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“The Real Cost of Mining: How Digging for Rare Earth Metals Could Pose a Greater Cost than EVs Can Save”

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INTRODUCTION

This paper investigates is the Paris Climate Agreement's proposal to have 20% of all road transport vehicles be electric by the year 2030. The vehicles specifically targeted are two and three wheel motor vehicles, cars, buses, trucks, and light commercial vans (Paris climate conference 2015). According to the Paris Climate Conference officials implementation of this policy is critical to help obtain a 2 degrees Celsius reduction in the increase of global temperatures by 2030. Climate change policy and electric vehicles are becoming more and more relevant in today's world. The current United States President, Joe Biden, ran with a major campaign promise of implementing plans to slow climate change and clean up the environment. Further President Biden has worked to bring the United States, one of the largest leaders in greenhouse gas emissions back into the Paris Climate Agreement. Electric Vehicles (EVs) are some of the most revolutionary and modern of technologies with social and scientific leaders such as Elon Musk gaining extreme popularity and success for their work in this field. This study will be looking into the specific cost of meeting the Paris Climate Agreement's goals for transportation vehicles by calculating specifically the cost of both earth dug up and emissions released during the mining process and the production of the vehicles to build the batteries for the electric cars we have today. The potential significance of my findings could weigh in on future alterations, or completely new climate policies.

LITERATURE REVIEW

Mills (2019) touched upon the topic of renewable energy came to the conclusion that if the world is going to increase the amount of renewables that they are going to use, countries around the world need to be prepared to drill. Specifically, the author compared current rates of mining and production today to predicted rates of future mining to reach current climate policy goals. Global silver and indium mining will jump 250% and 1200% respectively. If EVs replace conventional combustion cars, cobalt and lithium mining will rise 20-fold, Mills (2019). These are not small numbers, in fact they are almost impossible numbers given the current state of technology and mining. The author also touched upon the fact that an increase of mining and creation of renewable energy sources can have major effects on society both in an environmental and humanitarian way. Current production of renewables and mining processes take place in countries with weak protections of laborers. Mills predicts that specific increases in mining would occur in the labor oppressive countries of China and the Democratic Republic of the Congo (DRC). Further, 90% of the world's solar panels are built in Asia on coal-heavy electric grids, Mills (2019). Mills touches upon one of the key components of my analysis, the fact that the production of renewable energies, specifically electric vehicle components require a lot of mining. In addition, the countries that are going to be taking on these projects and mining for resources and building the finished products do not treat their workers fairly, and produce a significant amount of emissions in the process.

Tsadiras, Pempetzoglou and Viktoratos (2020) conducted a study where they used a fuzzy cognitive map method to try and figure out the causes and effects of global warming on society and how they interact with methods to stop these adverse effects. Cognitive maps show the relation ship between causes and effects of different events and have been used in disciplines across the board. The authors of this study implemented 'fuzzy' statistics into their cognitive map which allowed them to place weights on the correlation connections to determine which are the most significant causes and effects of global warming, Tsadiras, Pempetzoglou and

Viktoratos (2020). According to the Stern report (2007), the cost of the effects of climate change is estimated at about 5% of world GDP per annum. But the authors noted that if they took into account the effects of the global warming phenomena on human life and the environment this cost sharply increases to 20%. Global warming is the result of Earth's enhanced greenhouse effect and it is mainly due to the increasing concentrations of greenhouse gasses in the atmosphere. According to the study CO2 is the most common greenhouse gas. The top three human actions that contribute the most to the production of this greenhouse gas are fuel combustion, deforestation and land use change, and cement production Tsadiras, Pempetzoglou and Viktoratos (2020). When implementing the fuzzy data they ran the correlations on a scale of [-1, 1] with these representing the weakest and the strongest causal correlations respectively, the big increase of "burning fossil fuels" caused an quite big increase to "Social and Economic Pressures" (~0.65) which in turn lead to big increase (~0.7) in concepts, Tsadiras, Pempetzoglou and Viktoratos (2020). With greenhouse gasses being the leading cause of global warming and combustion engines ranking at the top for human production of greenhouse gasses it can be seen why political leaders are seeing and being pressured into strong environmental protections policies like the Paris Climate Agreement.

Kypreos (2007) conducted tests to see how reasonable it would be to reach reductions in increases of temperatures by 2 degrees Celsius by 2100. His reason for the study was tied to the fact that for researchers having an economic background typically argue that great emissions reductions will lead to dangerous economic impacts, Kypreos (2007). The scope of the study was to assess the effectiveness of climate-change mitigation policies in restricting global average surface temperature rise to below some critical thresholds (e.g., 2◦C above the pre-industrial levels). Kypreos (2007) concluded that a restructuring of the global energy system to a more sustainable and carbon based emissions exempt system is technically feasible. The main drawbacks from this though comes at expensive costs, and would require a massive mobilization of natural resources and a very strong societal commitment if we want to see this materialized Kypreos (2007).

Roach (2013) conducted a study to test where specifically the United States was at in terms of pushing for environmental protections policy. He did this by using the Environmental Kuznets Curve (EKC) which shows the relationship between income and the desire for what he calls a clean environment. The article seeks to contribute to the environment versus the economy debate by accounting for the aforementioned time-series problems through the use of monthly data on coal and vehicle use since 1974. The author also seeks to offer insights on the debate over whether a more developed/developing economy creates more pollution and a worse environment, or that a cleaner environment will lead to more economic growth. The initial hypothesis with the Environmental Kuznets Curve is that as income increases, so too does pollution until a point at which consumers begin to demand a cleaner environment (i.e. an inverted U-shaped relationship between income and emissions) Roach (2013). After completing the study it was found that the data from the United States has confirmed this theory, but not only that. Roach claims that the United States has passed the tipping point and is moving towards great push for decreases in combustion vehicles and their emissions. One important note is that he claims the US has not reached that point when it comes to electricity stating the psychological reasoning of it being harder to justify producing emissions from turning a light switch on and off than driving one’s car. Roach (2013) offers great insights not only in his finding that Americans want cleaner cars and reduced combustion engine emissions, but also that they have not realized this in electricity. With electricity seeming to be the solution to combustion, but still producing significant amounts of emissions itself, about 67% of electricity is produced from fossil fuels, there is potential for a greater threat of shifting mechanisms of pollution.

Lomborg (2021) in a series of articles written in The Wall Street Journal dives deeper into the breakdown of what energy sources we are currently using and how climate lockdowns affect, or rather don't affect the global emissions numbers. In 2019, the last complete year of energy data at the time of the article being written, 81% of the world's energy supply came from fossil fuels, according to the International Energy Agency (IEA). With western nations current goals the IEA estimates that fossil-fuels will still make up 73% of all energy sources by 2040. Even if the environmentally conscious nations part of the climate agreement are able to make their goals they will still be making an insignificant impact on global emissions. The author touches upon the argument that emissions can be decreased by doing something similar to the COVID-19 lockdowns. During the lockdowns people were asked to not leave their house, many people worked from home and no longer needed to commute. Shipping lines had been halted causing a decrease in freight travel. All this led to a slightly noticeable decline in CO2 emissions across the United States. This caused some climate change activists to propose future lockdowns to prevent rising emissions and temperatures. But the author points to the data. In 2021 emissions would have to drop by more than double the lockdown-induced decline. By the end of 2030, they'd have to have fallen by 11 times what they did in 2020 Lomborg (2021). Considering the parameters of how the first lockdown was initiated and the current state of our social and political climate, to get people to go into a lockdown at all would take significant effort and to hold them there to get the levels needed to see a significant change would be just as, if not harder.

THEORY:

There are two major economic principles that are the driving sources of theory behind the discussion of this paper on electric vehicles and their costs. Those theories are cost benefit analysis and diminishing marginal returns vs constant returns. Both of these will play a vital role in understanding the full picture of the electric vehicle market and the conclusions that will be drawn from this study.

The first theory is the cost-benefit analysis. This theory is very simple in nature essentially stating that there are two sides to consider in every decision, how much will this decision cost you and how much benefit will you receive from carrying out this decision. The key component in this is that each transaction is not solely monetary; costs can include time, effort, natural resources, energy, and the opportunity that is lost from not choosing another option. In the same stroke benefits are not only the value of the asset obtained from the transaction but also any effects that this could play on the environment and people in the community. This is the theory of externalities. Externalities can be either positive or negative. The most common ones that are discussed in economics are negative externalities that have impacts on the environment. For example, if you were to buy a combustion engine car and drive it around, the carbon emissions that are released from your vehicle can have a negative impact on the environment and people around you. This study will work to show that electric vehicles can have some of those same negative effects.

Thinking back to cost benefit analysis another key assumption is that the consumers are rational in their decision-making processes. Meaning that they will choose the option that provides them with the lowest costs relative to the highest perceived benefit. Buying a car has become a more and more salient transaction in this decision-making process. As environmental issues and climate change are continuously brought to the forefront of people's minds, they are starting to consider how the vehicle they drive will impact the environment. This has led to the major growth of electric car companies like Tesla to experience rapid growth and popularity as well as companies like Ford and GM to increase their production of electric vehicles. Marketing of the electric vehicles conveys the images of cleaner sources of fuel and cars that are better for the environment. The advertising is focused solely on the benefits side of the equation. The problem that arises for consumers is that the benefits of EV are substantially more available to consumers than information about the costs. I argue that if consumers and even producers are going to make a rational decision about what is the best form of transportation in regard to the environment and community they need to see the whole picture, they need to know more about the costs to the environment that electric vehicles pose.

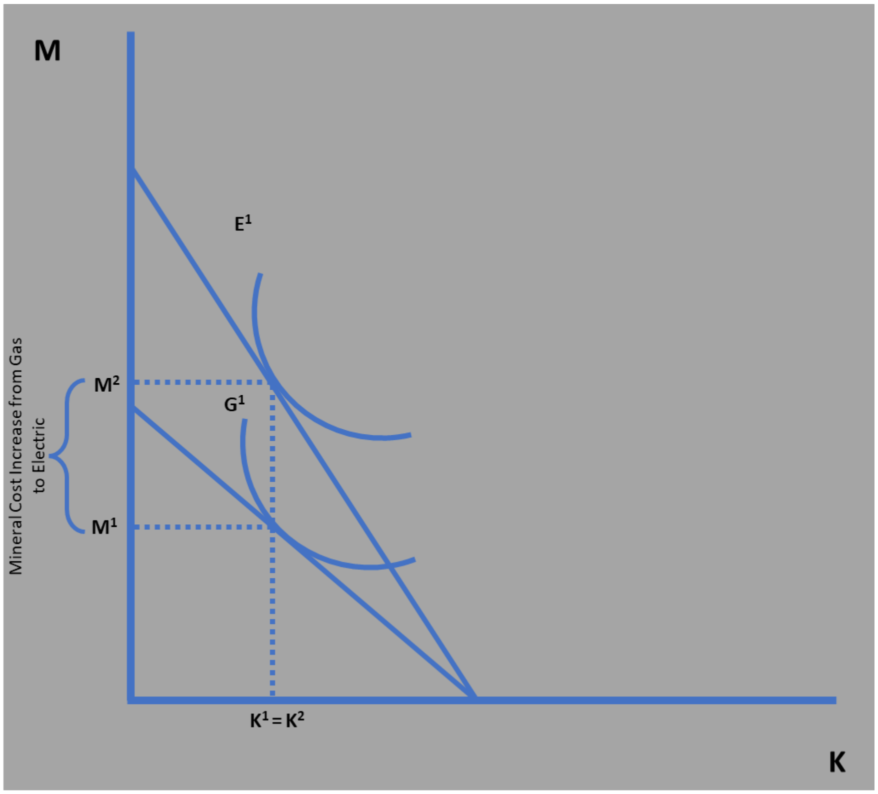
The other major theory that takes precedence in the electric vehicle debate is the law of diminishing marginal returns. The law of diminishing marginal returns is a theory in economics that predicts that after some optimal level of capacity is reached, adding an additional factor of production will result in smaller increases in output (Hayes 2021). For example, if someone is eaten a pizza, the first and second slices offer a great deal of utility to the consumer, but as subsequent slices are eating you start to get more full and experience less and less benefit from each additional slice and can even start to receive negative benefits. Similarly, if a business has a limited supply of machinery, they will gain additional returns from employees as they gain more people to operate the machines but there is a certain point where more people will cause clutter and dysfunctionality in the shop and they will increase output at a decreasing rate the more employees they hire. The same thing happens in the mining processes for metals needed to make electric vehicle batteries.

The main component of the electric vehicles is the battery on which the car runs. This battery has many different parts most of which include some form of the metals such as lithium and cobalt. These metals need to be mined out of the ground and this is where much of the carbon emissions and environmental expenditures comes from. The Paris Climate Agreement is based has the goal of converting 20% of [the world's] fleet to electric by the year of 2030 which would be approximately 289,200,000 cars. Predictions can be made about how much metal needs to be used to achieve this goal and from there it can be determined how much Earth would need to be dug to get this metal. Now the issue with making those calculations is that they assume a constant rate of return from the mines. But mines, like everything else have diminishing marginal returns and therefore the more earth that the mining companies dig up does not necessarily mean they will get the same amount of metal in return. Here we see that even some of the initial predictions as to how much it will truly cost to make electric vehicles may be inaccurate if they do not factor into this the diminishing returns of the mines. This is why this study is so important because we will be looking at all factors of the cost benefit analysis and taking into account diminishing marginal returns into the equation to provide the best possible analysis of Paris's expectations.

When thinking of cost, it is important to link this to actual resource use. The theory of monopoly power (monopolistic competition, oligopoly and monopoly) shows that output prices are a combination of two things: monopoly power of the firm and the resource costs of production. Behind any cost curve is actual resource use. Higher costs imply more resources are used assuming relatives competitive input markets. Therefore, if market prices are higher for electric vehicles, relative to comparable gas-powered vehicles, this implies either that there is more monopoly power in the electric market or more resources are used in the production of electric cars. Of course, Tesla has substantial monopoly power in the electric market, but we are seeing substantial increases in competition from other firms as new electric options are becoming commonplace. For theoretical purposes, therefore, we will assume away monopoly power so that we can highlight the resource component.

Assume two vehicles we will call electric (E) and gas (G). Production requires two inputs in production mined materials (M), and other capital (K). Therefore, $Q_i = f(M_i, K_i), i = E \ and \ G.$ Further to simplify the analysis, we will assume that each unit of M and K are prices at 1, $P_M = P_K = 1$.   For simplicity of argument, I assume $K_1 = K_2$, so that the cost differentiation is in terms of M. this is justified given that the main cost difference in electric cars vs gas is the battery. Given this framework, we can write unit isoquants and isocosts as depicted by **Figure 1** below. As shown by the graph, G^1 represents the isoquant curve of a gas powered vehicle and E^1 represents the electric vehicle isoquant curve. These two curves would be the same if the input variables and costs of the two cars were the same, but we know that they are not. Electric vehicles cost more, even despite the fact that they have been subsidized in recent US policy actions. This means that the increase has to come from somewhere else, that other place being mineral/mined inputs. This explains the difference in isocost curves and the shift from M1 to M2.

Figure 1: Isoquant and Isocost Curves of Electric and Gas Powered Vehicles Showing a Difference in Input Costs



METHODOLOGY:

The focus of this study is to determine the costs to the environment from the production of electric vehicles if the Paris Climate Agreement goal are met. To do this we will be taking in as many of the factors of production of an electric vehicle we can when it comes specifically to the battery (the main differentiator in electric vs internal combustion engines). To do this we compiled data on the key rare earth metals that are required to create the batteries. Then we will take information on how much of each metal is needed to produce one electric car battery. In this process we will break down all the associated costs of mining for those metals, such as earth being dug up, water, usage, ground water contamination, and CO2 emissions from the trucks and other carbon-based mining equipment involved in the process. Once we determine the true social cost of one battery, we will be able to multiply those factors to the scale at which the Paris Agreement's goal is set to then know the true cost of the electric vehicle goal. From there we will conduct the same process with the benefits. These will include the reduction of CO2 emissions and the expected reduction in the increase of global temperatures. After these comparisons are complete we will be able to see the side by side comparison of the costs and benefits to determine if the Paris Climate Agreement's goals are realistic and beneficial.

DATA ANALYSIS:

Benefits

Though the costs of mining for electric vehicles is significant, it would not be a true cost benefit analysis without looking at the benefits side. The main benefit that electric vehicles would bring, based on the Paris Climate Agreement, would be their subsequent reduction in greenhouse gas emissions as they emit no exhaust when driven. The methodology for this calculation involves taking how much greenhouse gases are emitted by the car transportation sector every year converting it down to a singular car and then seeing how much the 20% conversion to electric cars would decrease those emissions by. According to the United States Department of Energy, 14% of greenhouse gas emissions comes from the transportation sector with 52.2% of that coming from light duty transportation vehicles which include, passenger cars, motorcycles, SUVs, and small trucks. In 2021, a report released by the International Energy Agency estimated that there was a 6% rise in global greenhouse gas emissions produced in 2020 totaling approximately 36.6 billion tons of GHG. If we calculate 14% of that for the transportation section and then 52.2% for the small transportation vehicles we find that 2,674,728,000 metric tons of GHG came from small transportation vehicles in 2021. If we follow the Paris Climate Agreement's recommendations and convert 20% of these vehicles to electric we can infer that this would be the amount of GHG that would be taken out to yearly production from this sector. By multiplying this by 0.20 we can conclude that 534,945,600 metric tons of GHGs would be reduced if the Paris agreement's electric vehicle goal is met.

However this is not the final estimate for the benefits of green house gas emissions for electric vehicles. Although they do not produce any emissions during the driving process they do emit greenhouse gases when the batteries are manufactured. According to an article by Iris Crawford in 2022, member of the Massachusetts Institute of Technology Mechanical Engineering Department, a Tesla Model 3 holds an 80 kWh lithium-ion battery. CO_2 emissions for manufacturing that battery would range between 3120 kg (about 3 tons) and 15,680 kg (about 16 tons) over the lifespan of this particular vehicle. Rough estimates put electric vehicle battery life at 10-20 years, Charleut and Van Barlingen (2021). Taking an average of 15 years per vehicle we can calculate that .633 tons of greenhouse gasses are produced by the manufacturing of an electric vehicle battery per year. If we multiply this by our number of vehicles that need to be electric by 2030, 289,200,000 we see that approximately 183,160,000 tons of GHGs are emitted by the manufacturing of the needed amount of electric vehicle batteries to reach the Paris Agreement.

Once taking into account these added emissions into the atmosphere we can find the true greenhouse gas reduction benefit of the creation of these electric vehicles which comes out to [534,945,600 tons of gasses saved - 183,160,000 tons of remitted gases = 351,785,600 tons of GHG saved by the electric conversion]. It is easy to look at this number and think of it being quite significant, but when doing the cost benefit calculation there are more costs that need to be thought of besides simply greenhouse gases.

Costs: Mining

When looking at the costs of electric vehicles one key concept to keep in mind are the implicit, or as some say, embodied costs. These are costs that don't typically show up on a billing sheet or analysis of a product's effects because they occur outside of the main use of the product. In the case of the electric car most of its costs occur during the gathering of the component parts and production of the vehicle rather than the main use of the product which would be driving the car itself. For example, Mills (2021) states that an EV self-evidently emits nothing while driving, about 80% of its total lifetime emissions arise from the combination of the embodied energy in fabricating the battery and then in "fabricating" electricity to power the vehicle. Further he says that the ratio is reversed for internal combustion engine vehicles where about 80% of its emissions happen during the driving process of the vehicle's lifetime and the fabrication of gasoline. Therefore, it is important to take a look at all the potential costs that can occur with fabrication of the battery including the mining for its component parts.

Most electric vehicles including popular companies such as Tesla use a lithium-ion battery as their source of power in their cars. A typical 1,000-pound EV battery contains about 30 pounds of lithium, 60 pounds of cobalt, 130 pounds of nickel, 190 pounds of graphite and 90 pounds of copper, Mills (2021). Analyzing each type of mineral mine is a long and lengthy process but let's start with lithium mines. As seen above, lithium is one of the smaller component parts in the vehicle. According to Penn and Lipton (2021), the United States is currently only producing about 2% of the world's lithium. It gets most of its lithium from Latin America and Australia. Most of that metal is then processed in Asian countries like China and Japan. But times are changing, and Lithium America is proposing building a new mine on top of a dormant volcano in Nevada. Lithium America, their consultants and authors Ivan Penn and Erich Lipton have dug into the numbers of what getting a project like this up and running would cost.

The first component of mining that poses a major threat to the environment is the amount of wastewater that is produced and subsequently contaminated for sometimes tens if not hundreds of years after the mining is complete. Using water is a key component in the mining process. The metal ores which contain the desired metals such as lithium, copper, cobalt etc. are removed from the ground through drilling and blasting processes. That residual ore and earth is then sent up conveyer belts to the processing factories where they are ground and then mixed with water and chemicals to extract the desired metals from the ore. Water can also be used in the transportation of the ores through the systems of the processing and for practices such as hydraulic fracturing. There are many stages of the mining process that include the use of water which is often times why it is not reported in the mining withdrawals USGS (2019). Mining in the US uses a significant amount of water as the United States Geological Survey (USGS) calculated 4 billion gallons of water were withdrawn for mining operations in the U.S. in 2015. This included more than 70% of mining withdrawals coming from groundwater sources, 65% of which were saline; and 77% of the surface water used was fresh water (Fluence News Teams, 2018. Looking specifically at the Lithium Americas mine in Nevada we see similar patterns. The company has said the mine will consume 3,224 gallons per minute. That could cause the water table to drop on land owned, for example, by rancher Mr. Bartell [local rancher whose property is located close to the Nevada mine] by an estimated 12 feet, according to a Lithium Americas consultant Penn Lipton (2021). Permit documents for the mine submitted show that 5,800 tons of sulfuric acid will be used to mix with clay and rock from the mountain side for ore extractions. This whole process will also create 354 million cubic yards of mining waste that will be highly congested with toxic chemicals such as the sulfuric acid and other chemicals causing a loss of wildlife from byproducts of the mine. The Nevada mine project by Lithium America has come under scrutiny for this specific reason as local Native American tribes and farmers say that they have seen some estimates showing the contamination of the ground water from this mine could last up to 130 years well outside of the 41-year production life of the mine (Penn and Lipton, 2021.

The contamination of the ground water is a key component of environmental damage done by the mining process for electric vehicles. This contamination though is not the end of the line. One has to think about the escalating effects of what this damaged ground water could mean. It could lead to destroyed local farms and food supplies causing shortages and the US to start looking elsewhere and even outside of the country for food sources. It also damages wildlife habitat throwing off the ecosystems of that region. All these can be added to the embodied costs of electric vehicles.

The next component of the mining process that is a cost to the environment is the transportation of the refined metals once they are extracted from the ores. During the process rocks are moved with heavy duty dump trucks. Considering American mines, they are most likely to get their equipment from the leading American construction equipment producer home and abroad Caterpillar. Their newest model the 797F has been equip with a Tier 4 EPA regulation engine. This vehicle is far from fuel efficient with a tank that holds 1,000 gallons of gas and gets approximately three tenths of a mile per gallon of diesel fuel (LECTURA Specs,2022. The tier 4 is currently the best engine on the market for fuel efficiency cutting down NOx emissions to 2 g/kw-hr (Diesel Technology Forum, 2011). Though this number has been on the decline it is small relative to personal vehicle standards those of which are measured in a factor much smaller than that of heavy-duty construction equipment such as the 797F. The release of these gases by the heavy-duty dump trucks is a significant cost that would continue to stay a part of the mining process unless mitigated by the creation of a truck that would not release this level of exhaust. An electric engine dump truck could be the solution but as we have seen in the study thus far, and will see throughout the rest, this does not come without its own costs.

The costs that come from the mining of minerals to make electric vehicles are not solely environmental. There is potential for some major human and societal costs. We know that lithium is one of the major components of the Lithium-Ion batteries that are used in electric vehicles. Lithium can be mined from places like the US and will start to be in future projects but currently the majority of the Lithium mined comes from Australia and Chile who extracted 55,000 and 26,000 metric tons of lithium in 2021 respectively (Statista, 2022). But lithium mines in the world's second largest producer, Chile comes with some significant costs. Reports from Sengupta and Zegers (2021) show that one fifth of the world's lithium is produced by SQM (Sociedad Química y Minera de Chile), most of it in the Atacama Desert in northern Chile in the shadow of ancient volcanoes, including the oldest and still-active one, Lascar. There is significant potential for disturbing the volcano in which these mines are operating near which could cause significant consequences to the environment but also the individuals and communities that live close to the mining site. Like the Lithium America mines, the farm owners that live near SQM's mines have experienced decreases in the water supply of local lakes and rivers and face the potential dangers of the poisoning of their land due to contaminated wastewater. The company Sociedad Química y Minera de Chile does not have a clean track record either; it has been fined by Chile's stock market regulator and by the U.S. Securities and Exchange Commission over violations of the Foreign Corrupt Practices Act Sengupta and Zegers (2021). The country of Chile is currently working on amendments to their constitution to try and take some of the powers away from these large mining companies but companies like SQM have already started to bend the wording of the law to redefine what 'water' is. They claim that salt water that is found underground is not restricted for them to use since it is undrinkable by humans but the contamination that is done with this water can still harm the surrounding ecosystems and wildlife Sengupta and Zegers (2021). The mining companies also are having effects on the indigenous people that live in Chile.

Indigenous peoples have the closest ties to the land of Chile than any other people that have lived in the region before. But this connection is starting to move away from living off the land to digging up the land and dividing their people, especially those that live near the salt flats of SQM's lithium mines. Many indigenous people used to be herders of sheep and goats, but after the grazing spaces that they used to use start to get contaminated and damaged from the poisoned ground water and destruction of the ecosystems from the lithium mines they are being forced to choose a different option. For some this means giving up family tradition and working in the lithium mines being it their only source of income. This is starting to create a major divide amongst the indigenous people, some that say they should continue their traditional way of life and those that see the necessity of having to work for the very mines that are preventing them from living that traditional lifestyle (Sengupta and Zegers, 2021). These mines are not only contaminating the surrounding environments but destroying communities that have been on this world for hundreds for hundreds of years. It is not just the lithium mines where human costs occur but other major components of the Lithium-Ion battery.

Cobalt is a major component of the lithium-ion battery in electric vehicles, it works as a stabilizer for the battery. The majority of Cobalt that we currently have found is concentrated in the Democratic Republic of the Congo. Dummet (2017) finds that more than half of the world's cobalt comes from the Democratic Republic of Congo (DRC). Despite its immense mineral density, the DRC is one of the poorest countries in the world, suffering from decades of war and corrupt leaders. The mines in the Congo have a long history of terrible working conditions and international law violations. Working with a Congolese NGO, Afrewatch, Amnesty International found children as young as seven in the mining areas. In addition to this, none of the children or adults working had any sort of facial protection, Dummet (2017). This is important because inhaling the Cobalt dust can lead to sever lung diseases that are often fatal. Mines collapse frequently, burying people underground. No one knows the exact figure, but UNICEF estimates that 40,000 children work in mining across the south of the DRC where cobalt is found (Dummet, 2017). The situation in the Cobalt mines is severe and they are a result of a phenomena that is happening in the country called 'artisanal mines.' These mines claim to produce Cobalt at a significantly lower cost. But the caveat to this is that they are significantly less regulated than other mines meaning that they can use cheaper labor than is the standard for mines across the globe, (Dummet, 2017). This is even more concerning considering that with the expansion of demand for electric vehicles more and more of these artisanal mines are starting to emerge or plans for them are being drawn up. But the artisanal mines are not the only mines in the area to be worried about when conducting the true costs of electric vehicles. A significant portion of the Cobalt mined and used is controlled by China.

China is the leading producer of Cobalt for electric vehicles in the world. In August of 2021, China Molybdenum Company (CMOC), a major Chinese mining firm, announced an investment of $2.5bn (£1.8bn) to double copper and cobalt production at its Tenke Fungurume Mine, already one of the largest in DRC. That followed its purchase of a 95% stake in nearby Kisanfu copper and cobalt mine for $550m (Pattisson and Firdaus, 2021). This was a major investment for China as they grow to dominate and consolidate the market for electric vehicle ready Cobalt and they are making significant progress. Cobalt specialist suppliers Darton Commodities estimate that Chinese refineries supplied 85% of the world's battery-ready cobalt in2020. China is clearly making a significant impact in the Cobalt, and subsequently the electric vehicle market. But this is not good news for the people of the DRC. Reports from those working in Chinese mines claim that the Chinese managers of the mines in the DRC treat the works very poorly. One Congolese worker states that "They like to insult us. They like to raise their voices. Even for a small fault, you're punished. The Chinese are there as the boss to control Congolese" (Pattisson and Firdaus 2021). Workers at the Sicomines in the Democratic Republic of the Congo claim that they are paid less to do the same work as the Chinese workers and are subjected to degrading treatment by their Chinese supervisors. Considering China's large stake in the Cobalt industry and the mines in the DRC this only adds more to the cost of production of lithium-ion batteries for EVs.

Electric vehicles are not just the car that you see driving down the road they are the summation of all of the component parts and processes of extraction of those component parts and the overall production of the vehicle. These production processes come with significantly more costs to society, the environment, ecosystems and the people that live in the areas of production and should be taken into account in the true analysis of the benefit that these vehicles will bring to our world.

Mining Productivity:

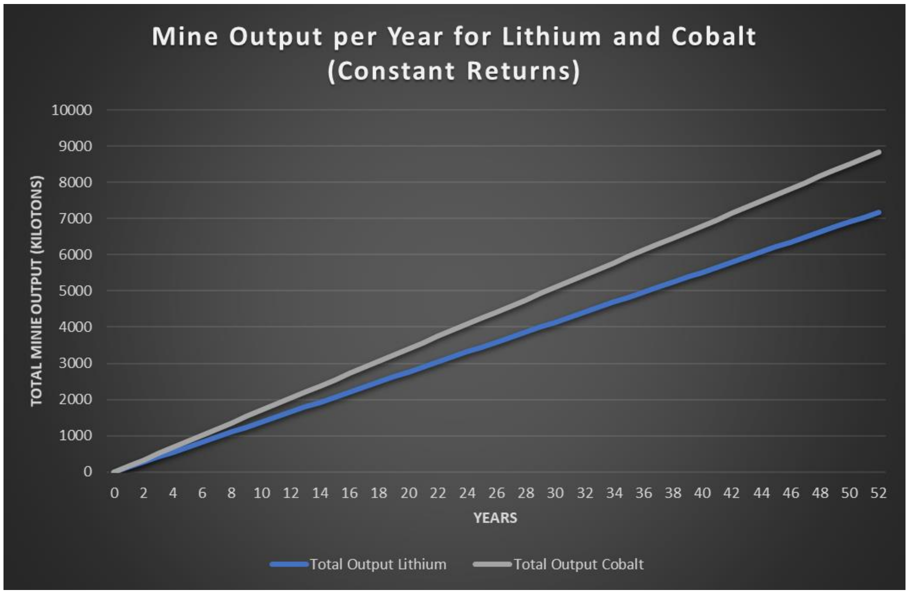
In addition to the various embedded costs mentioned above, the sheer raw material costs of producing electric vehicles is significant but little has been done prior to try and evaluate exactly how much this would cost in relation to the Paris Agreement. As we saw earlier we know A typical 1,000-pound EV battery contains about 30 pounds of lithium, 60 pounds of cobalt, 130 pounds of nickel, 190 pounds of graphite and 90 pounds of copper (Mills, 2021). The two major component metals in these batteries are Lithium and Cobalt. There are two conditions in which we can look at the production rate of mining. First, let's look at how much Lithium and Cobalt are needed to produce the total amount of vehicles under our first condition, constant returns.

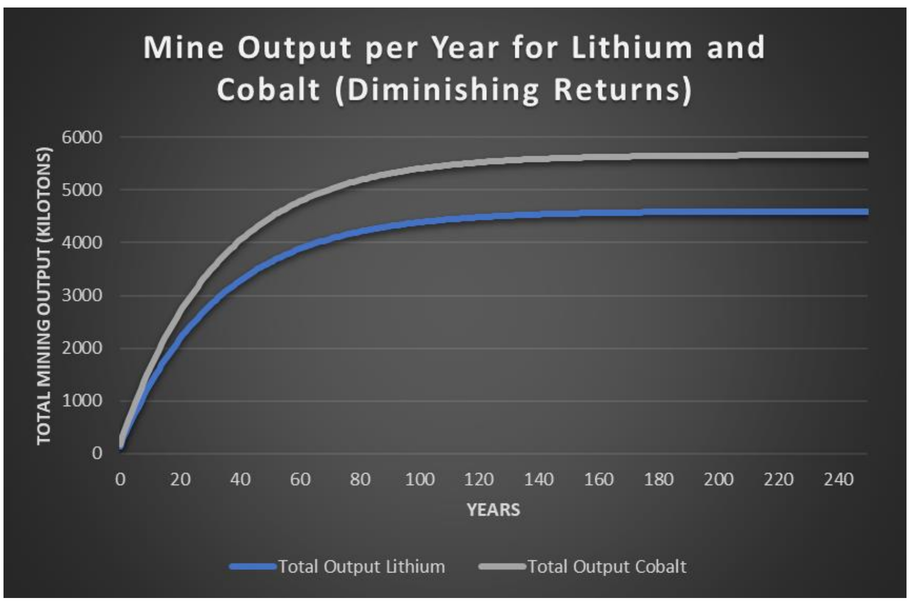
According to Statista "SQM Lithium Production 2020" and "Production volume of cobalt from mines worldwide from 2010 to 2021" we know that global Lithium and Cobalt mines produce 138 kilotons and 170 kilotons of Lithium and Cobalt respectively annually, Under the assumption of a constant rate of return we can predict how long it would take to produce enough of each metal to make the 289,200,000 electric vehicle car batteries that are required to reach the Paris goal. This is with the assumption that the batteries will not have to be replaced making it on the lower side of estimations. With each car needing 30lbs of Lithium and 60lbs of Cobalt we know that to make the 289,200,000 car batteries we would need approximately 4,338 and 8,676 kilotons of each metal respectively. When we take these two figures and divide them by their yearly production rate per mine we see that it would take approximately 31.4 years to produce enough Lithium and 51 years to produce enough Cobalt to make the required amount of batteries for our goal. These rates can be seen plotted on **Figure 2**.

There are two main things to consider here after making these initial calculations. The first being that we are well over the allotted time for the Paris Agreement's goal to be achieved. At the time of this study there is only 8 more years until the year 2030 which is when the change is supposed to be fully implemented. Therefore at current rates of production from our mines we are not close to a position that can sustain the requirements of output that we need. The second realization is that Cobalt production is significantly lower than Lithium production for its proportional need as an input for the electric vehicle. The need for an increase in production is something that must happen across the board and not just in one mineral sector. These predictions though, stray along the low side of estimates mainly due to that initial assumption of constant rate of returns.

As discussed in the theory section above we know that in Economics most, if not all, things do not experience constant rates of return, in fact, most experience a decreasing marginal rate of return. This fact is true for the mining industry as well. McKinsey and Company did a study on relative mining production rates. They found that over the past decade, mining productivity as measured by MPI has declined 3 percent per year, meaning that mining companies are 28 percent less efficient in digging and moving a ton of total material today than they were ten years ago (Lala, Moyo, Rechach, Sellschop 2015). Once we factor in the fact that mines have been experiencing a notable decrease in their output and production rate, the things that stood out under constant returns become much more significant. First off, after factoring in a 3% decline yearly, we see that to produce enough Lithium and Cobalt to reach the Paris Agreement's goals, it would take approximately 94.5 years to produce enough lithium and >250 years to produce enough Cobalt. The reason in which there is no approximate Cobalt number is due to the fact that the calculation would not produce an attainable figure, therefore productions will not be able to reach the Paris Climate Agreement's goal at all. As seen in **Figure 3** both the production curves eventually hit a plateau point in which the diminishing marginal returns becomes so significant that productions is essentially finished and the actual goal is never reached.

Figure 2-3:





It is important to note that these assumptions rely on the fact that mining productivity will stay at a constant decline. The McKinsey project did find though that there are some mines, in particular a Copper mine in South America that has shown some increases in production when initially looking at the data, the increased outlays on labor and, in particular, on operating costs across the full 2005–2013 period resulted in productivity declining almost 2 percent per year on average over the period (Lala, Moyo, Rechach, Sellschop 2015).

Mining productivity rates are not where they need to be in order to produce enough of the two major component minerals for the Paris Agreement's electric vehicle goal. For sake of argument if producers did want to produce enough Lithium and Cobalt to make the 289,200,000 cars by 2030 production would exponentially need to be increased. Lithium production would need to increase from 138 kilotons per year to 542.25 kilotons. Cobalt would need to increase production from 170 kilotons annually to 1,084.5 kilotons. These are figures that are just not possible under the current production rates.

POLICY RECOMMENDATIONS

The study mentions above two different dilemmas the first of which is that with current rates of mining production it would take upwards of a 100 years to produce enough of the essential minerals in order to create the amount of electric vehicles for the Paris Climate Agreement's electric vehicle goal. Considering the significant amount of time it would take it seems almost unlikely to just push off the goal for another 100 years until we have enough minerals to make the cars we need. It is probable to infer that the makers and signing countries of the Paris Agreement probably were not going to stop at 20% and their ideal goal would be to have the majority of the worlds transportation sector be operated by electric vehicles. Therefore we could be talking potentially about 1,000s of years before we see a policy like that enacted at a point where many of the policy makers and generations after would not be alive to witness this feat. So if pushing back the goal is not the right answer that leaves another alternative which points to the secondary dilemma.

If at current production rates we are not able to produce enough minerals that we need, then the first logical answer would be to increase production. But what would an in increase in production look like? It would take a significant increase in the input variables of the mines. Thus increasing the costs of the mines and not just the monetary but the imbedded costs that were mentioned above. Higher production in mining with current equipment and methods would mean hundreds of millions of gallons more water being used to extract the Lithium from the brines. It would mean hundreds of millions of gallons of waste contaminating the surrounding environments and ground water. It would mean tens if not hundreds of thousands of more children working in the Democratic Republic of the Congo's Cobalt mines along with hundreds of thousands of more workers being mistreated and put into danger. It would mean destruction of ecosystems, endangerment of species and segregation within indigenous people's societies for the purpose of partially reaching the goal of decreasing global temperature increase by 2 degrees Celsius by the year 2030.

There are three distinct policy paths that the global community could take for them to reach some of their goals. The first of which would be improving mining technology. Mining technology as it exists today is not efficient or productive enough to obtain the goals that the global community wants to see. This study has already calculated out the declining marginal productivity rates, but that assumes that mining technology will stay the same forever leading up until that point. We know from countless examples throughout history that the human species is one of innovation and has constantly been improving technologies at an increasing rate. As the call for electric vehicles becomes louder and there is potential for significant profitability in that sector it will not take long for human innovation to catch up in a way that would make mining the amount of minerals needed to make large amounts of electric vehicles possible. If productivity rates in mining were to see significant increases due to improvements in the mining technologies then the Paris Agreement's goals would be more attainable.

The next policy recommendation that could have less costs and potentially a significantly higher benefit to society would be to invest money and resources into the electric vehicle batteries. Many major car companies such as Tesla, Ford and GM have put significant hours of R and D into creating their versions of electric cars and batteries. Although they have very strong and working prototypes, this does not mean that the innovation is complete. Right now, as seen by the analysis of this study above, electric vehicle batteries take too high of a costs in not only mining the earth but also in human lives, and the environment. If more money were to be put into electric vehicle battery technologies to significantly reduce the amount of mineral input costs we may be able to reach a point where converting 20%, of the entire fleet of transportation vehicles to electric is a very real and attainable goal. Policies such as subsidies to companies that decrease the amount of controversial mineral costs like Cobalt or taxes for the amount of controversial input variables per vehicle could have the power to incentivize innovation. With this new innovation we could see a world where large amounts of electric vehicles are attainable.

The final policy recommendation, and the one that may be the most attainable would be switching the Paris Agreement's policy goal from individual vehicles to public transportation. A policy focused around public transportation could both eliminate green house gasses emitted from the public transportation sector and reduce the use of private vehicle emissions with one stroke. If policies by the governments who signed the agreement would agree to invest money in improving their public transportation sectors infrastructure to make it more efficient and desirable to use amongst its citizens then less people would be driving their individual cars and trucks. This would lessen the amount of emissions coming from that sector. Furthermore, if these governments would also focus and subsidize the production of electric public transportation vehicles such as busses and railway systems this would decreases the amount of emissions from that sector as well. We would see people using public transportation more and greenhouse gases less. Major car companies are just starting to join the electric vehicle movement and a policy such as this would see some significant pushback, however governments have the power to use their money for projects that the see as more beneficial to their citizens as well as incentivize private businesses through taxes and subsidies to attain their goals.

CONCLUSION

A world dominated by the electric vehicles seems closer than it has ever been. Yet with our current output and knowledge of the costs that come with taking on a mining project as large as the Paris Climate Agreement, it also seems very distant if nothing changes. With our current production rates the Paris Climate Agreement’s electric vehicle goal is not just a bad one, but it is unattainable. The mining cost alone should be a deterrent, and if not, then the human and environmental cost should be enough to make policy maker realize that they need to change course. All in all, improvements in technology and investment in infrastructure could pose a more beneficial solution to this very real problem we are at the crossroads of.

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