GERMAN-MONGOLIAN INSTITUTE FOR RESOURCES AND TECHNOLOGY

Faculty of Mathematics, Computer, and Natural Sciences

Bachelor Thesis

Resource Management in Electromobility: Case Study on Copper

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PREFACE

This bachelor thesis work was partly done in a team work with 8th semester environmental engineering student Ulziitogtokh Altan-Ulzii. In the initial duration, thesis was part of a project on electromobility done in Freiberg, Germany with other students participating in the project. The project divided the class in groups, and each group did research on a certain raw material used in electromobility (lithium, nickel, REE, etc.). Ulziitogtokh and me, were assigned in one team, after which we chose copper as the raw material of choice. The initial stage of the project ended on 18th of March, 2020. After this, Ulziitogtokh and I continued out thesis works focusing on our own focuses. Consequently, some parts of the thesis will include parts which were contributed by both of us. In detail, in chapters Copper Resources and Copper Production Ulziitogtokh made contributions.

Working in team while writing this thesis work was useful in many ways. The research of my thesis does not go only in one direction. Environmental and economical aspects are always entwined together. Ulziitogtokh helped me see a bigger picture and include considerations regarding the environmental implications in my thesis work. From my side, considerations of economic and management aspects hopefully helped in Ulziitogtokh's thesis work. In my opinion, in cases, where thesis topics are interconnected together, similar structure would be an applicable choice for the future graduates.

ABSTRACT

Electromobility is expanding in a rapid pace as it was considered a potential solution to reducing environmental pollution and oil shortage issues. Every type of electric mobility, such as Battery Electric Vehicles, Plug-In Hybrid Electric Vehicles, Hybrid Electric Vehicles rely on critical mineral resources heavily. Raw materials such as lithium, cobalt, copper, rare earth elements are crucial to the production of electric vehicles. Copper is one of the priority elements that are essential to electromobility technology. While copper is used throughout electric vehicles, charging stations and supporting infrastructure because of the metal's durability, high conductivity, and efficiency, it has the largest impact on the environment regarding CO2 loading. This study shows various scenarios of the electric mobility technology types and forecast of future electric mobility demand worldwide by 2030 to estimate the demand of copper that is associated with electric mobility. Bass diffusion model which is used to predict the demand of newly introduced products was chosen as our main prediction tool. An analogous prediction of variables in the Bass diffusion model. In total, in year 2030, total demand for copper for electric mobility in general (all three types of vehicles) under the pessimistic, neutral, optimistic scenarios are 5Mt, 10Mt, 20Mt respectively. It is obvious that there are no temporary shortages that will be occurred because of the lack of resources, but the production supply might face excess demand or shortage.

Policies continue to have a major influence on the development of electric mobility. Government regulations will play a crucial role in expanding the sales of electric vehicles. Following this rise in demand, enough research and forecasting has to be done in order to prevent bad environmental consequences, in order to minimize the cost of implementing this system to countries. Entire automotive industry, its supply chain, technological aspects, research and development, operations, service and maintenance departments will require a completely different set of workforce and knowledge, systems will go through major changes. On top of this, the public opinion has to be changed and the period of adjusting will not be overnight. Due to lack and shortage of information, it is not possible currently to come up with a definite answer on Mongolia's position in this industry. The electric transportation industry is only at its beginning stages in Mongolia, therefore further research has to be made consistently in this field in order to come up with a consistent answer.

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LIST OF ABBREVIATION

BEVs	Battery Electric Vehicles
ICEVs	Internal Combustion Engine Vehicles
EVs	Electric Vehicles
PHEVs	Plug-in Hybrid Electric Vehicles
REEVs	Range-extended Electric Vehicles
PLDVs	Passenger light-duty vehicles
LCVs	Light Commercial Vehicles
REEs	Rare Earth Elements

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1. INTRODUCTION

1.1 BACKGROUND

1.1.1 ELECTROMOBILITY

Electric mobility comprises all street vehicles that are powered by an electric motor and primarily get their energy from the power grid. This includes battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs), range-extended electric vehicles (REEVs). If electric groups are grouped in another way, it includes passenger light-duty vehicles (PLDVs), light commercial vehicles (LCVs), buses, trucks, two/three-wheelers. Aside from electric cars, the whole concept of electric mobility also includes the energy supply side as well as the charging and traffic infrastructure, since those components are interconnected and together, they lead to sustainable mobility. One thing all definitions have in common is the narrow interpretation of the term electric vehicles, which is based on the idea of electricity as "fuel." This was chosen for good reason. Because when you consider the entire energy chain, only electricity offers efficiency advantages and – as long as it comes from renewable sources – a significant reduction of greenhouse gas emissions (1). EVs were first invented in the mid 19-th century, however, the rise of internal combustion engines contributed to the decline of electric cars and led to its reintroduction in the last few decades as the environmental impact of a vehicle became high in priority (2).

Electric mobility is expanding at a rapid pace. According to the report done by BloombergNEF, over 2million electric vehicles were sold in 2018 compared to a few thousand in 2010, showing the implication that the number will get much bigger in the future (3). The same report states that by 2040, 57% of all passenger vehicle sales and over 30% of the global passenger sales will be electric.

1.1.2 RAW MATERIALS IN ELECTRIC MOBILITY

In comparison to conventional vehicles, electric vehicles require a much higher amount of technology metals in their propulsion systems. Key components of electric vehicles are traction batteries, electric motors, and power electronics and each of them relies on different kinds of metal respectively. Whereas the motors are in need of rare earth, several specific materials, in particular, lithium and cobalt are essential in electric car batteries. In power electronics, copper and precious metals such as gold, silver, and palladium play an important role. In addition, lightweight materials are essential in vehicle construction as well, including aluminum and carbon fiber-reinforced polymer (4).

In terms of the situation with regard to their demand and availability, undoubtedly lithium attracts the most attention in the electric vehicle field due to its high demand. This list is followed by cobalt. Apart from lithium and cobalt, there are sufficient resources available to meet the growing demand for technology metals in the medium and long term (4).
However, from the ecological and economical perspective, certain consequences will definitely arise due to the supply for these drastically increasing demands. It shows that secondary material usage from recycling and innovative technologies, that reduce specific and absolute resource demand, is strategically significant in the electric mobility field in the future. While the recycling of the rare earth is questionable in electric motors, lithium, cobalt, and nickel are the main focus of interest. In power electronics, copper and precious metals also should be considered similarly.
Substitution can also be an alternative solution for scarce resources and other arising issues. Substitution means the replacement of the raw materials with other materials with similar properties but is either economically or ecologically beneficial.
For example, neodymium-iron-boron permanent magnet motors can be replaced by asynchronous motors, which are rare earth-free (4).

1.1.3 COPPER

Copper is a reddish-gold metal by the appearance that is accounted for by its properties of ductility, malleability, and machinability. Traditionally it has been one of the metals used to make coins, along with silver and gold. However, it is the most common of the three and therefore the least valued. Most copper is used in electrical equipment such as wiring and motors. This is because it conducts both heat and electricity very well, and can be drawn into wires. It also has uses in construction (for example roofing and plumbing), and industrial machinery (such as heat exchangers). Copper metal does occur naturally, but by far the greatest source is in minerals such as chalcopyrite and bornite. Copper is obtained from these ores and minerals by smelting, leaching, and electrolysis. The major copper-producing countries are Chile, Peru, and China (5). As a general guiding principle, however, it is evident that the closer that an EV becomes to replicating the performance of ICE, the more copper content it will require to do so. Therefore, the larger the vehicle the greater the amount of copper will be used. This is because copper is an essential element to an electric vehicle’s motor, battery, power electronics as well as the infrastructure, which includes charging infrastructure and possible update on the current power grid.

1.2 RESEARCH QUESTION

- Following the knowledge gaps presented in the introduction, this paper raises one main research questions and one sub-question as follows.
- RQ1. Considering the fast paced demand of electromobility, do we have enough copper supply worldwide in the coming years?
- RQ2. If and how Mongolia can contribute to this industry?

2. STATE OF THE ART

2.1 ELECTROMOBILITY

2.1.1 ELECTRIC VEHICLE INDUSTRY

Electric vehicles, compared to ICEs, which run on fuel, rely on electricity as their driving part. These types of vehicles run on an electric motor which either get their energy from a battery or in case of a hybrid – partly from a combustion engine. Batteries are of various types: lithium ion, molten salt, nickel-based, etc. The main reason why electric vehicle industry has become this popular is because of its environmental advantages. It is considered as a replacement of diesel engine cars which are one of the biggest factors of climate change with its high amount of carbon emissions. Electric vehicles stand out for other reasons too: low cost fuel, low maintenance, convenience of charging at home, reduced noise, smooth driving experience. These factors are in fact the driving force of its future demand.

For now, the demand of electric cars has been relatively low compared to conventional cars. The technology of batteries are improving day by day increasing the driving range, governments are still adjusting to this change and one by one adding regulations which favor this type of transport, more production of electric vehicles reduces the price which was considered very expensive at first. Because of the changing process, this industry will rise in demand exponentially, experts believe.

Key players in the electric vehicle industry are as follows

Type of Vehicle	**By Region**	**By companies**
Battery Electric Vehicles	China	Tesla
Hybrid Electric Vehicles	United States	BMW Group
Plug-in Hybrid Electric Vehicles	Norway	Nissan Motor Corporation
Fuel Cell Electric Vehicles	Japan	Toyota Motor Corporation
	Germany	Volkswagen AG
	United Kingdom	General Motors
	Netherlands	Daimler AG
	Sweden	Ford Motor Company
	Canada	Energica Motor Company S.p.A
	France	BYD Company Motors

Figure 1. Key players in the electric vehicle industry.

2.1.2 MARKET OUTLOOK

The rapid growth in EV sales and fleets is one area where world electricity consumption will begin to accelerate. In 2017 global EV sales reached 1.1 million units, a 54% year-on-year increase although only 2.2% of all new auto registrations. Over 2 million electric vehicles were sold in 2018, up from just a few thousand in 2010, and there is no sign of slowing down (3).

In Figure 2, shares of annual electric vehicle sales can be seen compared to the share of annual sales in internal combustion engine vehicles. A clear rising behavior can be seen in electric vehicle slope, while ICE is losing popularity, consequently being overtaken by electric vehicles around 2035 to 2040.

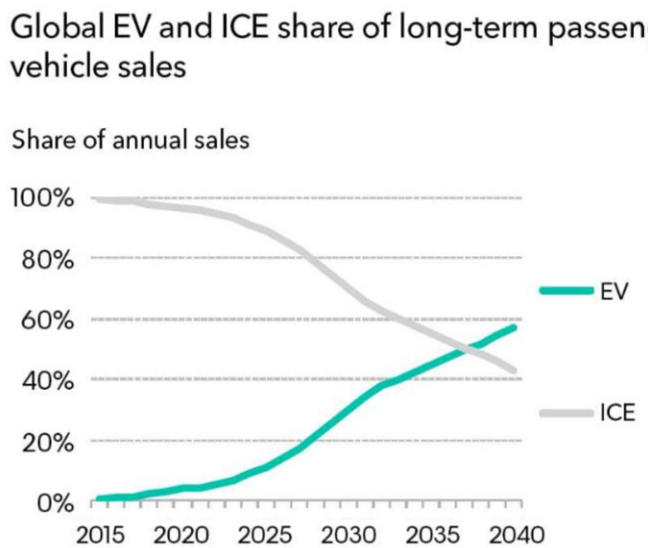

Figure 2. Global long-term passenger vehicle sales by drivetrain. Adapted from 'Electric Vehicle Outlook 2019' (3)

Europe is implementing national vehicle taxation and grants for a smooth change over to the EV industry. In 2019, Europe has 44% growth in EV sales, where they are aiming to meet the 95 gCO2/km target by 2020/2021. Within Europe, Norway, Iceland and the Netherlands are key countries for new electric car sales. At the end of last year, the global fleet of plug-ins was around 7 and a half million, adding up to more than 8 million counting heavy commercial vehicles.

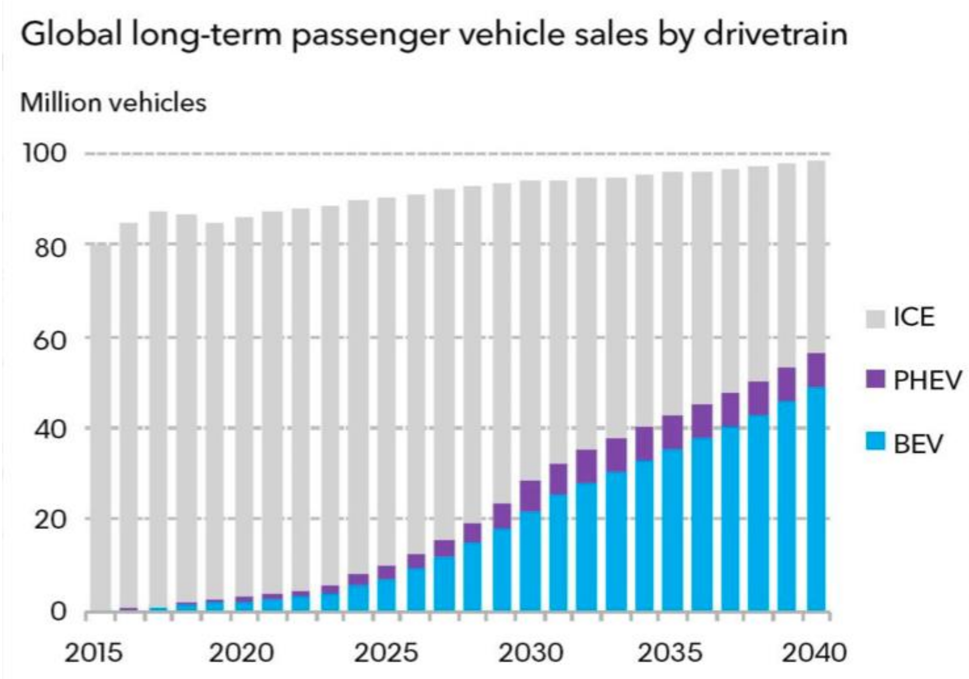

Figure 3. Global EV and ICE share of long-term passenger vehicle sales. Adapted from 'Electric Vehicle Outlook 2019' (3).

A study by BloombergNEF says that despite the rapid uptake of electric vehicles across many different vehicle segments, direct CO2 emissions from road transport continue rising for the next 10 years before peaking in 2030, mainly due to a growing internal combustion vehicle fleet. If additional power sector emissions from generation are added, the peak is 2-3 years later.

By 2040, direct emissions from passenger cars, commercial vehicles and buses have returned to similar levels as in 2018. If national governments want to hit the aggressive emissions reductions targets they have set, a stronger policy push will be needed to accelerate adoption (3).

Due to the COVID-19 pandemic, the sales of electric vehicles becomes a bit more difficult. 2020 started with plant shutdowns for most car manufacturing companies, shutdowns of raw materials processing plants, which is still ongoing in most parts of the world, and considering the economic crisis worldwide, the EV market will face a huge slump. If quarantine measures continue into the second half of 2020, which most likely it will, there will be insufficient parts supply, which will require recovering in the next years (6).

2.2 COPPER RESOURCES

2.2.1 GENERAL DATA

According to the Reilly II (2019), the future availability of minerals is subject to the concept of reserves and other identified resources, undiscovered resources which will be discovered in the future, and material that will be recycled from currently being used stocks of minerals or from minerals in waste disposal sites. As of 2019, total world copper reserves are assessed at 830 million tonnes and yearly demand is rated at 28 million tonnes. (Reilly II, 2019)

As a result of the U.S. Geological Survey (2015), the research team found that South America is the predominant source for both identified and undiscovered porphyry copper resources. Furthermore, several regions of Asia including China have also a remarkable potential for undiscovered porphyry copper assets.

In case of sediment-hosted stratabound copper deposits, sedimentary basins in the Northwest Botswana Rift in Botswana and Namibia, the Benguela and Cuanza Basins of Angola, and the Cambrian rocks of Egypt, Israel, and Jordan are evaluated as having huge potential for undiscovered copper resources; however, these regions require extra examination, research, and assessment. (U.S. Geological Survey, 2015)

In addition, North America has huge influence for an identified copper resource among states, Arizona was considered as the leading copper-producing State and was responsible for about 66% of domestic output, followed by Utah, New Mexico, Nevada, Montana, Michigan, and Missouri. (Reilly II, 2019)

2.2.3 LONG-TERM AVAILABILITY OF COPPER

According to the International Copper Study Group, 2019, experts assume that it is exceptionally impossible to run out of copper. They come up with this assessment because of the following three main reasons.

At first, United States Geological Survey annual studies have been confirming that increases in reserves have grown despite increased demand for copper. In the period 2008-2018, 197 million tonnes of copper have been mined. In that same period, however, reserves have grown by 280 million tonnes. This reflects additional exploration, technological advances and the evolving economics of mining. (USGS, 2018)

In the second place, technology plays a key role in addressing many of the challenges faced by new copper production. Experts assume that known and as yet unknown innovations will ensure new mine production continues to provide vital copper supplies.

In addition, copper recycling has to be considered as an essential part of copper availability since today's primary copper is tomorrow's recycled material. The most significant advantage of copper recycling is that copper can be recycled repeatedly without any loss of performance. On the other hand, experts believe that copper will continue to be an inseparable and affirmative contributor to industry innovation and sustainable developments in the future based on the latest knowledge and data on geological availability.

2.3 COPPER PRODUCTION

2.3.1 Mining

The extraction of copper-bearing ores is the first step of primary copper production. There are three basic types of copper mining, namely surface, underground mining, and leaching. Among them, open-pit mining is the predominant mining ways all around the world. Since 1900, world production was less than 0,5Mt copper. Whereas world copper mine production reached 4Mt by 1960s, as of 2018 it has grown into a total of 21,6Mt copper. (Anyadike, 2002)
Concentrate and SX-EW are considered as two main processes of extracted copper. While there was no virtual existent of SX-EW technology before the 1960s, this stood now at 3.9 million tons in 2018. The studies state that this gain will continue to increase in the future.
The most influential region in copper mine production is Latin America and the countries including Chile and Peru provide 42% of world total copper mine production as of 2018. In 2018, the world copper mine capacity is recorded as 24,1Mt and it is expected to reach 28,9Mt in 2023. (International Copper Study Group, 2019)

2.3.2 Concentrator

After the extraction step, copper is crushed and ground followed by a concentration by flotation. In this process, copper concentrates on the product reach typically around 30% of copper, but grades can range from 20 to 40 percent. (U.S. Geological Survey, 2014)

2.3.3 Smelter

In the following smelting process, sometimes preceded by a roasting step, concentrated copper is transformed into a "matte" containing 50-70% copper. Smelting is the pyrometallurgical process used to process copper products which has up to 98.5-99.5% copper content. This end product of the smelting process is called blister copper. In 2018, world copper smelter production reached 20.1 million tonnes of copper and Asia, in particular, China has a huge influence on production. Apart from the primary smelter, secondary smelter which use copper scraps as their main source of feed. Within the last 40 years, secondary feed smelter production reached more than 3Mt that was 0,3Mt in 1980. (International Copper Study Group, 2019)

As of now, the following 5 main technologies are applied all around the world: Flash/Continuous, Modified Reverb/Convert, Chinese technology, Reverb/Black/Rotary, and Electric. Among them, the use of Flash and Continuous technology accounted for 69 % of total copper smelter capacity in 2018. (International Copper Study Group, 2019)

2.3.4 Refinery

In the final step, the blister copper goes to the refinery and re-melted and cast into anodes for electro-refining. The output of electro-refining is refined copper cathodes, assaying which is over 99.99% of copper. Since the 1980s, secondary refinery technology was introduced and as of 2018 almost 5Mt out of 27,2Mt of world refined copper is produced with refinery from the secondary feed. The main technologies in copper refinery industries are Electrolytic, Electrowinning, and Fire Refining. While the world copper refinery capacity is 27,5 Mt in 2018, it tends to reach 32Mt by 2023. The most influential region by refined copper production is Asia which accounted for 13,5Mt alone in 2018. (International Copper Study Group, 2019)

2.4 COPPER APPLICATION

2.4.1 APPLICATION

Copper has many desirable attributes that promote its widespread use in many applications across a number of end-use markets. However, its key property is that it is an excellent conductor of electricity, with 70% of total consumption solely due to this characteristic. It is mainly used as the conductor core in wire and cable and in electrical parts and connectors. These generally represent the highest added-value applications for copper.

Copper is also an effective conductor of heat, which represents a further 10% of its applications, mainly in tubes and pipes in heat exchanger devices. Copper is also malleable, ductile, machinable, formable, corrosion-resistant, antimicrobial and aesthetic which consumes for the remaining 11% of all other areas of use measured by property. Copper can be alloyed with other metals such as zinc (to form brass) or tin (to create bronze), and many other metals to develop new features for different applications. It is also one of the most recycled metals as it can be endlessly reused without any loss of performance. The industry claims a global Recycling Input Rate of 35% that enhances copper's green and sustainability credentials.

In general, refined copper is used in those applications where electrical conductivity is paramount, ensuring supreme reliability over a very long product lifetime. An example is wires and cables that use very small conductor sizes, such as electric motor windings or electronic leads or flexes. Refined copper enables wire rod to be drawn efficiently down to very fine diameters with a very low incidence of wire breaks that might otherwise harm equipment productivity. Cheaper wire rods made from recycled copper contain more impurities that increase the risk of wire breaks at lower diameters, which outweigh any initial cost savings. Refined copper also offers superior properties in heat transfer applications such as air conditioning tubes. 62% of total world consumption is continuously cast into wire rod, which is the starting point for copper wire drawing, and ultimately the production of a myriad of insulated copper wire and cable that are sold to end user industries.

High purity refined copper is mainly consumed in those applications requiring excellent electrical conductivity and particularly in those where wire is drawn clown to a very thin gauge (impurities lead to wire breaks). Examples include most types of insulated wires and cables, including winding wires for electric motors, electrical connectors, semi-conductors and bus bars. Copper tubes for HVACR (Heating, Ventilation, Air Conditioning and Refrigeration) applications utilize refined copper as well for its superior heat transfer characteristics.

In 2018, the size and ranking of the top five leading individual semi-manufactured markets:

Copper wire rod (18,7Mt)

Alloy rod and bar (2,9Mt)

Copper industrial tube (2,7Mt)

Alloy plate, sheet and strip (2,2Mt)

The industry's best assessment of the structure of copper's main end use markets is as follows:

Building & construction – 28%

Utility Network Infrastructure – 17%

Industrial equipment – 11%

Transport equipment – 13%

Consumer & general products – 9%

HVACR equipment – 8%

Electronic goods – 5%

Diverse uses – 10%

In practice, it seems that the structure of the end use markets for copper has been fairly stable as there has been little shift in the overall shares over time.

China is by far the largest national consumer of copper (refined and direct melts scrap) accounting for 50% of world demand with an output of copper and alloy semi-manufactures in excess of 14,7Mt copper content. The USA is the next biggest with an output of semi manufacturers of 2,2Mt. Germany (1,6Mt), South Korea (1,0Mt), Italy (1,0Mt) and India (0,9Mt) are the other major consumers with semis production of around 1.0M.

The markets for copper and alloy semi-manufactures are regional in nature. This is because copper is dense heavy metal, and with the added value on semi-manufactures being relatively low, it is generally not economic to transport them long distances. For most types of wire and cable, the market is also national or regional due to prevailing standards and specifications and the difficulties in maintaining adequate inventories in multiple product lines, to serve the local market from a remote location (7).

2.4.2 COPPER MARKET OUTLOOK

Over the forecast period, we are projecting that total copper consumption in all forms will increase from 30,6Mt in 2018 to 43,6Mt by 2035 at a compound annual growth rate of 2,1%. Based on projections of world population growth, this implies that the world total consumption per capita will advance from 4,0kg in 2018 to 4,5 kg by 2025 and 5,0kg by 2035. The primary demand drivers are growth in population, gross domestic product, urbanization and the resultant increase in demand for electricity for heat, light and power in utility distribution networks, buildings, equipment and devices (7).

Table 1. Compound annual growth rates of direct use scrap and refined copper respectively in 2035. Adapted from COPPER: Demand to 2035 (10).

	Direct use scrap			Refined copper		
	In 2018	In 2035	Compound annual growth rate	In 2018	In 2035	Compound annual growth rate
Global volumes	6.9Mt	11.1Mt	2.9%	23.7Mt	32.5Mt	1.9%
Demand	Secondary requirements of smelters and refiners; steady			Grow to 27.7Mt at an annual rate of 2.2%py out to 2025 then slow to 1.6%py		
Per capita	0.9kg (1.0kg in 2025)	1.3kg		3.1kg (3.4kg in 2025)	3.7kg	
	Semis production (consumption)					
	In 2018	In 2035	Compound annual growth rate	Output of copper wire rod, the most important semi-manufacture, is forecast to grow at a rate of 2.0% from 18.7Mt to 26.4Mt over this period. China, ASEAN, India, Eastern Europe and the Middle East will be the main centers of semis production growth. Among the major countries, output is expected to decline in Japan, South Korea, Taiwan and France.		
Global volumes	33.0Mt	46.7Mt	2.1%			
Total semis output	30.6Mt	43.6Mt	2.1%			
Copper wire rod	18.7Mt	26.4Mt	2.0%			

Total copper demand in electrical applications is predicted to grow at a compound annual rate of 2.2% and contribute just under 84% of all the tonnage increase over the forecast period. Heat transfer applications should grow at a faster rate of 2.6%py and will provide just under 13% of all of the increase while demand in other properties will rise by just 0.8%py to generate only 3.5% of all projected consumption growth.

It should be noted that this data does not take into account the potential rise of the electric vehicle industry in the next decades. A specific study done on the impact of electric vehicle sales on the copper industry is explained in detail in part ‘Discussion’.

2.4.3 COPPER DEMAND OUTLOOK BY REGION

For some of the most mature economies which are export-reliant, there is likely to be some further decline as they lose market share to the newer emerging, lower-cost consumers. The growth in electro-deposited copper foil production, mainly driven by the electric vehicle (EV) market will provide some positive opportunities in Eastern Europe and North America. Currently, there is only limited capacity in these regions and foil capacity in these regions and foil will need to be made locally for EV batteries to serve the JIT supply chains of the automobile industry. However, in aggregate, Asia and China will remain the most important part of the copper market and the main focus of consumption growth.

Table 2. Copper production demand outlook by region until 2035. (Mt) Adapted from COPPER: Demand to 2035 (10).

Region/ Country	2018	2019	2020	2025	2030	2035	CAGR 2018-2035 (%)
Total Americas	3.4	3.5	3.5	3.6	3.8	3.9	0.8
Total Europe	5.7	5.7	5.8	6.1	6.3	6.5	0.8
Africa & Middle East	0.9	0.9	1.0	1.3	1.3	1.5	2.9
Industrializing Asia	2.4	2.5	2.7	3.5	4.2	4.9	4.2
China	14.7	15.2	15.7	18.8	21.7	24.3	3.0
Industrialized Asia	3.4	3.4	3.3	3.0	2.7	2.5	-1,9
Total World	30.6	31.1	31.9	36.2	40.0	43.6	2.1

2.5 COPPER IN ELECTROMOBILITY

2.5.1 FUTURE TREND OF COPPER IN ELECTROMOBILITY

The automotive industry is a significant end use market for copper, accounting for around 10% of total copper demand. However, copper demand for EVs at present is probably only 0.1-0.2%. In the first half 2018, the automotive sector was among the strongest growing end uses thanks to a steady increase in auto sales reinforced by rising intensity of use of around 5%py due to the increasing functionality and complexity of the harness. A large number wiring harness assemblers amasses huge order books during this period and as a result committed to major programmes of capacity expansion, mainly through the commissioning of new plants in low labour cost locations. American suppliers made multiple investments in Mexico, Nicaragua, Guatemala, Paraguay and El Salvador. Asian manufacturers built new capacity in China, the Philippines, Vietnam, Indonesia, Cambodia, Thailand, India and Bangladesh. Meanwhile European suppliers have been constructing new plants in Bulgaria, Romania, Moldova, Ukraine, Macedonia, Serbia, Lithuania, Albania, Tunisia, Egypt and Morocco.

Compared to the 20-25kg of copper in internal combustion engines (ICEs), hybrid electric vehicles (HEVs) might have double (~40kg) the copper intensity, plug-in hybrid electric vehicles (PHEVs) up to triple (~60kg) the intensity and battery electric vehicles (BEVs) up to four times (~83kg) the copper intensity. E-bus might use anywhere between 205kg (if it were a Hybrid) or 370kg (if it were purely Battery driven) The potential impact on copper demand is not just the rate of growth of EVs, but also the mix of EV types and the type of vehicles such as automobiles, SUVs and commercial vehicles. It is evident that the closer that an EV becomes to replicating the performance of ICE, the more copper content it will require to do so. It might wait mid-2020s before the copper industry sees the incremental tonnage growth over traditional ICEs.. The three positives are: a rising average intensity of copper per vehicle, more copper cables in **charging infrastructure**, and eventually a need to selectively upgrade parts of the **low voltage distribution power grid** that are unable cope with the additional electricity demand. Given the many possible variables in the forecast it is impossible to be too precise on the ultimate positive impact on copper demand. However, by 2035 it is estimated that the incremental gains in EVs alone over their ICE equivalent might range between **1.85-2.25Mt**. On top of this are the gains in the network infrastructure (charging cables and grid upgrades) which we estimate may range between **1.25-1.75Mt**. This is divided **0.5-0.6Mt in charging cables** and **0.75-1.15Mt in distribution grid upgrades**. The center point of these combined estimates is **3.55Mt** of additional copper demand by 2035 which would alone represent an **11-12%** increase on world demand in 2018 (7).

Many industry commentators believe that ultimately the growth rate of EV sales will be determined by the level and type of incentives offered to buyers. These might include such measures such as subsidies or exemptions to value added tax or car tax or free parking, free toll road use or free entry to congestion charging zones in major cities.

EV users will have a slow charging cable to use at home, usually overnight, but they will also need a broad network of charging stations across the country. This would include work places, kerbside parking, car parks, train stations, airports, shopping centres, supermarkets, petrol stations and motorway service stations, etc. In order to ensure that the charging infrastructure is ready, governments may bring in legislation to ensure that all-build housing and multiple dwelling units must have charging points pre-installed (7).

Despite the rapid uptake of electric vehicles across many different vehicle segments, direct CO2 emissions from road transport continue rising for the next 10 years before peaking in 2030, mainly due to a growing internal combustion vehicle fleet. If additional power sector emissions from generation are added, the peak is 2-3 years later.

By 2040, direct emissions from passenger cars, commercial vehicles and buses have returned to similar levels as in 2018. If national governments want to hit the aggressive emissions reductions targets they have set, a stronger policy push will be needed to accelerate adoption (3).

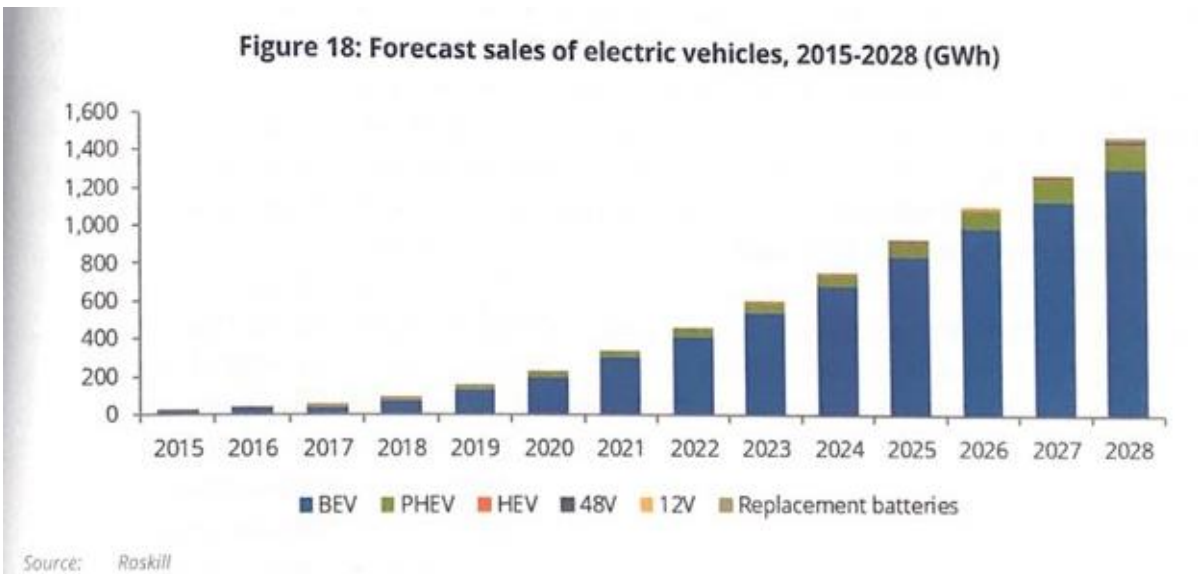

Figure 4. Forecast sales of electric vehicles, 2015-2028 (GWh) (7)

3. METHODOLOGY

3.1 DEMAND AND SUPPLY PRINCIPLE

3.1.1 DEMAND

Demand and supply analysis can be done in order to answer the first research question. Demand and supply analysis is the study of behavior of buyers and sellers which in result shows transaction prices and quantities (8).

The term demand is used by economists to describe the amount of goods or services customers are willing to pay for at each price (9). Demand is centered on needs and wants, from an economist's perspective both are considered the same thing while for a customer need and want may be different. Another feature of a demand is the ability of the consumer to pay for certain goods or services. If a consumer cannot pay for it, the demand is considered no longer effective.

Price is the amount of money a buyer is paying for a unit of a specific good or service. Consequently, the total number of items sold at that price is called quality demanded. An increase in price of certain goods or services inevitably decreases the quantity demanded of that item. Contrarily, a fall in price will result a rise in the quantity demanded. For example, if we assume that the price of car fuel increases, car drivers will look for ways to reduce their time travelling by cars with ways of using public transportation, walking, carpooling and managing their travel destinations to be closer to their homes. This inverse relationship between price and quantity demanded is called the law of demand (9).

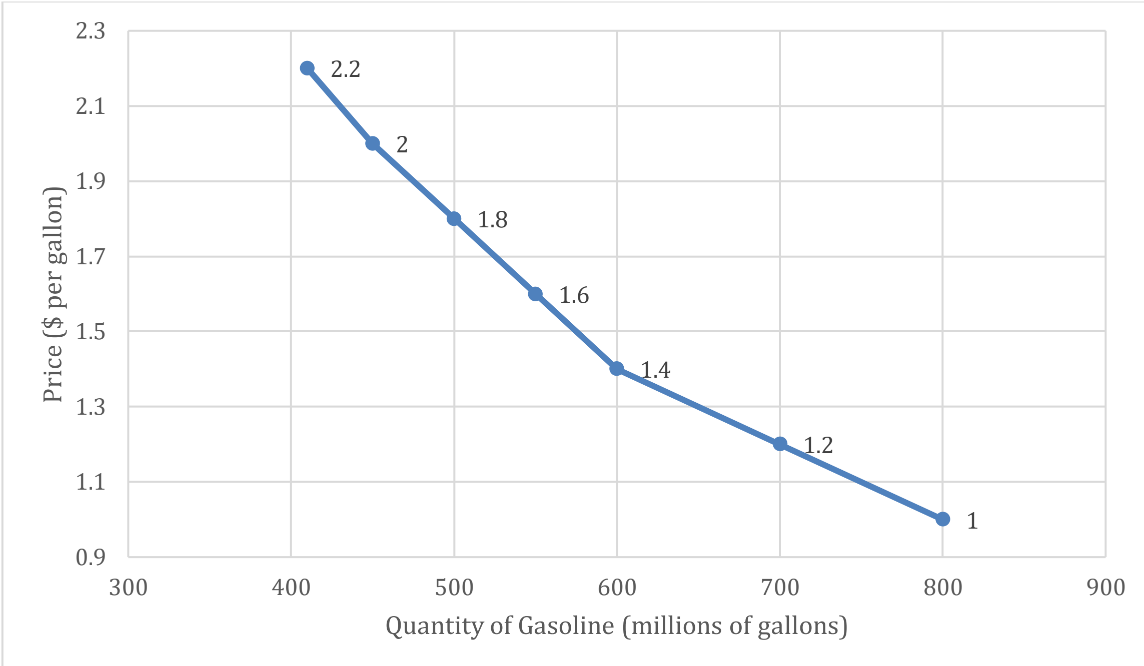

Figure 5. Example demand figure for gasoline. The demand schedule shows that as the price rises, quantity demanded decreases, and vice versa (12).

An example demand curve can be seen in Figure 5, it shows the relationship between price and quantity demanded in a clear way. These curves look different for different goods and services: some will appear steep, some will appear flat, straight or curved. However, the general similarity of having a slope down from left to right is constant.

3.1.2 SUPPLY

The amount of a particular product a producer is willing to supply at each price is called supply. Rise in price almost always means rise in the quantity supplied of that product, and vice versa. Taking the same example from the previous section: if the price of car fuel increases, industries will try to expand oil reserve exploration, build new oil refineries, increase hours of existing gas stations, etc. (9). Law of supply shows a positive relationship between price and quantity supplied.

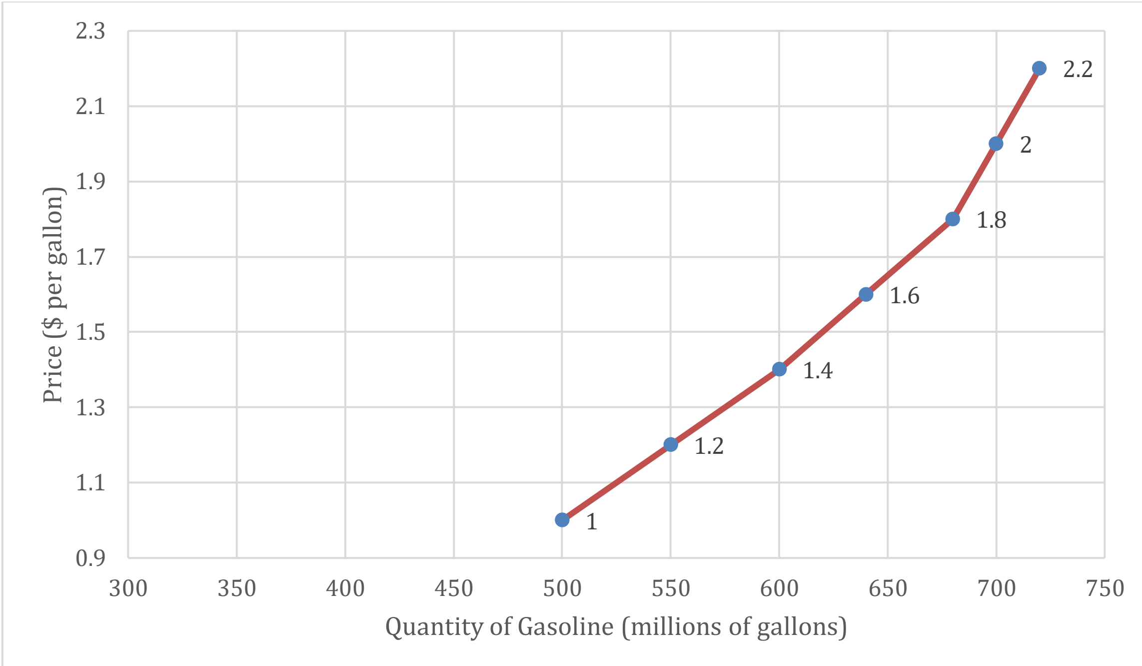

Figure 6. Supply curve for gasoline. As price rises, quantity supplied also increases, vice versa. (12)

Demand and supply curve combined together create a demand and supply curve, which decide the price and the quantity to be bought and sold.

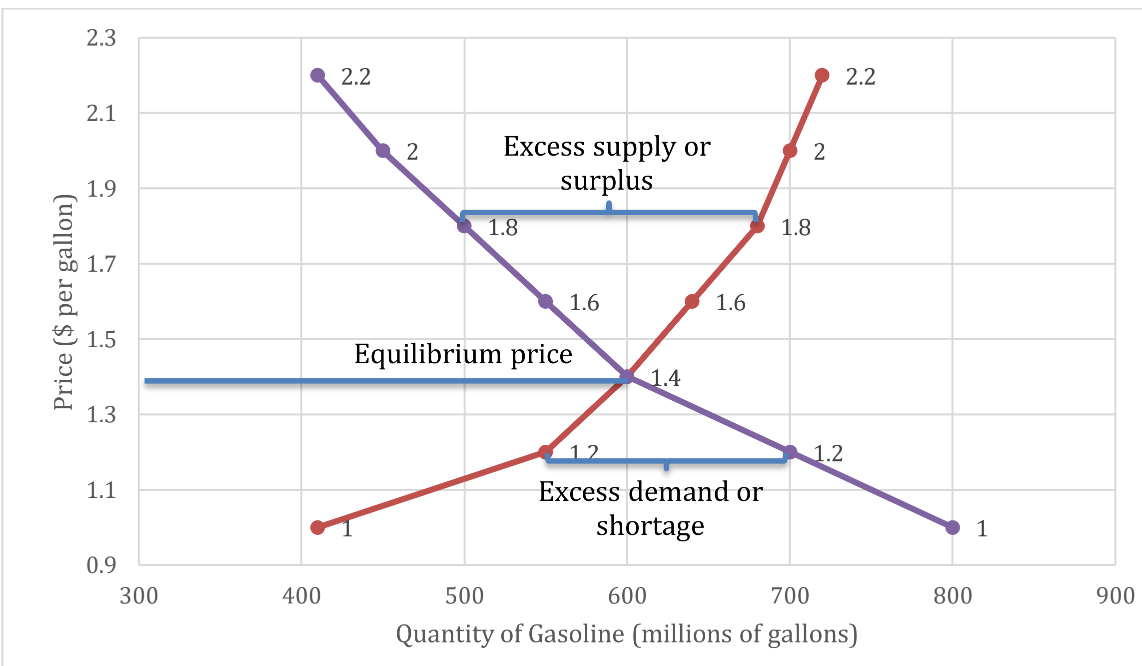

Figure 7. Demand and Supply Curve for Gasoline. Example. (12)

The demand curve (purple) and the supply curve (red) intersect at $1.4 price and quantity of 600. This is called the equilibrium line. At a price above equilibrium, quantity supplied exceeds the quantity demanded leading to a excess supply. The same thing with price below equilibrium this will lead to excess demand (12).

Following the concept of demand and supply and its correlations, efficiency plays a big role. Efficiency is “when it is impossible to improve the situation of one party without imposing a cost on another” (9).

3.2 BASS DIFFUSION MODEL

Forecasting the potential supply and demand is crucial for businesses strategic planning. The assumption of forecasting is normally based on a belief that the future sales pattern will imitate the past pattern. Many methods of forecasting such as Kaes and Azeem, Laplan and Whisler are available, however, for new products, lack of previous data and market research get in the way of showing realistic forecasts. Bass diffusion model is used as a tool to determine potential supply and demand for new goods or services at a certain time based on parameters such as coefficient of innovation (p) and coefficient of imitation (q).

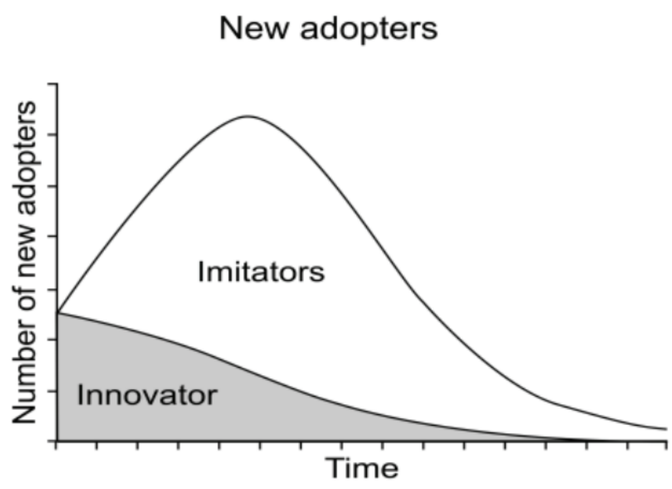

Figure 8. Bass diffusion model. Number of adopters versus time (13).

Bass diffusion model focuses on the adoption and imitation of new products. Adoption is the growth part of the product whereas imitation is the spread part. Therefore, under this method, consumers are divided into two groups: innovators and imitators. Innovators would be the buyers who are open to new changes and are willing to buy new products, imitators are people who are influenced by the purchase of the innovators and who buy the product from the interaction with the innovators (10). Figure 8 illustrates the change of numbers of innovators and imitators over time. This principle is also defined by its mathematical formulas Equation (1) – (5).

$$\frac{f(t)}{1-F(t)} = p + q \times F(t) \quad (1)$$

$$F(t) = \int_0^t f(t)dt \quad (2)$$

$$F(0) = 0 \quad (3)$$

$$n(t) = m \times f(t) = m \times \frac{p \times (p+q)^2 \times e^{-(p+q) \times t}}{[p + q \times e^{-(p+q)^t}]^2} \quad (4)$$

$$N(t) = m \times F(t) = m[\frac{1-e^{-(p+q) \times t}}{1+\frac{q}{p} \times e^{-(p+q) \times t}}] \quad (5)$$

Variables are:

$f(t)$ – proportion of adopters to potential adopters at time t;

$F(t)$ – cumulative proportion of adopters;

p – coefficient of innovation;

q – coefficient of imitation;

m – maximum market potential of adopters;

$n(t)$- number of adopters at time t;

$N(t)$ – number of cumulative adopters.

Out of these parameters, p, q & m should be defined. These parameters are estimated by analogy. Analogy method "compares data for a similar type of product in a specific region or same product in different regions" (11). A study by Li et al. has parameters for electric vehicle in China for four different technology pathways under pessimistic, neutral and optimistic demand scenarios. In this paper, we will use the parameters in Li et al.'s study and set values for worldwide market by looking at the correlation of China versus the world.

Two parameters innovation and imitation form an S-shaped curve at time t.

4. DISCUSSION

RQ1. COPPER AVAILABILITY

This section will provide an answer for the first research question of my study.

RQ1. Considering the fast paced demand of electromobility, do we have enough copper supply worldwide in the coming few decades?

The contributions of the study are as follows:

(1) based on the global electric vehicle sales data, the estimated scale of automotive electrification is shown from 2018 to 2035 using the bass diffusion model, which will show us the number of electric vehicle sales demand in this duration;

(2) future supply of copper is found for this duration in the future, however, this data will not account the future demand of electric vehicles;

(3) three electric vehicle pathways are considered to predict the demand for copper in electromobility industry;

(4) by accounting the additional demand of copper in electromobility to the normal copper demand, conclusion of copper supply can be made; and

(5) availability of other raw materials will be included in this analysis to complete the big picture of raw materials in electric vehicles.

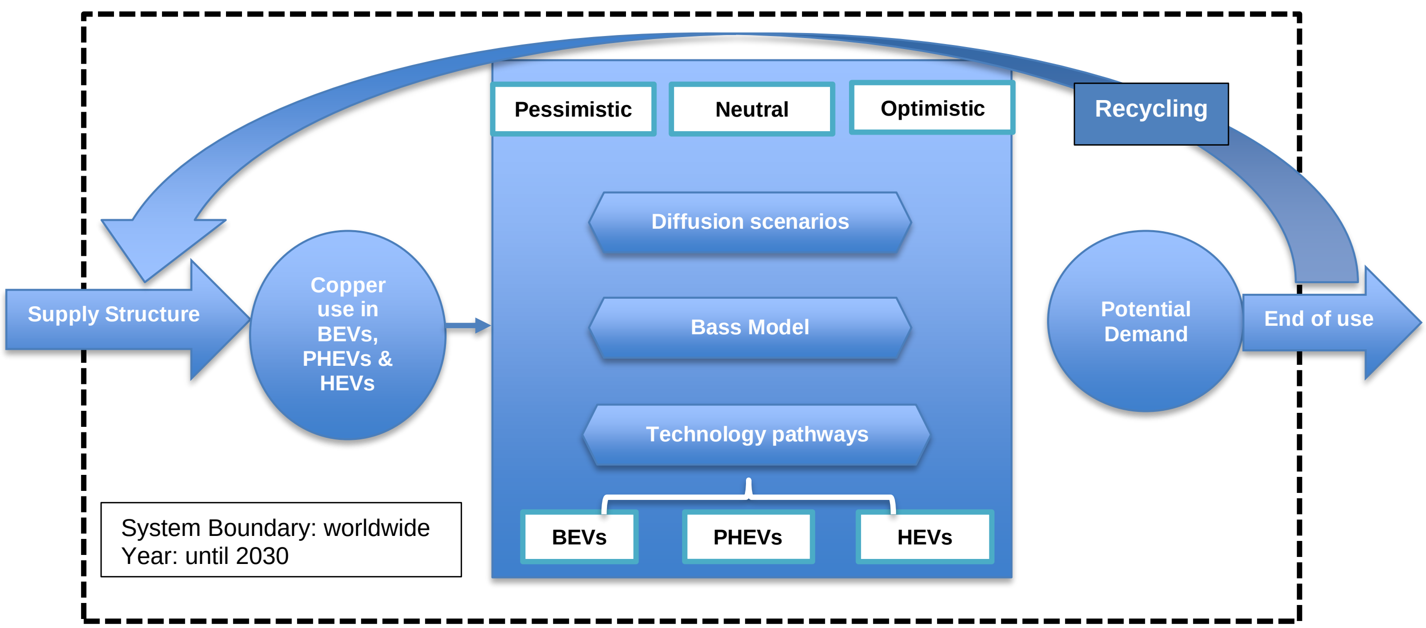

Figure 9. Framework for predicting the demand for copper in electric mobility.

In order to have an effective answer to the research question introduced before, many factors of the electric vehicle industry has to be considered: from policies from financial perspectives, innovation perspectives, and infrastructure availability. Following these considerations, the development of electric vehicles accelerates, thus the principle of demand and supply will start being implemented according to the law of demand.

4.1.1 SCALE OF ELECTRIC MOBILITY UNTIL 2030

Use of electric vehicles has been expanding rapidly thanks to the above mentioned government policies, technological advancements allowing for increased range and faster battery charging. But for now, the sales of electric vehicles are only at its beginning. Even though, automotive industry companies such as Volkswagen and Daimler are placing big investments for EVs, $50 billion and $23 billion respectively, electric vehicles represent only 2.2% of the worldwide vehicle market (12). However, it is worth noting that in five years, global sales of electric vehicles expanded more than ten times from 2015 until 2020: in 2015, China and Europe accounted for more than 560,000 units, following with 775,000 in the next year, 1.22 million in 2017, more than 3 million in the first quarter of 2018, 5 million at the end of 2018, 7.5 million by the end of 2019 (13).

Table 3. Light-duty plug-in electric vehicle cumulative sales, annual sales in the top EV selling countries and regional markets as of December 2018 (14).

Country	Cumulative sales		Annual sales	
	2018	2017	2018	2017
China	2,243,772	1,227,770	1,016,002	579,000
USA	1,126,000	764,666	361,307	199,818
Norway	296,215	209,122	86,290	71,737
Japan	257,363	205,350	52,013	54,100
UK	197,000	137,000	59,911	49,182
France	204,617	149,797	53,745	42,799
Germany	196,750	129,246	67,504	54,492
Netherlands	145,882	121,540	29,187	11,085
Canada	81,435	45,950	33,879	18,746
Sweden	79,579	49,670	29,909	19,793
Global Total	5,127,297	3,109,050	2,018,247	1,148,700

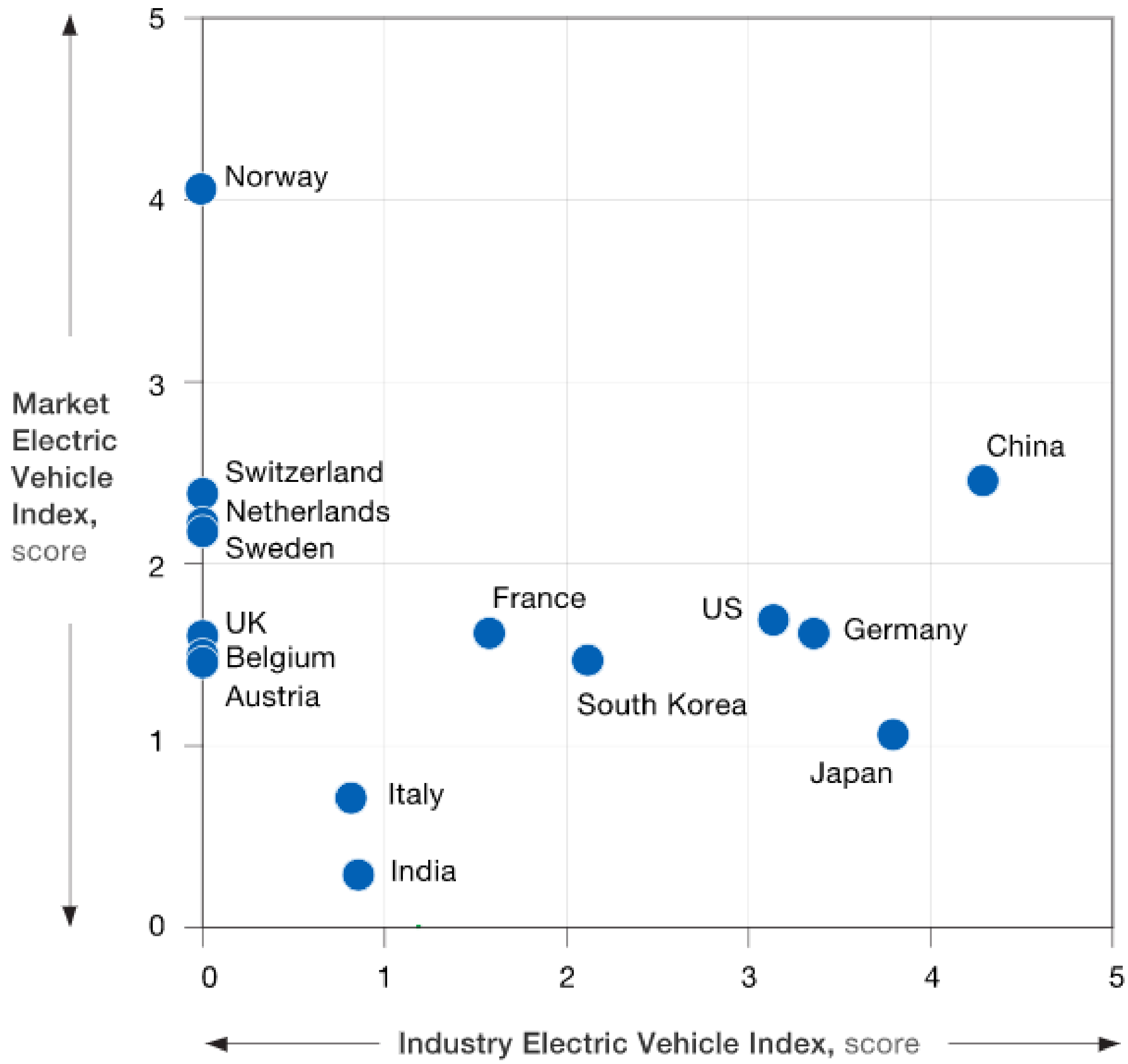

Figure 10. Electric Vehicle Index development of key countries, score out of five.

From Figure 10, Market Electric Vehicle Index rank goes as follows:

(1) Norway,

(2) China,

(3) Switzerland,

(4) Sweden,

(5) Netherlands,

(6) US,

(7) France,

(8) UK,

(9) Austria,
(10) Belgium,
(11) South Korea,
(12) Germany,
(13) Japan,
(14) Italy,
(15) India.

Industry Electric Vehicle Index rank goes as follows:

(1) China,
(2) Japan,
(3) Germany,
(4) US,
(5) South Korea,
(6) France,
(7) India,
(8) Italy (14).

Equation 6. Arithmetic average

$$\mathrm{AM} = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{a_1 + a_2 + \cdots + a_n}{n}$$

From Table 3, it can be seen that the main sales market for electric vehicles is in China. 2.2 million out of 5.1 million worldwide is 43,76% in 2018; 1.2 million out of 3.1 million is 39.49%. By calculating the arithmetic mean, we can assume that China's electric vehicle cumulative sales account for 41.62% of the worldwide sales. Looking at the annual sales, 1 million out of 2 million is 50.34% and 580 thousand out of 1.1 million is 50.40%. The arithmetic mean shows that China's annual electric vehicle sales takes up half of global sales.

Table 4. Parameters in the Bass model under 3 scenarios (2030) (14).

	Scenarios	m	p	q	R_2
BEV	Pessimistic	41 million	0.00040	0.73	0.98
	Neutral	82 million	0.00021	0.73	0.98

	Optimistic	164 million	0.00011	0.72	0.98
PHEV	Pessimistic	16 million	0.00089	0.57	0.98
	Neutral	32 million	0.00045	0.56	0.98
	Optimistic	64 million	0.00023	0.56	0.98
HEV	Pessimistic	16 million	0.0032	0.65	
	Neutral	32 million			
	Optimistic	64 million			

The BEV:PHEV ratio was 69:31 in 2018 and it rose to 74:26 in 2019. Therefore, because of lack of data in other years, it was considered that the ratio between BEV:PHEV is 72:28 (13). In the research article, the ratio between BEV:PHEV in China was 1:4 (11). Therefore, there are some slight changes compared to the worldwide ratio. We are also considering that the ratio between PHEV and HEV is relatively similar, but it should be noted that this was also predicted by analogous methods. As China is projected to reach 16 million vehicles by 2030, worldwide projection can be seen as 32 million. Other parameter values are added following these correlations.

Scenario for BEVs:

BEV:PHEV = 72:28;

PHEV = 32 million sales in 2030;

BEV = 32/28 * 72 = 82 million sales in 2030;

As stated before, parameters p and q are estimated in analogous method. First, values of coefficient of innovation p has to be higher than coefficient of imitation q. The diffusion process is related to the difference of these two parameters. As shown in Figure 8, the innovation parameter shows the slow growth speed and imitation parameter increases over time, which leads to a fast growth of the product. Also, as parameter p decreases, the number of imitators increases and the S-curve becomes steeper.

The diffusion model in Figures 11-13 show S-shaped curves. With market scale diffusion, technology for production of electric vehicles will increase, workforce will have more knowledge, and manufacturing costs will decrease, which will lead to a rapid growth of electric vehicles by approximately 2025. Then, as the industry will gradually mature and the growth will slow and come to the forecasted total number m.

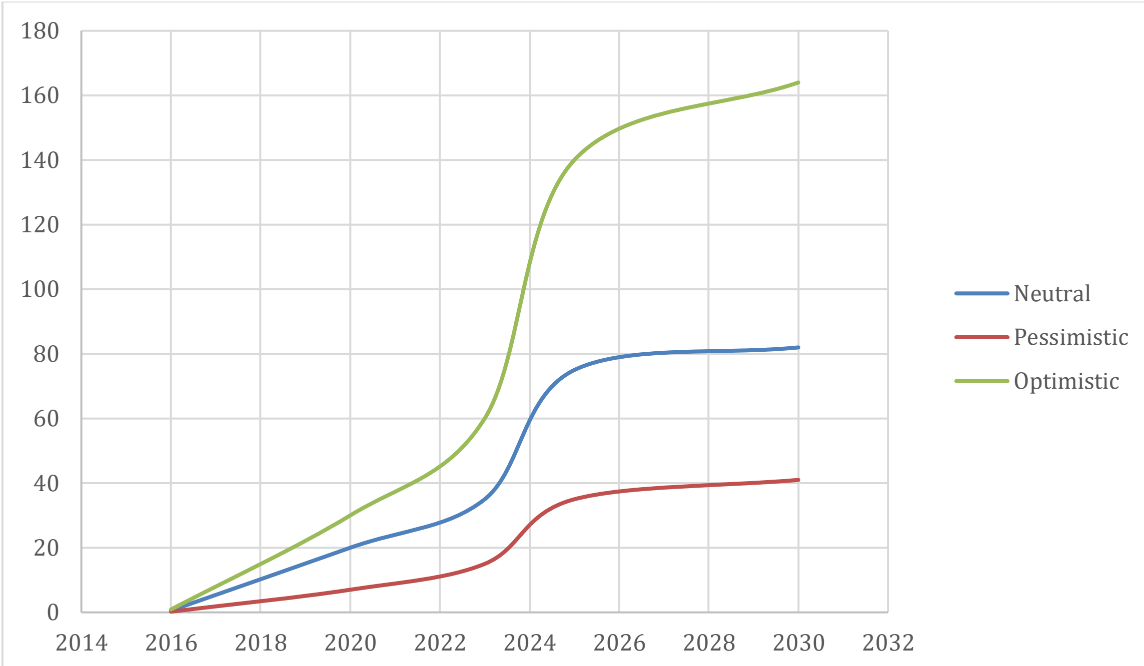

Figure 11. Diffusion curve of BEVs (until 2030)

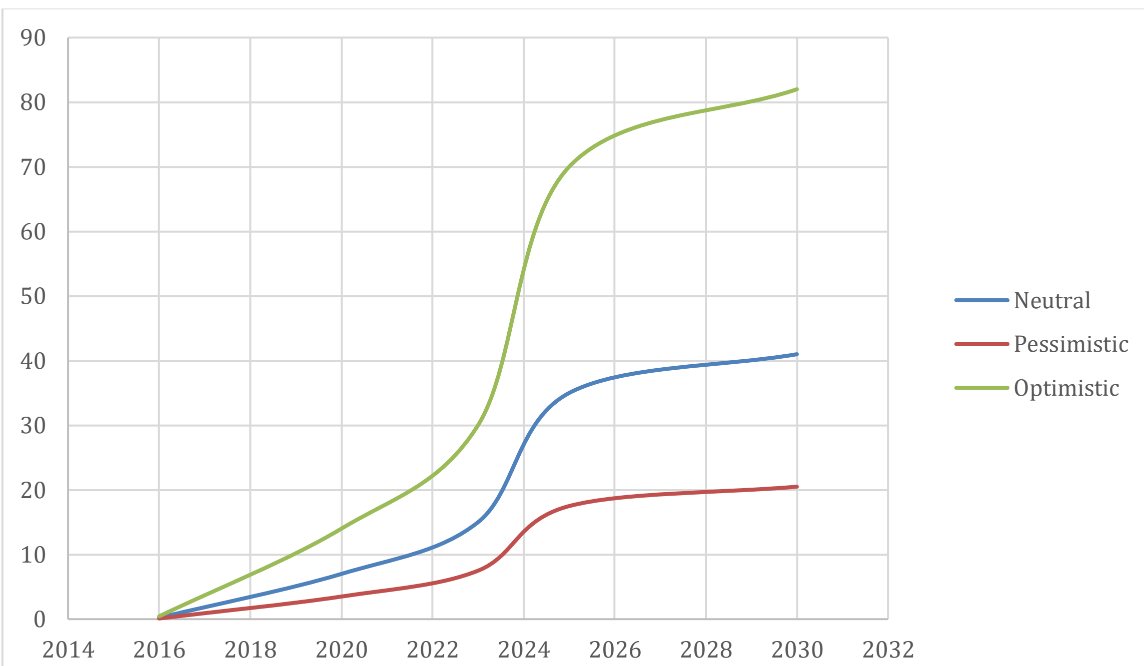

Figure 12. Diffusion curve of PHEVs (until 2030)

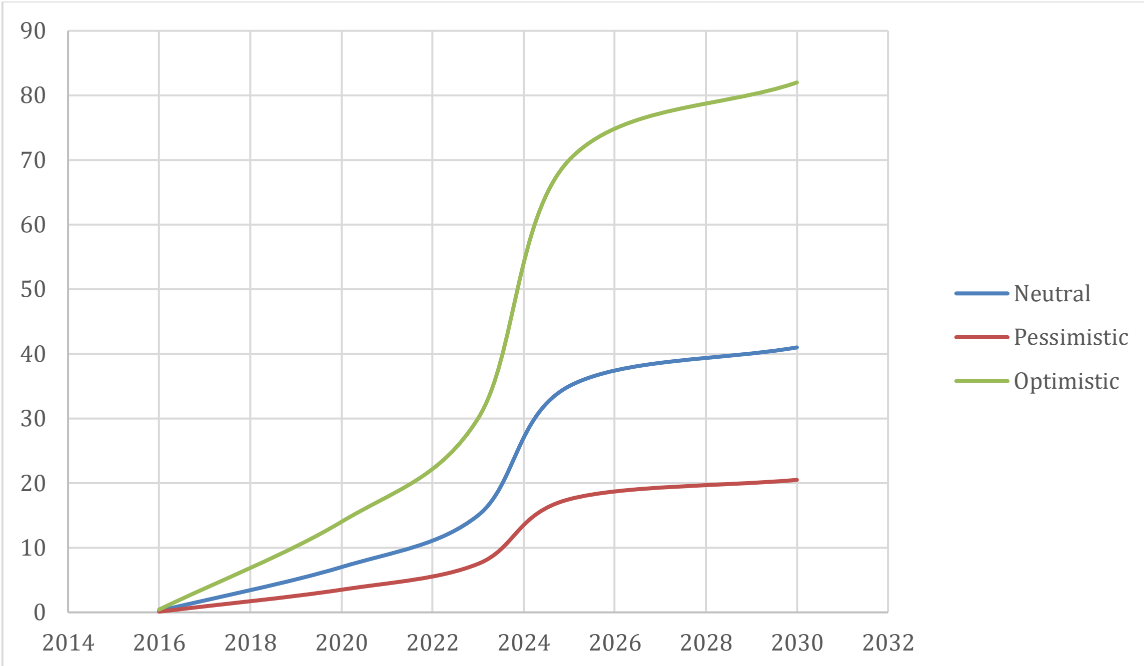

Figure 13. Diffusion curve of HEVs (until 2030)

4.1.2 DEMAND FOR COPPER IN ELECTRIC MOBILITY

Based on the prediction of electric mobility scale until 2030, potential demand for copper can be estimated. There is an estimated 20-25kg of copper in internal combustion engines (ICEs), ~40kg in hybrid electric vehicles (HEVs), ~60kg in plug-in hybrid electric vehicles (PHEVs) and ~83kg in battery electric vehicles (BEVs).

If the rise in demand of electric vehicles is not accounted, total copper consumption in all forms will increase to 40,0Mt by 2030 at a compound annual growth rate of 2,1% (7).

Table 5. Total demand of copper in electric vehicles.

	Units in demand (pessimistic, neutral, optimistic)	Amount of copper used in one car (kg)	Total demand for copper in Electric Vehicles	Total demand for REE in Electric Vehicles (10)
BEV	41 million	83 kg	3.4Mt	0.088Mt
	82 million		6.8Mt	0.178Mt
	164 million		13.6Mt	0.356Mt
PHEV	16 million	60 kg	0.96Mt	0.05Mt
	32 million		1.92Mt	0.1Mt
	64 million		3.84Mt	0.2Mt
HEV	16 million	40 kg	0.64Mt	0.05Mt
	32 million		1.28Mt	0.1Mt
	64 million		2.56Mt	0.2Mt

In total, in year 2030, total demand for copper for electric mobility in general (all three types of vehicles) under the pessimistic, neutral, optimistic scenarios are 5Mt, 10Mt, 20Mt respectively. From the paper by Roskill (7), it was estimated that the incremental gains in EV alone over their ICE equivalent might range between 1.85-2.25Mt., however, the number estimated through this calculation is a much higher number and is likely to take significant percentage of total copper demand.

From the data presented previously, the demand of copper will be around 40Mt in 2030. From the Bass diffusion model, in a neutral scenario, copper’s demand will increase by 10Mt, which makes the total demand 50Mt. Similarly, in a pessimistic scenario, total demand will be 45Mt, in an optimistic scenario, total demand will be 60Mt.

Looking at these numbers, we have to look at whether there is a sufficient amount of copper resource and copper supply to provide this rapid increase in copper demand that we calculated. Total resource of copper is 5600Mt and the total reserve is 830Mt. It is obvious that there are no temporary shortages that will be occurred because of the lack of resources in the near 100 years if the annual demand is assumed 50 Mt. Therefore, it is obvious that there will be enough reserves available.

However, problems may arise in the supply chain aspects of copper production. For example: According to Reilly II, world copper mine production and the mine capacity of copper are 20,6 Mt and 24,1 Mt respectively. In 2018, world copper smelter production reached 20,1 Mt. Furthermore, world copper refinery production accounted as 24 Mt, while its capacity is around 27,5Mt (15).

Here, we can see that we have not yet enough capacity and facilities to produce the calculated copper amount for 2035. As of now, the total world supply chain capacity is available for only around 28Mt copper production (15).

On the other hand, the ratio between production rate and capacity rate in each copper production sector looks affirmative. Being constantly lower than the capacity rate in all of the mining, smelters, and refineries indicate that it is not yet working at full capacity and they have always developed situations in each sector including new technologies, facilities and also manpower. According to the Reily, the world copper refinery capacity will reach 32 Mt by 2023 (15). In addition, the influence of copper recycling in the world copper market is continuously increasing year by year. Copper is 100% recyclable, without losing its electric conductivity properties.

For these reasons, we can assume that even though there are enough copper reserves globally to meet the demand, the production supply might face excess demand or shortage.

4.1.3 AVAILABILITY OF OTHER RAW MATERIALS

Rare Earth Elements

A similar study was done to estimate the demand of rare earth materials needed in electric vehicles. With no substitution case of REEs, the demand for these metals will be 25-100 thousand tons for HEVs, 8-33 thousand tons for PHEVs and 44-179 thousand tons for BEVs. The largest total demand for REEs will account for 22% of the world production in the period of 2018-2030. The highest demand for specific rare earth elements are as follows: Nd, Dy, Ce, Pr, La, Sm, Sc, Y, Eu, and Gd (11). An interesting observation is that the five most commonly used elements mentioned above account for 99% of the total demand. Compared to copper demand, case for REEs is a little more complicated due to its lack of exploration, not enough mines, and high prices. Rare earth elements are also considered environmentally unfriendly due to its complicated production process. To satisfy this demand, factors such as substitution materials and recovery technologies could help the demand for REEs in long term. (11)

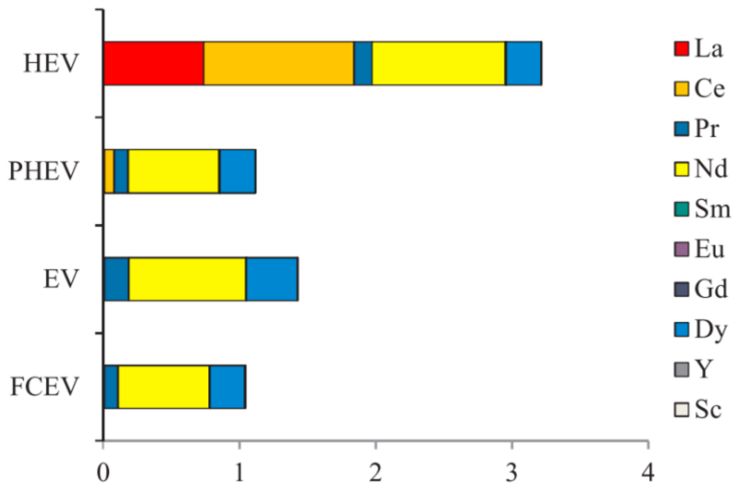

Figure 14. REEs used in HEVs, PHEVs, EVs, and FCEVs (14).

Lithium

Lithium is used as a critical element needed in the battery of electric vehicles. This metal is used in many industrial sectors such as small electronics with portable batteries, which has already resulted in fourfold increase in reserves since 2000s until 2017. Studies say that the demand of lithium would reach around 1.5 times the current lithium reserves in 2050. This identifies major risks on the lithium market, such as inability to meet the demand on time, uncertainties about environmental aspects and commercial strategies. The study suggests further implementations of a supply chain network for electric vehicle battery which takes into account remanufacturing and recycling of its metals (16).

In general, an average battery electric car contains 1200kg of metals, while ICEs – 800 kg; Hence, the market for metals used in BEVs will rise following the rise in demand of electric vehicles. Ultimately, all metals are limited, therefore, a further step has to be thought out in recyclability of identified parts, design and simulation processes have to be researched for the best recycling processes for maximizing metal recovery (17).

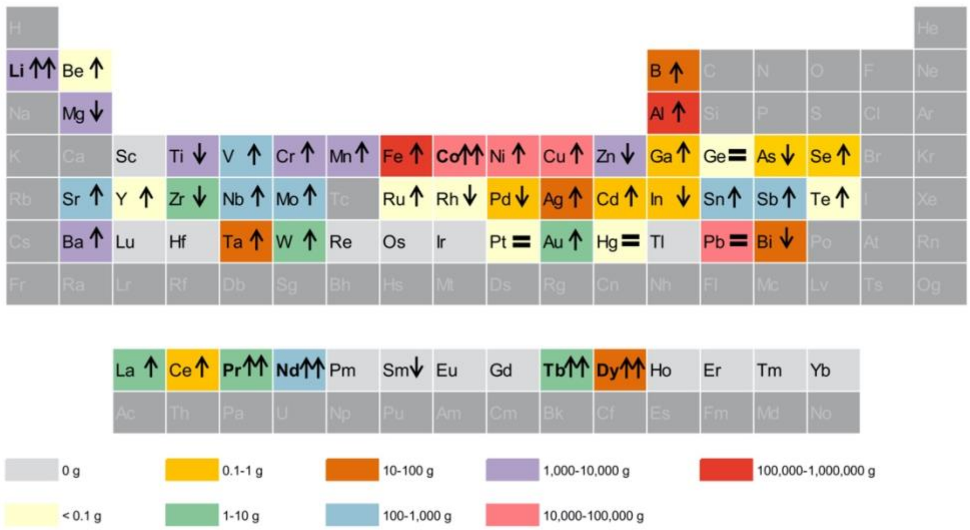

Figure 15. Metals contained in BEVs with a Li-ion battery NMC 6:2:2. The Arrows indicate the difference in comparison with the ICE Vehicles (16).

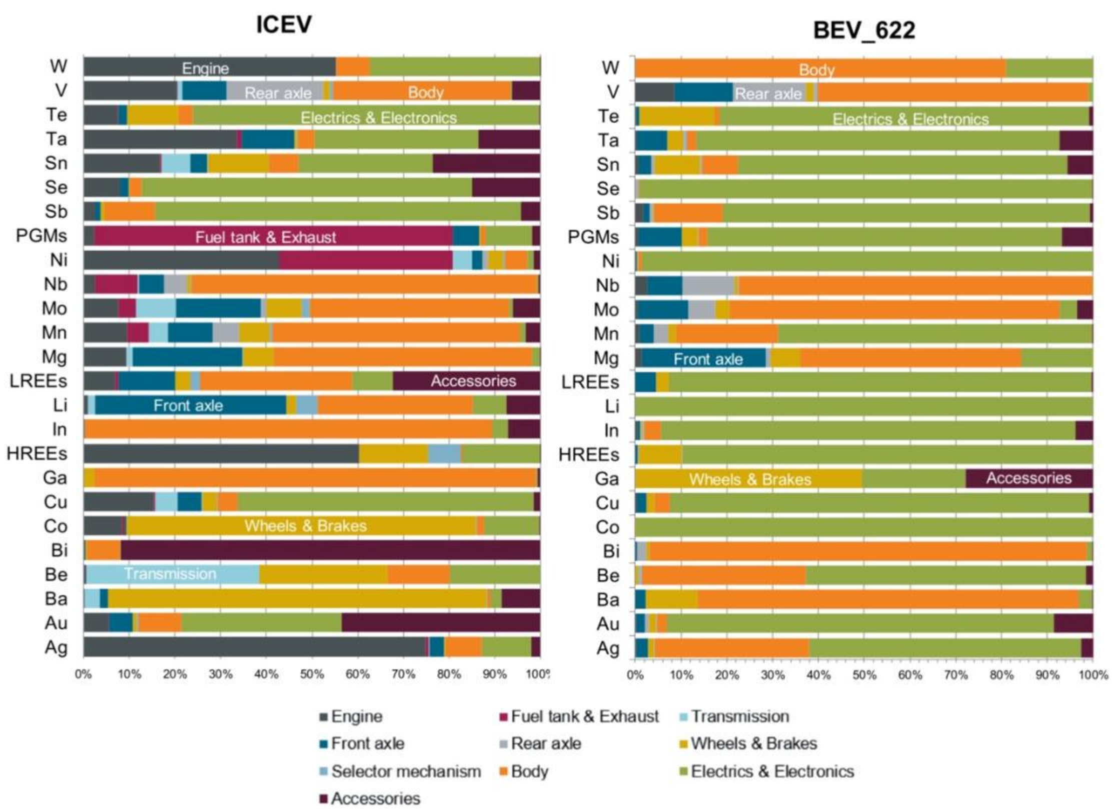

Figure 16. Metal distribution within the ICEs and BEVs. The electric vehicle uses a Li-ion battery NMC 6:2:2 (16).

RQ2. IF AND HOW CAN MONGOLIA CONTRIBUTE TO THE EV INDUSTRY?

This section will provide an answer for the second research question of my study.

RQ2. If and how can Mongolia contribute to the EV industry?

The structure of the study are as follows:

(1) Current state of electric vehicles in Mongolia is briefly introduced;

(2) Current state of copper production in Mongolia is briefly introduced;

(3) Study is made on the key factors of electric vehicle supply chain management

(4) Recommendation will be made based on the previous information.

4.2.1 Electric Vehicles in Mongolia

Mongolia is still very new to the trend of electric vehicles. Even though a big percentage of cars in traffic today are Hybrid Toyota Priuses, pure electric cars are not quite popular in Mongolia yet. In 2018, 74 pure electric vehicles were present in the capital of Mongolia, Ulaanbaatar (18). Due to lack of information, an exact number of electric vehicles was not possible to be estimated. This is connected to many issues within the country: the road system, charging infrastructure, public awareness, etc.

(1) Because of extreme climate conditions such as freezing winter, winds with sand particles and so on, the roads cannot hold out in long periods of time.

(2) The capital does not have enough charging infrastructures for electric vehicles.

(3) The price of new technology vehicles are inevitably high. Current GDP of Mongolia does not allow for average working class to purchase electric vehicles easily.

(4) The adaptation of electric vehicles to the public will also take a considerable amount of time.

(5) Mongolia does not use 2 wheelers or 3 wheelers as constant transportation compared to other Asian countries.

However, Mongolia is not entirely behind. Usually, cars are not able to use their cars once a week depending on the car license plate number. The Mongolian government implemented no license plate restrictions for electric vehicles, making it possible for electric vehicles to transport any day of the week.

4.2.2 Electric Buses in Mongolia

Trolleybuses in Mongolia

There are currently 47 trolleybuses in Mongolia. Trolleybuses draw power from dual overhead wires which are connected to electricity. In one trolleybus, which are in traffic in Mongolia since

1987, it is estimated that around 200-300kg of copper are present, main copper consumption going to the wiring system. An average life cycle is 12 years. Mongolia assembles the trolleybuses themselves with equipment and parts that are bought and imported from other countries. In order to avoid the risk of power outage In Mongolia, some of the trolleybuses are using additional built-in diesel engine generators. Once the assembling is done, the main cost of trolleybuses go to the maintenance of the wiring systems. Because there has been a lack of attention in the maintenance of the wiring systems, the speed and the efficiency of trolleybuses have been decreasing. The public transport of Mongolia is allowed to use electricity at a discounted price, therefore the daily average cost of trolleybuses is 12’000 Tugriks (~$5) (19).

Trial electric buses in Mongolia

There are 8 trial electric buses in Ulaanbaatar’s public transport which were introduced on February 12th, 2020. The trial run will end soon, however, the exact date is unknown. The buses are made in China and have LTO, LFP battery types. The lifecycle of the buses is 8 years, and the lifetime of the chargers and the battery is 30 years. There are 2 charging stations for these buses: on both base buildings of Public transport. The daily average cost of trolleybuses is 12’000 Tugriks (~$5).

Figure 17 shows that the number of buses in Ulaanbaatar in 2018 was 4482 (20), 55 of them are electric. A normal ICE bus daily cost of fuel is approximately 200’000 Tugriks (~$80). A simple comparison can be made here that if a proper maintenance and quality management of electric buses and trolleybuses were made, The electric bus and relatively electric vehicles will be a better choice in terms of costs (19).

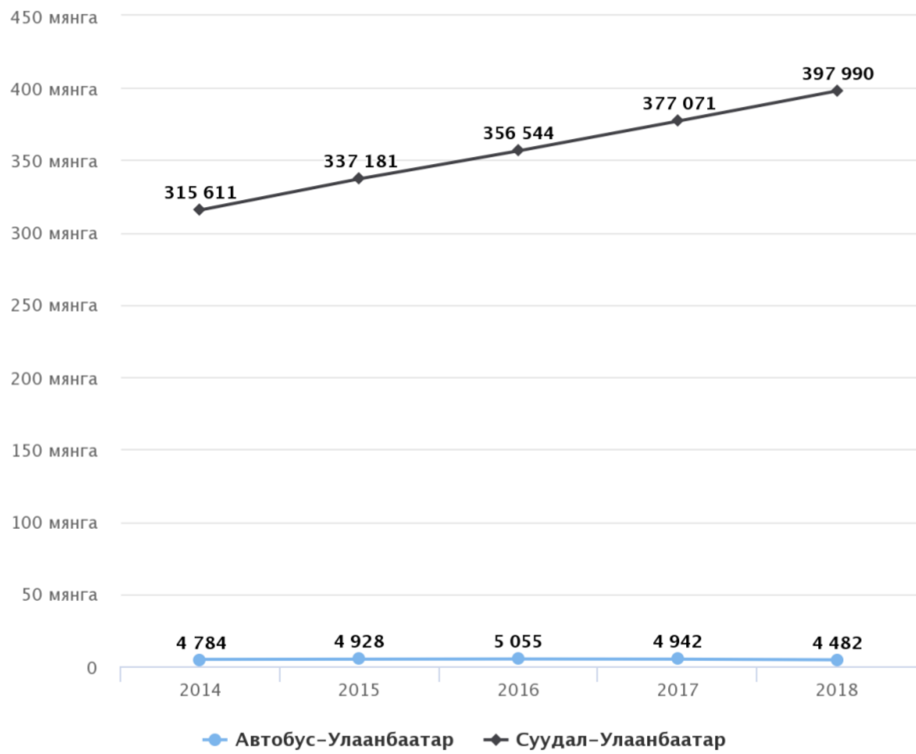

Figure 17. Total number of light vehicle cars (in black line) and total number of buses (in blue line) in Ulaanbaatar from 2014 to 2018.

Copper mining is a major economic factor of Mongolia. Currently, Erdenet Mining Corporation and Oyu-Tolgoi mine are producing copper concentrates. Oyu Tolgoi mine, which is located in the South Gobi region of Mongolia, is one of the largest known copper deposits in the world with an estimated 35 million tons of copper. However, Mongolia exports the copper concentrates. In 2019, 1406.6 thousand tons of copper concentrates were exported (21).

4.2.3 Electric Vehicle Industry Situation

Policies continue to have a significant impact on electric mobility growth. EV uptake usually starts with setting a set of goals, followed by vehicle implementation and charging conditions. There exist Fiscal incentives, especially as long as the selling price of EVs is higher than that of ICE cars, which are often paired with legislative initiatives to improve the market proposition of EVs (e.g. exceptions of requirements, reduced tolls or parking fees) or to implement zero-emission regulations. Policy to encourage the installation of charging infrastructure requires minimum standards to guarantee accessibility for EV in new or refurbished buildings and parking lots, and the implementation is available to the public chargers in towns and on highway networks.

Technology developments are delivering substantial cost reductions. Advances in technology and cost cutting are expected to continue. Other technology developments are also expected to contribute to cost reductions: these include the possibility to redesign vehicle manufacturing platforms using simpler and innovative design architecture that capitalize on the compact dimensions of electric motors, and that EVs have much fewer moving parts than ICE vehicles.

The problems related to electromobility are mainly related to its lack of sales and low popularity. Tracking down the specific reasons behind it, it can be concluded that the most important cause lies in the socio-political field.

A study by Bergman et. al, which focused on the reduction of greenhouse emissions from transport focused on two innovations (electric vehicles and car clubs) helped reach emission reduction targets (22). It continues to state that in the results of their research in the United Kingdom, battery electric vehicles along with hybrids, hydrogen vehicles, biofuels are the main recent technological innovations that play a crucial role in reducing fossil fuel use.

By replacing internal combustion engine vehicles, the benefit that electric vehicles could bring to the rising concern of climate change is evident, however, the paper continues to state some of the difficulties that come with implementing such an idea. The public, in other words, consumers, will have to change their preference for private car owners. This, as the paper states, will be quite difficult due to several reasons: financial considerations being the dominant reason for not switching their current vehicle type. Another difficulty that arises with the idea is stated as “visions of the future of automobility are, and must be understood, as profoundly political and as conditioned by prevailing power structures.” (22). “ We nonetheless observe a paradox: visions of simple technological substitution do not play to the strengths of EVs and –

often unintentionally – perpetuate ownership and use of ICEVs as the norm against any other form of mobility has competed.”

Another study by Tyfield & Zuev paid special attention to issues of power and states that it might be the biggest hurdle in order to transition to electric vehicles for China (23). The paper tried to present the “power relational perspective at work in an insightful analysis of the case of Chinese urban e-mobility innovation”. Stating its general result as disappointing in terms of mass adoption and continues to suggest that the focus should stay on the issue of power/ knowledge reshaping and by introducing new paths of socio-technical and politico-cultural change, the results would probably show an improvement in the mass adoption of e-vehicles.

One of the improvements electric vehicles could bring to urban cities is noise reduction, says Ehrler & Hebes (24). Considering that the percentage of the population in cities will increase from 50% to 70%, the paper implemented empirical research in Berlin, the results of which showed up in a positive way. The paper states that consumers in the cities have good user acceptance of e-vehicles and neighbors were giving positive feedback (25).

One impact that the transition from ICEVs to EVs could bring is the Automotive Service Industry, which says a study was done in Germany by Dombrowski & Engel (26). The paper mentions the inevitable change that will have to be done in the entire supply chain of the automotive industry. It continues to express how difficult it would be for small and medium-sized repair shops to make new strategies in their day-to-day business in order to adjust to the change to the electric vehicles.

In terms of environmental aspects, BEVs have a potential to significantly reduce the carbon emissions. However this can only be achieved if the electricity consumed by the electric car is drawn from non-fossil energy sources (27). Even though EVs appear as environmentally friendly, some studies have shown that the greenhouse gas emissions from EVs may even be higher than that of ICEs during their life cycle (28). A study made in Beijing, China reported that the air pollution contributed from electric taxis during their life cycle was higher than the pollution amount of diesel engines taxis.

1. CONCLUSION

This paper was written in order to estimate the demand of copper used in electric cars with variations in electric car types until the year of 2030. Bass diffusion model showed that in year 2030, total demand copper for three electric vehicle types combined under the pessimistic, neutral, optimistic scenarios are 5Mt, 10Mt, 20Mt respectively. Battery electric vehicles will have a demand between 3.4 – 13.6Mt, Plug in hybrid electric vehicles will have a demand between 0.96- 3.84Mt, and Hybrid electric vehicles will have a copper demand of 0.64 – 2.56Mt. There will be no shortages in reserves of copper, however supply shortages may occur due to the limited capacity of copper production plants.

As a result of this increase in demand, sufficient research and forecasting needs to be done in order to avoid adverse environmental consequences, in order to minimize the costs of implementing this system for countries. The whole automobile sector, the manufacturing chain, engineering elements, R&D, logistics, service and repair divisions would need a totally new collection of staff and expertise, and significant adjustments must be made to the processes. At the same time, the public opinion needs to be changed and the adjustment period will not be overnight. It is currently not possible to come up with a definite response on Mongolia 's position in this industry due to lack and shortage of information. The electric transportation industry is in Mongolia still at its early stages, so more work in this area must be carried out continuously in order to arrive at a clear response.

In the future, it is recommended that more data should be generated to see the situation of electric vehicles in Mongolia. On top of that, continuing the work done, more research could be done on the copper production capacity and how to meet the demand that is electric vehicle industry is about to bring in the near future. More research is recommended to be done on the recycling and reusing system of copper in the electromobility industry.

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Appendix

	Series 1
410	2.2
450	2
500	1.8
550	1.6
600	1.4
700	1.2
800	1

Appendix 1. Example demand figure for gasoline. The demand schedule shows that as the price rises, quantity demanded decreases, and vice versa

	Series 1
500	1
550	1.2
600	1.4
640	1.6
680	1.8
700	2
720	2.2

Appendix 2. Supply curve for gasoline. As price rises, quantity supplied also increases, vice versa.

	Series 1	Series 2
1	410	800
1.2	550	700
1.4	600	600
1.6	640	550
1.8	680	500
2	700	450
2.2	720	410

Appendix 3. Demand and Supply Curve for Gasoline. Example.

BEVs	Neutral	Pessimistic	Optimistic
2016	0.56	0.22	0.88
2020	20	7	30
2023	35	15	60
2025	75	35	140
2030	82	41	164

Appendix 4. Diffusion curve of BEVs (until 2030)

PHEVs	Neutral	Pessimistic	Optimistic
2016	0.22	0.11	0.44
2020	7	3.5	14
2023	15	7.5	30
2025	35	17.5	70
2030	41	20.5	82

Appendix 5. Diffusion curve of PHEVs (until 2030

HEVs	Neutral	Pessimistic	Optimistic
2016	0.22	0.11	0.44
2020	7	3.5	14
2023	15	7.5	30
2025	35	17.5	70
2030	41	20.5	82

Appendix 6. Diffusion curve of HEVs (until 2030

БҮРТГЭЛТЭЙ ТЭЭВРИЙН ХЭРЭГСЛИЙН ТОО, төрлөөр, бүс, аймгаар, жилээр

Статистик үзүүлэлт	Аймаг	2014	2015	2016	2017	2018
Автобус	Улаанбаатар	4,784.	4,928.	5,055.	4,942.	4,482.
Суудал	Улаанбаатар	315,611.	337,181.	356,544.	377,071.	397,990.

Appendix 7. Total number of light vehicle cars (in black line) and total number of buses (in blue line) in Ulaanbaatar from 2014 to 2018.