Life Cycle Analysis of Metal: Copper’s Assessment on the Circular Economy in Industries from the Perspective of the European Green Deal

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1. INTRODUCTION

The technology has progressed in different areas, being constant development, with the aim of improving people's living standards and becoming comfortable. The new era of human beings was the discovery of metal to provide tools for society to build, evolve and design. Metals have a significant role in the construction of society, due to this being the substrate of several processes that occur in different industries that develop our society. They are used in nearly all fields of present life, being indispensable ranging from home appliances to construction of buildings and structures. Occupying a central position in the formation and evolution of the economy, technics, and culture of societies, being one of the major priorities of human development from the creation of tools to the development of high technologies.

This raw material must have to be applied in various processes including extraction, processing, production, usage, disposal and recycling. But in the old days, society has utilized raw materials with the "take-make-dispose" mentality. The take-make-dispose model is an old production and consumption model of a linear economy. The society used the products of the material that was extracted (take), transformed into product (make) of utility for the society. However, when these products have reached their life cycle, they are discarded (dispose) without considering the destination and environmental problems of this disposal. This linear approach ignored what could happen with the discarded products and possible forms of reuse or recycling, creating new uses for the materials of that product.. This approach to linear economics was able to bring about a considerable degree of pollution of our soils, erosion and deforestation, water pollution, burning of fossil fuels, and toxic wastes. The poor care with the use of this raw material meant the problem that has been with us today, pollution of the ecosystem.

Seeing this problem that we are living in the present times, there was a need to create a more sustainable economy, in search of a better planet. Being created an analysis to describe and find solutions for the materials produced and discarded, can have a broad view of the impacts caused by the process, the Life Cycle.

The Life Cycle of a product is an approach to be able to analyze the steps that a material or product goes through, from the extraction of raw materials, through production, distribution, use and final disposal. This concept allows to define and evaluate the environmental, social and economic impacts generated in each phase of this process, allowing a complete view of the effects caused throughout the existence of the product. Through life cycle analysis, it allows to find which are the steps that solve problems for the environment, being able to find or develop measures for its improvement, for example, emission reduction, use of sustainable materials or recycling processes. *"Life Cycle Analysis (LCA) is a standardized scientific method used to quantify the environmental requirements associated with a product or service throughout its entire life cycle." (Delmás, 2022, p3)*. The aim of this study is not only to review the life of the material copper, but also to understand the interactions between the production and disposal of materials.

In this study, the metal life cycle will be analyzed, as it is from extraction, use, disposal and creation of reuse of this material. Using the circular economy, a sustainability model that focuses on how to keep the material for as long as possible in use, seeking not only to reduce waste but also to minimize the demand for new raw materials.

For the EU to become a sustainable and carbon-free economy, an initiative has been created to put into practice the goals, The European Green Deal for creating a more ecological and balanced future by 2050.. Even though the European Green Pact is an ambitious goal, it is a very important step to constructing a better, more sustainable and balanced future.

In this work, with the intention of applying the principles of the European Green Deal with regard to the industrial part, the use and life cycle of metal will be analyzed. The goal is to analyze new strategies, looking for ways to improve the environment through the analysis of information and data regarding sustainable development focusing on copper, which will discuss its properties, production and effects. This project will analyze the recommended solutions for waste management and options for recycling, with reference to the circular economy in this document.

The growing demand for clean electricity and renewable energy sources has made copper one of the most important and strategic goods in the global economy and the European Green Deal. Copper is gaining significance as a result of its convenient properties: Its capacity to be fully recycled without altering its physical and chemical characteristics. As a result, its importance in the circular economy is growing. Copper recycling can be one of the sustainable solutions to help solve one of the main problems of today's world - the need for new resources made by extraction, which affects interfering in the environment and contributes to increased carbon dioxide content in the atmosphere. "*Being an opportunity for the production of metals for* *energy generation using cleaner and efficient production technologies, as well as the development of effective recycling strategies to solve metal supply problems and waste disposal"* (Phiri et al., 2021, p1)

Copper also has significant usages in energy transition, since massive amounts of this metal are used in forms such as solar panels, wind turbines, and the like to conduct electricity. Through different recycling and reusing activities, global industry is able to conserve available resources, while embracing the environmental and economic sustainability of copper, and presenting it as an important metal in the green and renewable energy sources of the future.

The choice of the theme Life cycle analysis of copper within the circular economy based on the European Green Deal was due to the growing importance of a sustainable future. since the environmental problems caused by greenhouse gas emissions and environmental degradation have become urgent search for effective solutions.

The objective of this study is to show the circular economy as an important strategy to minimize these impacts, showing that the reuse of copper - due to its properties that are not changed after recycling - being a vital solution to help create a more sustainable world. This study aims to show that recycled copper is an important ally for the circular economy, as it can reduce the negative effects of new resource extraction. Copper is widely used in renewable energy systems, which are an important part of the Cleaner and sustainable energy matrix. Secondary copper can be returned to society in an effective, swift manner of reintroduction in line with the goals of the European Green Deal.

2. LITERATURE REVIEW

These important natural resources are a part of such vital processes in many spheres of our everyday life. Used in every aspect of the contemporary society *"First of all, metals are vital in the uses of the new and the current society. Finite mineral resources and fossil fuels have given the advantage of economic growth and prosperity"* (Sauvé et al., 2016, p3). As one of the branches of civilization history for centuries, as one of the main focuses of training and development of the economy, technology and culture of societies, being one of the main driving forces of human development from tool making to creating high technologies.

Another aspect that can be linked to economy and mining technologies has been vital in delivering materials to industrialists like aluminum, copper, lithium among others though this sector affected the environment. With the article "Reprocessing of Mining waste:combining environmental management and metal recovery?" Gaël Bellenfant (2013) analyzed the data on the growth of consumption of material-raw materials by industries. As a result of the rapid growth it has experienced, a lot of raw material is being consumed, and in many cases gets to the point of maximum exploration on a large scale. "*The rapid growth of industries generates significant increase in the need for raw materials, increasing exploration and extraction of these materials to their full potential on a large scale. This situation is visible in the mining sector, the extraction of metals has intensified to supply large needs of the global economy" (Bellenfant* et al., 2013 *p12)* Excessive exploitation of copper recklessly and haphazardly may cause a scarcity of this material. Such excessive application gives negative effects to the economy, society, as well as to development issues with effects on technology development, increased material cost, economic disparities or even disappearance of the material.

2.1 Mines

Extraction of metals such as iron and copper are mainly from mining, which provides the raw material for the industrial process, and this has been a serious challenge to the environment resulting in irreversibility of the extraction sites. One of the biggest waste streams within the EU is a by-product of mining and mineral processing industries, extracting heavy metals that pollute the soil surface, and damage biodiversity.

Mining waste includes the residues of processed materials, the by-products of the exploration of minerals, and the mining and processing of substances regulated by the laws of mines and quarries organizing the processes of materials. The term “mining waste” refers to leftovers generated by the process of materials. These types of waste are refined materials, with consistencies reflecting the processed minerals needed for production and economic development, having high commercial value. Waste, on the other hand, partially consisting of rejected minerals, have no economic value.

Lacking further purpose, they are carefully deposited in enormous constructions called tailings dams. These structures are some of the biggest challenges to environmental protection, because they contain water used in mining processes.”*These storage facilities help the physical containment of mining waste, but they cannot completely avoid environmental problems” (Bellenfant* et al., 2013 *p5)* The water contained in these buildings is used to leach metals from minerals, having fine particles and chemicals employed in mining, therefore contaminates the water used in mines. These types of waste are known to contain toxic material, if these wastes find their way into the soil they have the ability to pollute water source areas, disrupting the water ecosystem, being a threat to human society.

In addition to the pollution of water there is also the problem of the dam rupture where toxic sludge and waste is released over populated areas. The social impact of such ruptures is destruction and loss of life to the population living close to the dam. If these wastes cross the dams, cities, rivers and forests around them may be ruined.

3. Primary copper

Copper is one of the oldest being used by man in today's world and has been authenticated to be used 10,000 A.C in the Middle East. It is suggested in some reports that copper might have been the first metal that man ever either mined and used. Thanks to the excellent work characteristics, man employed copper in the manufacture of tools, household items and weapons and thereby acquiring human abilities and information. Therefore, starting from metallurgy using copper as the first metal in human hands and actively affecting the development of human civilization, the Metal Ages came.

After millenia of development, modernization and assembly, copper is still one of the most important metals consumed today. Serving a vital role in the global economy, due to its high electrical and thermal conductivity, resistance to corrosion and malleability, widely used in electronics, civil construction, transport and renewable energy, this metal has become essential in the growth of human civilization on the planet.

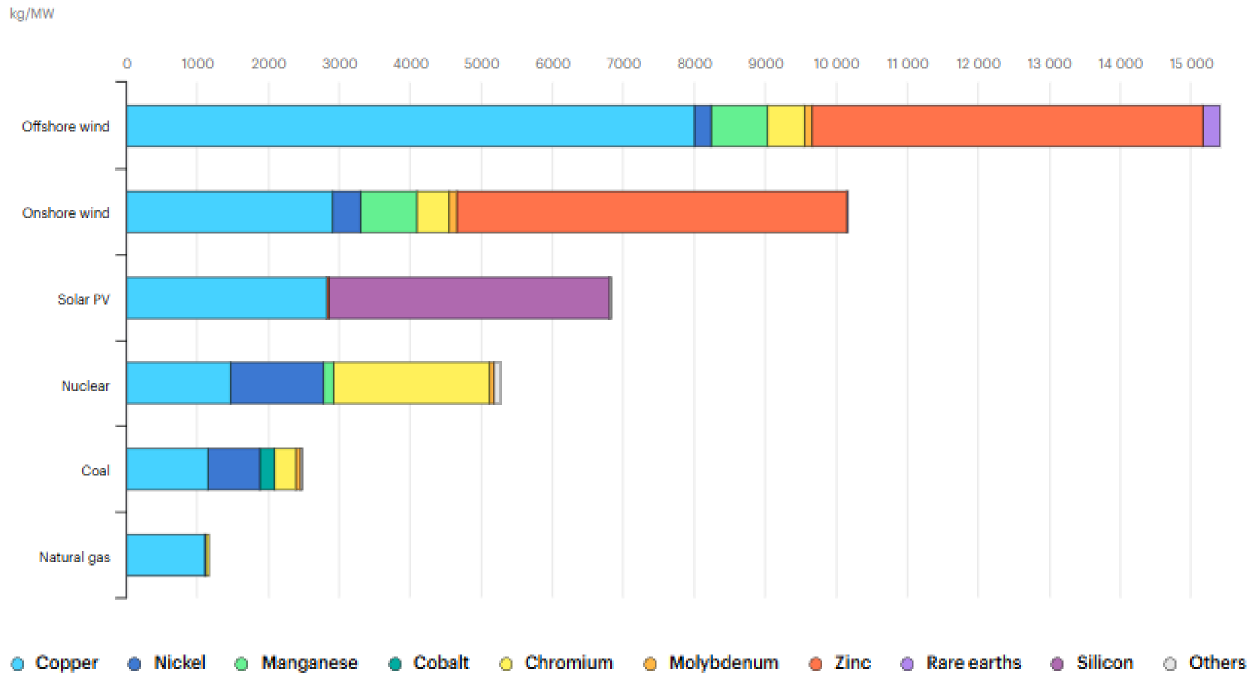
"*Copper is one of the most recycled metals. The ability to recycle metals once or more makes them an adaptable material. Recycled copper, known as secondary copper, cannot be distinguished from primary copper, copper originating from ores, once reprocessed. Recycling copper increases the efficiency of metal use, results in energy savings and contributes to a sustainable source of metal for future generations.*" (International Copper Study Group, 2024)

Gaining great contemporary importance in the area of technology, copper has undergone extensive analysis and development, applied in a wide range of usage. As a great ally in the production of solar panels and wind turbines due to its property of electrical and thermal conduction, copper has proved fundamental in current efforts regarding sustainability.

These properties make copper essential in the matrix of new renewable energy technologies today, due to its ability to conduct electricity and heat. It has become widely used in solar panels directing electricity generated by the Sun, and wind turbines, which convert energy into electricity. "*This perspective aims to analyze copper, an essential metal for the energy transition and focuses on the analysis of material availability*" (Castillo et al., 2020, p1).

A study by IEA(2021) analyzing minerals used in clean energy technologies and comparing them to sources of power generation, describes copper as vital in the transition to renewable energies, being one of the main materials used in clean technologies, such as Offshore wind, Onshore wind and Solar PV, in comparison to other metals as well, with an emphasis on sustainable technologies.

Figure 1- Minerals used in clean energy technologies compared to other power generation source



Source: IEA (2021)

In Figure 1 the demand for copper in renewable energies reached approximately 17,072 Kg/MW in 2021, surpassing other materials.

Copper in clean energy technologies is also special because its electrical conductivity is higher than other metals for wire, generators and transformers. It is the critical success factor for productivity in converting wind and solar power to electricity. Increasing amount of renewable energies is being used with the help of environmental legislation and the need to reduce the use of fossil fuels.

Table 1 - Minerals used in clean energy technologies

Clean energy technologies	Kg/MW kilograms of Copper per megawatt
Offshore wind	8.000
Onshore wide	2.900
Solar PV	2.822
Natural gas	1.100
Coal	1.150
Natural gas	1.100
Total	17.072

Source: IEA (2021)

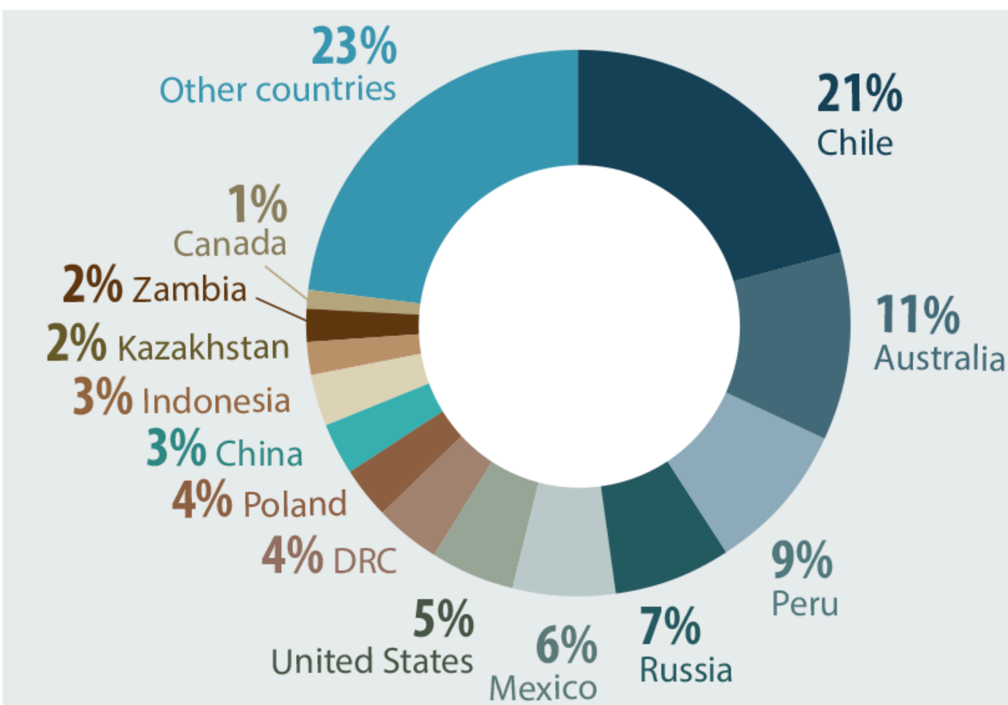
Copper production mainly takes place with pyrometallurgical processes, that is, the treatment of ores and concentrates at raised temperatures. The process also occurs in phases, the number of which differs because of the type of the ore or concentrate used. The most abundant copper concentrates from natural sources are sulfide types like chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4) and chalcocite (Cu_2S), and copper sulfide in metal must go through certain processes for its conservation.

First, copper is sintered or dried when the copper is heated to a level that it will be able to facilitate the removal of moisture while at the same time gains compactness in concentrates. Such preparation is done to ready the material for the next stage which is the melting stage in the process. The copper concentrate undergoes reduction in the blast furnace or melting furnace with use of high temperatures of above 1,200 °C used for reduction of copper sulfide. At this degree a chemical reaction takes place which in turn forms liquid waste with all the impurities and other necessary elements. This is the phase that brings out the matte which is a liquid alloy of copper, iron and sulfur. *"The primary copper concentrate is made in a drying process, and then after a pyrophoric fusion in the flash drive, which uses oxygen-enriched air. In the flash furnace, a top layer of slag is formed, with the bottom phase (matte) containing 55-70 wt. % Cu and a range of other metals such as Fe, Zn, Au, Ag, Ni" (Delmás et al., 2022, p4)*. The matte, which is mostly sulfide, has to undergo other processes including conversion, where iron sulfide is extracted from the substance and in the process copper is converted to a pure metal.

3.1 Main copper deposits in the world

Copper deposit sites are located in various parts of the world, mostly in regions which possess specific characteristics allowing copper to develop. These sites are usually associated with regions with high seismological activity, including subduction zones, mountain regions and volcanic regions where geological processes have been depositing large natural reserves of minerals over millions of years. Techniques of volcanism and tectonics help the fixation of minerals including copper in big amounts located in the layered deep crust of the earth and by geological processes move it to the nearest layer so that copper can easily be accessed. The information collected from reports provided by the Government of Canada 2022. We can analyze the largest copper producers in the world.

Figure 2 - World reserves of copper, by country



Source: Government of Canada (2022)

Being the world’s largest producer of copper, Chile accounts for about 21%of copper production in the world. The world’s biggest source of copper is Escondida mine in the Atacama desert in the Andes of Chile stretching through the length of the country; this is because the area has been tectonically and volcanically very active. The common copper mines in Chile are Chuquicamata and Collahuasi apart from those mentioned above.

As the second largest site of copper deposits, Peru is responsible for about 9% of the global copper production since the country ranks second in copper deposit. In the country there are very big fields of copper like the Cerro Verde, Las Bambas and Antamina. Beginning from the colonial period, Peru has been amongst the leading world suppliers of copper and, as a result, the exploitation of these locations has been massive. However, the country continues to be relevant for copper supply in Latin America, and globally.

China is the world’s largest copper consumer, but the country also has a large reserve of copper in its territory, in Jiangxi and Yunnan. The Dexing mine in Jiangxi is one of the biggest copper mines in the country. This is a promising metals sector of domestic mining, though China relies on imports due to its colossal industrial requirements, which produces a definite 3% of the used copper

In the USA, Concentrated in the USA, which represents 5% of the world’s copper production, the largest producer of copper in the country is Morenci in the state of Arizona. Utah houses the Bingham Canyon mine and Nevada, the two principal extraction states in the United States. Copper bearing zones continue to exist in the USA and the country boasts of huge opencast and underground copper mining firms.

As can be observed in the Figure 2 below, these countries meet the major actor roles of the world’s copper production, other countries that support the area of copper producers include Australia with about 11% , Russia 7%, and Zambia 2%. These countries are relevant sources of copper which is becoming a very necessary metal in many sectors of industries and technologies

3.2 Copper processing

Copper mining is an extremely technical industrial process that takes a number of stages starting from mining to the final copper metal refining stage. Extraction methods can be classified into two main groups: open pit mining and underground mining. The decision on which of the methods will be used depends on the extent of copper deposit and possibilities of the economy.

Open pit mining is applied for the surface deposits and it is widely used in big companies, for example in Chile at the Escondida and Chuquicamata mines. This step is done by removing most of the rock and soil to dig up the resource, excluding large amounts of soil and rock from the path. While open pit mining is effective, it challenges the surface with regard to environment and resources when it is employed.

Underground Mining is the type of mining that is carried out on large deposits located at great depths. This method is however costly and it also calls for some kind of infrastructure to be put in place. Chile's El Teniente mine is an example of this mining format, being the biggest in the world. Underground mining provides access to such parts of deposit that cannot be included in the process used in open pit mining, it involves high costs and is rather delicate as for working conditions of employees.

The processing of copper from its ores is on a that comprises steps starting from the extraction of the ore to getting highly refined copper, which is an important consumable in various industries. These processes are important so that copper is produced to meet the world demand that is in industries like renewable energy, transport, construction among others.

This process mining of copper ore is one of the important steps of the metal production; there are some techniques which can be divided depending on the type of the ore as well as the efficiency of the process. Copper extraction is followed by the process tilling, crushing or grinding, flotation (concentration), smelting, refining.which converts the mineral to a higher purity product that is available on the industrial market.

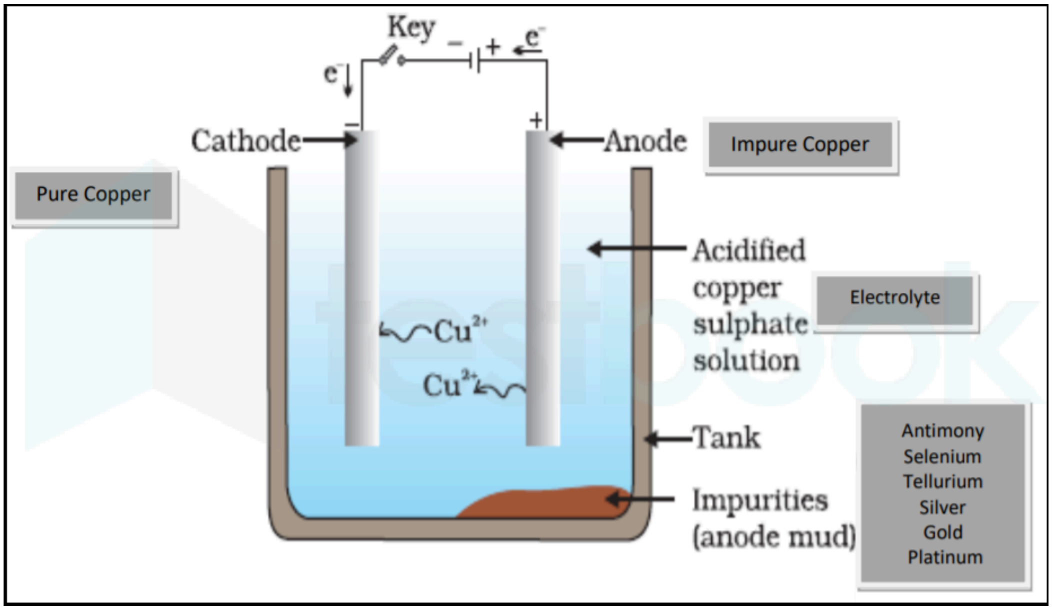
It begins with mining of copper ore out of the ground. It can be via an open cast mine or through an underground mine depending on copper ore deposit type and going through crushing stage or grinding stage. Following isolation and demineralization of the mineral and bringing it to an industrial-like ready form. The process in this mechanism is the flotation of copper sulfide ores both from new ore sources and from old ones. *"Crushed ore is subjected to foam flotation producing copper concentrates, which contain on average about 30% copper." (ICSG, 2024, p15).* The ore is ground and slurried with water and as the chemical reagents are added the copper particles stick to the air bubbles. These fine bubbles float to the surface and form a foam containing copper which is collected especially for the extraction of sulfide ores.

For the oxidized copper ores leaching is applied where the copper dissolves in an acid solution, mostly sulfuric. This solution is called leaching liquor and after being subjected through solvent extractant and electrodeposition steps, the metallic copper can be recovered. Though leaching has lower yield compared with other methods, it is more sustainable.

Subsequently, the pyrometallurgical method is used to increase the copper content of the product. After flotation, the copper concentrate contains 20% to 30% content, then the smelting process is used to heat it and melt the copper of other minerals. This process takes place the production of copper bubbles , containing the highest quality of copper. *"Blister copper is fire refined or cast into anodes for electro refining. Electro- refining involves dissolving of anodes and depositing copper on the cathodes making it to have a purity of more than 99,99%." (ICSG, 2024, p15)*

In the following, the bubble copper is thermally refined so that sulfur and iron are eliminated. Pyrometallurgy needs a lot of heat, this process is suitable for the treatment of quantities of ore. The latest technique is known as electrorefining which is done in order to obtain a level of refining of 99,99% copper purity. Here the 'Pure Copper' is connected to an electrolytic cell in which it acts as an anode. As a component of the solution copper goes into cathode through layers of pure metallic copper while impurities remain in solution or at the bottom of the electrolytic cell in sludge form known as anode. These methods if well employed enable one to get pure copper of relatively high quality that can meet industrial uses.

Figure 3 - Electrorefining process



Source: Byju's (2024)

3.3 Environmental impacts caused by copper mining

The copper mining industry has great issues, in terms of environmental impacts and economics which affect operations and sustainability. They are complex and connected, meaning that the copper mining industry has had to come up with innovative efficient methods of managing environmental issues. *"The production of long-term mineral resources needs a greater focus on sustainable mining, research for environmentally sound mining and processing technologies, as well as the social and economic aspects of mining"* (Bellenfant et al., 2013, p575)

Primary copper production is important for the economy, but the production comes with several negative effects on the environment, including high energy use, emission of gaseous pollutants in the environment and impact on the soil to the point of affecting water resources. These environmental effects are significant causes for extraction and sustainable production of copper and are significant causes of urgency progression of new technologies that will assist in reducing environmental effects of such copper productions.

Primary copper production which involves extraction of copper ore to processing of copper brings different environmental impacts. Copper mining and copper refining that cause exploitation of water resources leading to pollution of ground and water resources, energy resources with air borne pollutants such as sulfur dioxide (SO_2), and carbon dioxide (CO_2). These effects affect the extraction areas and are also a source of world environmental pollution and climate change because the process emits greenhouse gasses and destroys natural resources.

Heavy consumption of energy is one of the major impacts caused by mining. The primary copper production is highly energy intensive, requiring large amounts of energy resources at all stages: Extraction, processing, smelting and refining are the most common areas of operation of mineral beneficiation. In mining, copper separation and purification, energy is used to facilitate the movement of massive equipment, transport and thermal processes. The high energy consumption is amplified, since copper is present in very small concentrations (around 0.5 to 2%) it requires the treatment of vast quantities of the rock to yield a relatively small quantity of copper.

Extraction, especially in open pit mines, depends on sources of energy that emit CO_2 and other gasses with the greenhouse effect. There is always having to use high electricity when crushing and grinding. Current smelting and refining processes need high temperatures, using coal, oil or natural gas, which leads to the emission of air pollution and greenhouse gasses.

This high energy consumption require natural resources and many of the times it uses non renewable resources which contributes to the environment problems like climate change and acid rain and have an effect on the local and global biodiversity

Copper mining sets free a large amount of CO_2 and other harmful gasses because of the high energy consumption used in the extraction and processing.It has been estimated that production of one tonne of copper exposes the atmosphere to emission of between 3 and 4 tonnes of CO_2, a known greenhouse gas. Other environmental impacts are caused by emissions of nitrogen oxides (NOx) and sulfur dioxide (SO_2), affecting the environment generating acid rain. *"Energy use in mining and milling are the main contributors to greenhouse gas emissions, these high energy intensity processes.These processes require large amounts of electricity and diesel, leading to high carbon dioxide emissions."(Memary* et al.*, 2012, p105)*

Extraction and processing of copper involves the use of large quantities of water , a challenge that affects most copper mining companies globally especially those that operate in water stressed regions such as the Atacama Desert in Chile, which affect local communities and water using agriculture in their operations hence contributing to water shortage. This deficiency has been managed through the development of some solutions, including sea water desalination, a process that while assisting in the supply of demand, uses energy to perform this desalination process, increasing carbon emissions from copper mining.

In addition, every extraction process contaminates groundwater; the release of heavy metals and toxic chemicals affects water quality and, in turn, public health and aquatic life. *"SO_2 emissions contribute to acid rain phenomenon which has implied negative impacts on ecosystems, and bodies of water and soils. emissions also contribute to the emission or pollution of air, which has impacts on the health of the people, and the environment." (Huang et al., 2010, p4178)*. This company also faces another serious environmental problem in the form of emission of sulfur dioxide (SO_2) during smelting of copper, which is an ingredient of acid rain, which has implied negative impacts on the ecosystem.

This acid rain is disastrous for natural and agricultural systems, with effects of making soil and water more acidic, affecting organisms and making the sources of water fatal for human consumption or use in plant irrigation. These environmental problems complement the above mentioned problems of copper mining, namely CO_2 emissions and energy intensive consumption. Combined, these problems raise the need for improvement of more reasonable mining practices that take into account water conservation and the reduction of pollution and climate consequences.

4. Secondary copper and sustainability

Secondary copper or copper recycling is defined as recycling operations that involve scrap and waste copper with the objective of using the maximum life cycle possible for this material. This process makes the most of the concept of the circular economy and environmental sustainability *"Effective recycling of scrap or metal-rich waste in copper is useful in many ways, including reducing the burden on primary resources, saving on processing involved in primary ore stacks, and energy consumption will be reduced." (Agrawal et al., 2009 p414).* This information shows that secondary copper recycling is a strategy that can be an important tool for more sustainable practices.

The applied circular economy became an ecological activity and a solution to ensure the continuity of supply for a material critical for many industries, such as renewable energy, electronics and civil construction. This reutilization cycle is essential for climate change mitigation, showing that secondary copper is an important and indispensable component of an effective circular economy. *“On average, copper products worldwide contain more than 30% recycled content. Recycling preserves resources, reduces the environmental impact, mainly in greenhouse gas emissions, and also saves energy, since the energy needed for mining, processing and, depending on the purity level, does not need to melt or rectify.” (Kupfer, 2024)*

This process shows the importance of recycling copper is pertinent with the increasing scarcity of natural resources and the escalating environmental pressure that is being occasioned by excessive mining. Primary copper extraction has the negative effect of degrading ecosystems and also involves the use of energy intensive resources hence contributing greatly to emission of greenhouse gasses. *"Secondary copper refers to copper that is recycled from scrap, there being no need for mining. Including both new scrap (from manufacturing processes) and old scrap (from end-of-life products). (International Copper Study Group, 2024, p10)*

Recycling copper was not only minimizing the start up of new mining processes, but also offering a new improved sustainable and effective way to produce copper. According to the Kupfer, IEA and ICSG copper is a renewable metal, as it has high conductivity and corrosion resistance, and it is applied in various areas of industries such as electronics energy and construction industries. *"Copper is one of the most recycled metals, because of its ability to maintain its chemical and physical properties without losing its characteristics after the recycling process." International Copper Studies Group, p 10.* However, due to increasing demand for this product, the natural stock has been under pressure constantly, thus, making recycling more than just feasible.

Recycling copper requires some steps, which include; collection of the recyclable copper and separating, purifying and smelting of copper. These measures are taken in order that the extracted copper will be able to meet the primary copper quality and be reused in new applications. This reutilization cycle allows to reduce waste and also reduce negative effects of on environment that impacts that the extraction and processing of copper generate

In addition, copper recycling also has the economic advantage as well. Copper scrap is renewable, helps reduce the costs of industries, and at the same time contributes to the development of a sustainable market. Promoting recycling also encourages new technology, because new methods and approaches to reuse are being created. Secondary copper is not only an effective way to strengthen the principles of a sustainable economy, but also a viable solution for problems related to natural resources and the environment.

4.1 Recycling Processes of Copper

The copper scrap collection is fundamental for the economic and an environmental way. Copper is found in wires, cables, pipes and electronic components, which if recycled earns income for waste pickers and companies in the sector. It allows the company to play its role in promoting and implementing the circular economy and improving the future sustainability. In figure 4 we have an infographic, showing the circular economy of copper.

Figure 4 - Simplified Value Chain for Copper

Source: International Copper Association (2020)

Electrical cables are the main source of copper scrap. They are usually discarded after the change of wiring in buildings, renovations or the replacement of electrical equipment. The cables that are collected because they have great importance for recycling use, due to the high percentage of copper that can be recycled.

Piping is common in plumbing and facilities in constructions including pipes for distributing and conveying fluids in building systems. In the course of refurbishing structures or owing to the processes that may require the introduction of new systems of pipes these are replaced hence producing a considerable stream of scrap.

Electronic equipment such as computers, appliances and printed circuits have copper in different parts of their structures, with various amounts of copper. Given the short life cycle of these products, the amount of discarded electronic appliances is growing at an accelerated pace. The accumulation of tons of waste in landfills means a great waste of resources, and leads to environmental deterioration. For this reason, the collection and recycling are inevitable for recovering copper and reducing the need for new extractions of raw materials.

Industrial scrap is a major contributor to waste of copper. In the processing of products that use copper, residual material is usually considered as waste. These wastes can be collected directly in the factories as a strategy of keeping the cycle of recycling simple without the need to deforest. Second, the residual produced by industries contains relatively high-purity copper; therefore, the extraction of usable copper is easier and quicker; thus, no need for energy wastage and high costs

"Copper recycling is extensive and has included various types of scrap that can be recycled, including copper scrap, alloy scrap and iron-copper scrap. The copper content in scrap can range from 10% to almost 100%, with associated metals such as zinc, lead, tin, iron, nickel and aluminum being removed during processing to ensure a maximum quality of copper." (EEA, 1995)

4.2 Secondary copper: Focus on sustainability

The use of secondary or recycled copper, can be obtained from the recycling of products containing copper and have been discarded, such as electronics, wires, and pipes, being considered as another good approach to the great environmental sustainability and economic development within the metallurgical industry. Such a recycle system of copper is fundamental for a world that wants to reduce the environmental impacts and economic cost of mineral extraction.

Secondary copper is more than just a recycled material. It is a strategic resource that contributes to minimizing the dependence of humanity on new natural resources. The first method for copper extraction is mining, known for consuming a significant amount of energy, as well as producing huge amounts of waste and CO_2 emission. The copper recycling consumes

80% less energy compared to primary copper and therefore reduces the levels of carbon emissions and other negative effects of the environment. *“Copper is a 100% recyclable material and can be recycled repeatedly without loss of its chemical or material properties. It is estimated that two-thirds of the 690 million tons of copper produced in the last 100 years are still in productive use in applications such as computers, cars, cell phones, plumbing, motors or wires. And in urban areas, the Society contains a quantity of copper equivalent to 33 years of mining production.“ (International copper association, 2022)*

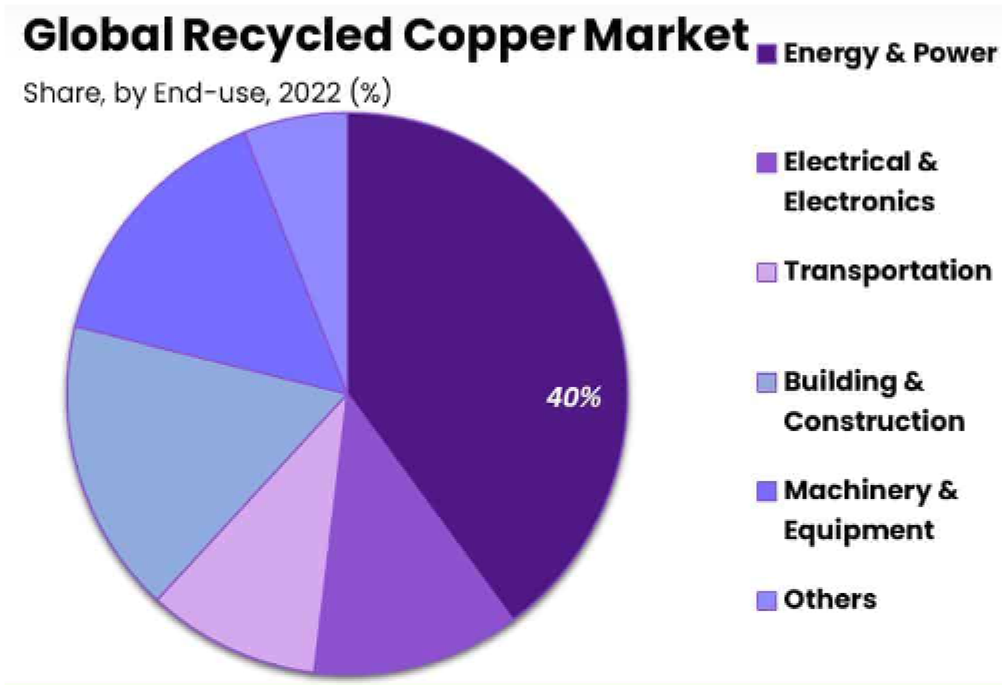
The integration of secondary copper in the concept of the circular economy becomes more important as the focus increases on reducing, reusing and recycling material, and optimizing the life of resources and decreasing negative environmental consequences. In this view, secondary copper has a crucial function of ‘cycling’ the material, allowing it to be reintroduced to the market without having to without need for new mineral extraction. This closure of the cycle means reduction in the exploitation of new natural mineral resources and contributes to sustainable industrial practice.

Besides this, the secondary use is also economically advantageous and viable, because it reduces the industrial dependence on mining, the impacts of which have been growing as easily accessible copper deposits have become scarce.

4.3 The role of copper in renewable energies

Copper is of great importance in renewable energy and has a significant role to fulfill to support the global energy transition process and the development of renewable energy technologies being one of the most important and valuable metals in this process. Copper is ideal for use in the electrical and electronics industry because of its high quality electrical conductivity, making copper suitable for various areas, from electrical wires and cables, small parts used in electronics and renewable energy infrastructure. As we can see in the graph “Global recycled copper market” (Figure 5), we can see the great growth of copper use in renewable energy, where 40% of the recycled copper and decommissioned renewable energy.

Figure 5 - Global recycled copper market



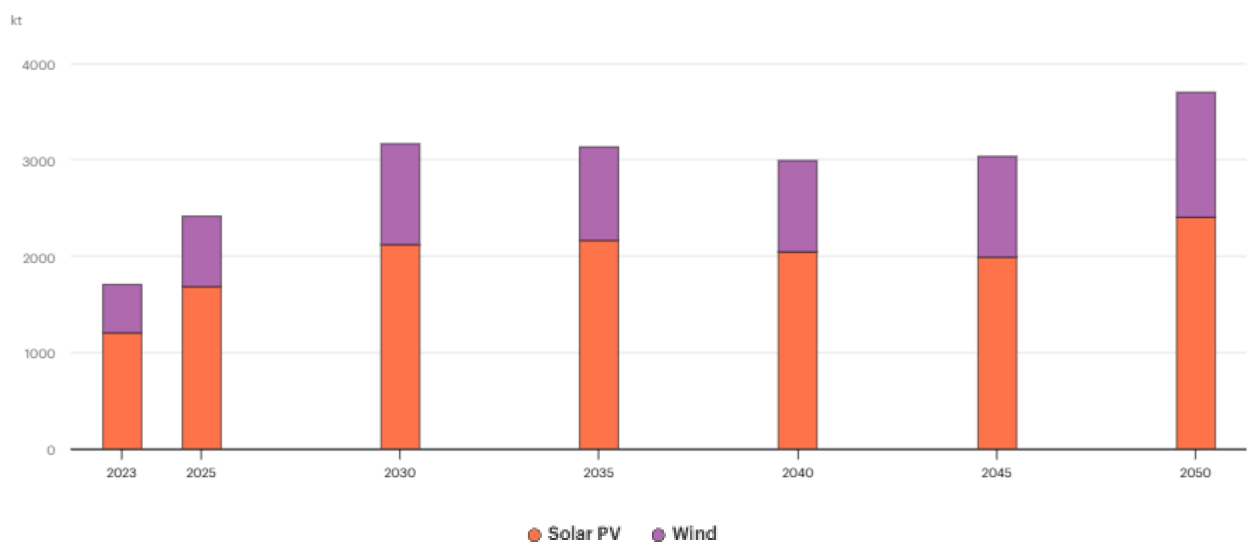
Source: Market research report, 2023

As for the electrical conductivity copper ranks second to none among metals, though slightly lower than that of silver. Copper has high conductivity due to the electrons distribution system of copper. The atoms of copper have one moveable electron known as the valence electron, that is relatively free and allows the movement between the atoms .Copper is a highly electrical conducting metal at room temperature with coefficient of 5.96 x 107 S/m. Copper is 60% larger than aluminum and therefore best suited for the transportation of electricity particularly in systems with high energy needs.

This high conductivity in the industry is crucial in clean energy generation and distribution including wind turbines, solar panels and electrical networks. These systems use material and technology that has minimized electrical resistance through which energy can be conveyed efficiently. Referring to the field of global energy transition in electricity conduction efficiency is not only a technical issue but also economic and environmental. The reduction of losses during the transition may result in resources can be saving and reduced emissions of greenhouse gasses

These properties make copper a basic element in the area of renewable energy solutions. For instance in wind turbines ,copper is utilized in generator and transmission systems. In solar energy systems, it is in wires and cables to enhance conduction of energy amassed in various countries.

Figure 6 -Total Supply & Demand for Key Cu in PV Solar and Wind



Source: IEA (2024)

The copper consumption of solar photovoltaic (PV) in the electrical sector began at 1,208 kiloton in 2023 and aimed at 2,401 kiloton in 2050. This growth is due to solar activities in several different parts of the world thus showing how the utilization of government policies promoting the take up of renewable energy is part of the decarbonisation process.

The chart shows that copper plays a crucial role in solar cell production, the fundamental element for the PV system. Because of its electrical conductivity property, copper is the best solution to make singing wires for efficient conversion of sunlight into electricity. Since the installation of solar PV is continuously escalating in countries that intend to decarbonize their economies, copper has become more essential.

In the wind energy sector the demand has been outstanding because it offers one of the most promising renewable resources for sustainable solutions to clean electricity solutions.

From the analysis, it is clear that demand for copper increases at a higher rate than that of Solar PV, because this technology is relatively young. The demand of copper in wind energy use starts at 501 kilotons in 2023 and has an expected growth to 1.297 kilotons by 2050. This increase means more than a 150% growth over the analyzed period, while showing the growing importance for this technology in the following decades.

Copper is used in generators, transformers and control systems; all which are components that are widely incorporated in the process of converting kinetic energy of wind into electricity, thus copper is a critical material in wind power technology.

Table 2 - Total Supply & Demand for Key Minerals - Cu

Total demand for copper in the announced pledges scenario							
million toneladas/ kt	**2023**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Solar PV	1,208	1,685	2,117	2,168	2,049	1,984	2,401
Wind	501	724	1,052	968	939	1,046	1,297
Total	1,709	2,404	3,169	3,136	2,988	3,030	3,698

Source: IEA (2024)

This table also shows the new demand for copper by 2050 in renewable energy, particularly solar photovoltaic (PV) and wind energy. Solar energy was 1,208 thousand tons, and wind was 501 thousand tons. The total demand for copper in 2023 was 1,709 thousand tons.

By 2050, the demand for copper for solar energy is expected to grow to 2,401 thousand tons, while wind power reaches 1,297 thousand tons. This rise is as a result of the higher demand for copper in the production of solar panels, and wind blades, crucial in the green energy revolution.

4.3.1 Use of copper in solar PV

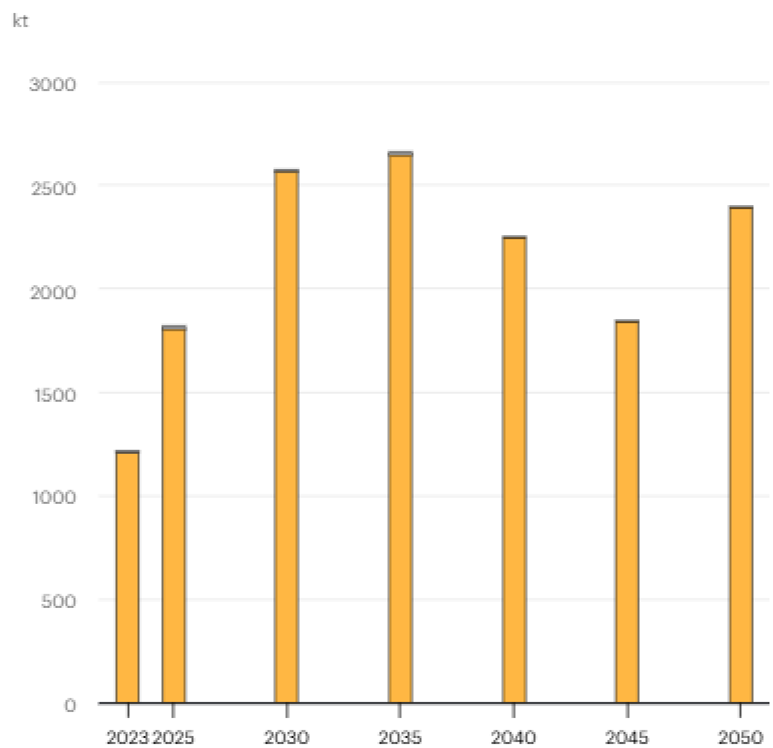
Photovoltaics or PV is derived from photovoltaic effect which is the physical and chemical phenomenon that results from light transforming into voltage or electric current. This process occurs in the solar cell being the basic unit of photovoltaic modules. As the question of renewable energy and environmental consciousness aiming to offset the manufacture of greenhouse gasses gains more importance the application and incorporation of photovoltaic solar energy is undergoing onsite, huge global expansion.

The Photovoltaic effect refers to a physical process through which light photons are captured in the semiconductor material and this mostly uses silicon. When the sunlight photons hit on the surface of the solar cell then energy is able to move in the direction of the electrons in the semiconductor material thus producing electron gaps. Thus, a "conventional current" is established as a flow of electrons and it is situated behind the material

Copper is used as conduction of this generated electricity. Its function is indispensable as it is involved in establishing electrical contacts in solar cells, with this is possible in collecting and controlling the flow of the electrical currents in the external circuits. Copper wires do the function similar to that as found in the application of electronic gadgets interconnecting the solar cells in a module interconnecting the modules to an inverter and electrical system. Since copper is very conductive, it retains the function of transporting the generated energy well.

"Crystalline silicon modules are expected to continue to dominate the solar photovoltaic market, more progress in alternative technologies can see these technologies reaching growing market shares by 2040." (IEA,2024). In figure 4 we can analyze the copper demand for the next decade for Solar PV technology.

Figure 7 - Mineral demand for Solar PV in the Net Zero Emissions by 2050 Scenario



Source: IEA (2024)

4.3.2 Use of copper in Offshore and Onshore wind

Wind energy is thus a form of renewable energy, which is produced through harnessing of blowing wind in the production of electricity. Wind is a source of energy with low environmental impact and has grown globally as a strategy for sustainability, as an alternative for fossil fuels. Wind power is generated via two structures. Onshore wind energy is created on land and offshore structures work in maritime areas

Onshore wind energy is the traditional form of renewable energy generation that uses onshore turbines, converting wind force into electricity. These installations are usually located in rural areas, open fields or mountains since the speed and frequency of wind is strength and these are requirements of energy production. Locations are applied to optimize this technology, because in areas of high wind velocity, energy production is better, and in larger amounts.

Technologically, onshore wind power enhances both the turbines and towers in small, medium and large sizes and capacities for the flow of winds at different heights. In this technology, copper plays a significant part since it is used in generator coils, transmission cables and turbine electrical connection systems. It is used because of the electrical conductance characteristics as electricity is transferred from the generator with minimal energy loss. Technological improvements have enabled the production of more cost-efficient turbines, and onshore wind power has become more cost-effective than the installation of turbines offshore at sea.

However, on-shore wind turbines, which may be one of the most efficient energy production machines, have several impacts on the environment and the communities living close to them. These structures can disrupt the space making noise in the surrounding areas and negatively influencing the local fauna, particularly birds that inhabit or are in transit in these places, and may fly into the turbines. On the one hand, there are issues to solve; on the other hand, wind produced by onshore wind turbines is clean, renewable energy that plays a crucial role in the energy shift.

Offshore wind power is a potential alternative for generating electricity, using constant and strong winds. This technology, therefore, remains an option for countries with extensive coastal space and presents a realistic solution for a more reliable energy generation than that of onshore wind power. *"Europe is the cradle and leader in offshore wind industries, having 75% of the global total of offshore wind energy, which were installed in 2019 and 25 GW of installed capacity in 2020. The distribution of offshore wind farms is not homogeneous along the Atlantic Arc. The UK, Germany and Denmark account for more than 70% of offshore wind farms installed in Europe." (Costoya et al., 2022, p1)*

Offshore Turbines require suitable equipment and parts that can endure all the worst conditions on the seas. Special consideration is given to the kind of technology utilized, and the materials used in constructing offshore wind turbines, considering that they are installed in marine environments where different problems are including corrosion caused by salinity of water, the waves and the weather changes caused by climate change.

Therefore, copper is important in this context and is mainly used in the application of cable systems and some internal parts of turbines. In this case as well, its common usage and efficiency is due to its excellent electrical conductivity properties which meet the specific requirements for power transmission in maritime areas, and increase the life cycle of equipment under the hostile conditions of the sea environment. Another advantage of using copper in this technology is that the metal can be recycled every time maintenance work or an exchange of components is necessary.

5. Conceptual structure of the Life Cycle Analysis (LCA)

In the last decades, there has been an urgent need to take care of the environment. In order to meet new emerging environmental challenges, the Paris Agreement was created. The agreement articulates a global commitment aiming to stabilize global climate, prevent rise in the average temperature of the planet, with emphasis on reducing temperature by 1.5°C, concerning the Paris Agreement. *"The overall objective is to keep global average temperature rise below 2°C above pre-industrial levels and to continue efforts to limit temperature increase to 1.5°C above pre-industrial levels." (UNFCCC, 2024)*

UN conference in Rio, representatives of different countries, scientists, politicians and leaders of international organizations and NGOs to discuss the solutions to protect the environment and enhance the population's future on the planet. These meetings largely concentrated on formulating an action plan which reduces the impact of man's activities on the ecosystem, providing partnership to countries in search of a solution.

With the growing concern for the environment, the Life cycle Analysis (LCA) was developed, an environmental assessment of the production associated impacts was evaluated looking at the extraction of the raw material until the disposal or recycling of the material. LCA enables industries to detect the opportunities of minimizing impacts of environmental and economic losses from their processes and products and can identify ways to optimize the use of resources.

Historically, environmental management in industries was focused on controlling emissions, resource use and waste generation, relative to direct impacts on industries processes.This more traditional approach used the PDCA (Plan-Do-check-Act) cycle, limited view of environmental effects caused.of the impacts on the environment.. The content of Life Cycle Analysis (LCA) was introduced with a more extensive perspective, analyzing not only the impact caused in the site due to the processes, but also analyzing the responsibility of the manufacturer in the production chain.

LCA concept is an approach to understanding the potential of materials production in its chain, examination of the life cycle of the products and the effects of their usage impacts the environment. This analysis confirms the steps from the extraction of raw material and up to the substitution by new technologies or be discarded, seeking to evaluate the environmental impacts throughout the life cycle of the product. *"The life cycle assessment is an effective tool for us to analyze sustainability and help evaluate how metal contributes to sustainability. The LCA methodology is a different method from other methods that pay attention to the single life stage of the product, the LCA evaluates the stages of the life of the product in terms of entry and exit. such as energy and raw material consumption, atmospheric emission, soil and water waste and soil occupation" (Chongjie Gao*et al., *2021,* p460). Figure 4. illustrates the concept of sustainability through three connected areas: environmental, society and economy. These pillars are the most fundamental that needs to be struck in order to achieve sustainability.

The practice of Life Cycle Analysis is fundamental for the metals industry, as these industrial operations consume large amounts of energy and natural resources, which are responsible for the emission of greenhouse gasses. This analysis allows a complete and deep evaluation of the environmental impacts occurring before, during and after industrial processes, i.e., during the extraction of raw materials, through the use of generated products, up to the disposal of materials. The practices displayed by the analysis enable the identification of various opportunities for improvements in different industrial stages, such as the reduction of energy consumption and increased recycling.

Figure 8 - The sustainability relationship between the environment, society, and the economy

Author: Chongjie Gao (2021)

5.1 Environmental impact comparison: recycled copper vs. primary copper

Comparing the environmental profiles of recycled copper on the one hand and primary copper on the other is still a relevant subject in sustainability and in the management of the environmental footprint of mining as a process.

Copper is used in the construction industry and in electronics and automotive industries as well,where it is preferred for its ability to be recycled without degradation, making it important in the transition towards applying the concept of circular economy.

Conventional copper production includes mining and milling of the copper containing ore mostly by surface or underground mining. These processes guzzle a lot of energy and water, and produce a lot of greenhouse gasses, essentially as a result of the extensive use of fossil energy in the extraction and transportation processes. Another important aspect is the effect on local flora and fauna: copper mining entails soil erosion, deforestation and water courses pollution by heavy metals, and other chemicals used in the ore extraction.

New copper production is considered more dangerous to the environment than secondary copper production. The latter uses up to 85% less energy and releases far fewer Greenhouse gas emissions , and these are just a few of the benefits that are so crucial in the modern world. Recycling also plays a part in protecting possible threats that new mining sites could bring in terms of interference with ecosystems and plants and animals. In addition, the recycling of copper from the municipal solid wastes or industrial scrap minimizes the amount of waste which has to be treated and disposed of.

Comparing recycling of copper to the primary production of copper, it is important to understand that both serve two different processes meeting the constantly growing world demand for copper. Recycling alone cannot cover the market demand in its complete term, and thus mining persists. However, the rates of recycling processes and the measures of the utility of waste management systems are also important in determining the extent of decrease in the industrial dependence on primary extraction, and in increasing the environmental value of recycling processes.

"Copper is one of the most recycled metals. The ability to recycle metals once or more times makes them an adaptable material. Recycled copper, known as secondary copper cannot be distinguished from primary copper to copper originating from ores, once reprocessed. Recycling copper increases the efficiency of metal use, results in energy savings and contributes to a sustainable source of metal for future generations." (ICSG, 2024).

The possible transition to using recycled copper and implementing non-mechanized but efficient technologies have remained a preferable method of minimizing environmental impacts in the entire copper production line, in harmony with global emission and environmental conservation objectives.

6. Circular Economy and LCA

In this analysis we are able to link the Circular Economy to emerge as a complete strategy to assist the Life Cycle Analysis. The life cycle analysis (LCA) in the information allows the industries to comprehensively center on processes in a more sustainable manner in accordance to the adopted methods in recycling and reuse of materials. Applying this circular economy process also works to the extent of trying as much as possible to maintain the product or production materials in the cycle for as long as possible in an attempt to avoid production of waste materials hence conservatively using the raw materials. *"Recycling has become an essential and crucial part of the copper industry not only as a complement to primary supply but an important help to a sustainable circular economy and as a means to supply increased future demand for copper." (ICSG, 2024 p61)*

Over the past decades, the increase of the population has been very large, resulting in an increase in consumption in areas such as food, energy, and water. However, our resources on the planet are limited, and studies show that without proper gestation, available resources of raw material are bound to run out. The exhaustion of these resources is estimated to occur in the foreseeable future. The current amount of solid, liquid and gaseous types of waste to account for is creating pressing environmental issues regarding the future impacts of irresponsible waste management on the planet.

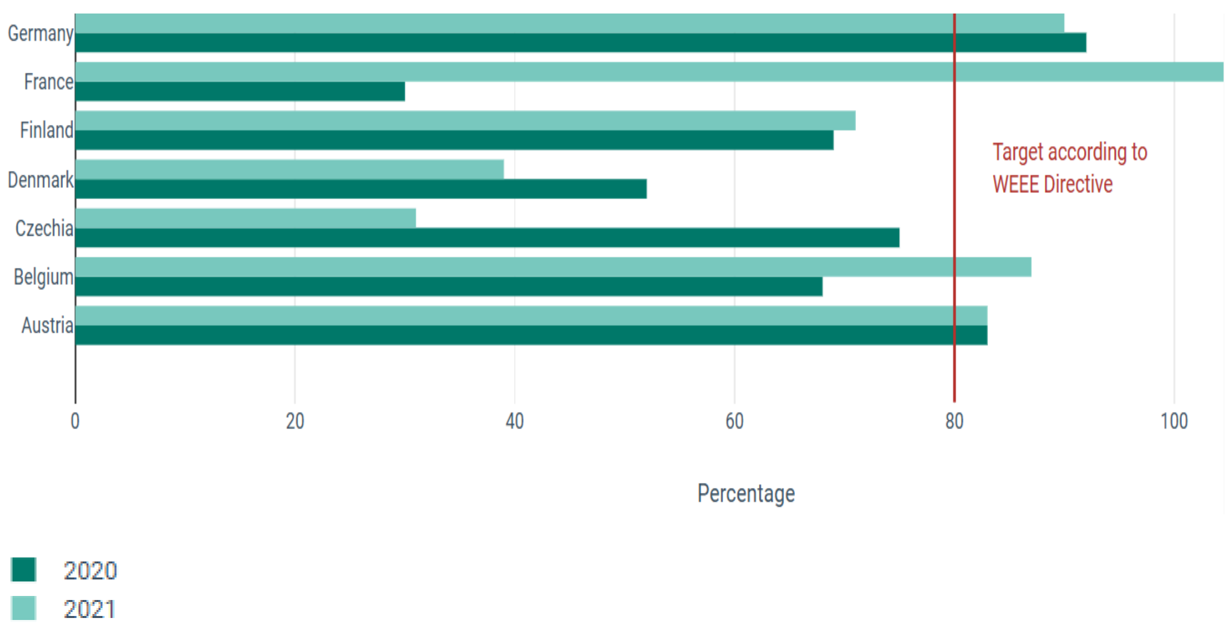
In order to address these emergent problems an economical model was created whose objective was to reduce waste and to make efficient use of materials throughout its life cycle in the industrial sector. Presenting a change in the linear economy that currently applies the "Extract, produce and discard". In this process the impacts that occur by the extraction of non-renewable natural resources, waste during production and disposal after use or end-of-life products are not the main concerns of the industry.

In the metal industry, the concept of Life Cycle is fundamental to achieve a reduction of environmental impacts, saving energy and reducing the extraction of new raw materials. *"The need to start a transformation towards a circular economy (CE), where waste generation will be minimized and materials and resources are optimized, remaining in the cycle of the economy for as long as possible, making processes more sustainable" (Tukker, 2017, p76)*

6.1 Contribution of copper recycling and circular economy

According to recent data from the International Copper Study Group (ICSG) and Kupfer, about 40% of global copper demand is currently met through recycling. In Europe where about 50% of the copper used is from recycled sources, Germany has taken the lead with over 45% being the minimum target of its copper production from recycled material. This increase is a promising backdrop for the circular economy, where consumers rely on recycling to access more copper that fuels the economy in the process of environmental conservation.

Figure 9 - Percentage of photovoltaic (PV) panels waste recycled or prepared for reuse



Source: European Environment Agency, 2024

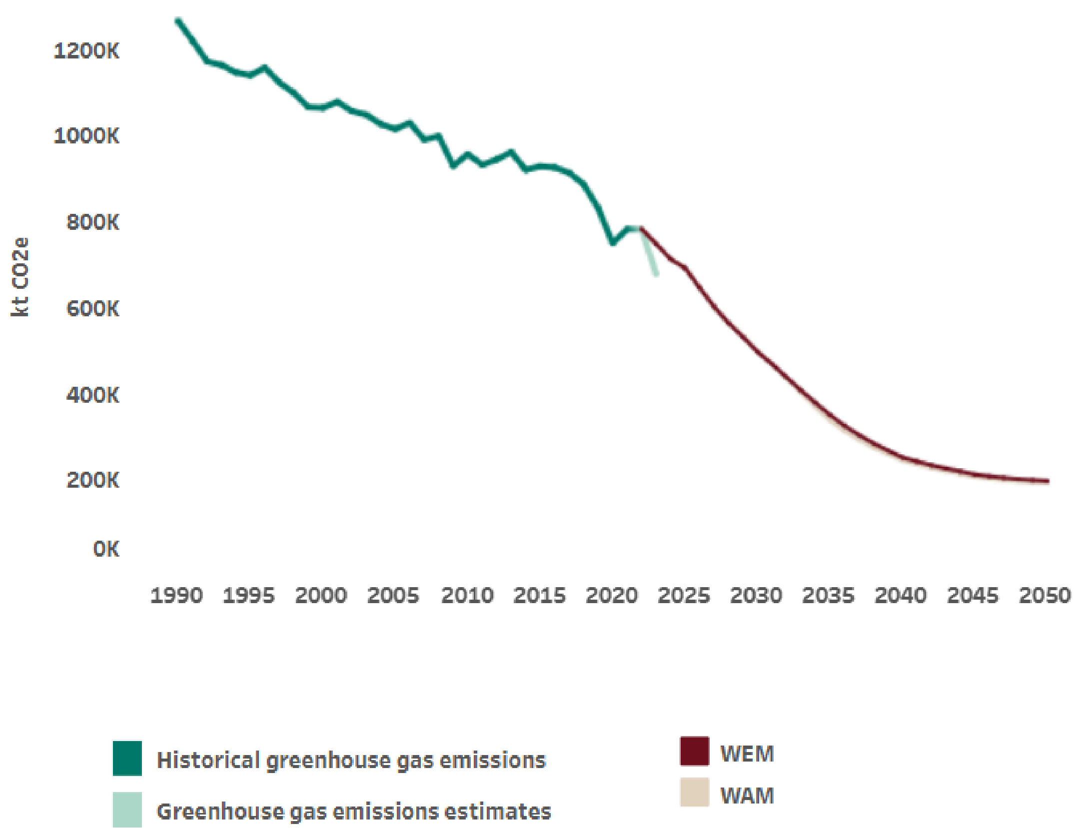
According to Figure 5 Germany is a leader in the recycling of solar PV, being an example of the success of the recycling policies driven by WEEE, which allow efficient reuse of resources and reduce dependence on virgin raw materials. Waste Electrical and Electronic Equipment (WEEE) and is a European directive to foster the proper treatment of Waste Electrical and Electronic Equipment, the legislation restricts the disposal and promotes the recycling of these materials. Adopted by the European Union through Directive 2012/19/EU, WEEE intends to address issues on the handling of end-of-life products in order to contribute to the development of a circular economy.

The European sector is one of the most effective when it comes to the recycling of copper using recycled copper being fundamental in the conservation of natural resources, energy conservation and reduction of carbon emission.

Copper Recycling is an effective and a viable way to meet the demand for this metal, which is used in many high technology and renewable energy products. Studies demonstrated that copper can be recycled infinitely without loss of quality, and being able to be reinserted into the chain of production. The role of recycling is not only important in terms of the amount of copper recovered, but in addition to its contribution to reducing energy consumption.

"Recycling copper is a highly effective way to reintroduce this material into the production cycle. In fact, copper production from secondary materials requires only 20% of the energy needed to extract primary copper from ore and concentrates. Globally, this saves 100 million MWh of electricity and reduces CO_2 emissions by 40 million tonnes per year. The copper recycling process covers several steps, including collection, sorting, processing and manufacturing of new copper products from recycled copper." *(Kupfer, 2024)*

Figure 10 – Total historical and projected emissions in Germany



Source: European Environment Agency (2024)

Figure 6 on greenhouse gas (GHG) emissions of the European Union member states, according to the EEA, shows a significant reduction since 1990. In that year, emissions were around 1,200,000 tons of CO_2 equivalent. In 2020, they fell to 800,000 tons as a result of existing policies (WEM - With Existing Measures), such as increasing renewable sources and greater energy efficiency. The 2050 target is 187,402 tonnes by 2050, focusing on climate neutrality. Achieving this goal will depend on additional measures (WAM - With Additional Measures), including new green technologies and decarbonization policies, essential for commitment to the Paris Agreement.

However, copper production is essential for a wide range of sectors and remains a minor portion of global annual CO_2 emissions estimated to be 35 billion tonnes at under 0.15% and final energy consumption at only 0.1%, according to the Global mining review. Furthermore, the copper industry recycles some three billion cubic meters of water each year,

The pressure to adopt sustainable solutions has been growing not only within industry, but also among customers and governments who take into consideration the cradle-to-grave life cycle of products, when considering their environmental impact. The cycle of copper can be considered as durability and the opportunity to reuse the material without deterioration, which makes the metal suitable for the circular economy strategies.

The global circular economy enables copper to meet the needs of industries and markets at a reasonable price and with minimal negative impact on the environment; copper is mostly recycled in EU countries, having a leading role in the recycling industry. At the global level, Europe is uniquely one of the biggest consumers of recycled copper, using around 50% of its local demand from recycled copper.

The main focus of copper in the shift towards renewable energy and emission decrease is another important element in the progress of the sustainable technologies, since the element is crucial in the creation of renewable energy forms. Copper is crucial to products like solar panels, wind turbines and electric vehicles, as they all need it to be energy efficient and reduce CO_2 emissions. These products are made from copper because copper is the best conductor of both electricity and heat hence making the product more energy efficient. Copper consumption is tied up with energy that results in considerable energy savings in electricity generation and distribution to reduce carbon emissions on a broad base.

In addition, copper is classified as a "carrier metal", that is, a key element in the extraction and refining of other non-ferrous metals, many of which are essential for Europe's strategic value chains. Copper refining and recycling plays an important role in obtaining precious and critical metals which cannot be produced without them. There are many electronic and technological products that contain copper. Through copper recycling processes, more than 20 types of metals can be recovered from complex products such as electronic equipment. Therefore, copper metallurgy is ideal for the recycling of electronic waste as well as composite products to meet more usage cycles with strategic metals hence minimizing new mineral extraction.

This paper aims to discuss future perspectives for recycled copper in the frame of the global economy. It is clear from the European Union guidelines and technological improvements in recycling that the importance of recycled copper in the new economy will be further enhanced, more increasingly as the push for Sustainable and Renewable resources continues to emerge.

International Copper Study Group's (ICSG) has analyzed future perspectives for recycled copper in the global area involving data collection and analysis of copper production trade and recycling shows that improved recycling rates in Europe and Asia in particular is beginning to offer key supply security away from reliance on primary mined copper. This information is relevant so as to demonstrate how the recycling policies generate the right demand while enhancing the uptake of natural resources and at the same time reducing the negative effects of mining.

Kupfer's report of 2024, also strengthens the evidence that copper plays an essential role in supporting new technologies and renewable energies and that copper-containing products are fundamental for enabling energy-efficient products in a low-carbon economy. The recovery of copper, in addition to being energy-efficient, enables copper to be utilized and reused over and over again to meet future demands while little effort is made to locate new copper deposits. In the longer term it helps support the stability of ecosystems, the lowering of costs of production and the stability of the supply of copper in world markets.

European countries are leading the way in recycling copper and therefore show the rest of the world how growth and urbanization can be sustainable. The scrap copper not only provides about a third of the total copper supply of copper globally, but saved energy to provide, used resources efficiently, and lowered environmental footprints. In these ways, the sector generates direct value towards the construction of the circular and sustainable economy for today's and future generations. While the key principles of the global copper industry are innovation and protection of the environment, the industry remains one of the most efficient and responsible, striving to create a sustainable future.

With these objectives, the European Green Deal emerged, proposed by the European Union at the close of December 2019 is an agreement into which Europe has entered with the vision of being the first climate-neutral continent by the year 2050. The key concept under which this initiative operates is the achievement of sustainable economic growth.

The European Green Deal was conceived as a comprehensive set of policies that could include governments, civil society actors and the private sector in the fight against what can be considered climate change and the deterioration of the planet's ecological base. In these many states, large amounts are spent on the public sector, and all efforts are focused on employing the population sustainably and ensuring a decent life for all.

Established in 2019 the European Green Deal is an EU strategy that aims at dealing with climate and environmental change through transition to a circular green economy. For an aspiration to see the first continent achieve climate-neutrality by 2050 to reduce greenhouse gas emissions where environment protection and the economy is considered. *"Union-wide greenhouse gas emissions regulated in Union law shall be balanced within the Union at the latest by 2050, with the goal thus reducing emissions to net zero by that date, and the Union shall aim to achieve negative emissions thereafter" (European Union, 2021)*. The main thrust of the Green Deal is to achieve climate neutrality in the EU before the middle of the century. The EU has also committed to reduce them by 55% by the end of 2030 relative to 1990 levels which will mean radical over-sectoral shifts in the energy, transport, industrial and farming sectors. *"European Union, (2021) Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 setting the climate neutrality target and amending Regulations (EC) No 401/2009 and (EU) 2018/1999" ('European Climate Law, 2021)*

Clean and renewable energy is one of the strategic development agendas of the European Green Deal through investments for higher solar, wind and green hydrogen usage. Another goal is more energy efficiency of the buildings and development of energy storage through less use of fossil fuel. Sustainability in the economy is enhanced through implementation of circular economy entails efficiency in resource utilization, discouraged disposal and encouraging recycling and reusing of products. This approach entails various sectors such as the plastic, electronics, textile and construction among others and which are helped to 'green' up.

But as a positive effect, the European Green Deal is positive for creating a favorable environment in Europe and for being recognised and rewarded for similar actions around the world to achieve the goals set out in the Paris Agreement. This is a gigantic and difficult change and the concept is to create a cleaner and healthier world.

7. Recycled copper in the Circular Economy target of the European Green Deal

Recycled copper is among the essential strategies for achieving circular economy objectives set out in the European Green Deal and becomes the key resource for developing a sustainable European economy. In demand for copper, the European Union revolves around recycled copper; it dispenses the primary resource extraction and contributes to the intellectual fight against climate change and promotion of sustainable practices.

The biggest benefit of recycled copper is that recycling copper saves up to 70% of the energy needed to produce new copper and reduces the large quantities of greenhouse gas emissions. Secondary copper production from scrap is less harmful to the environment, and also less energy-intensive than extraction of the metal from its ores. The utilization of recycled copper in production lines will benefit Europe in its climate neutrality goals using the circular economy priority.

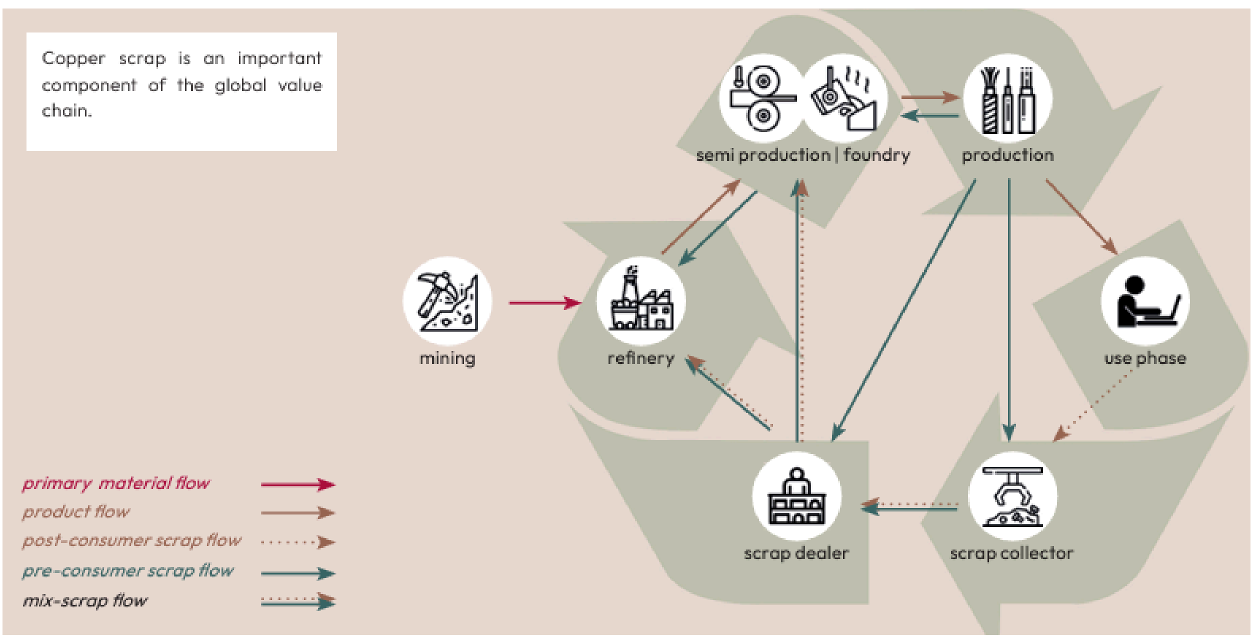
The importance of recycled copper is becoming increasingly significant as Europe redirects resources to strategically sustainable areas , such as electrification of transport and the expansion of renewable energy contributes to the development of a strong and healthy market, which in turn increases the economy of Europe.

In addition, dependence on recycled copper strengthens an internal market that creates valuable and a sustainable economic base for the region. Seen from the EU viewpoint, the recycling and utilization of materials creates jobs in recycling and waste management industries and at the same time reduces the dependency on metal imports and increases the self-sufficiency concerning strategic materials.

Another important application of recycled copper in the European Green Deal's Circular Economy goal is that the recycled copper have special relevance to the role of renewable energy like that of solar and wind power. Copper plays an important role in solar photovoltaic (PV) systems because of the wiring and connectors used to improve transmission of electrical currents. A single PV power system can include several tons of copper and, accordingly, as the capacities of solar energy in Europe grow, the demand for recycled copper is growing accordingly.

Similarly, onshore and offshore wind energy generation is indispensable. Some of the applications of wind turbines include copper wiring and generating processes that transform the wind's energy to electricity. Offshore wind uses copper with a single project needing up to 10,000 tons. As Europe trends its wind energy up, alternatively using Recycled Copper Copper in the power sector provides a feasible way to meet this demand and fulfill the sustainability objectives. In figure 11 we can compare the life cycle of copper, based on the circular economy with a focus on the European Green Deal.

Figure 11 - Recycling champion copper



Source: Kupfer(2024)

The recycled copper fits nicely into the parameters of the circular economy envisioned by the European Green Deal – to make Europe a modern, competitive, and resource-efficient, greenhouse gas-neutral economy by 2050. Apart from that, it explains the attainable technique for facing various environmental problems and to open up the way toward sustainable use or efficient consumption of the earth's resources in the future. Since the promotion of the global circular economy answers the demand for increased demand for renewable sources of energy, Europe has an opportunity to position itself as a leader in sustainable development, with recycled copper being a fundamental element in the ongoing shift.

8. MATERIAL AND METHODS

For the methodological part of this study focused on the Copper Life Cycle Analysis in the context of the EU's Circular Economy and European Green Deal, the method used included qualitative and quantitative analysis, data were collected from reliable sources

Data collection was carried out through documents provided by highly credible intergovernmental organizations, such as the International Energy Agency (IEA) and the International Group of Studies on Copper (ICSG), recognized for their energy efficiency assessments, clean energy technology applications and the global impact on emissions. , providing reliable and relevant data for analysis.This data contributed to a broad view on the efficiency of copper use in renewable energy technologies, and to analyze its role in the context of the European Green Deal and the circular economy.

The quantitative analysis of data, graphs were evaluation that indicate copper demand in the future showing the graph "Total Supply & Demand for Key Cu in PV Solar and Wind" from 2024 (Figure 3), which allows to quantify copper demand for the next decades, indicating the growth and importance of copper for the future. Another important graph was the "Total historical and projected emissions in Germany" (figure 6) which was used to estimate greenhouse gas emissions, demonstrating the decrease of CO_2 emission, obtained through the recycling of materials. According to these data, Recycled copper consumes only 20% of the energy required for primary copper extraction.

With the data provided by the IEA, it was possible to quantify the demand for copper for use in renewable technologies, and compare with other sources of power generation, showing the growth in demand for copper in renewable energy technologies such as solar photovoltaic (PV) and onshore and offshore.

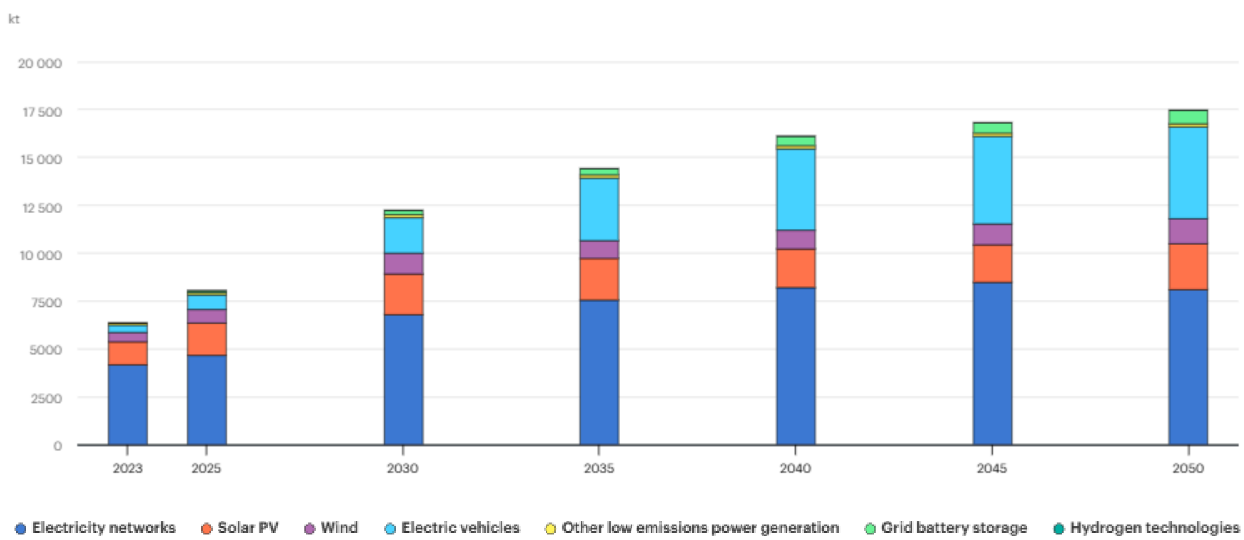
One of the important points of this study was the analysis of the role of secondary copper, or recycled, in the circular economy. Copper recycling is a process that consumes 85% less energy, reduces greenhouse gas emissions and minimizes the exploitation of natural resources.

This methodology based on reliable and comparative data analysis allowed to identify and evaluate the environmental impacts throughout the life cycle of copper, including CO emission rate, energy intensity, Water use intensity and resource use intensity at various stages of the copper life cycle.

9. RESULTS AND DISCUSSIONS

Given these demand projections and emerging global copper commitments on renewable energy and low-carbon economy, sustainable copper sourcing strategies are of utmost importance. In the Announced Pledges Scenario, as stated by the IEA, the total copper demand is projected to increase rapidly to meet the growing renewable energy projects and increasing requirement of recyclable energy. Such a growing demand not only pointed to the strategic value of copper in the energy transition but also raised questions about the viability of producing primary copper.

Figure 10 – Total Supply & Demand for Cu



Source: IEA (2024)

To address the challenge of implementation of a circular economy, especially regarding the recycling and reprocessing of copper from residues like copper slag, Electrical cables, Piping, Electronic equipment, Industrial scrap is considered a viable option. Based on insights from the articles "The Potential for Copper Slag Waste as a Resource for a Circular Economy: A Review (Parts 1 and 2)", secondary copper represents a valuable useful resource. Therefore it is feasible to cut the reliance on primary copper production and make a positive contribution to the European Green Deal, focusing on improving efficiency in the use of resources, bringing down emissions of greenhouse gasses, and lessening adverse effects on the environment.

The recovery of copper from slag and other secondary sources are conservation of natural resources and energy consumption as set by the EU's sustainability goals. The production of copper from secondary sources needs 85% much less energy than from freshly mined copper ore and concentrates, and thus has a significantly lower carbon value. Producing primary copper leads to elevated CO_2 emissions and depletion of water resources. On the other hand, circular economy entails the proper eradication of waste by using industrial wastes because of the three R's of waste management – reduce, reuse, and recycle.

Secondary copper not only reduces the environmental harm caused by copper mining and smelting but also provides an almost equally efficient solution to the growing need for copper. This way industries can get its requisite copper without having to add pressure to the natural ecosystems any further. Thus, the concept of employing secondary copper as an additional source of primary copper in a closed loop system is the right approach to meet the copper demand more especially for manufacturing of renewable energy technologies. It also makes provision for future electricity usage, coupled with support of the objectives of sustainable development with regard to emissions of greenhouse gas, water usage, and primary copper production as per the provisions of the European Green Deal.

CONCLUSION

In this study, the relationship between copper production, copper recycling and the use of the circular economy model are discussed, including the role of the circular economy model in the European Green Deal. There is continuing global demand for copper through development of new technologies and switching to green energy; therefore it becomes more significant to look for new means of sustaining the negative impact of mining and conserving the Earth's resources.

A comparison between primary and secondary copper production shows that copper recycling has an advantage environmentally. Primary copper production is an energy and water demanding process with high water and energy intensities and high levels of greenhouse gas emissions. Alternatively, copper recycling consumes as little as 15% of the energy as that used in the refining process, releasing 40 million tons less CO_2 emissions every year. The process of being able to reuse copper with no loss of performance within a circular economy makes it a potential valuable resource. This model not only enables reduction of waste, but also the consumption of resources, which helps to keep those resources in use for as long as possible.

One of the key points of this study is the focus on second copper paper, or recycled copper, for a circular economy. Recycled copper remains with the same properties as primary copper, while maintaining the physical and chemical characteristics. Copper recycling is a process that consumes 85% less energy, reduces greenhouse gas emissions and minimizes resource exploitation.

The data presented here reveals that, in 2023, recycled sources accounted for around 17% of global refined copper production at the end of last year; with Europe being the leader in recycling – over 50% of the demand is met from recycling. This development shows the principles of recycling in replenishing natural reserves and minimizing reliance on mineral processing. Also, the fact that more European countries are recycling more than 40% of its copper through recycling ought to act as a benchmark to the rest of the world.

While changes in an economy are at the core of turning a society into a sustainable one, renewable energy is an important component of the European Green Deal. Along with the deployment of renewable technologies, in order to decarbonize the energy sector, the share of imported fossil fuels in the regional energy consumption decreases, contributing to the improved energy security of the region. There is considerable potential for copper recycling and renewable energy coupling because copper is widely used in production of components for green technologies including solar panels and wind turbines which are efficient in energy creation.

The examination of the effects of mining and copper production explains why, even with enhancements in the recycling of copper, primary mining plays a role in polluting the environment. It is for this reason that the loss of large areas of vegetation and soil, water body pollution and soil erosion bring negative impacts that have to be fixed. Recycling is also encouraged not only because it helps to relieve pressure on local ecosystems but also because there is an increased demand for copper in the world.

The direct connection of copper recycling activities in the concept of the circulate economy along with the guidelines of the European Green Deal is one of the ways to fulfill the specified goal for the environment. Through the adoption of recycling and reusable energy Europe creates a market for efficient energy use and develops sustainable growth. In this regard, Europe offers a ‘best practice’ model of sustainable practices within the copper industry – so important to the global economy – that other industries ought to emulate.

This project shows the importance of copper recycling in support of sustainability goals in Europe, which helps to minimize dependence on raw materials.The effectiveness of copper in renewable sectors with other materials, through graphical analysis, highlighted the compatibility of copper with clean energy in manufacturing. The standardization of data has made it possible to compare types of clean energy technologies and periods of growth, demonstrating the importance of copper for the European circular economy.

Therefore, this study underscores the need for recycling copper in the global economy to support the cycle economy and, in particular, the use of renewable energy.

On the basis of conclusions, it could be stated that recycling copper plays an important role in the achievement of the objectives of the European Green Deal. To achieve these objectives, the strategy concerns the decrease of environmental impacts, the decline of the demand for primary copper, and the enhancement of the industrial sector’s performance with respect to sustainability. This copper LCA also shows the ability of recycled copper to meet renewable energy requirements in terms of metal circulation, as well as making the industrial supply chain a sustainable circular source.

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LIST OF FIGURES AND TABLES

APPENDIX - STUDENT AND SUPERVISOR DECLARATION

DECLARATION

The public access and authenticity of the final thesis

Student's name: Higor Dantas de Almeida Gonçalves

Student's Neptun code: E8A9DA

Title of thesis: Life Cycle Analysis of Metal: Copper's Assessment of the Circular Economy in Industries from the Perspective of the European Green Deal

Year of publication: 2024

Name of consultant's department: Agroecology and Organic Farming

I declare that the final thesis submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography.

If the above statement is untrue, I understand that I will be disqualified from the final examination by the final examination board and that I will have to take the final examination after writing a new thesis.

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Higor Dantas de Almeida Gonçalves **(student Neptun code: E8A9DA)**

As a consultant, I declare that I have reviewed the final thesis and that I have informed the student of the requirements, legal and ethical rules for the correct handling of literary sources.

I recommend the final thesis to be defended in the final examination.

The thesis contains a state or official secret: **yes** **no***

Date:11 November, 2024

Dr. Paulina Jancsovszka

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