employed in order to get desired outcomes from the recycler.

8. Future work

In the next semester following the results we obtained this semester we will make it more accurate. Also, we will work on the metals recovered from the e-waste and try to find out what percentage of metal is recovering from the following metallurgical processes.

9. References

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