LIFE CYCLE ASSESSMENT OF COPPER RECOVERY PROCESS FROM PRINTED CIRCUIT BOARDS

KOUSALYA D/O SUBRAMANIAM

Bachelor of Engineering Technology (Energy & Environment) with Hons

UNIVERSITI MALAYSIA PAHANG

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LIFE CYCLE ASSESSMENT OF COPPER RECOVERY PROCESS FROM PRINTED CIRCUIT BOARDS

KOUSALYA D/O SUBRAMANIAM

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the award of the degree in Bachelor of Engineering
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ABSTRAK

E-waste merupakan salah satu masalah yang perlu dipertimbangkan untuk kebaikan alam sekitar global. *E-waste* dianggap sebagai sisa daripada peralatan Elektrik dan Elektronik (WEEE) ia merujuk kepada semua teknologi maklumat dan komunikasi *(ICT)* yang dibuang atau tamat hayat. Setiap tahun jumlah sisa elektronik yang berakhir di tapak pelupusan meningkat. Pengurusan pelupusan sisa elektronik merupakan salah satu isu besar dimana 80% daripada sisa elektronik telah dibuang di tapak pelupusan sampah. Pembuangan sisa elektronik ke tapak pelupusan akan menyebabkan beberapa kesan kerana ia mengandungi bahan-bahan berbahaya dan bertoksik seperti plumbum, arsenic dan merkuri yang membahayakan alam sekitar. Ia boleh menimbulkan risiko serius kepada kesihatan manusia. Walau bagaimanapun, sisa elektronik masih mengandungi bahan lain yang berpotensi untuk digunasemula. Contoh bahan digunasemula ialah tembaga, emas, titanium, besi dan perak yang boleh dipulihkan melalui perlombongan kitar semula. Justeru, kajian ini adalah untuk menentukan kesan alam sekitar menggunakan penilaian kitaran hayat bagi pemulihan tembaga daripada sisa elektronik. Perisian GaBi dan *Tool for the Reduction and Assessment of Chemical and Other Environmental Effects* yang dikenali sebagai *TRACI 2.0* daripada *US EPA* telah digunakan untuk menilai kesan alam sekitar bagi proses pemulihan tembaga daripada sisa elektronik. Kajian ini menunjukkan bahawa perlombongan kitar semula memberi impak yang kurang berbanding perlombongan konvensional dalam aspek pemanasan global *(GWP)*, Pengasidan, Eutrofikasi, Penipisan lapisan ozon, Ekotoksik, *Human health particulate air*, sumber bahan api fosil dan pencemaran udara.

ABSTRACT

E-waste becoming a global environmental concern. E-waste is considered as a waste from Electrical and Electronic Equipment (WEEE) refers to all discarded or end-of-life ICTs and other electronic/electrical equipment that requires an electrical current from an electromagnetic field (circuitry) in order to function. The amount of e-waste ending up in landfills increasing every year. Disposal management of e-waste is one of the biggest issues in this case where 80% of e-waste was ending up in landfills. The e-waste disposal to landfills will cause several impacts because generally it contains hazardous substances like lead, arsenic and mercury which is harmful to the environment and pose serious risks to human health. However, e-waste still contains other valuable materials that potentially can be recovered. This recovery process is known as urban mining. Thus, this study is to determine the environmental impact using life cycle assessment of copper recovery from e-waste. The GaBi software and Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts known as TRACI 2.0 from US EPA was used to assess the environmental impact of recovery process. This study shows that urban mining having less impact compared to conventional mining in the aspect of Global Warming Potential (GWP), Acidification, Eutrophication, Ozone depletion air, Ecotoxicity, Human health particulate air, Human toxicity cancer and non-cancer, Resources fossil fuels and Smog air.

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LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
COP26	Glasgow Climate Pact
CFC	Chlorofluorocarbon
CTU	Comparative Toxic Unit
GWP	Global Warming Potential
KCI	Pottasium Chloride
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Megajoule
NH_4CI	Ammonium Chloride
PCB	Printed Circuit Board
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
UNEP	United Nations Environment Program
WEEE	Waste of Electronic and Electrical Equipment
WPCB	Waste Printed Circuit Board

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CHAPTER 1

INTRODUCTION

1.1 Background of study

The Covid-19 pandemic has brought unprecedented and abrupt changes into human society (Yu et al., 2020). The outbreak of Covid-19 has accelerated the shift to telecommuting and online learning (Chiu et al., 2020). The number of employees working from home was estimated to increase by 300 million (International Labour Organization, 2020) and around 1.3 billion students began online learning from home (Li and Lalani, 2020). According to McKinsey & Company, the rate of digital adoption by consumers and businesses over a five-year period took only approximately two months (Baig et al., 2020). This rapid digital transition introduced a virtual experience for producer-consumer interaction, as well as increased the number of products available to consumers at the convenience of a few clicks. Furthermore, this shift suggest that the disruption can act as a catalyst towards more sustainable lifestyles even in the post-pandemic world (Chiu et al., 2020). This is because some people use electronic devise such as mobile phone for a prolonged period for their entertainment by watching videos, gaming, and surfing social sites to overcome boredom during the lockdown or containment period. Moreover, during the Covid-19 pandemic technology has become a necessity to satisfy daily work and personal requirements(Tyagi et al., 2021). Therefore, the evolution of electronic devices has seen remarkable progress and technological advancement in economy. As an outcome, it led to unprecedented advances in society (Reyna et al., 2018).

E-waste has become the fastest growing waste stream in the industrialized world. The life span of these products has been shortened due to the demand for newer, more efficient, and effective technology. As a result, an increasing number of electronic products are ending up in landfills (Gem Celestial, 2018). According to the Global e-waste Statistics Partnership (GESP), about 53.6 million tonnes of e-waste was produced globally in 2019 and could increase up to 120 million tonnes by 2050. In Malaysia, e-waste is categorized as Scheduled Wastes under the Code SW110, First Schedule, Environmental Quality (Scheduled Wastes) Regulations 2005 (Organization, 2021). The e-waste generators who consume electrical and electronic equipment (EEE) and dump it as waste can be broadly divided into two categories. Corporate consumers such as commercial, industrial, government entities, and private or household consumers are considered as the e-waste generators (Celestial et al., 2018). As technology grows rapidly and electronics reach to the end of their life span faster, there is an urgent need for end-of-life management options (also known as e-waste management).

When combined with the destiny of discarded electronic devices, the increasing amount of waste causes even more concerns. Management of e-waste is an issue in both developed and developing countries, where stockpiling is the preferred method of disposal(Shaikh et al., 2020). In 2016 only 20% of global e-waste was properly recycled or disposed of, with the fate of the remaining 80% undocumented might likely to be dumped, traded or recycled under inferior conditions (Ilankoon et al., 2018). Another unrecognised issue is the downstream evaluation of e-waste value and associated toxicity of e-waste components, particularly when disposal procedures are informal include open burning and dumping (Shaikh et al., 2020).

According to Ikhlayel (2017), in developing countries (low-income, lower-middle-income, and middle-income), open dumps account for 12.5%, 48.8%, and 32.4%, respectively, and 58.51%, 11%, and 59% for landfills. Globally, high volumes of the e-waste reporting to the landfill sites without proper disposal or recycled process will lead to major environmental consequences as well as equally serious health risks(de Waal, 2019). This is because e-waste generally contains of hazardous substances like lead, arsenic and mercury which are harmful to the environment and pose serious risks to human health. Moreover, when the copper content in water and soil is too high, inhibiting the growth and reproduction of organisms and microorganisms which causing damages to the ecological environment. Besides, it also leads to water and soil pollution because after a long period of water migration and soil accumulation, copper is absorbed by crops and finally passes through the food chain (Zhang et al., 2021). However, it also has valuable metals such as gold, copper, platinum and other metals (Shaikh et al., 2020).

Thus, it is essential to recover the source of valuable materials from e-waste which known as urban mining. These metals are usually found in Printed Circuit Boards (PCBs) which making it the most metal-value components. The PCBs known as an attractive resource for metal recovery. The metal compositions in PCBs are copper 13.20%, titanium 0.31%, gold 0.12%, iron 7.62%, and silver 0.09% (Liu et al., 2022). This demonstrates that copper contains the highest metal compositions in PCBs. Generally, value-added metals were extracted from ore mining which is high in operation cost and impacts high environmental pollution as well as health problems to humans. Therefore, the recovery of valuable metals from urban mining could be an alternative way to reduce the waste, cost effective and environmentally friendly. It is also supporting by circular economy which gaining high attraction in recent times because of the demand for copper production by globally and locally increased along with technology where gives major important for its production (Zhang et al., 2021). The circular economy concept viewed as a lower input of raw material, minimal waste generation, and decoupling economic growth from the only use of natural resources can be potentially actualized.

1.2 Problem statement

The growth of e-waste products without proper disposal or recycle at landfill site becoming major problem in Malaysia for upcoming years. Because during the Covid-19 pandemic, the usage of electric and electronic devices increased as well as the number of products available to consumers at the market. This has accelerated public for online learning and work from home due to the movement control order (MCO) in Malaysia. As the demand for the electronic products increases, the e-waste production ending up in waste streams also increases due to its shortened life span (Celestial et al., 2018). On the other hand, the improper disposal or recycle of high volume of e-waste into the landfill site will causing major environmental impacts as well as poses serious health risks to human health. This is because the e-waste contains of hazardous substances like mercury and lead which needs proper waste disposal management to avoid the environmental damages and risks the human health. Furthermore, e-waste also contains of valuable metals such as gold, copper, platinum, silver and iron metals that could be recovered.

Generally, value-added metals were extracted from conventional mining which is high in cost for purchasing the raw materials and also impacts high environmental pollution as well as health problems to humans. This is because it involves with chemicals at which the chemicals tend to accumulate with soil and water and provide damages to the ecological environment. Moreover, when the copper content in water and soil is too high, the growth and reproduction of organisms and microorganisms is inhibited. In addition, the excessive copper intake in the human body adversely affects haemoglobin, causes haemolytic anaemia, and affects the normal biliary excretion of copper (W. Zhang et al., 2021b). Therefore, the recovery of valuable metals from the increasing number of e-waste could be an alternative way to reduce the waste, cost effective and environmentally friendly. Since, the continuous growth of e-waste needs the development of an efficient method for recovering its metal content in order to improve recycling rates.

1.3 Objective of study

The objectives of the study are:

1. To determine percent recovery of copper from e-waste using spectrophotometer.

2. To assess the environmental impacts of the e-waste recovery process by using a life cycle assessment method.

1.4 Scope of study

The scope of this study is to determine percent recovery of copper from e-waste recovery process using spectrophotometer. Furthermore, the environmental impacts of the e-waste recovery process will be accessed by using a life cycle assessment method (Chen et al., 2019a). LCA is an essential tool for determining the environmental burden associated with recovery process concepts and life-cycle stages should be considered. The life cycle assessment may range from one processing stage to another (gate to gate life cycle inventory). This might include the impacts of processing materials as well as the impacts of electricity usage.

1.5 Significant of study

Generally, the major production of e-waste from the industry, households and other sources will be disposed at the landfill sites or recycle without proper waste management. Therefore, the e-waste which contains of hazardous substances like mercury, lead and other chemicals will harm the environment as well as human health. Moreover, the e-waste also contains of valuable metals such as gold, copper and other metals which becoming the major demand in upcoming years. Thus, the conventional mining process was conducted to extract valuable metals from the ores which causes adverse impact to the environment. The alternative solution that could take to eliminate the negative impacts was by recovered the valuable metals from the e-waste so it can use again.

This study focuses on the recycling method of leaching and electrolysis process where recovery of copper from the end life of PCBs which also helps to minimize the environmental impacts. Copper is a chemical element, reddish, and extremely ductile metal with very high thermal and electrical conductivity. The copper demand has been increasing along the rise of technology because every electrical and electronic device needs copper since its high in conductivity. Therefore, the electrolysis process was chosen because of its simple and essential process and also low in cost compared to the conventional mining method. Furthermore, the electrolysis process is an environmentally friendly and a productive method to recover high purity of copper powders from the e-waste (Y. Zhang et al., 2018).

Additionally, even though the electrolysis process is an efficient method to recover the copper from e-waste but the environmental impacts from this process should be taken into consideration. Thus, the life cycle assessment method will be conduct to assess the environmental impacts of the e-waste recovery process. Overall, the importance of this study is to determine the percent recovery of copper and access the environmental impacts of e-waste recovery process which is urban mining is less compared to conventional mining method in terms of GWP, Acidification, Eutrophication, Ozone depletion, Ecotoxicity, Human health particulate air, Human toxicity cancer and non-cancer, Resources fossil fuels and Smog air.

CHAPTER 2

LITERATURE REVIEW

2.1 Electronic waste (e-waste)

The usage of Electrical and Electronic Equipment (EEE) is reliant firmly on the global economic growth. EEE comprises various electrical devices such as cooling equipment, TV sets, PCs, laptops, and a wide range of electronic gadgets like smart phones, earphones, pen tablets, smart watches, printers, PSPs, and memory cards. The products can be classified into six general classes based on their waste management characteristics which are temperature exchange devices (cooling and freezing hardware), lamps, display units, large-scale equipment, small-scale equipment, and telecommunication equipment. Globally, the amount of EEE used increases by 2.5 million metric tons (MT) per year due to the technology growth and people's lifestyle. Once the EEE reached its end life, it will be discarded and generates e-waste that contains both hazardous and valuable substances (Misra et al., 2021).

Electronic waste or e-waste contains 10 different categories according to Annex 1A to the EU waste electrical and electronic equipment directive (WEEE Directive) and the generation of e-waste is considered as one of the fastest growing waste streams in the world. E-waste is classified as a hazardous waste stream due to the presence of toxic metals (e.g. lead in cathode ray tubes or CRTs, batteries and PCBs, mercury and cadmium containing parts) and chemicals, such as halogenated flame retardants (e.g. plastic fraction) (Yong et al., 2019). Besides that, e-waste also contains of valuable metals such as gold, copper, silver, platinum and other metals which considered as high value in economics. E-waste is generally classified into two groups based on its generation sources for example industrial e-waste and household e-waste (de Waal, 2019). Globally, e-waste generation increased by 9.2 million metric tonnes in 2014 and expected to reach 74.7 million metric tonnes by 2030, nearly doubling in just sixteen years. The growing market demand for electrical and electronic equipment (EEE) and its short lifespan contribute to the high e-waste production. Furthermore, another reasons for the e-waste disposal might be that new products at market are less expensive than repairing old ones and also technology advancement makes the product cheaper, smaller, and lighter in weight which attract consumers compared to the existing product (Misra et al., 2021). Therefore, this would result in high volumes of the electronic waste reporting to the landfill sites without proper waste management or recycling process (de Waal, 2019). Figure 2.1 shows the material flow of e-waste in Malaysia.

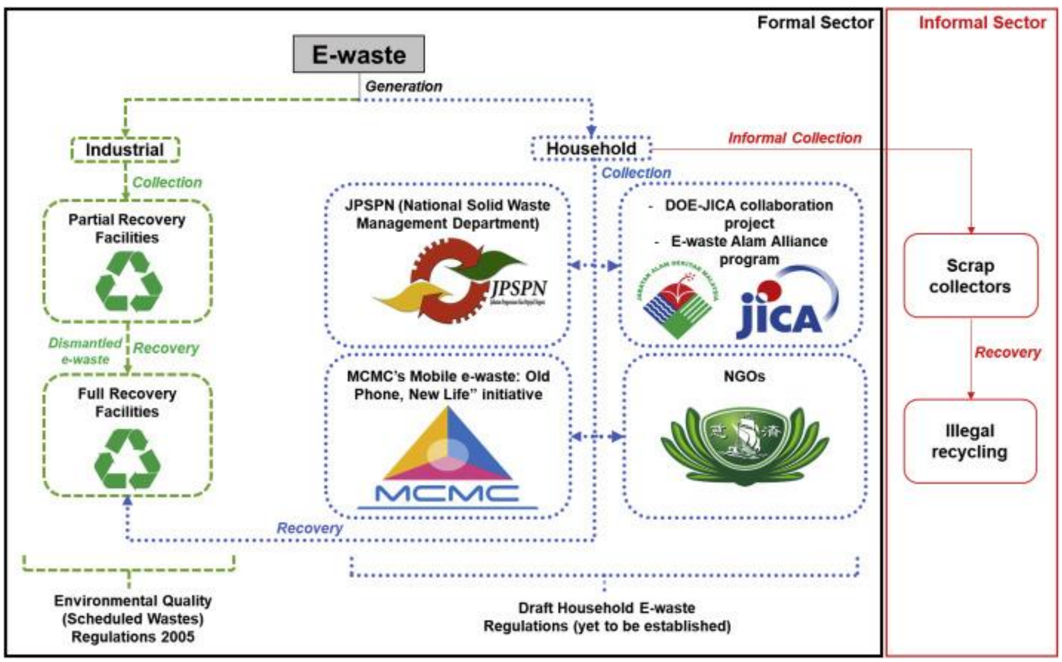


Figure 2.1 Material flow of e-waste in Malaysia

Source: (Ilankoon et al., 2019)

2.2 Disposal of e-waste at landfills and the environment impacts

E-waste management becoming huge challenges in several developing countries including Malaysia which domestically generated or imported illegally as used products. Many countries dispose a significant proportion of e-waste components in uncontrolled landfill sites. According to (Ilankoon et al., 2018) only 20% of global e-waste was properly recycled or disposed of while the remaining of 80% was disposed as unsanitary at landfill sites. Generally, informal e-waste recycling is widely practiced since the processes are high capital and operational expenses. Therefore, informal practices conducted to recover metals like burned electric wires at open spaces to remove plastic and recover copper. Moreover, acid extraction was practiced to retrieve precious metals like gold, platinum, palladium, and silver from Printed Circuit Boards (PCBs). In countries such as China, India, Pakistan, Vietnam, the Philippines, Nigeria, and Ghana was found to be carried out informal practices to recover valuable metals because of lack in facilities to safeguard the environment and public health. Figure 2.2 shows an example of improper e-waste handling practices in China, South Africa, and India (Ikhlayel, 2018).

Figure 2.2 Improper e-waste handling practices in China, South Africa, and India. Source: (Ikhlayel, 2018).

Malaysia was estimated to generate 53 million pieces of e-waste in the year 2020. According to Malaysia's Natural Resources and Environment Ministry, only the e-waste from industries were managed formally meanwhile, there is no formal system for household e-waste management which considered as the major waste production to the landfill sites. The major cause for e-waste disposal at landfills was lack of information or awareness from households, public irresponsibility, and financial limitation by waste management system. Therefore, uncontrolled and abandoned e-waste has an adverse impact on the environment and human health because e-waste contains of hazardous substances such as cadmium, mercury, chromium, zinc, lead, silver and copper which should not release into the environment. Disposal of e-waste in landfill through incineration process was considered as conviction offence. Because of toxic chemicals from the waste leach into groundwater which directly leads to the release of toxic gases into the atmosphere (Jayaraman et al., 2019). Thus, the disposal of heavy metals in landfills has a significant impact on the environment as well as human health.

Moreover, high volume of e-wastes severally damages the environment like soil contamination, water pollution, inhibits growth of plants and microorganisms, damages agriculture lands and others factors. It also poses risks to human health such as damage respiratory system, adversely affects haemoglobin, causes haemolytic anaemia, liver failure, chronic disease and active hepatitis (W. Zhang et al., 2021). Besides, the improper disposal of e-waste methods including open burning and dumping also causes serious environmental costs as the handling of the management required costly methods. On the other hand, by the improper disposal or recycled of e-waste can results in depletion of valuable resources in electronic waste such as gold, copper, platinum, silver and other metals (Shaikh et al., 2020). As a result, informal disposal, recycled, or dismantled of e-waste into the landfills should be considered as a major problem nowadays and should take an alternative way to save the environment as well as public health.

2.3 Coventional Mining

Conventional mining is about the production of minerals from an open pit or underground excavation include mine shafts, exploitations and air vents. However, it is not including excavations primarily caused by in situ extraction activities. Sustainable development in the mining industry is a critical concern because of the fact that it covers environmental, social, economic and human health approaches. Finding a balance between environmental, social, and economic factors is the major objective of sustainable development in order to maintain the stability of the system (Leiva González & Onederra, 2022).

According to (Xavier et al., 2021), the mining sector had a long-term impact on environmental sustainability due to the electrical and electronics equipment disposal impacts which was observed in mining waste management. The production of valuable metals such as gold, copper, silver, iron and titanium from conventional mining could impact environment in terms of GWP (kg CO_2-eq/kg), Acidification (kg SO_2-eq/kg), Marine eutrophication (kg N-eq/kg), Ozone depletion air (kg CFC-11-eq/kg), Ecotoxicity freshwater (CTUeco/kg), Human health particulate air (kg $PM_{2.5}$-eq/kg), Human toxicity cancer (CTUh/kg), Human toxicity non-cancer (CTUh/kg) and Resources fossil fuels (MJ surplus energy).

2.4 Urban Mining

Today's valuable metals production system faces a challenge from rising metals demand, scarcity of fundamental resources, and the earth's inherent constraints. Urban mining, such as the recovery of valuable metals from waste of electronic and electrical equipment (WEEE) through sustainable recycling procedures, is evolving to supplement scarce natural resources. As global demand for these valuable metals continues to increase, the United Nations Environment Program (UNEP) is calling for an urgent rethink of metals recycling processes. Sustainable recycling practises improve valuable metals production while also addressing environmental problems such as hazardous waste and pollution. In actual fact, despite its common categorization as a waste, e-waste is a major source of secondary resources. Table 1 shows that the average Cu, Au, Ag, and Pd grades in e-waste are much greater than those in mined ores. Moreover, valuable metals extracted from e-waste were found to be more cost effective and profitable due to energy efficiency compared to processing of primary raw materials from traditional mining procedures (Tesfaye et al., 2017)

Table 2.1 the average Cu, Au, Ag, and Pd grades in e-waste

E-waste	**Fe (wt%)**	**Al (wt%)**	**Cu (wt%)**	**Plastics (wt%)**	**Ag (ppm)**	**Au (ppm)**	**Pd (ppm)**
TV-board	28	10	10	28	280	20	10
PC board	7	5	20	23	1000	250	110
Mobile phone	5	1	13	56	3500	340	130
Portable audio	23	1	21	47	150	10	4
DVD-player	62	2	5	24	115	15	4
Calculator	4	5	3	61	260	50	5
Average EEE	-	-	13.8	-	1009	127	51.6
Ore/mine	-	-	0.6	-	215.5	1.01	2.7

Source: Tesfaye et al., (2017)

Apart from that, according to Xavier et al., (2021), the mining sector had a long-term impact on environmental sustainability due to the electrical and electronics equipment disposal impacts which was observed in mining waste management. The production of valuable metals such as gold, copper, silver, iron and titanium from conventional mining could impact environment in terms of GWP (kg CO_2-eq/kg), Acidification (kg SO_2-eq/kg), Marine eutrophication (kg N-eq/kg), Ozone depletion air (kg CFC-11-eq/kg), Ecotoxicity

(CTUeco/kg), Human health particulate air (kg $PM_{2.5}$-eq/kg), Human toxicity cancer (CTUh/kg), Human toxicity non-cancer (CTUh/kg), Resources fossil fuels (MJ surplus energy) and Smog air (kg O3 eq/kg).

Therefore, it is essential to create innovative technologies and economic strategies for processing complex feed materials from e-waste streams in a more energy efficient and environmentally friendly manner in order to solve the limitation of valuable metals from primary resources and environmental issues. Moreover, according to Boliden Rönnskär (Skelleftehamn, Sweden), extracting metals from e-waste requires only from 10 to 15% of the total energy in metals extraction. Based on the Commodities Research Unit of UK report in 2011, European Union (EU) is globally the leading e-waste recycler with a rate of 35% per year, e-waste recycling rate of USA is 27% per year. Therefore, the recycle method should be taken into consideration to recover the e-waste which contains valuable metals such as gold, copper, and platinum (Tesfaye et al., 2017).

2.5 Recycling method

From the research done by Khayyam Nekouei et al., (2020)stated that the most sustainable approaches to preserving natural resources and minimizing the environmental impacts of e-waste are through recycling and recovery. This is because, nearly 6–10% or 5 million tons of e-waste comprising annually and containing high value-added metals such as gold, copper, platinum and other metals. Thus, it considered as economics benefit to extracting as much as possible from the waste stream. According to Rasheed et al., (2022), stated that efficient recycling of e-waste reduces the impact on natural resources by around 80%.

The recycling methods was not practices much compared to disposal at landfills and mining due to the operational expenses, lack of facilities and management awareness. Moreover, recovery of advanced and value-added materials directly from the e-waste can reduce the dependence on expensive raw materials. Therefore, by recycling the production of e-waste can be decreases of both waste burden on society and also time and energy to spent on extracting the pure metals through conventional mining which is high on environment impacts as well as damages human health (Khayyam Nekouei et al., 2020).

The recycling procedures begin with e-waste collection, sorting, and size reduction, followed by extraction and metal recovery. The e-waste recycling involves the disassembly and destruction of the equipment to recover new materials. Recycling evaluation varies between nations based on accessible resource materials and pollution in the environment. There are few types of process for value-added metals recovery such as pyrometallurgy, hydrometallurgy, bio metallurgy, electrolysis, and supercritical fluid method (Yang et al., 2018). By using pyrometallurgical and hydrometallurgical processes to recover heavy metals, it releases toxic gases such as dioxins and furans that are harmful to the environment and also public health. Bioleaching is a promising technology that uses microorganisms to recover metals from PCB which is low cost and environmentally friendly process. However, they are not much investigation for bioleaching of valuable metals from e-wastes including from PCBs.

In this study, the focus is on e-waste recovery by utilizing the slurry electrolysis method. This is because based on the study from Liu et al., (2022) used environmentally friendly method of green electrolyte and regular anode and cathode. Additionally, there are no other restrictions because the electrode used in this study is widely used and accessible, unlike electrode utilised in other studies, which is expensive and difficult to find (Liu et al., 2022). Moreover, according to some researches, the electrolysis process had recorded the highest metal extraction efficiency from grinded metal powder (Choubey et al., 2021). Furthermore, this method is unlike other popular metallurgical leaching procedures, Slurry Electrolysis combines the electrodeposition and leaching stages into a single stage, and the reaction occurs under mild conditions at ambient temperature and atmospheric pressure (Liu et al., 2022). Therefore, the electrolysis process seems to be a promising method since it has many advantages and most importantly only producing less pollution to the environment (Y. Zhang et al., 2018). As a conclusion, recycling always has a lower ecological impact than landfilling of incinerated e-waste.

2.5.1 Pre-separation treatment of e-waste

E-waste processing usually starts with a manually intensive dismantling phase, during which circuit-board components and the lithium battery are removed for recycling purpose elsewhere shown in Figure 2.3. The shredded e-waste needs to be separated into metallic (ferrous and non-ferrous), and non-metallic (polymer and ceramic) components and a broad range of methods have been identified for this purpose, including mechanical crushing, followed by separation using gravity, electrical conductivity and magnetism, as well as delamination using organic solvents (Dhanunjaya Rao et al., 2020).

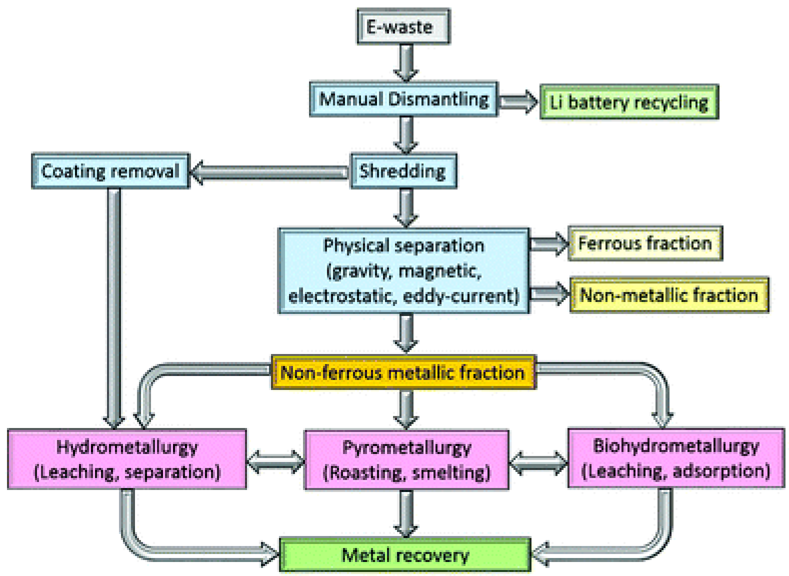


Figure 2.3 Overview of stages involved in metal recycling from electronic waste Source: (Dhanunjaya Rao et al., 2020).

2.5.2 Electrolysis method to recover valuable metals from e-waste

The continuous growth of e-waste needs the development of an efficient method for recovering its metal content in order to improve recycling rates. Several research have been carried to extract metals from grinding metal powder. The electrolysis process was recorded as an essential method to obtain high purity of copper powders directly from the e-waste (Y. Zhang et al., 2018). According to researches, the copper production in China has experienced rapid growth, from less than 2 million tons in 2001 to 9.03 million tons in 2018, an increase of 3.5 times. However, due to the relocation of major mines and the impacts of disasters, the growth in global copper production has been weak. Therefore, the demand for copper production by globally and locally increased and gives major important for its production (W. Zhang et al., 2021). Thus, recovering precious metal from existing material like e-waste is one possibility for preventing the resource from being depleted from beneath the earth. Thus, this experiment is focus on recover copper from e-waste using the electrolysis process. It is essential to develop a more efficient copper recycling system like electrolysis process to ease the demand for limited copper supplies with environmentally friendly (W. Zhang et al., 2021).

The slurry electrolysis in pH-neutral ethylene glycol (EG) electrolyte is used to extract and recover metallic components from the e-waste. The system operates at room temperature and atmospheric pressure, and the electrolyte can be recycled numerous times without the sign of chemical degradation. This is because the ethylene glycol electrolyte system can oxidize the metallic component without causing anodic gas development, thus it can able to integrate a reticulated vitreous carbon (RVC) foam anode to optimise metal recovery and oxidation. Moreover, this method demonstrated up to 99.1% Faraday efficiency for cathodic metal deposition and could selectively recover Cu from e-waste powder at 59.7% in the presence of 12 other metals. The slurry electrolysis reaction system was scalable and without any reductions in Cu recovery selectivity. This recycled system showed great potential for industrial-scale metal recovery due to its capacity to leach and recover metallic content from e-waste in a gentle and friendly environment. Figure 2.4 shows the slurry electrolysis process used to extract copper from the e-waste (Liu et al., 2022).

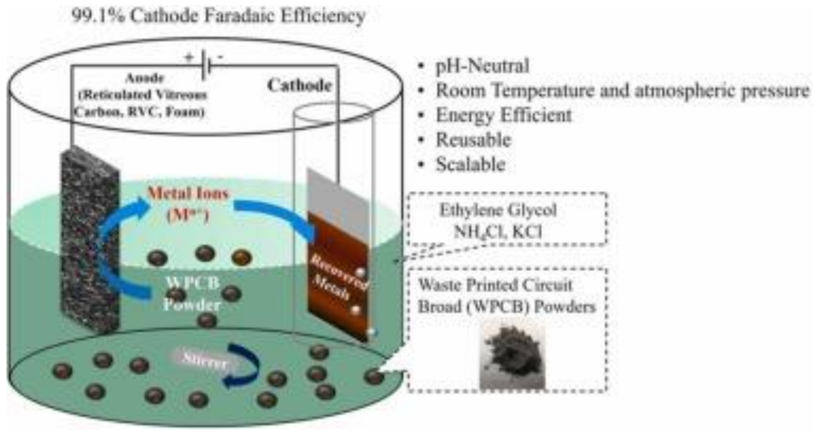


Figure 2.4 Slurry Electrolysis Process

Source: (Liu et al., 2022)

2.5.3 Determination of copper using Spectrophotometer

The sustainable detection of copper metals from the WEEE even with zero waste emission, extraction and spectrophotometric detection is considered as significant potentials over current industrial scheme of WEEE treatment. Therefore, the development of new analytical spectrophotometric methods for the selective determination of copper ion is also great significance (Kharade et al., 2022). There are several methods such as Atomic absorption spectroscopy (AAS), Voltammetry, High Performance Liquid Chromatography (HPLC), Ultraviolet-visible (UV–vis) spectroscopy, Atomic fluorescence spectrometry (AFS) have been proposed for simultaneous determination of valuable metals such as copper, gold and other metals. Although these techniques are highly sensitive and selective, but it is very expensive for the developing countries and require well qualified laboratory personnel. Furthermore, these methods need time-consuming sample preparation and multi-step pre-concentration procedures, and they might not be available in all conventional analytical laboratories. In contrast, spectrophotometry is well-known colorimetric methods by its low cost, fast analysis ability, robust and simplicity in its operation can easily monitor target ions with the naked eye in the visible range with high sensitivity. As a result, spectrophotometric methods have attracted our attention in the determination of percent recovery of copper from e-waste electrolysis process.

Among these methods, UV–vis spectroscopy has been widely used for a long time due to its superiority in accuracy, speed, versatility, simplicity and cost-effectiveness, and has become a highly important analytical method for determination of valuable metals. However, traditional UV–vis detection is mainly for single ion. When applied to multi-metal ions in a solution, it is necessary to pre-separate each component first by chemical method, the steps are cumbersome, and the real-time performance is poor. To avoid the separation step, several spectrophotometric methods have been widely utilized for multicomponent analysis such as principal component regression (PCR), difference spectrophotometry, partial least squares regression (PLSR), derivative spectrophotometry, Kalman filtering spectrophotometry and multi-wavelength linear regression analysis (MLRA). However, these methods are mostly used to analyse the multi-component ions with similar concentration (Zhou et al., 2019). In this study, the UV–vis spectrometry is developed for simultaneous determination of percent recovery of copper from e-waste mixtures. Figure 2.5 shows the mechanism for determination of copper content using spectrophotometer.

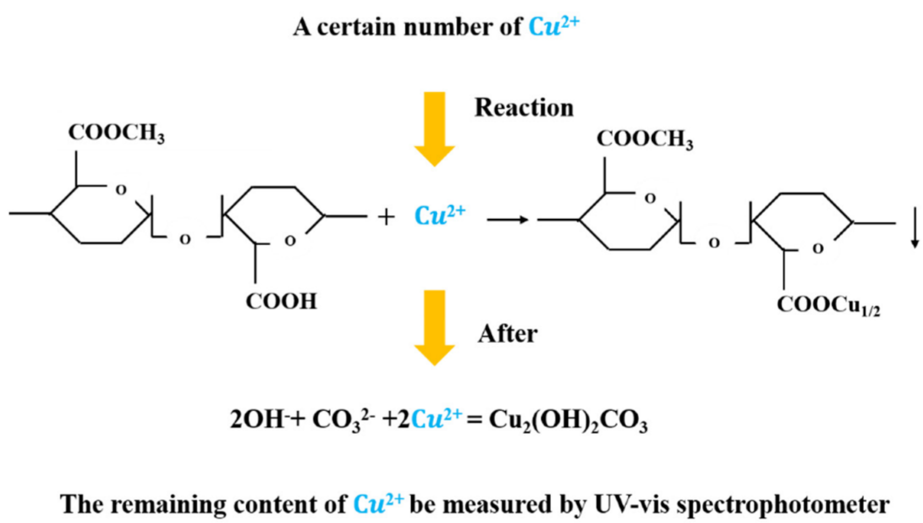
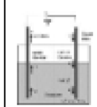
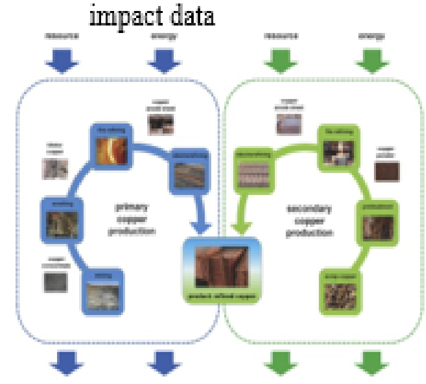
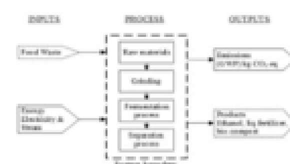


Figure 2.5 Mechanism for determination of copper content using spectrophotometer Source: (F. Wang et al., 2021)

Table 2.2 Literature Review

Author & year	Tittle	Objectives	Methodology	Findings	Recommendation	Limitation
(Choubey et al., 2021)	Recovery of copper from Waste PCB boards using electrolysis.	To recover cooper from waste PCB boards (nonferrous metal powder) using electrolysis.	 1. 8 gm of nonferrous metal was dissolved into H_2SO_4 and stirred at 80 °C temperature for 4 h. 2. Solution was filtered and 40 ml of aquaregia (30 ml HCl and 10 ml HNO_3) was added and stirred for 60 min at a temperature of 80 °C 3. Iron Anode and Copper cathode were used for electrolysis and the chambers were separated by an anti-acid filter cloth 4. Analysis sample using AAS 5. The Extraction rate of metals calculated using formula	- Cu recovery in this case is 98%. The extracted copper is collected from the cathode chamber.	- pH for the electrolyte should be between 2 and 3 (control with NaOH) - The preparation of electrolyte is important	
(W. Zhang et al., 2021b)	Analyzing the environmental impact of copper-based mixed waste recycling-a LCA case study in China.	assesses the environmental impacts of copper-based mixed waste recycling	1. Life cycle assessment method 2. Using Gabi software 3. Functional unit :1 000 kg electrolytic copper 4. cradle to gate 5. Material inventory 	-The effects of eutrophication and acidification are higher for copper based mixed waste recycling than for ordinary copper recycling life cycle environmental impact per unit of copper metal in new copper based		Failed to further analyze the process mechanisms associated with the consumption of various raw materials and discharge of waste

Author & year	Tittle	Objectives	Methodology	Findings	Recommendation
(Chen et al., 2019)	Environmental benefits of secondary copper from primary copper based on life cycle assessment in China.	To assess the potential environmental effects of refined copper from extracting primary ore(mining) and recycling scrap copper	1. Four stages, which are the goal and scope, the life cycle inventory (LCI), the life cycle impact assessment (LCIA) and interpretation 2. Using data from Gabi software and Ecoinvent database Life cycle environmental impact data 	The secondary copper was only 1/8 that of the primary copper production process, which indicates better environmental benefits. The mining and smelting process were occupy the major impact.	Only by reducing the amount of copper slag produced and reusing it into a useful product can the copper slag problem be solved Extended producer responsibilities (EPR) should be enforced to recycle the scrap copper more efficiently.

Author & year	Title	Objectives	Methodology	Findings	Recommendation	Limitation
(de Waal, 2019)	Evaluating the efficiency of a metal recycling process by means of life cycle assessment and exergy analyses.	-To investigate the overall environmental impact of a hydrometallurgical process proposed for copper and gold recovery. - Exergy and life cycle assessment (LCA) analyses.	-Life cycle assessment method -A hydrometallurgical process aimed at the recovery of both copper and gold from waste printed circuit boards (WPCBs) - Functional unit (FU) of 30000 metric tonnes/annum of bare PCBs - cradle-to-gate approach -Professional database in GaBi 	-Developed a hydrometallurgical process plant with overall yields for copper and gold of 81% and 97%. -LCA revealed that the gold elution, nitric acid washing stage and copper leach are the major contributors environmental impact.	-Process comparison and selection for sustainability - Empirical data and scalability -Exergy analysis and LCA of the impacts caused by the collection and dismantling stages, transport and waste treatment should be considered.	-Focus is only on inputs and outputs and streams are treated within the technosphere.
(Muhammad & Rosentrater, 2020)	Comparison of global-warming potential impact of food waste fermentation to landfill disposal	To compare the global-warming potential (GWP) impact of FW fermentation and landfill disposal methods.	Study complies with ISO 14040: 2006 includes the goal and scope of LCA, life-cycle inventory analysis (LCI), and life-cycle impact assessment (LCIA) and interpretation.	-FW fermentation options produced lower GWP impact values than a landfilling method. -The lowest total GWP value was 164.1 kg CO_2eq/1 Mg of FW.		

2.6 Life Cycle Assessment (LCA)

This study will present a comprehensive comparison on the environmental impact of the copper recovery from e-waste using recovery process. However, to determine the effectiveness of copper recovery rate from e-waste by utilizing the electrolysis method for the waste management, the environmental perspectives should be considered. LCA was conducted to estimate environmental impacts of GWP (kg CO_2-eq/kg), Acidification (kg SO_2-eq/kg), Marine eutrophication (kg N-eq/kg), Ozone depletion air (kg CFC-11-eq/kg), Ecotoxicity (CTUeco/kg), Human health particulate air (kg $PM_{2.5}$-eq/kg), Human toxicity cancer (CTUh/kg), Human toxicity non-cancer (CTUh/kg), Resources fossil fuels (MJ surplus energy) and Smog air (kg O3 eq/kg). From this study, we anticipated that by conducting recovery process to reduce the environmental pollutions compared to extraction of copper from conventional mining.

LCA is defined as compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. LCA is an objective process used to quantitatively evaluate the environmental burdens associated with a product, process, or activity throughout its entire life cycle (through the cradle, through all the gates, to the grave). It utilizes various mass and energy balance protocols as well as environmental impact evaluation techniques through 8 to model the associated impacts across every stage of the life of a product. This may include the impacts associated with processing materials as well as the impacts associated with subsidiary actions. For example, in the extraction of natural resources, LCA includes the impacts associated with the extracted materials as well as the impact associated with the recovery process. In this study, the purpose and background of life cycle assessment analysis, and point out the research functional unit, system boundary, and assess the environmental impacts copper recovery from e-waste using recovery process will be analysed.

Additionally, LCA process is often divided into four steps which known as goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and improvement evaluation (W. Zhang et al., 2021). The GaBi software used to link direct raw materials to the corresponding production processes and the emissions to be treated in the process of establishing a complete life cycle inventory. Consider the copper recovery from the e-waste using the leaching and electrolysis process. The impacts associated with this process include the environmental impacts from the copper recovery process from e-waste which is from both leaching and electrolysis process. Depending on the objective for which an LCA is performed, the scope may range from cradle to grave (raw materials extraction to the disposal of finished goods), cradle to gate (raw materials extraction to finished goods), gate to gate (one processing stage to another). Thus, in my study, I'm choosing the gate-to-gate approach due to limited information and time.

2.7 Introduction to Global Warming Potentials

A variety of greenhouse gases (GHGs) contribute to anthropogenic climate change. The dominant GHG was CO_2 which stays in the atmosphere for centuries to millennia. Unlike CO_2 and other long-lived GHGs, some greenhouse gases, such as methane are short-lived and decaying in the atmosphere over years to decades after emission. Any method for aggregating various GHGs must take into account the diverse nature of these gases. The most common methods for accounting different GHGs are forcing-centered metrics known as 'global warming potentials' (GWPs), which allow a basket of GHGs to be expressed in terms of CO_2 equivalent. GWPs express the ratio of the time-integrated radiative forcing effect of a pulse emission of a certain GHG relative to the effect of a pulse emission of an equal mass of CO_2. Since the mid-1990s, a 100-year time horizon (GWP100) has emerged as the common approach under the United Nations Framework Convention on Climate Change (UNFCCC). The Kyoto Protocol (UNFCCC 1997) and the Paris Agreement both use the GWP100 metric for reporting (UNFCCC 2018).

Introduced GWP as a new forcing-centered metric aimed at improving the warming representation of short-lived GHGs. A sustained change in the rate of emission of a short-lived GHG is evaluated as being similar to a one-off pulse of CO_2 emissions over a certain time period in GWP. GWP more accurately captures the direct impact of changes in short-lived GHG emissions on radiative forcing and temperature while still representing the long-term effects of long-lived GHGs including CO_2. Interpreting the Paris Agreement mitigation goal using GWP100 is fully consistent with achieving the Agreement's long-term temperature goal. It also refers to achieving net zero GHG emissions in the "second half of the 21st century". The net-zero GHG emissions is to be achieved and determined by the best available science (Climate analytics, 2019).

2.7.1 COP26 Glasgow Climate Pact

Reductions in greenhouse gas emissions are a lifeline for humanity. Governments from all around the world including Malaysia were expected to submit enhanced emission reduction targets for the year 2030 in the lead up to the COP26 UN Climate Conference to bring them in line with the Paris Agreement goals. Through the country's enhanced Nationally Determined Contribution (NDC) and its new commitment on achieving carbon neutrality, Malaysia has committed to take bold actions to tackle climate change. Malaysia has also endorsed the Glasgow Leaders' Declaration on Forests and Land Use which champions halting and reversing deforestation. In addition, the Global Methane Pledge, which commits goals to reduce global methane emissions by 30% before 2030 (British High Commission Kuala Lumpur, 2021).

2.7.2 The CO_2 Equivalents in 2019

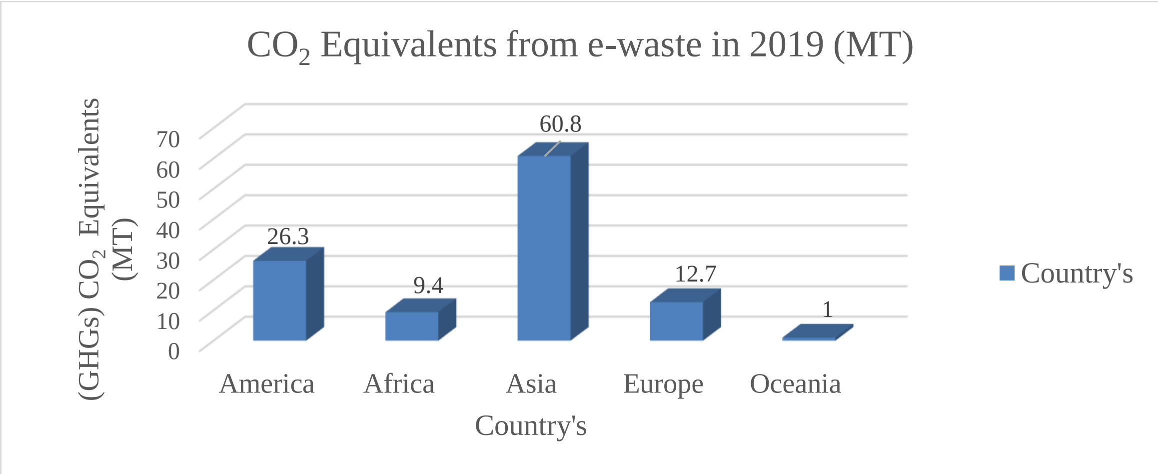


Figure 2.6 The CO_2 Equivalents in 2019

Source: Forti et al., (2020)

According to the research, only 17.4% of e-waste was officially collected and recycled in 2019. Iron, copper, gold, and other high-value, recyclable elements worth a conservative $57 billion, more than the GDP of most countries, were primarily dumped or burned, rather than collected for treatment and reuse. In 2019, Asia generated the most e-waste (24.9 MT), while Europe generated the most kg per capita (16.2 kg per capita). Europe also has the highest reported rate of formal e-waste collection and recycling (42.5%). On all other continents, the amount of e-waste that has been formally collected and recycled is significantly less than the anticipated amount of e-waste generated.

The importance of efficient e-waste management has begun to be recognized in the South Asian region. Since 2011, India has had rules in place to manage e-waste, mandating that only authorized dismantlers and recyclers collect e-waste. Some countries in Southeast Asia are more advanced than others. The Philippines does not have a specific e-waste management policy, but it does have a range of 'hazardous waste' regulations that apply to e-waste because it is considered "hazardous" waste.

According to current graph in 2019, Asia ranked first with 60.8 MT of CO_2 equivalents, followed by the America and Europe with 26.3 MT and 12.7 MT of CO_2 equivalents, respectively, while Africa was 9.4 MT and Oceania ranked last with 1 MT of CO_2 equivalents. The total e-waste generated in Asia in 2019 was 24.5 MT or 5.6 kg per capita and it also produced 60.8 MT CO_2 equivalents potential release GHG of emissions from undocumented wastage. The e-waste management systems found in Asia are rather broad. They range from highly developed e-waste management systems, such as those found in the Republic of Korea, Japan, and China (including the Province of Taiwan), to more informal activities that coexist with China's advanced recycling system but dominate e-waste management in the rest of Asia. In South Asia, informal sector activities for collection, dismantling, and recycling account for the majority of e-waste management (Forti et al., 2020).

2.8 Introduction to Acidification

Atmospheric deposition of inorganic substances such as sulfates, nitrates, and phosphates will cause changes in soil acidity. There is an acidity level that is optimum for almost all plant species. Acidification is the term used to describe a significant departure from this optimum that is harmful to that specific species. As a result, changes in levels of acidity will cause shifts in species occurrence. Major acidifying emissions are NO_x, NH_3, and SO_2. The unit of acidification defined as kg SO_2-eq. An atmospheric deposition model and a dynamic soil acidification model can be used to calculate the environmental persistence of an acidifying substance. Effect factors, accounting for ecosystem damage caused by an acidifying substance, can be calculated with a dose-response curve of the potential occurrence of plant species, derived from multiple regression equations per plant species (Mark. G et al., 2009).

2.9 Introduction to Eutrophication

The enriching of the aquatic environment with nutrients is defined as aquatic eutrophication. Eutrophication in inland waters because of human activities is one of the major factors that determine its ecological quality. The severity of water contamination on the European continent generally ranks higher than the emission of harmful substances. The long-range nature of nutrient enrichment, either by air or rivers, indicates that both inland and marine waters are exposed to this form of pollution. However, it is caused by different sources and substances and has different impacts. The unit of eutrophication known as the kg N-eq. Characterization of aquatic eutrophication in Life Cycle Impact Assessment (LCIA) typically only considers those nutrients that are limiting the yield of aquatic biomass, which is merely phytoplankton (algae) but also duckweed. The term "limiting" implies that there is an excess of one nutrient and that just one nutrient is controlling the growth of these primary producers. The physical and chemical composition of the receiving water bodies, as well as local factors like topography, determine whether aquatic eutrophication with nutrients causes an environmental problem (Mark. G et al., 2009).

2.10 Introduction to Toxicity

The characterisation factor of human toxicity and ecotoxicity accounts for the environmental persistence fate and accumulation in the human food chain exposure, and toxicity impact of a chemical. Effect factors can be determined from toxicity data on humans and laboratory animals, while fate and exposure factors can be calculated using "evaluative" multimedia fate and exposure models. USES-LCA, or the Uniform System for the Evaluation of Substances adapted for LCA purposes, is a frequently used model for evaluating the fate, exposure, and impacts of multimedia exposure. Emission identified were urban air, rural air, freshwater, seawater, agricultural soil and industrial soil. Table 2.3 shows the emission compartments, the environmental receptors and human intake routes that are identified in the fate factor (Mark. G et al., 2009).

Table 2.3 Emission compartments, environments and human exposure routes

Emission Compartments	Environmental receptors	Human exposure routes
Urban air	Terrestrial environment	Inhalation
Rural air	Freshwater environment	Ingestion via root crops
Freshwater	Marine environment	Ingestion via leaf crops

2.10.1 Exposure Routes

LCA assumes in the calculation of human population intake fractions for metals that the concept of bioconcentration, generally applicable for organic pollutants, also holds for inorganics. The bioconcentration factor and the exposure concentration of metals in the environment have an inverse relationship. To include the sensitivity of the human population intake fractions for metals concluded as the human exposure via all intake routes such as air, drinking water and food (Mark. G et al., 2009).

2.10.2 Marine Ecotoxicity

Metals' potential ocean fate and impacts are included in LCA. However, in a recent LCA workshop on non-ferro metals the potential effect of essential metals in oceans has been critised. The potential impact in the marine environment may strongly depend on the statement that additional inputs of essential metals to oceans also lead to toxic effects. For instance, the essential metals are cobalt, copper, manganese, molybdenum, zinc and other metals (Mark. G et al., 2009).

2.11 Human Health Damage Due to PM_{10} and Ozone

PM_{10}, or fine particulate matter, is a complex mixture of organic and inorganic materials with a diameter of less than 10 µm in diameter. When inhaled, PM_{10} creates health issues because it reaches the upper airways and lungs. Secondary PM_{10} particles are created in the atmosphere as a result of emissions such as nitrogen oxides (NO_x), sulphur dioxide (SO_2), and ammonia (NH_3). Inhalation of different particulate sizes can cause different health problems. According to recent WHO studies, $PM_{2.5}$ rather than coarser particles appear to be responsible for the effects of chronic PM exposure on mortality (life expectancy). Particles with a diameter of 2.5–10 µm ($PM_{2.5–10}$), may have more visible impacts on respiratory morbidity. PM has both anthropogenic and natural sources. For the unit of human health particulate air will be define as kg $PM_{2.5}$-eq and for PM10 as kg PM_{10}-eq (Mark. G et al., 2009).

Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NO_x and Non Methane Volatile Organic Compounds (NMVOCs). In the summer, this formation process is more active. Ozone can irritate airways and harm lungs, threatening to human health. Ozone concentrations lead to an increased frequency and severity of humans with respiratory distress, such as asthma and Chronic Obstructive Pulmonary Diseases (COPD). Ozone formation is a non-linear process that is influenced by weather patterns as well as background NO_x and NMVOC concentrations (Mark. G et al., 2009).

2.12 Resources Fossil Fuel Depletion

A group of resources that contain hydrocarbons is referred to as fossil fuels. The group includes both volatile materials (like methane), to liquid petrol and non-volatile materials (like coal). During these time periods, huge amounts of oil and gas were formed in oceans and large lakes. Unlike metals, we cannot use the concept of grade to express the quality of oil and gas resources. Conventional oil and gas will simply flow out of the well up to a certain point. t is still possible to extract more after that point, but this will increase the cost of production and the amount of energy needed for production. The ability to exploit other unconventional resources, such as tar sands, gas liquids, converting gas into oil or coal into oil, etc., also becomes possible as the price of energy increases. This means the increase of costs and energy is not caused by a gradual decrease of ore grade, but because more and more mankind will have to switch from conventional resources to unconventional resources The unit of resource fossil fuels known as MJ surplus energy (Mark. G et al., 2009).

2.13 Introduction to Ozone Depletion

In 1985, the so-called "ozone hole" over Antarctica was discovered. Ozone is continuously formed and destroyed by the action of sunlight and chemical reactions in the stratosphere. Ozone depletion happens when the rate of ozone destruction accelerates as a result of fugitive losses from anthropogenic pollutants that remain in the atmosphere. 90% of the ozone in the atmosphere, or in the stratosphere, is essential for life because it blocks dangerous UV-B light from the sun. If it is not absorbed, UV-B radiation with wavelengths below 300 nanometers will reach the troposphere and the surface of the earth, where it can increase the risk of skin cancer and cataracts in humans if the body and eyes are not adequately protected by clothes or other precautions. In addition, it may cause premature aging, inhibit the immune system, damage aquatic habitats, and affect terrestrial plant life. The stratospheric ozone layer is destroyed by anthropogenic emissions of ozone depleting compounds, which is taken into account by the characterisation factor for ozone layer depletion (ODS) (Mark. G et al., 2009).

Chlorine atoms in chlorofluorocarbons (CFC) and bromine atoms in halons are effective in degrading ozone due to heterogeneous catalysis, which leads to a slow depletion of stratospheric ozone around the globe. The chlorine and the bromine atoms that are released from these reactions have the ability to destroy a large quantity of ozone molecules in the stratosphere because it works as free radical catalyst. The Ozone Depletion Potential (ODP) has been defined as a relative measure of the ozone depletion capacity of an ODS and uses CFC-11 (trichlorofluoromethane) as a reference. The ODP unit will be defined as kg CFC−11-eq/kg. In LCIA the ODP is used as equivalency factors, characterizing ODSs at the midpoint level (Mark. G et al., 2009).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The procedure for experimental of copper concentration using UV-Vis Spectrophotometer in determining the percent recovery of copper from e-waste was discussed further. As defined by the ISO 14040-2006 standard, an LCA was structured by four stages, which are the goal and scope definition, the life cycle inventory (LCI), the life cycle impact assessment (LCIA), and interpretation. The methods described in this chapter are intended to accomplish the project's objectives.

3.2 Analysis

Figure 3.1 HACH DR/5000 UV-Vis Spectrophotometer

Figure 3.1 shows about the Hach DR 5000 UV-Vis Laboratory Spectrophotometer offers a broad range of water analysis methods with more than 240 pre-programmed tests. Automatic method detection capability with TNT plus reagents reduces test time and potential errors. The intuitive touch screen interface makes this instrument easy to use. The DR 5000 UV-Vis Spectrophotometer will be used to measure the copper recovery rate in the electrolyte for both leaching and electrolysis process. This is to determine the amount of copper can be recovered from e-waste using this recovery method. The concentration of copper (mg/L) is recorded and analyzed once the reading is completed.

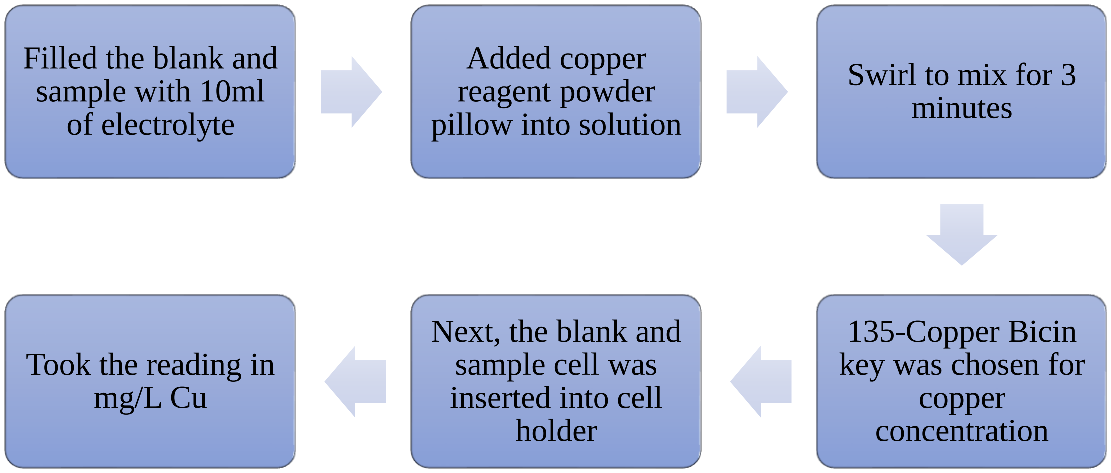


Figure 3.2 Procedure for Copper Concentration analysis

3.2.1 Copper standard solution

The copper standard solution use to analyze the result of an analytical test. These solutions contain a defined concentration of analyte which allows to quickly verify that instrument operation, reagent performance, and variations in operator technique within the program values. Standard methods recommend using solutions of known concentration of 5% sample of the time. Through control charting, verification of calibration curves, standard additions (spikes), and troubleshooting isolated problems, standard solutions are an essential tool in significantly increasing confidence in the laboratory process and test results. Table 3.1 shows the required reagents to determine the copper concentration (R.L Heller et al., 2017).

Table 3.1 Required reagents for copper concentration in spectrophotometer

Required Reagents	Quantity required per test	Unit	Cat. No
CuVer 1 Copper Reagent Powder Pillows	9 pillow	100/pkg	21058-69

Source: R.L Heller et al., (2017)

3.3 Life Cycle Assessment (LCA)

LCA is an important tool for determining the environmental burden associated with leaching and electrolysis processes, the concepts and life-cycle stages also should be considered, as shown in Figure 3.3. The e-waste management involves in collecting, disassembling, recycling, and disposing of residue (Mangmeechai, 2022). Based on ISO 14040:2006 standard, the framework of LCA consists of three phases: goal and scope definition, inventory analysis, and impact analysis, and each phase followed by interpretation according to the structure shown in Figure 3.4. The majority of these studies used LCA to examine the environmental impacts of production process and evaluated the impacts per kg of the copper recovered from the recovery process. This study will evaluate all input and output of the products that produced during the experiment. The environmental impacts should be assessed in terms of GWP, Acidification, Eutrophication, Ozone depletion, Ecotoxicity, Human health particulate air, Human toxicity cancer and non-cancer, Resources fossil fuels and Smog air. This method, which has been used in several studies to address the impact of global warming, includes three common GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which trap heat and insulate the earth. Therefore, it will increase global temperature and consequently leading to various catastrophic impacts on the ecosystem. Table 3.2 shows the GWP values in kg CO_2-eq/1 that will be used to multiply the GHG value with a conversion factor.

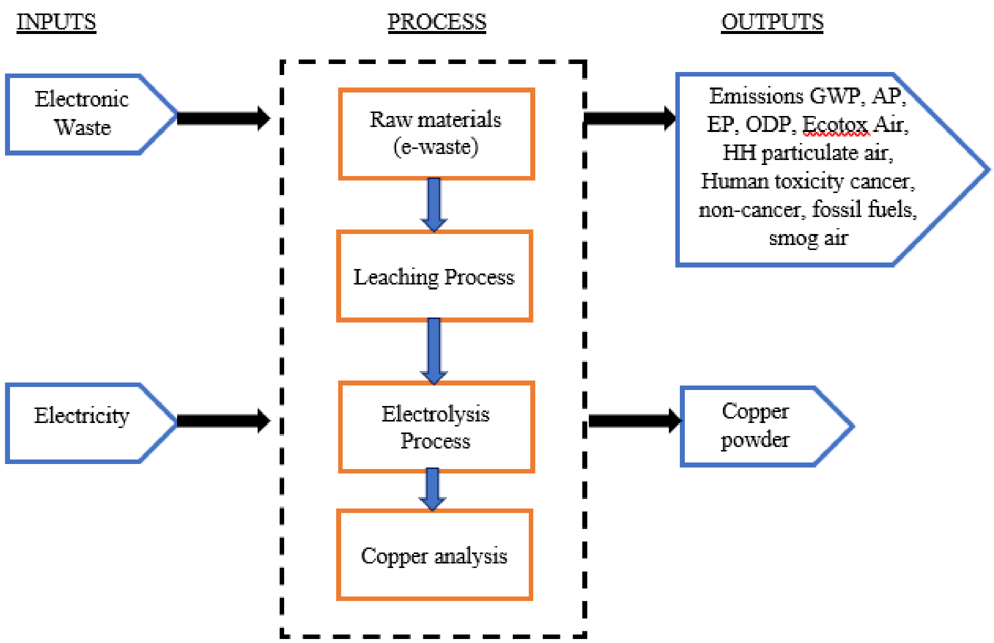


Figure 3.3 Life cycle stages for the project

Source: Muhammad & Rosentrater, (2020)

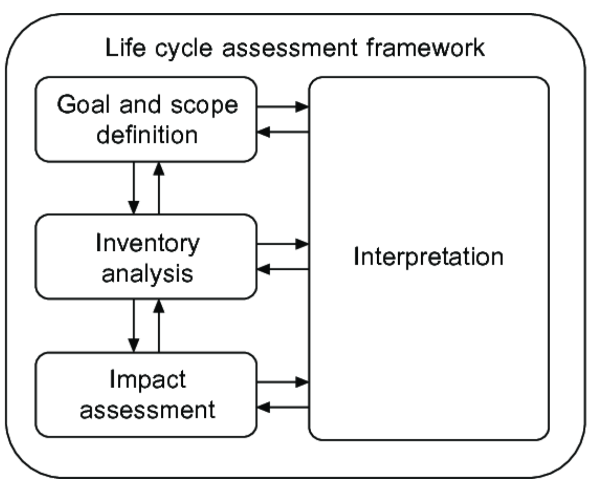


Figure 3.4 Life cycle assessment (LCA) framework based on ISO 14040:2016 standard

Source: Based on ISO 14040:2006, Environmental management

Table 3.2 Global-warming potential (GWP) values relative to CO_2.

Industrial designation or common name	**Chemical Formula**	**GWP values for 100-year time horizon (kg CO_2-eq)**
Carbon dioxide	CO_2	1
Methane	CH_4	23
Nitroxide oxide	N_2O	296
Hydrofluorocarbon-23	HFC-23	12 000
Tetrafluoroethane	HFC-134a	1300
Sulfur hexafluoride	SF_6	22 200

Source: IPCC Third Assessment Report (2001)

3.3.1 Goal and scope definition

The goal specifies the reasons for carrying out the LCA. The goal is important because the parameters to be used in the assessment are usually dependent on what the intended objectives are. The goal also specifies the intended application of the LCA as well as the intended audience. The scope helps to establish the system boundaries and the limits of the LCA. Thus, goal of this study is to assess the GWP (kg CO_2-eq), Acidification (kg SO_2-eq), Marine eutrophication (kg N-eq), Ozone depletion air (kg CFC-11-eq), Ecotoxicity (CTUeco/kg), Human health particulate air (kg $PM_{2.5}$-eq), Human toxicity cancer (CTUh), Human toxicity non-cancer (CTUh), Resources fossil fuels (MJ surplus energy) and Smog air (kg O3 eq) impacts of copper recovery efficiency associated with the leaching and electrolysis processes, aimed at recovering copper contained in the e-waste. The analysis follows the methodology defined by ISO 14040:2006 and it is performed using GaBi software and TRACI 2.0 adopting a gate-to-gate perspective (A. Striebig et al., 2016).

3.3.2 Functional unit

In this study, PCBs used as e-waste because of its highest composition of copper metal which is 13.20% (Liu et al., 2022). The 0.255 kg of copper considered as the primary unit from the recovery process.

3.3.3 System boundary

In this study, the gate-to-gate life-cycle inventory will be considered. The scenarios that presented in this study which is covered by system boundary are from the raw material (e-waste) separated copper to its final product. The system boundary is modelled with two main unit operations which is leaching and electrolysis process (A. Striebig et al., 2016).

3.3.4 Inventory analysis

Inventory analysis involves determining the quantitative values of the materials and the energy inputs and outputs of all processing stages within the system boundaries. The inputs are electricity energy and raw materials such as copper scrap, and the outputs are emissions to air, water, and soil; copper powder as products. The GaBi software and TRACI 2.0 are used to access the emissions from copper recovery processes in a complete life cycle inventory. The physical inputs and outputs of the inventory analysis should be balanced in terms of mass-energy. (A. Striebig et al., 2016).

3.3.5 Life Cycle Impact Assessment (LCIA)

LCAI is the core step of the LCA, which associates inventory data with specific environmental impact categories and category indicators and transforms into a potential of consumption on the resource, human health effects, ecological impacts, and other environmental impacts. Through characteristic transformation, the effects of the different types of environmental impact factors are compared and quantified. This assessment is achieved by using characteristic factors to convert the life cycle inventory results into measurable units for specific environmental impacts. For instance, the impact of various substances on global warming potential (GWP) is converted into CO_2 equivalents. Finally, the quantitative indicators of the various environmental impacts are obtained for comparison and analysis between conventional mining and urban mining. In the case of the same quality, taking the main impact factor of a certain type of environmental impact as a benchmark such as GWP (kg CO_2-eq/kg), Acidification (kg SO_2-eq/kg), Marine eutrophication (kg N-eq/kg), Ozone depletion air (kg CFC-11-eq/kg), Ecotoxicity (CTUeco/kg), Human health particulate air (kg $PM_{2.5}$-eq/kg), Human toxicity cancer (CTUh/kg), Human toxicity non-cancer (CTUh/kg), Resources fossil fuels (MJ surplus energy) and Smog air (kg O3 eq/kg) and obtaining each characterization factor (CF) according to the equivalent relationship between the various impact factors (A. Striebig et al., 2016). Table 3.3 shows the impact factors and units of TRACI 2.0.

Table 3.3 Impact factors and units of TRACI 2.0

Impact Factors	Units
Global Warming Potential	kg CO_2 eq / kg substance
Acidification Air	kg SO2 eq / kg substance
Human Health Particulate Air	PM2.5 eq / kg substance
Eutrophication Air	kg N eq / kg substance
Eutrophication Water	kg N eq / kg substance
Ozone Depletion Air	kg CFC-11 eq / kg substance
Smog Air	kg O3 eq / kg substance
Ecotox. CF, Em.airU, freshwater	CTUeco/kg
Ecotox. CF, Em.airC, freshwater	CTUeco/kg
Ecotox. CF, Em.freshwaterC, freshwater	CTUeco/kg
Ecotox. CF, Em.seawaterC, freshwater	CTUeco/kg
Ecotox. CF, Em.natural.soilC, freshwater	CTUeco/kg
Ecotox. CF CTUeco/kg, Em.agr.soilC, freshwater	CTUeco/kg

Impact Factors	Units
Human health CF, Emission to urban air, cancer	CTUcancer/kg
Human health CF, Emission to urban air, non-canc.	CTUnoncancer/kg
Human health CF, Emission to cont. rural air, cancer	CTUcancer/kg
Human health CF, Emission to cont. rural air, non-canc.	CTUnoncancer/kg
Human health CF, Emission to cont. freshwater, cancer	CTUcancer/kg
Human health CF, Emission to cont. freshwater, non-canc.	CTUnoncancer/kg
Human health CF, Emission to cont. sea water, cancer	CTUcancer/kg
Human health CF, Emission to cont. sea water, non-canc.	CTUnoncancer/kg
Human health CF, Emission to cont. natural soil, cancer	CTUcancer/kg
Human health CF, Emission to cont. natural soil, non-canc.	CTUnoncancer/kg
Human health CF, Emission to cont. agric. Soil, cancer	CTUcancer/kg
Human health CF, Emission to cont. agric. Soil, non-canc.	CTUnoncancer/kg

3.3.6 Interpretation

In the interpretation stage, a contribution analysis was performed to identify the impacts on production process. LCA results present the opportunities to reduce or mitigate identified environmental impacts arising from the leaching and electrolysis process, e-waste, copper recovery, chemicals and usage of electricity. The LCA represents the most objective tool currently available to inform decisions on the environmental sustainability of copper recovery process from e-waste by the recovery method (A. Striebig et al., 2016).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Governments are currently paying more attention to e-waste disposal because the growing amount of e-waste globally is a serious environmental problem. Copper is an essential element for human life and considered as a toxic element in drinking water at high concentrations. Thus, the determination of copper concentration amounts is becoming necessary. The spectrophotometric method was used to determine the concentration of copper from the electrolysis process. The spectrometry method was well-known as low cost, robust, fast analysis ability and target ions can be easily observed with the naked eyes in the visible range with high sensitivity (Zhou et al., 2019b). Moreover, all the reagents used were stable under the working conditions and the method was easy to perform for the determination of copper in pharmaceutical, biological, and water samples (Hashem et al., 2011).

In this chapter, the amount of copper recovered from e-waste through leaching and electrolysis process has been discussed in detail. The copper analysis was to determine the percent recovery of copper from PCBs using the recovery processes. Although the LCA of e-waste has been properly researched, there are many other potential environmental effects of e-waste management. This chapter also aims to analyze the environmental impacts of alternatives for recovering copper from waste PCBs through recovery also known as urban mining. Therefore, the life cycle assessment of copper recovery from PCBs for leaching and electrolysis process was demonstrated using GaBi Software and TRACI 2.0.

4.2 Copper concentration using spectrophotometer

Even though copper is not a highly toxic element, its content in environment, waste and boiler water is regulated by specialized metrological agencies. In analytical chemistry, the necessity for copper determination in environmental, biological, and industrial objects is highly important. Thus, the demand for perfect instrumental equipment which allows determination of copper in the presence of various other elements with high and accurate sensibility. Recently, spectrophotometry has proven itself as a simple and cost-effective analytical method that is important for laboratories. The DR 5000 UV-Vis Spectrophotometer was used to measure the amount of copper recovered from PCBs through the recovery processes for this experiment. The selected programme was 135-Copper Bicin in the spectrophotometer. The copper concentration was carried out on the UV-Vis spectrophotometer with 2 sample cells of 10 ml. As the blank cell used 10ml of electrolyte solution without copper powder pillow meanwhile, the other sample cell was 10ml of electrolyte solution with a sachet of copper powder pillow.

4.2.1 Percent recovery of copper from electrolysis process

The table 1 below illustrates about the results obtained from spectrophotometer for the electrolysis process in percentage. The leaching process was carried out with the electrolyte solution which consists of 0.4kg ethylene glycol, 0.023kg NH_4CI, 0.002kg of KCI and along with 0.255kg of copper scrap. The leaching process was carried out for 24 hours and 96 hours respectively to study the amount of copper recovered based on the reaction time. The data obtained for leachate 24 hours was 45.6 mg/L Cu meanwhile, for the leachate of 96 hours acquired 72.8 mg/L Cu. In order that, the leachate obtained for 96 hours was the highest compared to the 24 hours of leachate because the leachate characteristics may be expected to develop over time, increasing from initial values to a maximum value (R.K. Rowe, 2015).

4.2.2 Effect of reaction time on recovery rate of copper

The reaction was conducted for 1 hour, 3 hours and 5 hours respectively and the experiment were duplicated to study the reaction time on the amount of copper recovered. The average was calculated for every 1 hour, 3 hour and 5 hours. The copper recovery amount increases for the first 3 hours and began to decline due to the deposition and depletion of copper ions and the presence of hydrogen. Therefore, when the time varies from 1 hour to 5 hours, the copper recovery rate also changes accordingly. On the other hand, as discussed above the current efficiency showed an inflection point during the entire reaction phase. In summary, the optimum percentage of copper recovery process was acquired at 3 hours with 85% recovery rate with the current of 0.81A and 1.85 Ω resistance. Table 4.1 shows the copper recovered concentration in percentage over various time periods.

Table 4.1 Effect of reaction time on recovery rate of copper

Time	**1 Hour**	**3 Hour**	**5 Hour**
Copper recovery process (%)	75%	85%	78%

4.2.3 Effect of current

The table 4.2 shows the results of copper concentration at various current and resistance in the recovery process. From the data obtained shows that the highest copper yield recovered was on 3 hours at 1.0 mA and resistance of 1.5 kΩ with 81% of copper yield. At the same time, 0.5 mA current variable obtained 77% of copper yield at 3 hours using resistance of 3 kΩ. Furthermore, the current variable of 0.2 mA shows the lowest copper yield of 75 % at 3 hours with 7.5 kΩ compared to other current variables. Therefore, can conclude that the optimum copper yield was obtained at 1.0 mA with the resistance of 1.5 kΩ at 3 hours.

Table 4.2 Effect of current on copper concentration using electrolysis process.

Reaction Time (hours)	**Current (mA)**	**Resistance (kΩ)**	**Copper Concentration (%)**
3	1.0	1.5	81
3	0.5	3.0	77
3	0.2	7.5	75

4.3 Life Cycle Assessment (LCA)

A life cycle assessment (LCA) is a scientific tool for evaluating the amount of resource consumed and the environmental effects associated with a process, product, or operation during its entire life cycle. The purpose of most LCA studies is to find the design alternatives that reduces the life cycle impact of the process. LCA was applied using the 4 phases of goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. To define the LCA scope boundaries, the processes directly involved in the recovery and utilization of the wasted printed circuit boards are identified (W. Zhang et al., 2021c). The field research data are used to create the life cycle inventory of the recovery process, and GaBi software is implemented to determine the inventory, resource consumption, and waste emissions of the copper recovery process per unit mass. GaBi software combines the world's leading Life Cycle Assessment (LCA) modeling and reporting software with reliable and consistent environmental data. In addition, TRACI 2.0 method also used to determine the environmental impacts of the recovery and utilization of copper-based wastes along with copper production and to evaluate the changes in environmental impacts associated with recovery.

4.4 Goal and Scope Definition

The goal of this study was to analyze the life cycle assessment and assess the GWP (kg CO_2-eq/kg), Acidification (kg SO_2-eq/kg), Marine eutrophication (kg N-eq/kg), Ozone depletion air (kg CFC-11-eq/kg), Ecotoxicity (CTUeco/kg), Human health particulate air (kg $PM_{2.5}$-eq/kg), Human toxicity cancer (CTUh/kg), Human toxicity non-cancer (CTUh/kg), Resources fossil fuels (MJ surplus energy) and Smog air (kg O3 eq/kg) impacts of copper recovery rate efficiency associated with the recovery processes. The recovery of 0.255kg of copper from PCB was selected as the functional unit. Thus, the air, water emissions, raw materials, energy consumption, and waste disposal measurements were based on this functional units. The "gate to gate" model was adopted to define the LCA research boundary which is from the raw materials (PCBs) separating copper to the recovery processing stage and the final product was copper powder. The analysis was followed and defined by ISO 14040:2006 standard and it is performed using GaBi software and TRACI 2.0.

4.4.1 Functional Unit

The functional unit used in this study was the quantified function provided by the recovery process which known as the recovery of 0.255kg copper from PCBs. The copper was recovered and deposited to the cathode in the process of electrolysis.

4.4.2 System Boundary

Figure 4.1 shows the copper recovery process plan applied in GaBi software. The process plan was conducted for both electrolysis and leaching process. The inputs and outputs are 0.255kg of copper scrap, 0.4 kg of ethylene glycol, 0.023 kg ammonium chloride (NH_4CI), 0.002 kg pottasium chloride (KCI) and 0.01404 MJ of electricity. Once run the programme, 0.22 kg of copper powder and some emissions were emitted as the final output of the process.

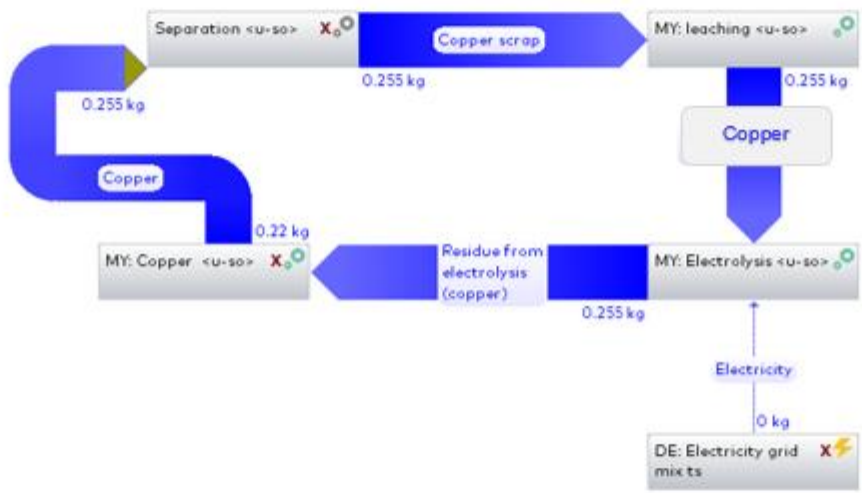


Figure 4.1 Copper recovery process plan in GaBi software

Figure 4.2 shows the total emissions that was produced from the copper recovery process. As shown in the chart of TRACI 2.0, the emissions of GWP, human health cancer and non-cancer, eutrophication, acidification, ecotoxicity, resources fossil fuels depletion and smog air were represented from the usage of electricity. The highest number of emissions was emitted from GWP and followed by ecotoxicity air due to the energy power usage.

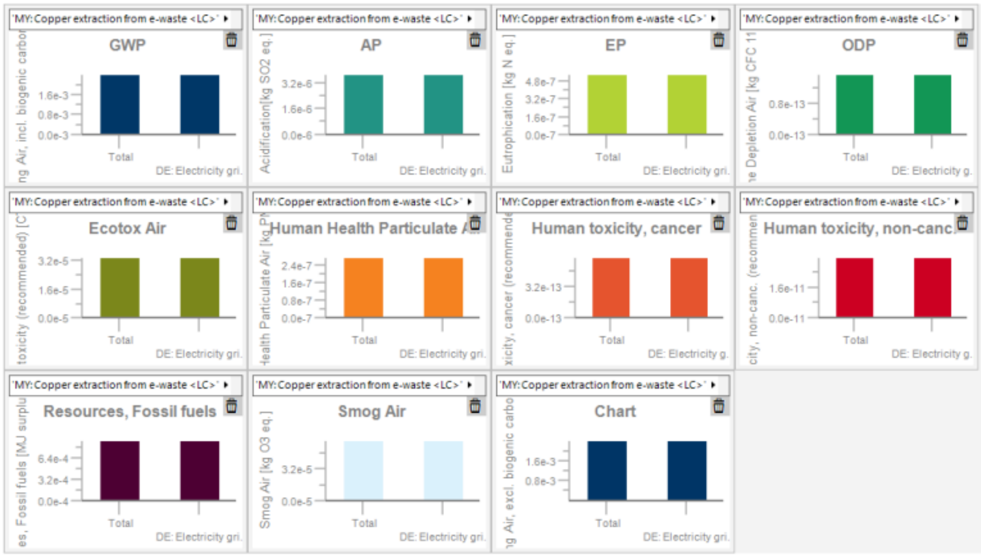


Figure 4.2 The total emissions for the usage of electricity in chart of TRACI 2.0 (GaBi)

4.5 Life Cycle Inventory Analysis

LCI includes data collection and calculation, with the primary goals being to calculate each unit's energy and resource usage as well as the quantity of various pollutants it produces throughout the research process. The data is then summarised through a calculation (Chen et al., 2019). The goal of LCI was to determine the mass flows of the inputs and outputs of two process in this study. The chemical contents used for the copper recovery of e-waste for recovery process was ethylene glycol, ammonium chloride (NH_4CI), potassium chloride (KCI). Therefore, the copper concentrate was relatively high which was suitable for electrolysis process. The recovery rate of copper for the electrolysis process were calculated based on GaBi software and validated from experimental. The LCA software GaBi links the direct raw materials used to the corresponding recovery processes and the emissions emitted in the process of establishing a complete life cycle inventory. The physical inputs and outputs of the inventory was balanced. Tables 4.3 and table 4.4 shows about the material input and output of the leaching and electrolysis process.

The copper recovery process consumes only few resources. The energy consumption was used in the electrolysis process where, the total energy consumption was 0.01404 MJ. In terms of material resources, the chemical used was 0.4 kg of ethylene glycol which was considering as the most environmental friendly and effective solvent to induce electrochemical leaching and recovery of copper. In addition, 0.023 kg of NH_4CI and 0.002 kg of KCI was considered as small amount of intake in the electrolysis process which was low in environmental impacts compared to other chemicals. Thus, in terms of emissions ecotoxicity air emits the most emission and followed by GWP from the recovery process. The highest emissions of GWP are generated during the electrolysis process compared to the other emissions which was 3.95 kg CO_2-eq/kg. Other than that, the highest emissions generated from the electrolysis and leaching process was smog air 3.13 kg O3 eq/kg and human toxicity (non-cancer) $3.53e^{-03}$ CTUh/kg.

Table 4.3 Material Inventory of the leaching process

Type	Material	Quantity	Unit	Amount
Input	Copper scrap	Mass	kg	0.255
	Ethylene Glycol	Mass	kg	0.4
	Ammonium chloride (NH_4CI)	Mass	kg	0.023
	Pottasium chloride (KCI)	Mass	kg	0.002
Output	Copper	Mass	kg	0.255
	Ethylene glycol	Mass	kg	0.4
	Ammonium chloride (NH_4CI)	Mass	kg	0.023
	Pottasium chloride (KCI)	Mass	kg	0.002

Table 4.4 Material Inventory of the electrolysis process

Type	Material	Quantity	Unit	Amount
Input	Electricity	Energy (net calorific value)	MJ	0.01404
	Copper	Mass	kg	0.255
	Ethylene Glycol	Mass	kg	0.4
	Ammonium chloride (NH_4CI)	Mass	kg	0.023
	Pottasium chloride (KCI)	Mass	kg	0.002
Output	Residue from electrolysis (copper)	Mass	kg	0.255
	Ethylene glycol	Mass	kg	0.4
	Ammonium chloride (NH_4CI)	Mass	kg	0.023
	Pottasium chloride (KCI)	Mass	kg	0.002

4.6 Life Cycle Impact Assessment (LCIA)

The component is important to produce potential consumption on a resource along with impacts on human health, the ecology, and other environmental impacts. Using the results from LCI phase, LCIA aims to evaluate the significance of potential environmental impacts (Ghodrat et al., 2017). Based on the results obtained, electricity usage has a potential impact on global warming potential (GWP), human health cancer and non-cancer, eutrophication, acidification, ecotoxicity, resources fossil fuels depletion and smog air. Figure 4.3 shows the environmental impacts from the copper recovery processes. The highest impacts were emitted from ecotoxicity air (CTU_{eco}/kg), GWP (kg CO_2-eq/kg) and smog air kg O3 eq/kg. Figure 4.4 shows the LCIA from electricity usage for copper recovery processes. The highest impact was recorded as GWP (2.35×10^{-03} kg CO_2-eq/kg), resource fossil fuels (8.80×10^{-04} MJ surplus energy/kg) and followed by smog air (6×10^{-5} kg O3 eq/kg). Furthermore, the

LCIA for chemical usage such as ethylene glycol, potassium chloride (KCI), ammonium chloride (NH_4CI) and copper were shown in figure 4.5. The usage of ethylene glycol was producing impact of ecotoxicity air (5.285 CTU_{eco}/kg) and followed by smog air of (3.13 kg O3 eq/kg). Meanwhile, copper and ammonium chloride (NH_4CI) producing impacts in terms of GWP which is 1.18 kg CO_2-eq/kg and 2.77 kg CO_2-eq/kg.

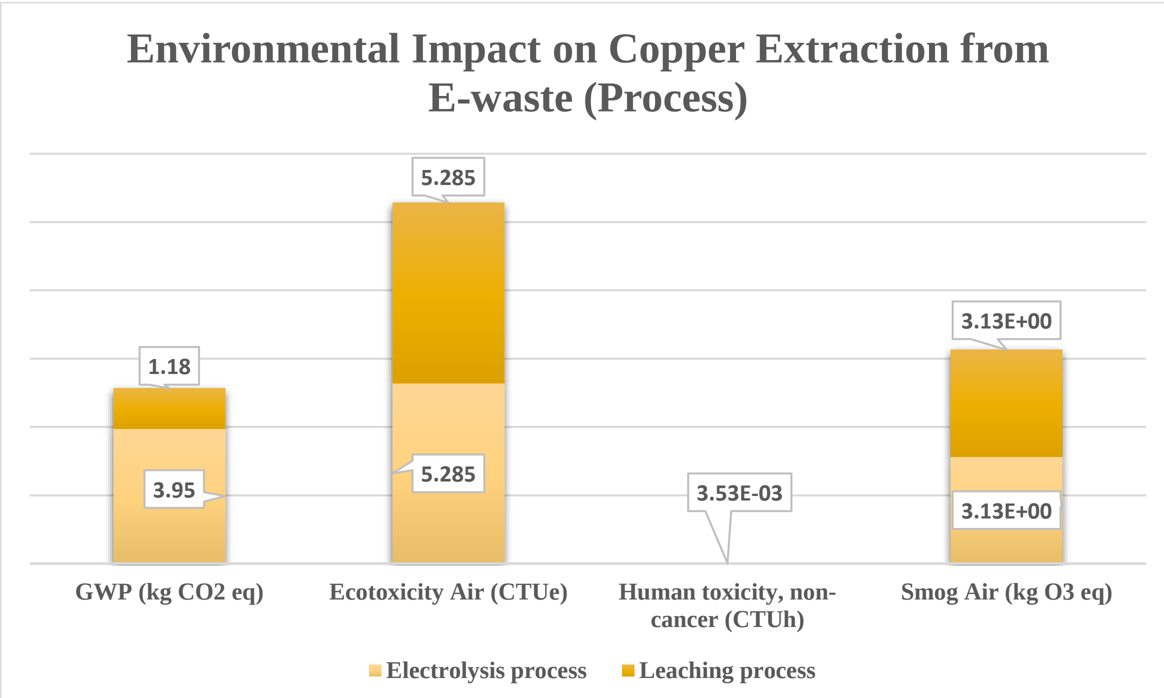


Figure 4.3 LCIA for copper recovery processes

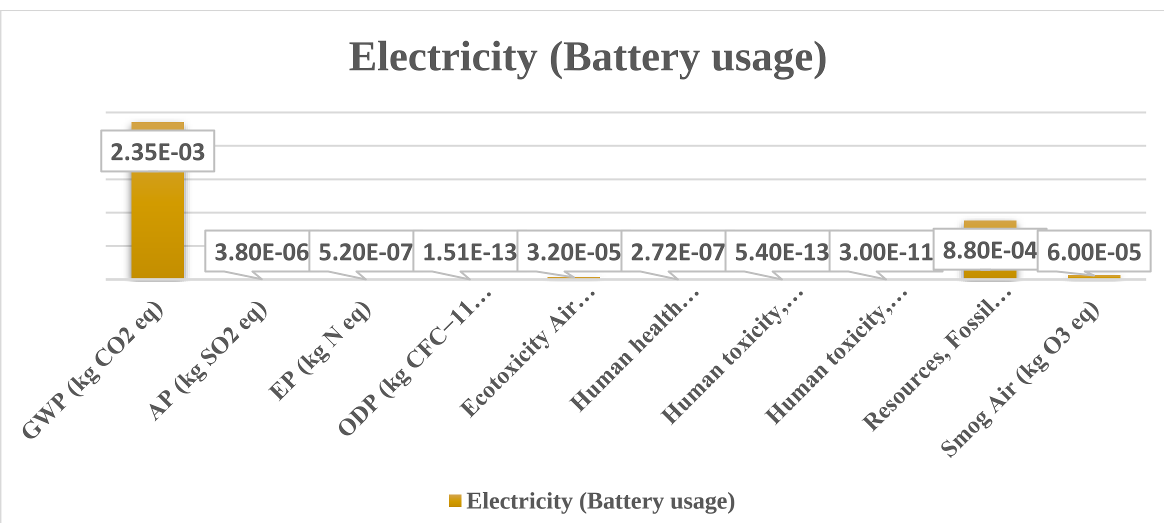


Figure 4.4 LCIA results of environment impacts indicator from electricity

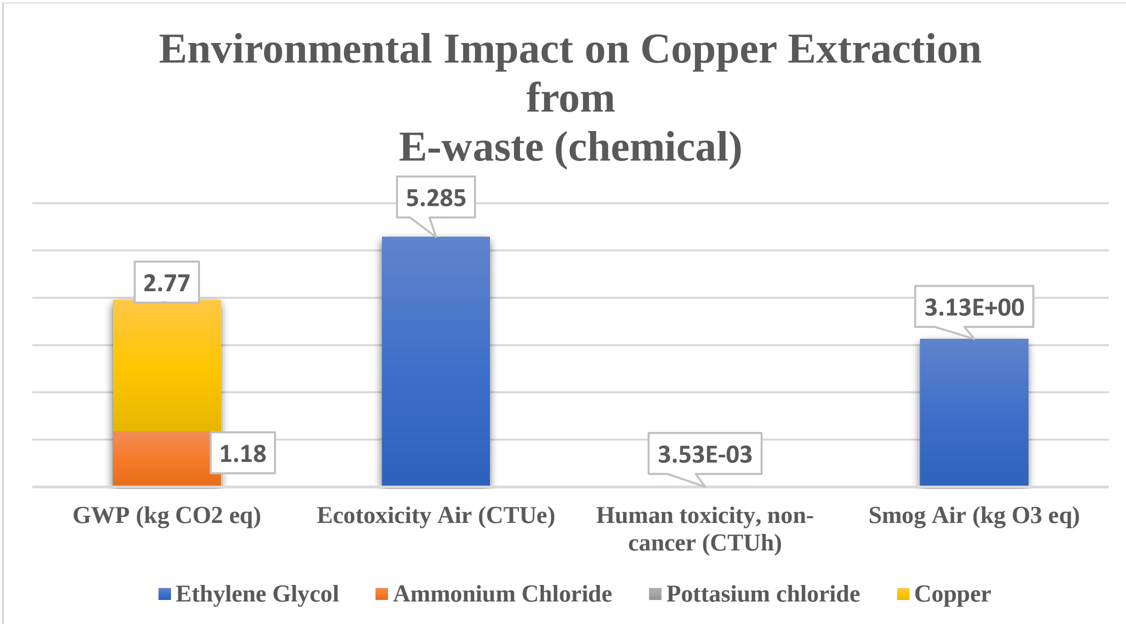


Figure 4.5 LCIA of environmental impacts on copper recovery by chemicals

Based on the results evaluated from this study, recovery of copper metals from e-waste was producing high impacts in terms of ecotoxicity air (5.31 CTUeco/kg), human toxicity non-cancer (0.18 CTUh/kg) and smog air (3.17 kg O3 eq/kg). The results indicate that the overall impacts of the urban mining of copper from e-waste was lower compared to the conventional mining as shown in Table 4.5 (Farjana et al., 2019). Meanwhile, using the conventional mining method on recovering copper from its ore producing high impacts such as GWP (5.44 kg CO_2-eq/kg), acidification (0.42 kg SO_2-eq/kg), eutrophication (0.018 kg N-eq/kg), ozone depletion air (2.68 x 10^{-07} kg CFC−11-eq/kg), ecotoxicity freshwater (9.25 CTUeco/kg), human health particulate air (0.024 kg $PM_{2.5}$-eq/kg), human toxicity cancer (2.54 x 10^{-08} CTUh/kg) and resources fossil fuels (2.12 MJ surplus energy/kg). Therefore, most of the impact factors such as GWP, acidification, eutrophication, ozone depletion air, ecotoxicity freshwater, human health cancer and non-cancer and resource fossil fuels shows the highest number of emissions was released to the environment and human health from the conventional mining method.

4.7 Interpretation

After analyzing and evaluating the results obtained from the LCA study, the significant issues was identified. The major environmental impacts to the environment were global warming potential and ecotoxicity air due to the consumption of electricity. Furthermore, human health cancer and non-cancer, eutrophication, acidification, resources fossil fuels depletion and smog air obtained minimal amount of impacts from urban mining. However, compared to the urban mining of copper recovery process, conventional mining shows the highest impacts in the factors of GWP, acidification, eutrophication, ozone depletion air, ecotoxicity freshwater, human toxicity cancer and non-cancer, and resources fossil fuels as shown in Table 4.5.

Table 4.5 Comparative life cycle impact assessment of urban mining and conventional mining

Impact Factors	**Unit**	**Urban Mining**	**Conventional Mining** Source: (Farjana et al., 2019)
GWP	kg CO_2-eq/kg	4.06	5.44
Acidification	kg SO_2-eq/kg	3.80×10^{-06}	0.42
Eutrophication	kg N-eq/kg	5.20×10^{-07}	0.018
Ozone Depletion Air	kg CFC−11-eq/kg	1.51×10^{-13}	2.68×10^{-07}
Ecotoxicity Air	CTUeco/kg	5.31	-
Ecotoxicity freshwater	CTUeco/kg	-	9.25
Human health particulate air	kg $PM_{2.5}$-eq/kg	2.72×10^{-07}	0.024
Human toxicity, cancer	CTUh/kg	5.40×10^{-13}	2.54×10^{-08}
Human toxicity, non-cancer	CTUh/kg	0.18	7.79×10^{-07}
Resources, fossil fuels	MJ surplus energy/kg	8.80×10^{-04}	2.12
Smog Air	kg O3 eq	3.17	-

In this study, we refer to the previous research study from Farjana et al., (2019) which is stated about the life cycle assessment of copper extraction process from mining and its impacts by using International Reference Life Cycle Data System (ILCD) method. The study was evaluated according to ISO standard 14040 for life cycle impact assessment. The functional unit was chosen as 1 kg of copper and the system boundary is cradle to gate which is to study all the emissions or impacts generated from the steps of ore mining to final waste emission. The results obtained from the study shows that the largest impact category was from global warming potential and ecotoxicity freshwater. Other significant categories consist of, acidification, eutrophication, ozone depletion air, and effect on human health as shown in Table 4.5.

The greatest contributor to the impacts felt from mining industries is electricity consumed for mining operations, smelting and refining processes, mining, well field related activities, fossil fuel consumption for electricity generation and process heat generation. When compare the study from Farjana et al., (2019), my study which is urban mining for the copper recovery process from e-waste shows less impact to the environment as well as human health. Even though the functional unit used in my study was different with her study but the factor was normalized by the calculation like kg CO_2-eq/kg. Therefore, this is the reason why her study was chosen as a reference for my study because the extraction of copper from conventional mining shows the highest impacts when compare with my study which is urban mining in the impact factors of GWP, acidification, eutrophication, ozone depletion air, ecotoxicity freshwater, human health particulate air, human toxicity cancer and resource fossil fuels.

CHAPTER 5

CONCLUSION

5.1 Introduction

The main objective of this project which was to determine the percent recovery of copper from e-waste using spectrophotometer and to assess the environmental impacts of the e-waste recovery process by using a life cycle assessment method was achieved. The amount of copper recovered by the recovery process from e-waste was thoroughly examined. The results obtained from the spectrophotometer showed that, the leachate obtained for 96 hours was greater compared to the 24 hours of leachate because the leachate solution will progress over time. The electrolysis process was run twice for every 1 hour, 3 hour and 5 hours and the average were calculated. However, the optimum percentage of copper recovery from the electrolysis process shown at 3 hours compared to the 1 hour and 5 hours of reaction time. Furthermore, the results studied from the effect of current was concluded as optimum copper yield was recovered at 3 hours in 0.8A with the resistance of 1.85Ω with 85% of copper yield. Furthermore, the effect of reaction time for recovery process was studied properly at where the data obtained showed that the copper yield efficiency achieved the optimum value when the reaction was conducted over 3 hours at 1.0 mA with 1.5 kΩ which is 81% of copper yield.

After analyzed and evaluated the impacts of copper recovery process using the life cycle assessment method by GaBi software and TRACI 2.0 showed that the most environmental impacts of urban mining caused by the usage of electricity which are the ecotoxicity air, human toxicity non-cancer and smog air. Electrolysis process were the main process that caused environmental impacts on copper recovery due to the impacts from electricity usage. Other than that, the usage of ethylene glycol causing environmental impacts of ecotoxicity air, smog air, and human toxicity non-cancer. Meanwhile, the ammonium chloride causing only GWP of 1.18 kg CO_2-eq/kg and usage of copper metal causing GWP of 2.99 kg CO_2-eq/kg. Therefore, the overall life cycle environmental impact per unit of copper metal for the recovered process was proven greater than the conventional mining method. In this project, the electrolysis method was chosen as the most effective technique to recover copper metals because of its short process with less impacts to the environment and human health.

Furthermore, this approach tends to recover metals from WPCBs with an efficiency of 85% and the copper purity was greater than 99% (J. Wang et al., 2021). The good results obtained from this urban mining was proven as a promising method for the copper recovery from WPCBs with low environment impacts compared to the conventional mining. According to the analysis of life cycle assessment, the environmental impacts was assessed for the recovery process where the consumption of electricity was the most sensitive factor for that method which emits high amount of ecotoxicity air of 5.31 CTUeco/kg followed by smog air of 3.17 kg O3 eq/kg. Therefore, the outcome of this study was achieved and proven as the urban mining of copper from e-waste was given less environmental impacts in terms of the ecotoxicity air, smog air and human toxicity non-cancer compared to the conventional mining method which gives highest impacts in terms of GWP, eutrophication, acidification, ozone depletion air, ecotoxicity freshwater, human health particulate air, human toxicity cancer and resource fossil fuels.

5.2 Recommendation

Several uncertainties are yet to be confirmed and some improvements need to be done in order to achieve more comprehensive work on the copper recovery process and as well life cycle assessment study.

The mining of copper ore has many environmental effects compared to the green slurry electrolysis method. Therefore, it is better to planned rationally before utilizing the copper mines for valuable metals by the management based on the impacts to environment (Chen et al., 2019b). The electrolysis process was carried out for a small amount of copper from the waste printed circuit boards which is 0.255 kg of copper scrap. Since there is no crusher machine at the laboratory, it was difficult to cut the copper into pieces manually for the recovery process. This results us to use small amount of copper for the copper recovery process. Therefore, the output which is in the form of copper powder also very less due to the copper intake that used for the recovery process. For future, it is recommended to use the crusher machine and to recovered large amount of copper so we can obtain more recovery rate of copper which is low in environmental impacts.

The life cycle assessment study can be accessed other than the GaBi software for example openLCA, SimPro and ecoinvent database for high performance and to ensure the sustainability of the environment. Furthermore, in future the electrolysis process can be carried for more than 5 hours to study the copper concentration with different current and resistance. Therefore, maybe the copper recovery percentage could be increased along with the reaction time, current and resistance.

Other than that, in future it is recommended to use the electrolysis process to recover valuable metals other than copper such as gold, silver, titanium and iron from Waste Printed Circuit Boards (WPCBs). This is because the electrolysis process was environmental friendly, short process and also less expensive compared to other recovery process. Moreover, recovery of valuable metals from e-waste can obtain high purity of metals as proven in this study.

REFERENCES

Chen, J., Wang, Z., Wu, Y., Li, L., Li, B., Pan, D., & Zuo, T. (2019a). Environmental benefits of secondary copper from primary copper based on life cycle assessment in China. *Resources, Conservation and Recycling*, *146*, 35–44. https://doi.org/10.1016/j.resconrec.2019.03.020

Chen, J., Wang, Z., Wu, Y., Li, L., Li, B., Pan, D., & Zuo, T. (2019b). Environmental benefits of secondary copper from primary copper based on life cycle assessment in China. *Resources, Conservation and Recycling*, *146*, 35–44. https://doi.org/10.1016/j.resconrec.2019.03.020

Chiu, A. S. F., Aviso, K. B., Baquillas, J., & Tan, R. R. (2020). Can disruptive events trigger transitions towards sustainable consumption? *Cleaner and Responsible Consumption*, *1*. https://doi.org/10.1016/j.clrc.2020.100001

Choubey, S., Goswami, P., & Gautam, S. (2021). Recovery of copper from Waste PCB boards using electrolysis. *Materials Today: Proceedings*, *42*, 2656–2659. https://doi.org/10.1016/j.matpr.2020.12.596

de Waal, A. (2019). *Evaluating the efficiency of a metal recycling process by means of life cycle assessment and exergy analyses*. *April*, 17–76. https://scholar.sun.ac.za

Dhanunjaya Rao, M., Singh, K. K., Morrison, C. A., & Love, J. B. (2020). *Cite this: RSC Adv*. *10*, 4300. https://doi.org/10.1039/c9ra07607g

Farjana, S. H., Huda, N., & Mahmud, M. A. P. (2019). Life cycle assessment of cobalt extraction process. *Journal of Sustainable Mining*, *18*(3), 150–161. https://doi.org/10.1016/j.jsm.2019.03.002

Forti et al., (2020). *The global E-waste monitor 2020 - SCYCLE* . Available at: https://www.scycle.info/wp-content/uploads/2020/12/GEM_2020_def_dec_2020.pdf

Gem Celestial, R. (2018). *E-waste management in the Philippines Parametric Study on the Anaerobic Digestion of Ice Production Residue for the Production of Biogas View project*. https://doi.org/10.13140/RG.2.2.17965.74728

Ghodrat, M., Rhamdhani, M. A., Brooks, G., Rashidi, M., & Samali, B. (2017). A thermodynamic-based life cycle assessment of precious metal recycling out of waste printed circuit board through secondary copper smelting. *Environmental Development*, *24*, 36–49. https://doi.org/10.1016/j.envdev.2017.07.001

Hashem, E. Y., Seleim, M. M., El-Zohry, A. M., & Seleim $, M. M. (n.d.). *Environmental method for spectrophotometric determination of copper(II)*. https://doi.org/10.1080/17518253.2010.546370

Ikhlayel, M. (2018). An integrated approach to establish e-waste management systems for developing countries. *Journal of Cleaner Production*, *170*, 119–130. https://doi.org/10.1016/j.jclepro.2017.09.137

Ilankoon, I. M. S. K., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018a). E-waste in the international context – A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. In *Waste Management* (Vol. 82, pp. 258–275). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2018.10.018

Ilankoon, I. M. S. K., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018b). E-waste in the international context – A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. In *Waste Management* (Vol. 82, pp. 258–275). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2018.10.018

IPCC Third assessment report (2001). Available at: https://www.ipcc.ch/assessment-report/ar3/

Jayaraman, K., Vejayon, S., Raman, S., & Mostafiz, I. (2019). The proposed e-waste management model from the conviction of individual laptop disposal practices-An empirical study in Malaysia. *Journal of Cleaner Production*, *208*, 688–696. https://doi.org/10.1016/j.jclepro.2018.10.125

Kharade, S. B., Chougale, R. K., Barache, U. B., Sanadi, K. R., Rathod, K. C., Gaikwad, S. H., Ling, Y. C., Anuse, M. A., & Kamble, G. S. (2022). Design and optimization of sensitive analytical spectrophotometric method for micro determination of copper(II) from e-waste by using of novel chromogenic extractant. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, *267*. https://doi.org/10.1016/j.saa.2021.120502

Khayyam Nekouei, R., Tudela, I., Pahlevani, F., & Sahajwalla, V. (2020). Current trends in direct transformation of waste printed circuit boards (WPCBs) into value-added materials and products. In *Current Opinion in Green and Sustainable Chemistry* (Vol. 24, pp. 14–20). Elsevier B.V. https://doi.org/10.1016/j.cogsc.2020.01.003

Leiva González, J., & Onederra, I. (2022). Environmental Management Strategies in the Copper Mining Industry in Chile to Address Water and Energy Challenges—Review. *Mining*, *2*(2), 197–232. https://doi.org/10.3390/mining2020012

Liu, K., Huang, S., Jin, Y., Ma, L., Wang, W.-X., & Lam, C. H. (2022a). A Green Slurry Electrolysis to Recover Valuable Metals from Waste Printed Circuit Board (WPCB) in Recyclable pH-Neutral Ethylene Glycol. *Journal of Hazardous Materials*, 128702. https://doi.org/10.1016/j.jhazmat.2022.128702

Liu, K., Huang, S., Jin, Y., Ma, L., Wang, W.-X., & Lam, C. H. (2022b). A Green Slurry Electrolysis to Recover Valuable Metals from Waste Printed Circuit Board (WPCB) in Recyclable pH-Neutral Ethylene Glycol. *Journal of Hazardous Materials*, 128702. https://doi.org/10.1016/j.jhazmat.2022.128702

Mangmeechai, A. (2022). The life-cycle assessment of greenhouse gas emissions and life-cycle costs of e-waste management in Thailand. *Sustainable Environment Research, 32*(1). https://doi.org/10.1186/s42834-022-00126-x

Misra, N. R., Kumar, S., & Jain, A. (2021). A Review on E-waste: Fostering the Need for Green Electronics; A Review on E-waste: Fostering the Need for Green Electronics. *2021 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS)*. https://doi.org/10.1109/ICCCIS51004.2021.9397191

Muhammad, N. I. S., & Rosentrater, K. A. (2020). Comparison of global-warming potential impact of food waste fermentation to landfill disposal. *SN Applied Sciences, 2*(2), 1–7. https://doi.org/10.1007/s42452-020-2035-6

Reyna, A., Martín, C., Chen, J., Soler, E., & Díaz, M. (2018). On blockchain and its integration with IoT. Challenges and opportunities. *Future Generation Computer Systems*, *88*, 173–190. https://doi.org/10.1016/j.future.2018.05.046

R.K. Rowe. (2015). *Leachate characteristics*. - nswai.org, Leachate characteristics. Available at: https://nswai.org/docs/Leachate%20characteristics.pdf

Shaikh, S., Thomas, K., & Zuhair, S. (2020). An exploratory study of e-waste creation and disposal: Upstream considerations. *Resources, Conservation and Recycling, 155*(January), 104662. https://doi.org/10.1016/j.resconrec.2019.104662

Tesfaye, F., Lindberg, D., Hamuyuni, J., Taskinen, P., & Hupa, L. (2017). Improving urban mining practices for optimal recovery of resources from e-waste. *Minerals Engineering*, *111*, 209–221. https://doi.org/10.1016/j.mineng.2017.06.018

Tyagi, A., Prasad, A. K., & Bhatia, D. (2021). Effects of excessive use of mobile phone technology in India on human health during COVID-19 lockdown. *Technology in Society*, *67*. https://doi.org/10.1016/j.techsoc.2021.101762

Wang, F., Du, C., Chen, J., Shi, L., & Li, H. (2021). *A New Method for Determination of Pectin Content Using Spectrophotometry*. https://doi.org/10.3390/polym13172847

Wang, J., Huang, Z., Yang, D., Zeng, X., Chen, M., Shu, J., Sun, Z., Sun, S., & Xiao, Z. (2021). A semi-scaled experiment for metals separating and recovering from waste printed circuit boards by slurry electrolysis. *Process Safety and Environmental Protection*, *147*, 37–44. https://doi.org/10.1016/J.PSEP.2020.09.030

Xavier, L. H., Giese, E. C., Ribeiro-Duthie, A. C., & Lins, F. A. F. (2021). Sustainability and the circular economy: A theoretical approach focused on e-waste urban mining. *Resources Policy*, *74*. https://doi.org/10.1016/j.resourpol.2019.101467

Yong, Y. S., Lim, Y. A., & Ilankoon, I. M. S. K. (2019). An analysis of electronic waste management strategies and recycling operations in Malaysia: Challenges and future prospects. *Journal of Cleaner Production*, *224*, 151–166. https://doi.org/10.1016/j.jclepro.2019.03.205

Yu, D. E. C., Yu, K. D. S., & Tan, R. R. (2020). Implications of the pandemic-induced electronic equipment demand surge on essential technology metals. *Cleaner and Responsible Consumption*, *1*. https://doi.org/10.1016/j.clrc.2020.100005

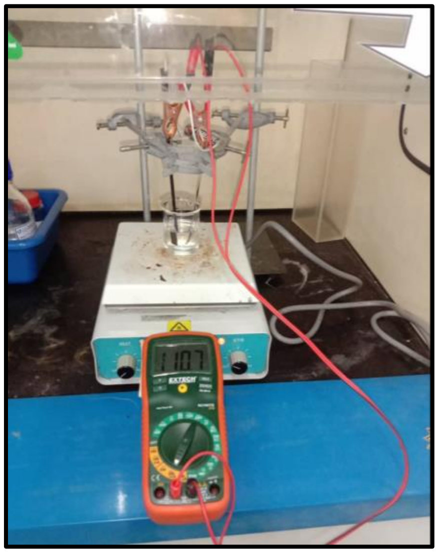
Zhang, W., Li, Z., Dong, S., Qian, P., Ye, S., Hu, S., Xia, B., & Wang, C. (2021). Analyzing the environmental impact of copper-based mixed waste recycling-a LCA case study in China. *Journal of Cleaner Production*, *284*(1), 125256. https://doi.org/10.1016/j.jclepro.2020.125256

Zhang, Y., Chen, M., Tan, Q., Wang, B., & Chen, S. (2018). Recovery of copper from WPCBs using slurry electrolysis with ionic liquid [BSO3HPy]·HSO4. *Hydrometallurgy*, *175*, 150–154. https://doi.org/10.1016/j.hydromet.2017.11.004

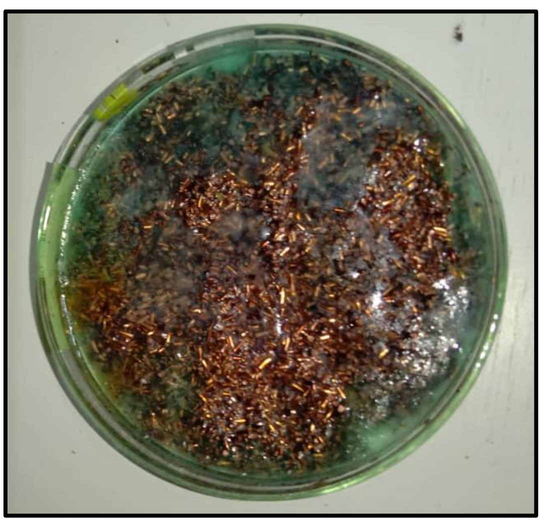
Zhou, F., Li, C., Zhu, H., & Li, Y. (2019a). Determination of trace ions of cobalt and copper by UV–vis spectrometry in purification process of zinc hydrometallurgy. *Optik*, *184*, 227–233. https://doi.org/10.1016/j.ijleo.2019.03.056

APPENDICES

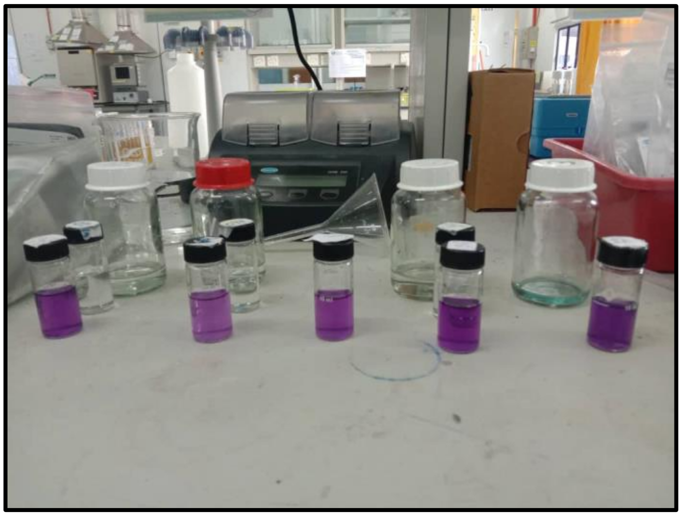
Appendix A: Electrolysis process



Appendix B: Copper leachate for 96 hours



Appendix C: Copper concentration analysis



Appendix D: Logo of GaBi Software

thinkstep
GaBi
Product Sustainability
Performance