COBALT MINING FOR THE PRODUCTION OF LITHIUM-ION BATTERIES

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INTRODUCTION

Cobalt mining is the process of extracting Cobalt from subterranean mineral reserves. One of the main uses of Cobalt is in the production of rechargeable Lithium-ion batteries [1]. In this report a multidisciplinary approach was applied in the study of the positive, negative, direct and indirect effects of Cobalt mining on the natural environment and on the quality of life of the people that inhabit it.

Engineering processes often have implicit burdens on the natural environment, the social wellbeing of people, the state of politics in a country as well as the economic health of areas in which the processes are being undertaken. This motivated the need of such a report as engineers need not only conduct technical analyses but also consider the other facets of life and the environment which sustains it. Understanding how a project might affect the lives of people in their environment is a key skill which could determine whether a process is sustained or quickly terminated and could also minimise possible hazards that were overlooked in the technical analysis.

Initially, an assessment of the environmental effects of Cobalt mining was conducted. This assessment determined whether this process is detrimental or conducive to the state of the natural environment. This assessment was conducted at various levels, from the effect of Cobalt mining on an ecosystem and scaling up to its resultant effect on the climate of an entire region. Subsequently, the social impact of mining Cobalt, on the inhabitants of the region in which the mine is situated, will be investigated. The social impact will be investigated at various boundaries i.e local, regional, national and international. Ethical dilemmas and unintended outcomes that arise in Cobalt mining will also be discussed. This will be followed by a life-cycle analysis of the Cobalt mining process in which the scope of the life cycle analysis, the inventory of materials used in the process and the effect of each material on the natural and socio-economic environments respectively. The overall study was concluded by an investigation on the sustainability of the Cobalt mining process where the importance of sustainability in a process was discussed. Indicators of sustainability, in the context of Cobalt mining, were used to evaluate the sustainability of the process in question. Conclusions were then drawn about the level of sustainability of the process of Cobalt mining.

In this report, a seemingly rudimentary process of Cobalt mining will be used to emphasize the pertinence of using a multidisciplinary approach when thinking about process design in order to expose any non-technical threats that could possibly delay or derail a particular process.

THE ENVIRONMENTAL IMPACT OF COBALT MINING

Impact on the Natural Environment

Air Pollution
It is little known fact but mine are sources of air pollution. They are a major source of airborne particulate matter like dust, which comes the general operation of the mine like drilling and blasting.

Mine Construction
The preparation of a mining site through construction and the removal of trees and other plants leads to massive destruction of the surface of the earth. That compounded by the levelling, soil compaction and digging leads to issues with sedimentation by releasing suspended solids in surface run off water. Furthermore, the construction for roads giving access to the causes further deforestation and that kills wildlife habitat further. Cobalt mining is slightly different in that it is often surface open pit mining, meaning that it is not associated with all the negatives of underground mining.

The disposal of waste rock and mine water are the big deal in the environmental impact of mining Cobalt. This is a major cause for concern as it the origins of the water is natural underground water that has trickled into the mine and is disposed of by pumping out. This water leads back to other sources but is now acidic as it contains trace elements which are harmful to the underwater habitat.

Operation
Cobalt mining requires the veins of the pits to be worked from the surface of the earth, and those trenches create an open pit in the modern mines. Cobalt ores are extracted using drifts and adits.

Ozone Depletion
The diesel burned in the machinery for harvesting Cobalt causes the depletion of the ozone layer, and not only in the cobalt production process but also in the refining of that diesel as much as that is an indirect effect

Eutrophication
There is a lot of nitrogen oxides emitted in the mining of Cobalt through blasting, these Nitrous oxide emissions are responsible for smog and acid rain that cause eutrophication.

Impact on Ecosystems

The construction of Cobalt causes deforestation, there is a lot of trees and vegetation that are removed which a natural habitat of many animals. When these forests are removed, the animals that live there are forced to migrate to other areas placed places which in turn causes over population of in the new surrounding areas. This is a huge concern as stocking rates of animals are controlled through a prey-predator type system that is based on the food chain.

So when there is a certain species that is migrating due to the destruction of its primary habitat, that specie then adds to the numbers of which ever food chain level in the area, which results in the prey of that species completely finishing and causing a chain a reaction of completed resources and as such the death of the ecosystem. And this phenomenon is only for the species which can survive the primary destruction of the vegetation and move, which is not all species in an ecosystem.

Those species that cannot migrate have a different reality that they must face. herbivores lose food, birds lose their homes, carnivores and omnivores lose their primary food and the soil is also destructed. All in all, the ecosystem where the mine is then non-existent.

Cobalt mines also affect their surrounding ecosystem in a harmful way. Because of the acidic water from the mines and the acid rain caused by the sulphur in the air caused by mines end up in neighbouring water bodies which are part of the separate ecosystems. This causes the organisms that live in water to be poisoned and die, it also causes the vegetation in the water to die as the acid affects the oxygen content in the water. Animals that also rely on the water as sources of hydration get affected as well because they might get sick from the water.

Impact on Climate Change

The effects of mining cobalt on climate change are a bit two folds; on the one hand the mining directly releases some harmful gasses in the environment, green houses like nitrous oxides and carbon dioxide which adds to the rising temperatures of the earth and the melting of ice caps. It was found that the bulk of the thing is carbon dioxide produced in mining cobalt is actually in the blasting stage [13]. And on the other hand, the batteries that are made with this cobalt are used many applications as cleaner alternative sources of power, effectively replacing fossil-fuel based energy as it has already contributed a lot to global warming. So, the usage of these batteries is an effective way to help slow down Global Warming.

THE SOCIAL IMPACT OF COBALT MINING

Impact on Society

Local
In a local setting the social well-being of members of a mining community are greatly impacted. There is a positive impact with respect to employment due to increased opportunities for employment in the mining sites. However, there is a detrimental impact due to the need to share resources with an increased population immigrating into a common area to also seek employment.

Regional
In a regional setting, due to the influx of people from other regions seeking employment, there is often a culture shock for the immigrants who need to learn the ways of that new region and also an adaptability challenge for people native to that region to adapt their culture to accommodate the new inhabitants. Engineers have to ensure that their mining processes do not infringe on the culture of the people inhabiting that region to avoid any conflict and also create an environment that enables workers to work in appreciation of their respective cultures.

National
Due to mining, the economic activity is improved at a national scale. The yield and rate of exportation of cobalt increases which results in income for the country exporting the cobalt. This allows the same country to import more goods using the income generated from exporting cobalt. This increases the flow of money and economic activity at the national level. Engineers need to ensure that big projects benefit the economic state of the country in which the projects are executed.

International
Big projects often draw political attention, especially if executed in a foreign country. This is due to different countries looking to get the best out of their joint venture. Political unrest can delay or even derail a project which could lead to a loss in capital. Engineers need to ensure that political tensions are eased before project commencement and also understand possible stages in the project that could lead to political unrest. The political operations of all stakeholders(countries) need to be understood to ensure that the project reaches completion without any disturbances.

Ethical Dilemmas

Health and well-being
Due to increasing demand for cobalt based products (i.e lithium-ion batteries), the extraction of cobalt, from subterranean deposits, has unintentionally exposed people, in nearby communities, to a myriad of health and well-being hazards. These hazards have in turn become a social burden on the community at large. Crops that are planted in areas surrounding cobalt mines have been found to contain large amounts of cobalt which in turn

had carcinogenic effects (among other ailments) on the people that consumed those crops [2]. This is especially problematic as the people that consume contaminated crops do so because it is their only option due to poverty and the cost of medical care makes them unable to even treat themselves in the case of illness due to these crops.

Food security, food costs and competition

Another pertinent issue with the presence of cobalt in crops is a reduced crop yield. The presence of cobalt in crops leads to crop death thus reducing the crop yield for consumers. This is detrimental to the food security of that region and thus increases competition for food which ultimately leads to an increase in food prices. This means that a significant portion of peoples' income will be used to purchase food and this will limit the potential for people to use their income to potentially break poverty cycles and improve their quality of living. This presents an ethical dilemma to the engineers that aim to service the ever growing need for cobalt at the cost of the quality of life of communities situated near mining sites.

Overcrowding and crime

In mining communities there is increased employment which results in an influx of people in search of employment to earn an income. Mining communities are often overcrowded due to an increased number of mine workers requiring residence. Many people are often left to seek shelter in temporary structures with minimal security. This draws opportunistic criminals to these areas which increases crime and negatively affects the quality of life of the residents.

LIFE CYCLE ANALYSIS OF COBALT MINING

Goals and Scope

A Life Cycle Analysis (LCA) is conducted to assess the impacts of the different stages in the mining and extraction process of cobalt ore, for the specific use in Lithium-ion batteries. The goal of this life cycle analysis is to examine the environmental and social impacts of cobalt mining production from cobalt ore to use in lithium-ion batteries [3]. Each item in the inventory will discuss how it impacts the natural and social environments and from this, conclusions will be drawn. The scope of this life cycle analysis is to evaluate all resources, products and processes needed for the extraction of the cobalt ore [3]. Because the process of cobalt extraction belongs to the primary sector, each respective input is industry-specific to mining and so the whole production process of each input should be taken into consideration in order to evaluate an accurate life cycle analysis. This extends until the cobalt ore is refined for use in Lithium-ion batteries.

Inventory

The life cycle inventory involves itemising every aspect of the process's complete life cycle. It includes every material, product and process which forms part of each stage of the life cycle. Since the process is divided into two parts, both parts will have their own inventory items. The following is the life cycle inventory for the extraction of cobalt ore:

- **Water** – usually from a river or groundwater, is used for mineral processing, dust control, slurry transport, and for general consumption [4].
- **Cement** – used for shaft stability and to prevent collapses from occurring, it helps prevent rock movement and absorbs stress from blasting [5].
- **Conveyer belt** – used to displace gravel and used to transport cobalt ore from the place of extraction.
- **Diesel** – used as fuel in mining vehicles and machinery.
- **Electricity** – large power consumption occurs to power mining equipment and machinery.
- **Heat & natural gas** – used for heat treatment for ore processing which can improve the efficiency and thus produce a better quality of extracted ore [6].
- **Transport** – ranges from heavy mining vehicles to transporting ore or gravel to mine shafts, these transport miners underground to different locations.
- **Blasting** – explosives are used to crack and break large portions of solid rock which is then cleared and enables deeper mining [7].

After the cobalt ore has been mined, it needs to be refined into a pure metal such that the cobalt can be used in Lithium-ion batteries. This follows the process as illustrated by the block diagram in Figure 1. The life cycle inventory for the refinement process is:

- **Cobalt ore** – after it has been mined, it needs to be refined such that it becomes pure cobalt metal which then can be used in the production of Lithium-ion batteries.
- **Electricity** – refineries consume large amounts of power during this phase.
- **Process water** – used in the process of refining the cobalt ore.

- **Sulfuric acid, technical oxygen, Caustic soda, Lime and Organic (Chemical compounds)** are all used in the process of refining the cobalt [8].

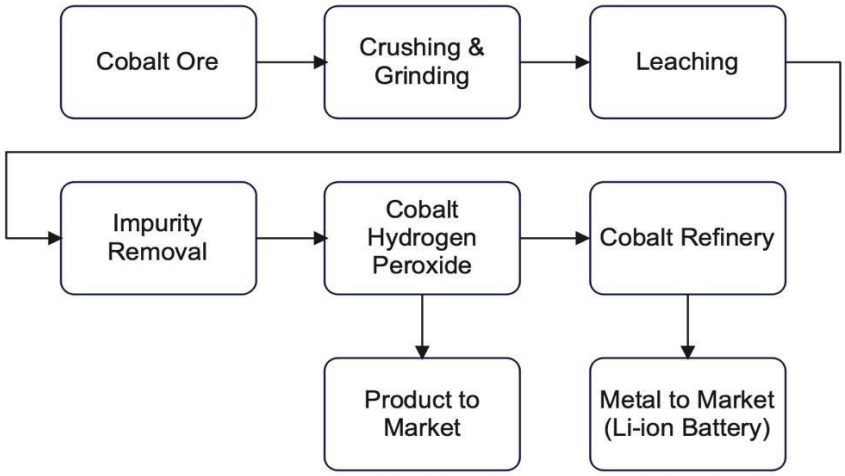

Figure 1: Block diagram illustrating the refinement process of cobalt.

Inventory Impact on Natural and Social Environments

The life cycle impact assessment measures the impact that each item in the inventory has on the natural and social environments. This includes all processes and energy requirements throughout the lifecycle of the product or process. This life cycle impact assessment details the environmental and social impacts associated with cobalt mining.

Water:
Water doesn't have a social or environmental impact in the process of cobalt mining, however cobalt mining could have an effect on surrounding water reserves.

Cement:
Cement has an environmental impact as it contributes to terrestrial ecotoxicity with fluoride being the main harmful emitter [5]. Terrestrial ecotoxicity is the impact of a chemical compound, in this case cement, on animals and plants [9].

Diesel:
Diesel used in cobalt production machines has an environmental impact specifically on ozone depletion [3]. Methane is the main contributor to ozone depletion which breaks up the O_3 (ozone) molecules and allows harmful rays from the sun to reach earth, thus having a negative impact on the natural environment.

Electricity:
Electricity production, which is used extensively in cobalt mining, is responsible for a wide range of both environmental and social impacts [3]. It is responsible primarily for climate change, freshwater ecotoxicity, cancerous human toxicity as well as non-cancerous human toxicity [3]. Electricity is the largest contributor to climate change as it emits fossil fuels which exacerbates the situation. Electricity is also responsible for freshwater eco-toxicity which

takes into account how toxic substance emissions affect ecosystems and freshwater resources (fluoride) [10]. Electricity also has cancerous and non-cancerous human toxicity with the harmful emissions from each being cadmium & cobalt and arsenic & manganese respectively [3].

Heat & Natural gas:
Heat and natural gas impact the environment through mineral, fossil fuel and resource depletion as natural gas is a non-renewable resource which can contaminate earthly minerals and will deplete fossil fuel reserves [3].

Transport:
Transport such as heavy machinery and mining equipment use fuel which has an impact on fossil fuel reserves, specifically crude oil and likewise emit harmful gases such as carbon dioxide contributing to climate change [3].

Blasting:
Blasting is responsible for both environmental and social impacts of which are eutrophication, marine aquatic ecotoxicity and cancerous human toxicity [3]. Nitrogen oxides from blasting are emitted, causing acid rain and smog, leading to eutrophication [3]. Eutrophication happens when the environment is enhanced with nutrients, causing estuaries and coastal waters to have more plant and algae growth, ultimately offsetting the respective ecosystems [11]. Marine aquatic ecotoxicity is the harmful substance impact, specifically fluoride, on the aquatic ecosystem. Blasting also has an impact on cancer-causing human toxicity with harmful emissions of cadmium and cobalt [3].

Cobalt ore:
When cobalt is mined, particles of the metal are discharged into the environment, this includes the use of coal, oil, fuel and other metallic compounds used in industrial operations [3]. This can lead to non-cancerous human toxicity and can have very consequential health effects for workers [3].

Chemical Compounds:
The different chemical compounds used in the refinement of cobalt after the mining process aren't significant impacts yet contribute to ozone depletion, eutrophication and acidification which is the decrease in pH levels, altering ecosystems and emitted mostly soluble compounds into freshwater [8].

There are a common group of impacts which multiple items in the inventory fall under, these being: climate change, eutrophication, ozone depletion, ecotoxicity and human toxicity. The extraction process ultimately has the most severe impacts on the environment with fewer social impacts.

Conclusion of Overall Impacts

Each inventory item has a specific environmental or social impact through the cobalt mining or refining process. Some impacts of which are common to multiple inventory items which

have far-reaching consequences on surrounding ecosystems, these include: human toxicity (cancerous and non-cancerous), ecotoxicity, eutrophication, acidification, climate change and ozone depletion [3].

The consumption of fossil fuels is the primary cause of the environmental impact of cobalt extraction and so using alternative energy sources is the ultimate way to lessen the impact on the environment [3]. Human health is another major impact that cobalt mining is a consequence of. This can be both cancerous or non-cancerous causing impacts through electricity consumption, blasting or cobalt ore used in the refining process before ready for use in Lithium-ion batteries [3]. This impact on human health can have an impact on both miners and people in the surrounding areas and stems from the actual physical excavation of cobalt, as particles are mixed in the air and inhaled leading to severe consequences [3]. The consumption of large electrical power has significant consequences on the environment not only through the emission of greenhouse gases, but also if fossil fuels are used for the generation which results in the depletion of these resources [3]. However, taking all of this into account, the actual impacts from waste emissions of cobalt mining itself is relatively little compared to other impacts from inventory inputs [3].

The environmental and social impacts from the mining of the cobalt ore to the refining of cobalt ore for use in Lithium-ion batteries has been detailed. The whole lifecycle impact of each product, process or resource input has been taken into account to yield an accurate and detailed life cycle analysis.

SUSTAINABILITY REPORT ON COBALT MINING

The Importance of Sustainability

Cobalt is one of the primary metals found in lithium-ion batteries - rechargeable batteries which are in high demand as they play an essential role in storing and transferring renewable energy (solar, wind, etc.) and are integral in electric vehicles. Lithium-ion batteries account for 57% of the total cobalt used in 2020, with a growing demand predicted reach an increase of about 2000% by 2050 [12].

It is clear that if a demand of that scale is to be met, a sustainable approach is necessary. This means practicing safe and maintainable extraction, as well as ensuring the natural resource itself is not overexploited. Current mining practices are considered unsustainable and unlikely to meet the growing market for cobalt. Most cobalt is produced as a by-product of copper and nickel production, from mines mostly in the DRC (home of over half of the global reserves). Alternative sources such as deep-sea mining are unlikely to be viable and are associated with significant environmental issues. Cobalt plays a large role in enabling renewable energy and it is therefore important that it be sustainable itself.

Relation to Key Indicators of Sustainability

The use of non-renewable, finite materials
Although cobalt is a finite element, it is considered to be fairly abundant. The same can be said about nickel (an element which plays a part in its production). As mentioned above, the lithium-ion batteries which contain cobalt actually reduce the need for fossil fuels and other non-renewable forms of energy (disposable batteries). In this case, cobalt may be considered sustainable.

Recycling/reuse/remanufacture
Copper (an element which plays a part in its production) is considered renewable as it can be recycled indefinitely. Cobalt enables rechargeable batteries, which may be reused after depletion (to a certain extent) and also act as a medium for renewable energy. This is cobalt's strongest contribution to sustainability.

Social responsibility
About 51% of global cobalt reserves are in the DRC, which is reported to be the 6th most fragile country and the 17th most corrupt country in the world [12]. Cobalt is regarded as a 'conflict mineral'. It is sourced under working conditions that violates human rights, shrouded in corruption and cheap labor (including many instances of child labor) and it pollutes the water, air and land – endangering both workers and any nearby residents. There have been legislative measures put in place to protect the human rights of the mine workers and residents of the DRC, but it is far from being sustainable socially.

Environmental health:
As mentioned above, freshwater and crops become contaminated, air becomes polluted and the health and safety of the environment both locally and to a larger extent (through eutrophication and ozone depletion) depreciates tremendously because of cobalt mining. The current mining practices are considered unsustainable largely due to its environmental impact.

Conclusion on Sustainability

Cobalt mining is considered a 'conflict mineral'. Although fairly abundant and enabling the use of renewable energy, it is far from socially sustainable with the human rights of mine workers and residents of the DRC (where majority of the cobalt reserves can be found) violated in more ways than one. It is also notorious for its negative impact on surrounding ecosystems - polluting fresh water and contaminating crops. The practices used currently are considered unsustainable and with a growing demand for cobalt in the form of lithium-ion batteries, this may cause major problems in the foreseeable future. It is imperative that sustainable practices be found as cobalt can have a positive effect on the environment. Rechargeable lithium-ion batteries allow a reduction in disposable batteries, enable the use of renewable energy and consequently reduce the need for fossil fuels. All of which are very important in ensuring sustainable energy.

CONCLUSION

Cobalt mining has many great negative impacts on the environment, it pollutes airways, water streams and causes deforestation, which results global warming and ecosystem destruction, but at the same time it reduces the carbon dioxide emissions these batteries are used to replace petrol and diesel power plants. The mining of this resource has some ethical dilemmas associated with it as there are reports of child labour that is being used in the mining process, Communities who live around the mines are also prone to many illnesses and diseases due to living in an area that is being polluted constantly by mines. The mine pollution extends to affecting food security of these areas due to presence of cobalt in food, but the mines also create employment for those who live in and around the mines. The usage of cobalt is vast and it is one of the resources that will drive the electrification of the transport industry and migration from usage of fossil fuels. This will drastically help us slow down global warming and us such we cannot avoid mining cobalt, we just need to mine in a very sustainable manner such it does not damage the environment and helps benefit the people who are involved in its mining so that they are not exploited.

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