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ROLE OF MINERALS IN GLOBAL ENERGY TRANSITION

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Dedicated to my family and friends in Turin…

Abstract

Renewable energy is energy derived from renewable resources that are renewed naturally on a human timeline. It includes sources such as sunlight, wind, rain, tides, waves, and geothermal heat. The reliable use of these resources has the least environmental effect, produces the least secondary waste, and is sustainable in terms of present and future economic and social demands. Renewable energy technologies provide a tremendous potential to reduce greenhouse gas emissions and global warming by substituting traditional energy sources.

A lot of countries now rely on renewable energy for more than 20% of their energy supply, with some generating more than half of their power from renewables. And statistics show that it will continue to grow year by year. In contrast to fossil fuels, which are concentrated in a small number of nations, renewable energy supplies occur throughout large geographical regions. International public surveys state that there is solid support for renewables such as solar and wind power. But at the same time, it is connected with lots of issues and challenges and it will be a long way to reach net-zero carbon emissions in recent years to come.

The shift to renewable energy is critical to meeting the goals of the Paris Climate Agreement and increasing the likelihood of keeping global temperature rise below 2 degrees Celsius. Renewable energy technologies are presently the most cost-competitive for new installations – and recent worldwide investment in new renewable energy infrastructure has been double that of new fossil fuel and nuclear energy investments.

High numbers of ecologically sensitive materials are required by renewable energy sources, electric cars, and battery storage. These energies rely on technologies that use a large number of mineral resources, which are not endless on Earth. To prevent producing additional negative social and environmental repercussions throughout the supply chain, the supply chains for these commodities and technologies must be effectively managed.

The success of the global energy transition will rely on renewable technologies, as well as on the availability of the necessary minerals and metals: the future access to several critical materials, the ability to ramp up the materials supply and fast enough production, the rising cost of such materials, and the geopolitical and strategic implications of new resource dependencies. Moreover, some concerns have been raised that the energy return on investment may be on the rise and could become an issue in the energy transition, as it could result in additional carbon dioxide emissions.

This labor is dedicated to the main challenges of the global energy transition. It clearly shows the trends in the global energy consumption, stresses and issues of energy demand, strategies of the main

policy-makers on energy transition, the role of power generation in the global energy supply chain. Since the topic of the energy transition is becoming more and more actual for the world's development, the number of challenges we, as a humanity, have to meet and successfully solve is drastically growing. This work is trying to explain how we can do it.

The biggest part of this labor is dedicated to the mineral demand, its importance in global energy supply and consumption, main issues and states. Moreover, the main minerals needed for the energy transition to be successful were listed. Top 5 minerals were chosen as the elements which could potentially meet fast-rising energy challenges. Next, the comparison table was developed and, on the basis of it, the key challenges for 5 critical minerals were distinguished. In the end, the results of the findings are controversial, since the global mineral industry is very complex and unpredictable.

During this work, the experience of the leading companies and scientists in the sphere of energy transition was analyzed and structured. Moreover, the most recent articles were used to unite all the information available to let this work be modern and cutting-edge.

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Introduction

The Earth is heating up. According to NASA, the global average temperature in 2020 was 1.02°C higher than the baseline 1950–1980 normal. In addition to melting polar ice caps and rising sea levels, global warming is producing other climatic changes such as desertification and an increase in extreme weather events such as storms, floods, and fires.

And the reason is obvious. Human activities have produced huge volumes of carbon dioxide and other greenhouse gases into the atmosphere since the Industrial Revolution, altering the earth's climate. Natural phenomena such as fluctuations in solar radiation and volcanic eruptions also have an impact on the earth's temperature. They do not, however, explain the warming that we have experienced over the previous and current centuries. [1]

From the historical point of view, today's energy transition, as we know it, is not the first. We have seen a couple of it: firstly, from wood to coal in the 19th century and from coal to oil in the 20th century. But, the main difference between those transitions and the current one is that now we need to protect our environment as fast as possible. And, fortunately, we could at least make an impact developing renewable technologies. [2]

After years of relying on regulation to drive sector expansion, renewable energy sources have emerged as a powerful and cost-effective source of electricity. Solar and wind costs have plummeted so dramatically that wind power is now cheaper than traditional high-carbon energy supplies in many countries. The renewable energy business will only develop and consolidate as a significant investment opportunity as costs continue to fall and wind and solar become more popular.

As demand for green energy technologies such as solar panels, wind turbines, electric cars, and energy storage grows, so does demand for the minerals needed to create and install them. Minerals and metals will be critical components in the transition to a low-carbon economy. For the foreseeable future, the production of solar panels, wind turbines, and batteries will impact the supply and demand for essential minerals. This will have far-reaching consequences for a wide range of sectors as well as mineral-rich developing countries. These nations stand to gain from growing mineral demand, but they must also manage the material and climatic footprints associated with rising mining activity.

While the mineral intensity of renewable energy has its challenges, research studies show that, even if low-carbon technologies are more mineral intensive, they only account for a fraction (6 %) of emissions generated by fossil fuel technologies. This means that the deployment of renewable energy is essential in helping us meet the Paris Agreement, even if it means that more minerals will be needed to get there.

However, today's investments and production of mineral resources are lagging behind of what our world needs to deploy green energy technologies. Most of minerals is produced from number of countries. High geographical concentration, long production cycle: from plans to extraction, decreasing quality in several fields and different social and environmental issues multiply anxiety about sustainable and responsible supply of critical minerals needed for effective energy transition. [3]

1. Overview of Global Energy Consumption

Oil, natural gas and coal are the dominant resources in the global energy mix today, and they will probably remain so in the years to come. And there are some reasons for this point of view.

If we observe what happened during the last century: population, economic wealth and energy consumption grew almost without any interruption. Global population was 1.6 billion in nineteen hundred (1900), 2.5 billion fifty years later, and we are more than 7 billion human beings today. Wealth, estimated by the gross domestic product in real value, has been multiplied by 40 over the same period.

Energy consumption has been both a support and a consequence of this growth, rising from slightly less than 1 billion tons of oil equivalent at the beginning of the century to more than 13 billion tons today. [4]

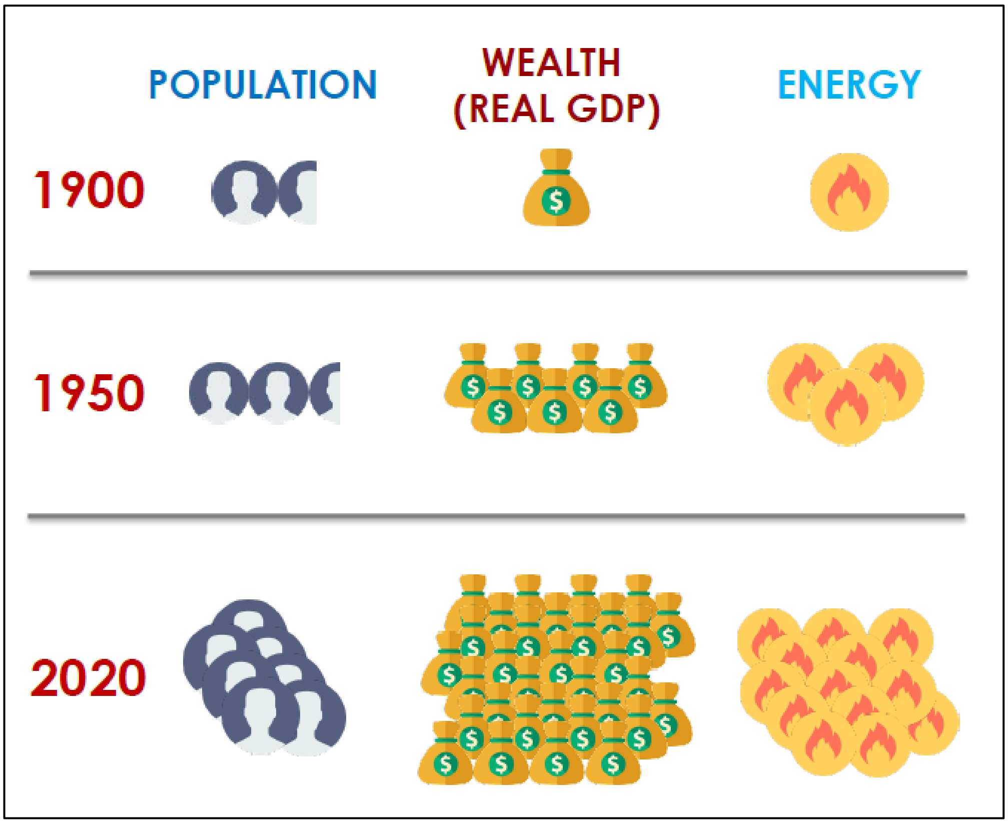

Fig. 1. Population, Wealth and Energy in the 20th and 21th century [4]

There is, however, no single form of energy. We hear a lot about energy transition these days, but it's important to remember that the global energy balance has been shifting continually since the beginning of the industrial revolution. In reality, in the beginning of the nineteenth century, we transitioned from a traditional-mix based nearly solely on wood to a considerably more diverse energy supply today.

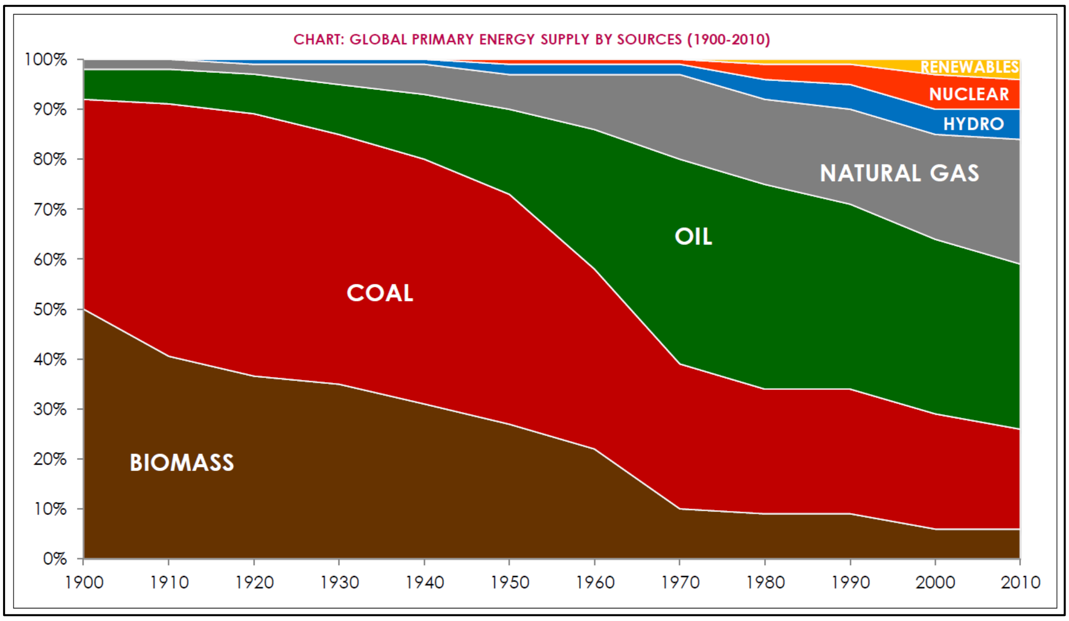

Fig. 2. Global Primary Energy Supply by sources (1900 - 2010) [5]

Indeed, our current primary energy consumption relies on oil for more than a third, coal for 28%, and natural gas for 23%. Then comes hydro with 7%, nuclear energy with 4%, and modern renewable energies such as wind, geothermal and solar with 3%. Renewable energies are mainly used for power generation.

Primary energy needs to be processed and transported before being available for end-users. From the 13 billion tons of oil equivalent of primary energy, we get only 9 billion tons in final energy, after withdrawing transformation and transmission losses.

Fossil resources dominate the current energy mix because they appear to be the most cost-effective and efficient energy sources for our primary applications. Heat, which accounts for over half of human demands, is mostly delivered by fossil fuels. Today, transportation accounts for about one-third of global energy consumption, while electricity accounts for barely 1%. Finally, coal and natural gas continue to generate more than two-thirds of worldwide electricity. [6]

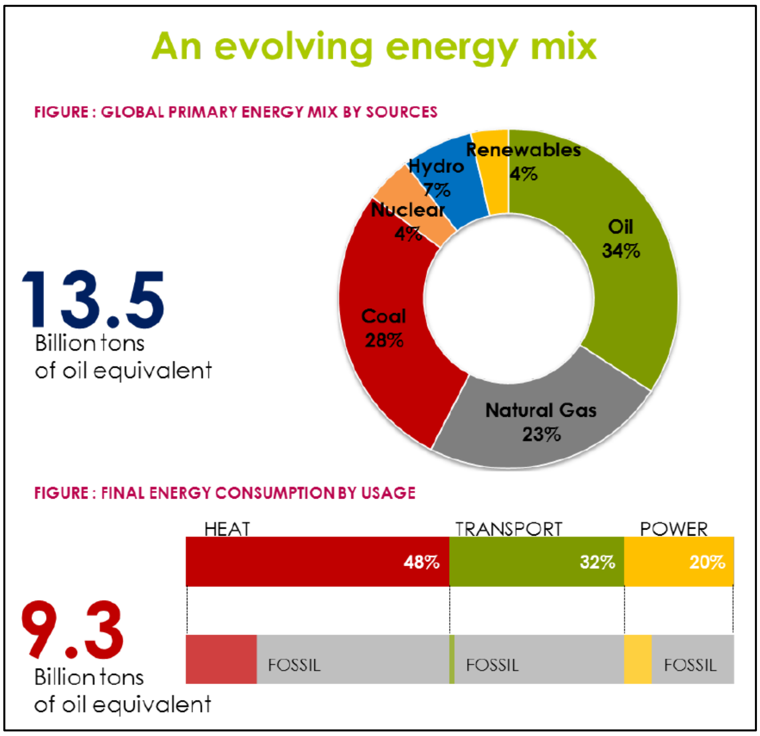

Fig. 3. Global primary energy consumption by source [6]

Renewable sources of energy are making the headlines these days. Indeed, last year in the power sector, 69% of net capacity additions were renewables. We see electricity prices going down because of very low-cost solar or wind installations development. However, these changes are not yet visible in the global energy mix. Solar, wind, biomass or geothermal still represent less than 4% of total primary energy consumption today.

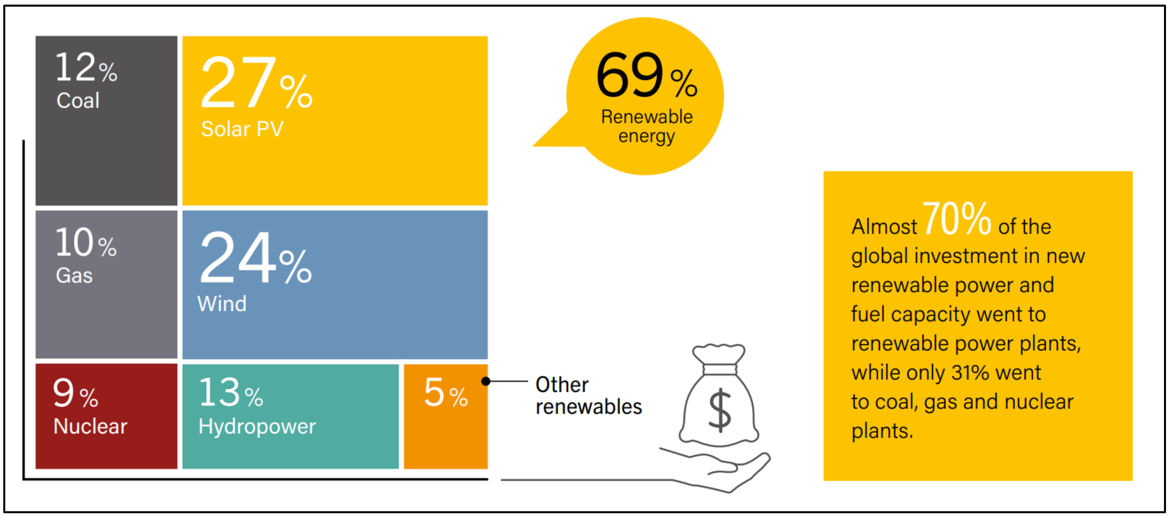

Fig. 4. Estimated Global Investment in New Power Capacity, by Type, 2021 [7]

Renewable energy projects have become more appealing, particularly in light of the COVID-19 crisis. A 2020 survey of institutional investors with USD 6.9 trillion under management found that investors planned to nearly double their allocation to renewable energy infrastructure in the near term, from 4.2% in 2020 to 10.8% in 2030.

The reason is that energy systems need heavy infrastructures, therefore they require time to evolve. Due to this inertia, the mix will not change rapidly and fossil resources will remain the dominant fuels in the energy mix for many years ahead.

By looking at the global energy demand chart, we can observe that the consumption growth of renewables does not necessarily lead to less demand for fossil energies. The world in which we live today, is a world of resource addition and not substitution, and it is always thirsty for new energy resources. Global energy consumption continues to grow, but it does seem to be slowing – averaging around 1% to 2% per year.

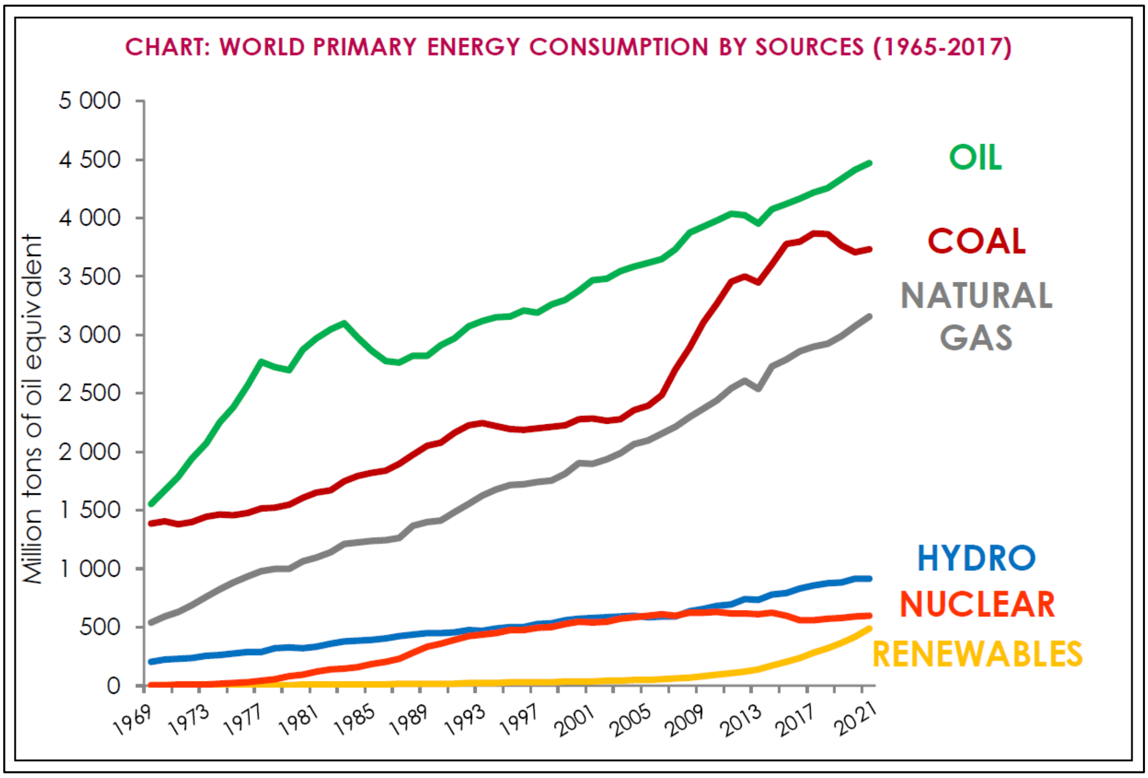

Fig. 5. World Primary Energy Consumption by sources (1969 - 2021) [11]

Last but not the least, we should not forget that global population keeps increasing, people become richer and more and more countries are developing. If this increased demand is not displaced by improvements in energy efficiency elsewhere, then our global energy consumption will continue to grow year-by-year. Growing energy consumption creates the challenge of transitioning our energy systems away from fossil fuels towards low-carbon sources of energy tougher: new low-carbon energy has to face this additional demand and try to offset existing fossil fuels in the energy mix. Therefore, our energy system will definitely face several challenges in the coming decades.

2. Stresses on the energy demand

2.1. Present & future constraints on energy supply

One thing we have to keep in mind is that no single source of energy is perfect: as a matter of fact, any energy policy is about finding the ideal balance to provide a reliable, clean and affordable energy supply.

The sustainable development goals (SDGs) proposed by the Open Working Group of the General Assembly of the United Nations recognize the importance of the natural environment and its resources to human well-being. It is definitely a worthy regulation for the 21th century, as it appeals the diverse challenges that we face as a global community. SDG 7—to "ensure access to affordable, reliable, sustainable and modern energy for all"—is a challenge withstanding every country, that touches everyone. The three dimensions of SDG 7 are affordability, reliability, sustainability. These different dimensions are not mutually exclusive. They overlap, and in some cases even entail each other.

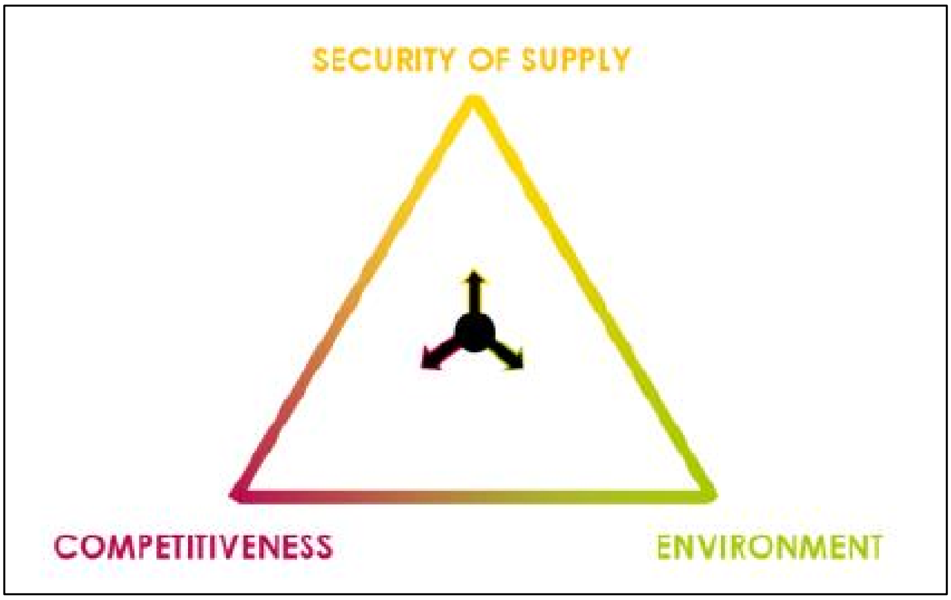

Fig. 6. Designing an energy policy is about finding the ideal balance between reliability, affordability and sustainability. [12]

The goal of reliability is to answer the question, "Is there enough energy for everyone?" Energy resources are unlikely to be scarce in the near future. Oil, natural gas, and coal reserves are determined by price, and as long as we are willing to pay for them, additional resources will be produced and delivered to the end user.

This is also true for renewables. There are no true resource restrictions on the supply of renewable energy since they are flows. The only question is whether we can capture energy from the sun, wind, biomass, or the sea. Furthermore, because solar panels, wind turbines, and batteries require metals and rare earth elements that are only available in finite quantities, a physical restriction might someday limit their supply.

Access to affordable, reliable, sustainable and modern energy is critical to 21st-century global development. Not all of the options required to achieve this task are available, and those that are may be obscure. It will be tough to find these answers and coordinate them across scales. However, if international organizations have enough vision, governments can collaborate, and communities and privates are given the right incentives and resources, the problem can be solved.

2.2. The relative prices of energy sources

Another question is the one of the prices. The design of an energy mix dominated at 80% by fossil fuels was mostly driven by the fact that coal, oil and natural gas proved to be the most affordable energies to support the world economic development during the 20th century.

This environment is fast changing as solar photovoltaic and wind technologies have significantly reduced the cost of generating power in recent years. When the whole cost of generating power throughout the entire life cycle of the technologies is evaluated, wind and solar are currently regarded to be extremely competitive with traditional sources of energy in many regions across the world.

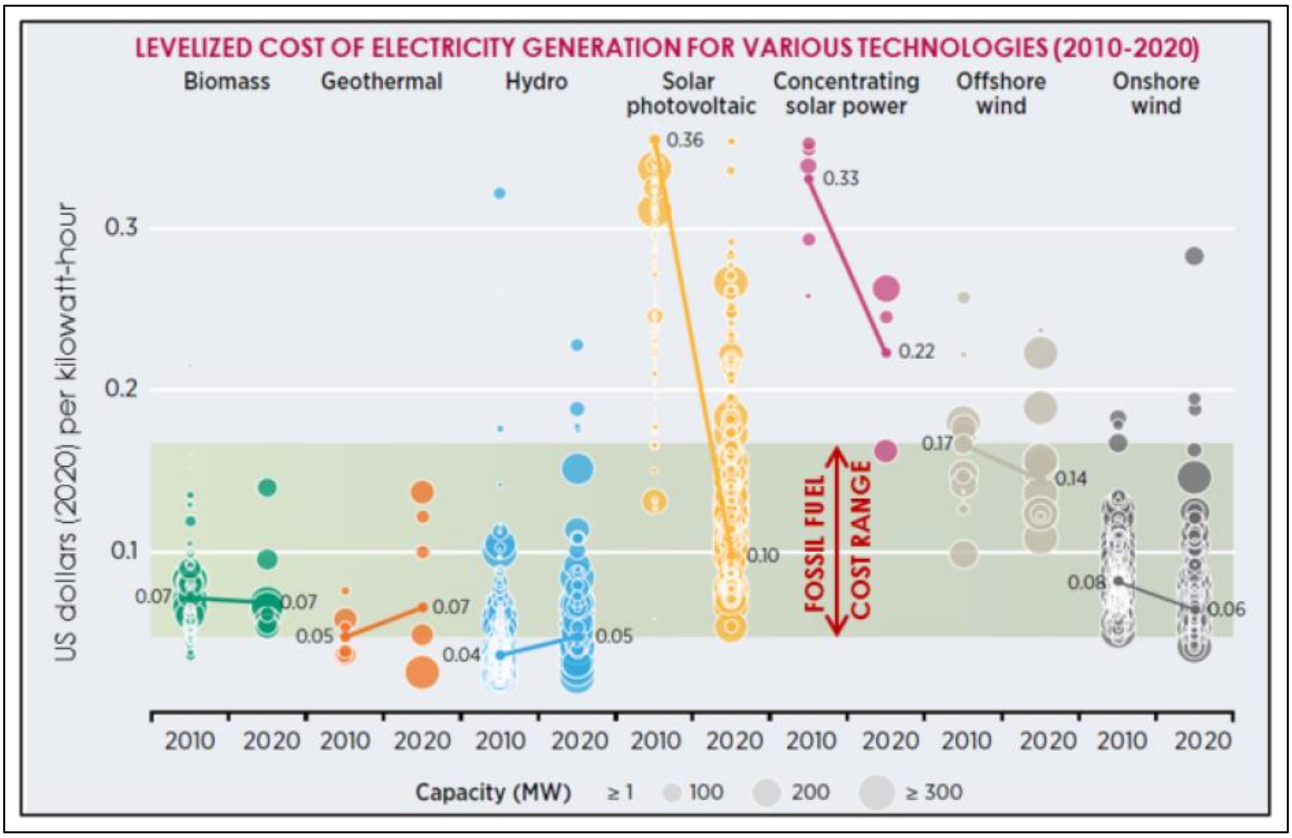

Fig. 7. Cost of electricity generation for various technologies (2010 - 2020) [13]

Renewable energy technologies follow learning curves, which is the main driver of this shift. That is, for every doubling of cumulative installed capacity, their price falls by the same percentage. Electricity prices from traditional energy sources, on the other hand, do not follow learning curves. As a result, it is projected that the price differential between expensive fossil fuels and cheap renewables would widen in the next decades.

This is a compelling argument to make significant investments in ramping up renewable technology right now. Rising installed capacity has the hugely significant secondary consequence of driving down prices, making renewable energy sources more appealing. The majority of the increased demand for more power in the future will come from low- and middle-income countries. We can now ensure that a large portion of the new power supply will come from low-carbon sources.

Reduction of energy prices mean that the real income of population increases as well. Investments to scale up production of energy with cheap electric power from renewable sources are therefore not only a possibility to reduce gas emissions, but also to achieve more economic growth – particularly for the poorest countries.

2.3. The issue of climate change

But, without a question, the most pressing problem is the subject of climate change. Because fossil fuels account for the majority of current consumption, greenhouse gas emissions from their burning accumulate in the atmosphere and contribute to an increase in global temperatures.

Traditional energy sources such as coal, oil, and gas now account for about 79 percent of global energy output, and as the chart below shows, they have significant negative side effects. The left-hand lines represent the number of fatalities, while the right-hand lines compare greenhouse gas emissions.

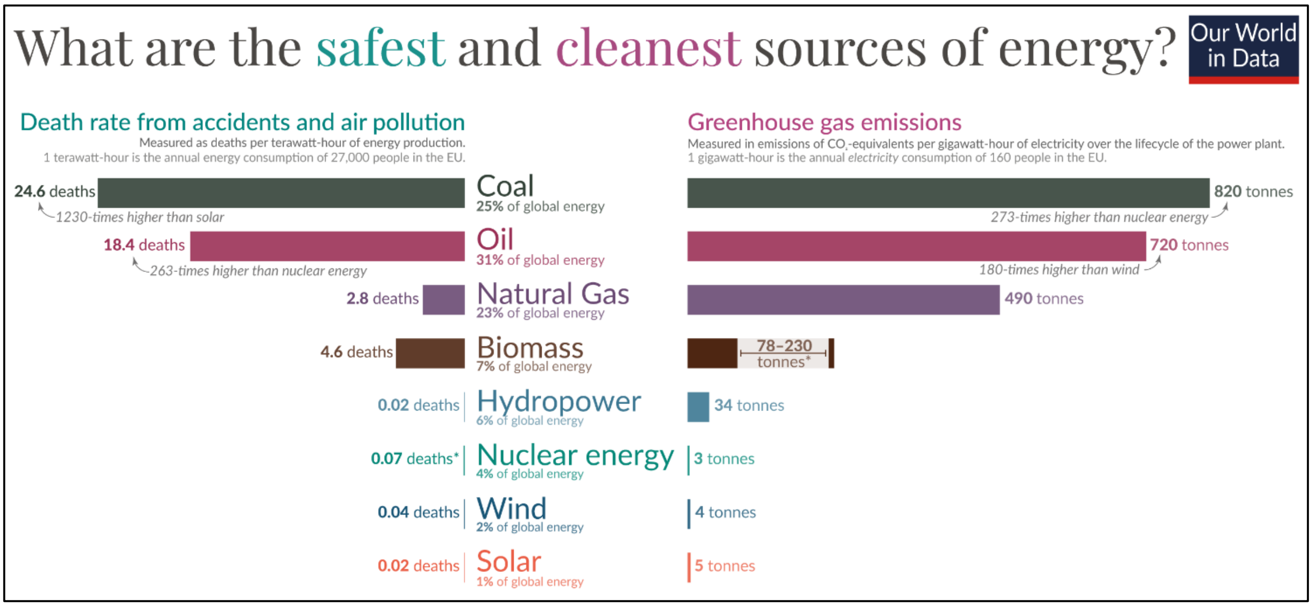

Fig. 8. Cleanest and safest sources of energy [11]

This graphic highlights two clear points. The combustion of fossil fuels accounts for 87 percent of worldwide CO2 emissions. As a result, existing energy sources are far from sustainable. It endangers the lives of future generations as well as the ecology. And the same energy sources are now causing population fatalities - burning fossil fuels causes air pollution, which kills 3.7 million people worldwide each year, which is six times the yearly mortality losses from all homicides, war deaths, and terroristic attacks combined.

It is very important to remember that electric energy is not the only one form of energy that people rely on; the transition to low-carbon energy is therefore a big goal than the transition to low-carbon electricity.

What is clear from this chart as well is that the alternatives to fossil fuels – renewable energy sources and nuclear power – are much safer and cleaner than non-renewable ones.

Since the dawn of humanity, climate change has had a tremendous impact on people's and animals' lives, as well as our other realms of activity. Shrinking sea ice and snow cover, rising sea levels, changes in precipitation, and more frequent extreme weather events will have a wide-ranging influence on communities, forcing them to adapt or relocate to more favorable areas.

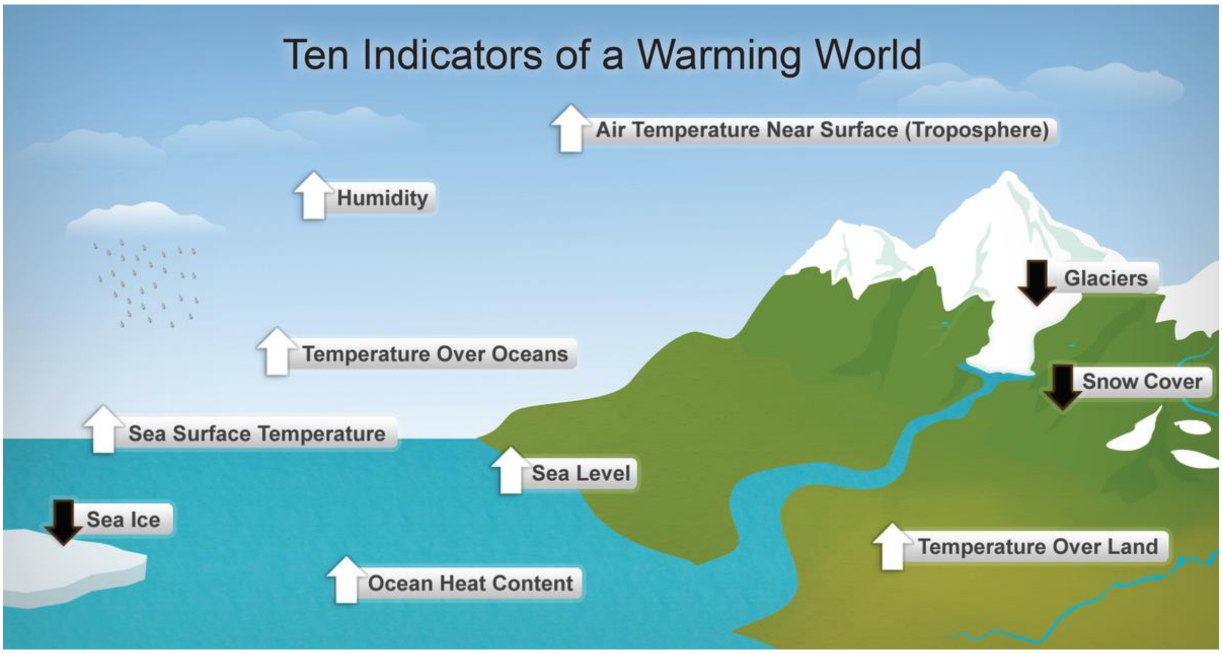

Fig. 9. 10 indicators of a warming world [12]

2.4. Towards a net-zero emissions world

To tackle this problem, all members countries of the United Nations' Convention on Climate Change agreed in 2015, when they adopted the Paris Agreement, to limit the rise of temperatures to "well below 2° Celsius" above the pre-industrial level, a level that is considered acceptable by the IPCC, the UN scientific body assessing the risks associated with global warming.

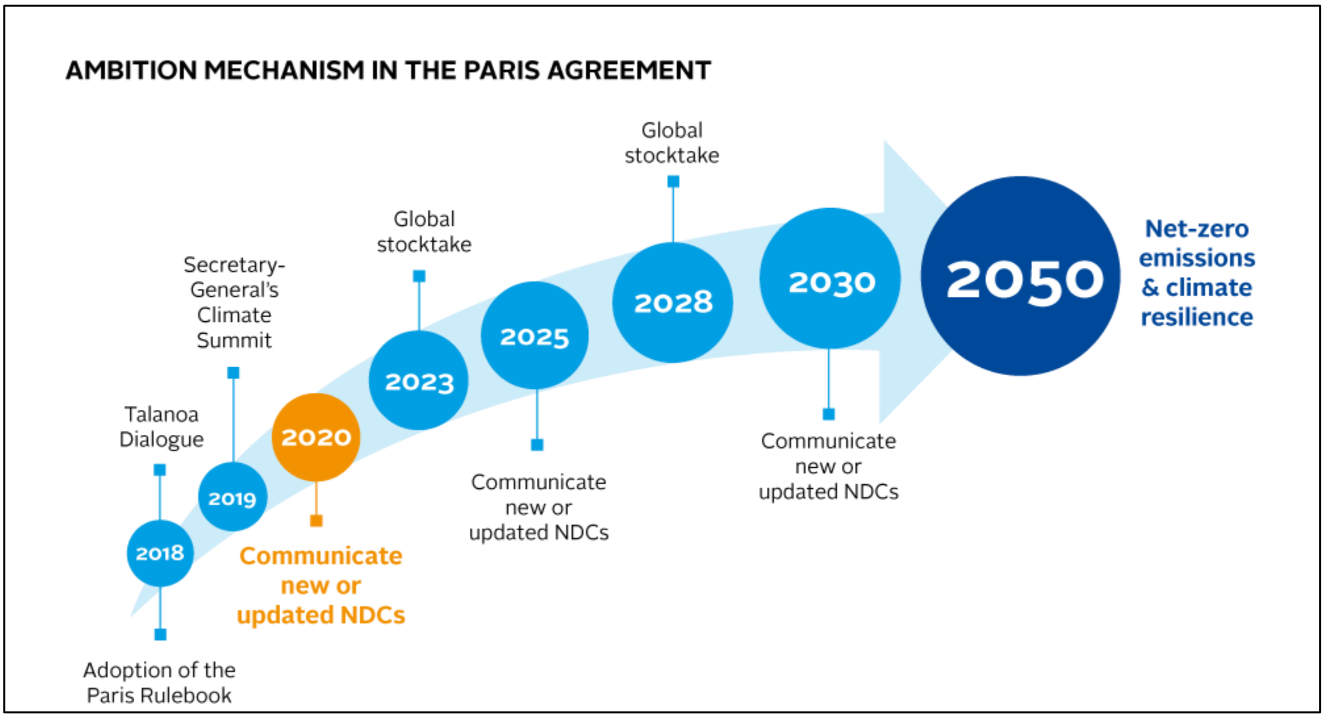

Fig. 10. Paris agreement goals [18]

The Paris Agreement's implementation necessitates economic and societal transformations based on the greatest available knowledge. The Paris Agreement is based on a five-year cycle of progressively aggressive climate action by governments. Countries filed their climate action plans, known as nationally defined contributions, by 2020. (NDCs).

In their NDCs, countries communicate actions they will take to reduce their Greenhouse Gas emissions in order to reach the goals of the Paris Agreement. Countries also communicate in the NDCs actions they will take to build resilience to adapt to the impacts of rising temperatures.

To better frame the efforts towards the long-term goal, the Paris Agreement invites countries to formulate and submit by 2023 long-term low greenhouse gas emission development strategies (LT-LEDS).

LT-LEDS provide the long-term horizon to the NDCs. Unlike NDCs, they are not mandatory. Nevertheless, they place the NDCs into the context of countries' long-term planning and development priorities, providing a vision and direction for future development.

For the IPCC, the +2° Celsius objective is compelling: all countries must collectively achieve a net-zero level of greenhouse gases emissions as soon as possible in the second half of the 21st century. This does not necessarily mean the end of fossil fuels, but it surely means that any emissions at this time will need to be stored underground (what we call “carbon capture and storage”) or compensated by negative emissions measures (such as afforestation or direct capture of carbon dioxide in the air).

In 2010, coal, oil, and natural gas accounted for 80 percent of world energy supply. This planet is not sustainable: growing greenhouse gas emissions, as well as accompanying local pollution in a more urban environment, will be the century's key issues. [15] [16] [17]

3. Towards a sustainable energy

3.1. The main drivers of greenhouse gases emissions

Greenhouse gases capture heat and warm the Earth. Almost all of the rise in greenhouse gases in the atmosphere over the last 150 years has been attributed to human activity. The burning of fossil fuels for power, heat, and transportation is the major source of greenhouse gas emissions from human activity. The Kaya equation is used to compute the quantity of greenhouse gas emissions.

The Kaya equation, named after a Japanese economist, Yoichi Kaya, who developed it in the 1990s, is a very simple model to assess the factors driving the growth of greenhouse gases emissions.

For Kaya, the evolution of the carbon emissions is the product of 4 factors:

• the evolution of the carbon content of the energy we consume (CO2 / energy),

• the energy intensity of our economic activity (generally measured by the amount of energy consumed per unit of Gross Domestic Product (GDP),

• the wealth per person (GDP / capita)

• and the growth of population. [21]

$$\text{CARBON EMISSIONS} = \frac{\text{CARBON EMISSIONS}}{\text{PRIMARY ENERGY CONSUMPTION}} \times \frac{\text{PRIMARY ENERGY CONSUMPTION}}{\text{GROSS DOMESTIC PRODUCT}} \times \frac{\text{GROSS DOMESTIC PRODUCT}}{\text{TOTAL POPULATION}} \times \text{TOTAL POPULATION}$$

Fig. 11. Kaya Equation [21]

All UN member countries pledged in Paris to achieve "net-zero" emissions as soon as feasible in the second half of the twenty-first century, in order to limit temperature, rise to +2°C. Many scenarios exist to investigate future trends that are consistent with this purpose. To restrict temperature, rise to 2°C, a simple trend would be to jointly divide emissions by three between now and 2050.

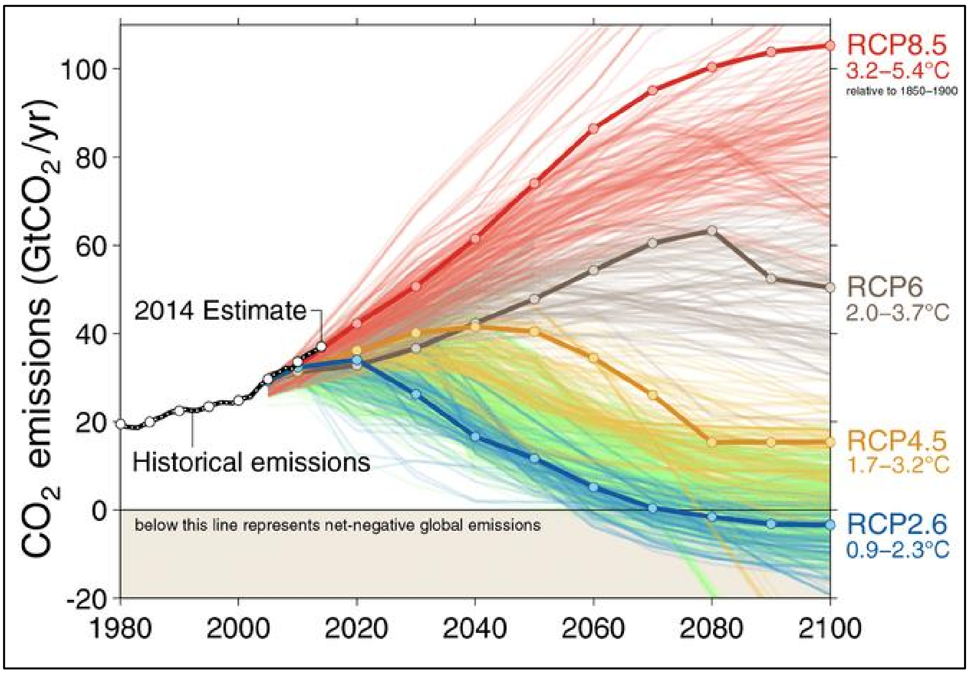

Fig. 12. Scenarios of future global CO_2 emissions. [23]

According to the most recent UN estimates, the global population is going to grow by 30% between today and 2050. At the same time, assuming that the global GDP per person is going to grow in the next 35 years as fast as it did in the last 35, this means that the term GDP/capita will grow by approximately 60% by 2050.

To sum up, this means that, to cut global emissions by 3 in 2050, with 30% more people and a 60% higher GDP per capita, we need to divide the two other terms of this equation, CO2 over energy or energy over GDP by more than 6!

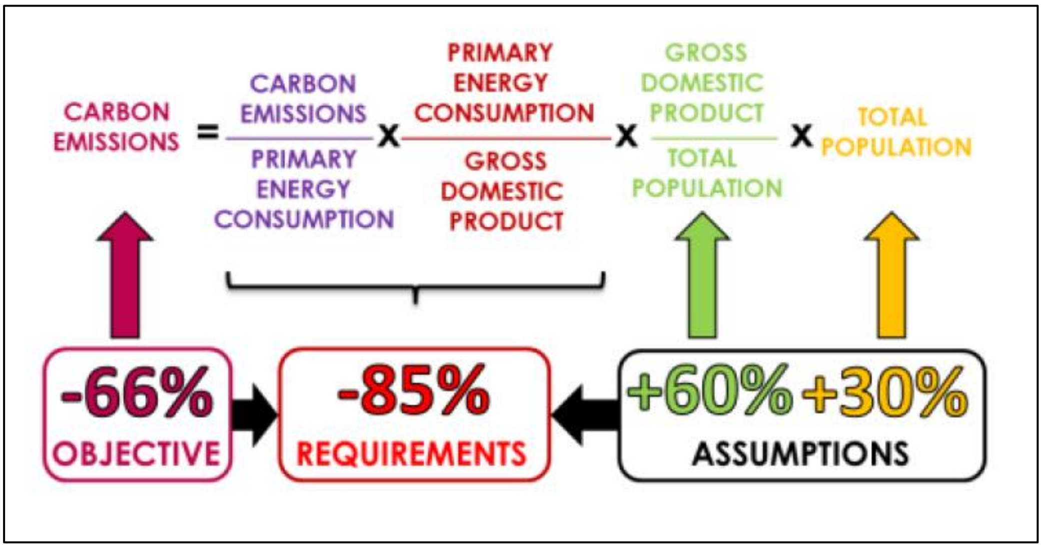

Fig. 13. Kaya factors evolution (2015 - 2050) [21]

In other words, we must cut the carbon content of our energy consumption by more than 5% per year, or lower the amount of energy required to create one unit of GDP.

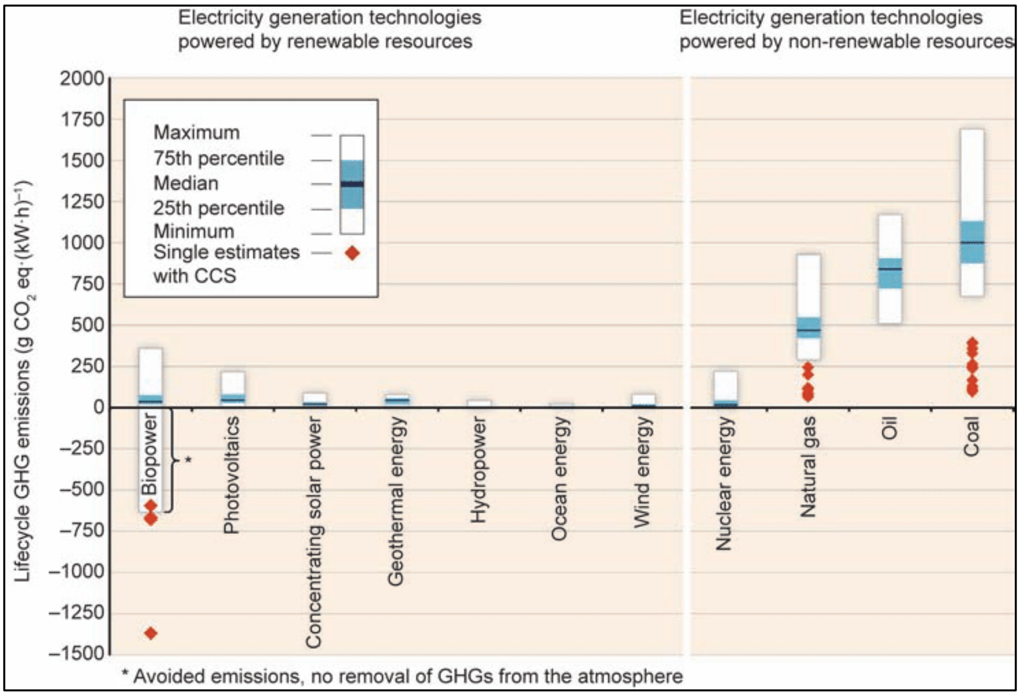

Fig. 14. Decarbonizing the energy mix implies shifting towards less carbon-intensive energy sources (renewables & nuclear), or abating CO2 emitted from fossil sources (with CCS) [24]

The graph above depicts the life-cycle greenhouse gas emissions from various electrical sources. The bars depict the findings of several studies that evaluated the carbon content (here measured in grams of CO2 equivalent) of each kilowatt-hour of energy produced. Decarbonizing the energy mix plainly entails shifting from our current 80 percent fossil-fueled mix to low-carbon sources such as hydro, wind, solar, or bioenergy. We can see how we could minimize CO2 emissions by using nuclear energy to meet more of our energy demands, or by capturing and storing the carbon released by fossil fuel sources.

When we look back in time. The carbon intensity of the world's primary energy source remains unchanged from 30 years ago. After a minor dip in the 1990s, it increased after 2000 due to the rapid economic expansion of numerous Asian nations, which was fueled by heavy consumption of coal and oil. Clearly, we are not on the right road, and decarbonizing our energy usage will be a major task in the next years.

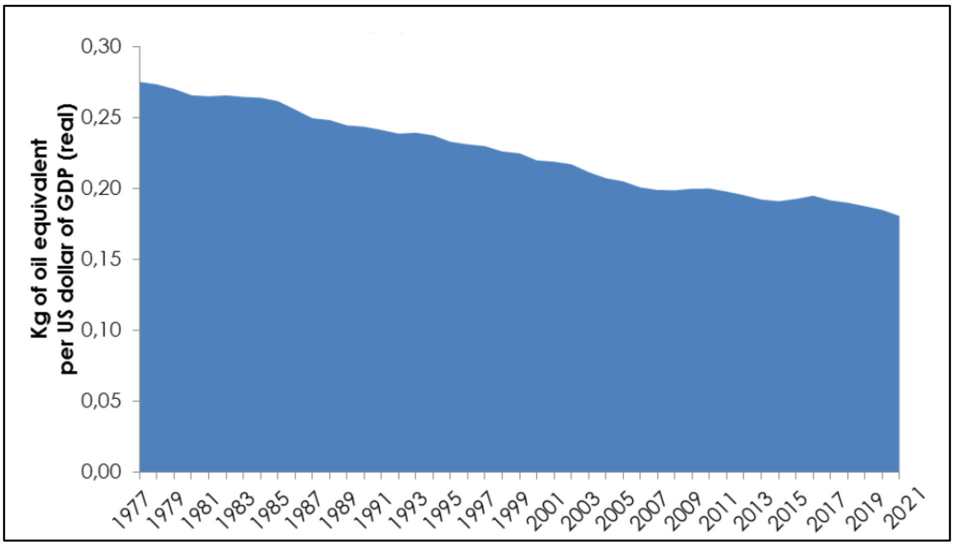

Fig. 15. Energy intensity of world GDP (1977 - 2021) [24]

When we look back in time, the carbon intensity of the world's primary energy source remains unchanged from 30 years ago. After a minor dip in the 1990s, it increased after 2000 due to the rapid economic expansion of numerous Asian nations, which was fueled by heavy consumption of coal and oil. Clearly, we are not on the right road, and decarbonizing our energy usage will be a major task in the next years.

Still, we are far from being in line with the requirement of -5% per year decrease of the global carbon intensity of the GDP, what is expected in a +2°C compatible scenario.

To sum up, greenhouse gases emissions are driven by the growth of population, their economic activity, but also the energy intensity of the GDP and the carbon intensity of the energy we consume.

Because population and GDP will probably keep growing in the future, we need to cut the energy intensity of the GDP and the carbon intensity of the energy mix by 5% per year to cope with the Paris Agreement long term objective.

Many solutions are possible: more renewables, more nuclear or capture & storage of emissions from fossil fuels combustion. But for the time being, we are not on the right track.

4. Power Generation in global energy demand

4.1. Electricity: an evital energy

Since Benjamin Franklin's earliest experiments in the 18th century, through the innovations of Michael Faraday and the efforts of Thomas Edison, electricity has become an increasingly important component of our daily lives. It is currently a vital energy carrier, supplying energy services such as lighting, heating and cooling, and information technology.

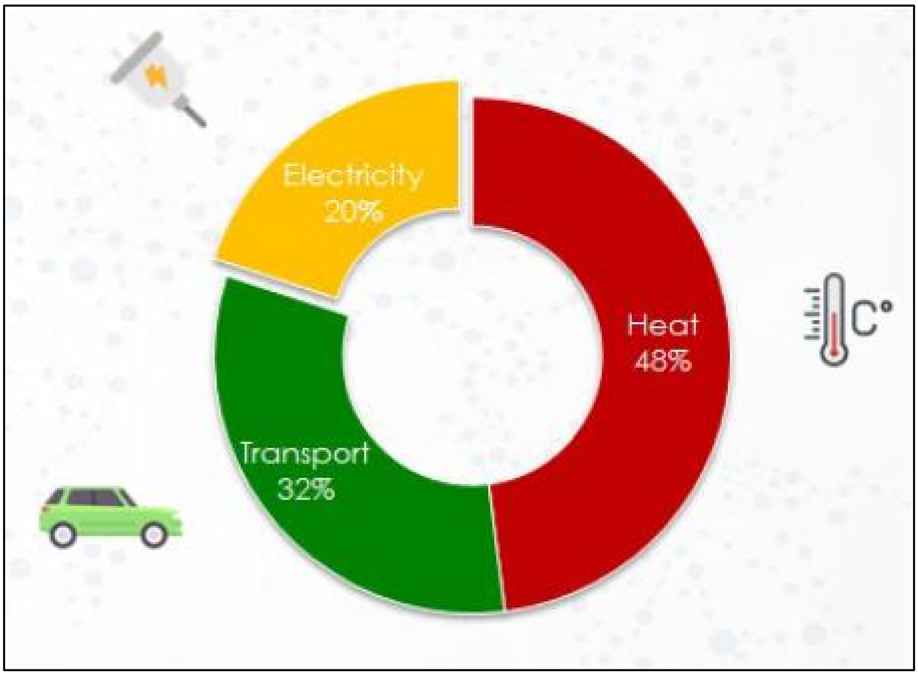

Fig. 16. Energy Distribution by usage [25]

In the current circumstances, coal, natural gas, and oil account for 63 percent of power production. Renewable energy accounts for one-quarter of worldwide power generation, with hydropower leading the way, followed by wind, biomass, solar, and geothermal power. Finally, nuclear power now contributes for 10% of total electricity output.

Today, electricity use accounts for only one-fifth of our total energy requirement. However, worldwide power consumption has more than quadrupled in the previous 25 years, while primary energy demand has climbed by just 60%. This trend is likely to continue in the future, driven by the surge in demand for motor systems, appliances, cooling, and information and communication technology. [26]

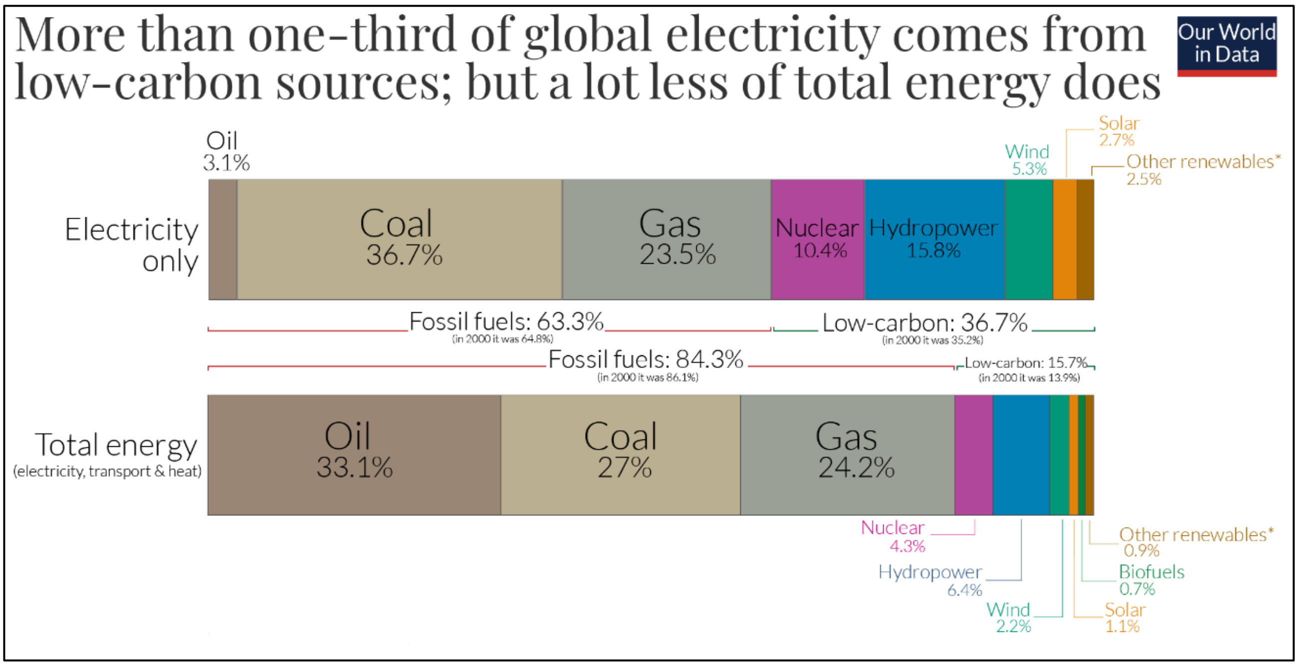

Fig. 17. Global Electricity production by sources [27]

Why have coal and natural gas been dominating the power generation mix?

Because in most cases, they have proven to be quite reliable, rather flexible and economically competitive means of production. If we take a look at the graph, showing recent data for the full life-cycle cost for producing one megawatt-hour of electricity, you can see that coal and natural gas were the least expensive fuel at the beginning of the study.

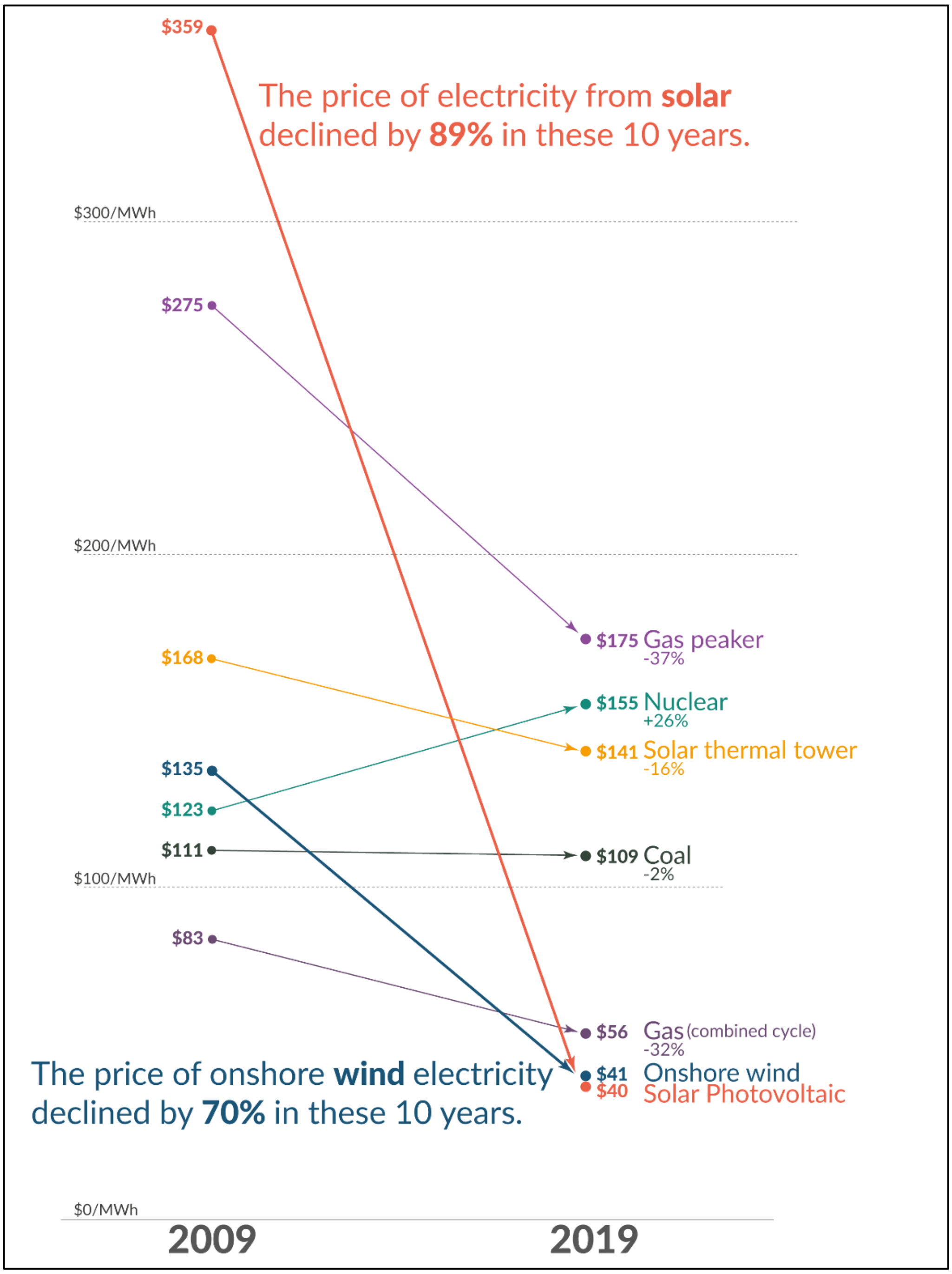

Fig. 18. The price of electricity from new power plants [28]

Sure, the situation is evolving now as the costs of producing wind and solar power have decreased dramatically, but power plants that are built today generally have an operating lifetime of 20 to 40 years. So, the current mix will require a few decades to evolve.

Moreover, because up to now, electricity could not be stored easily in an economical manner, many countries have favored the flexibility of dispatchable means of generation (such as nuclear and fossil fuels) over variable resources such as wind and solar.

4.2. Electricity: a key sector for decarbonization

However, using coal, natural gas, or oil to generate power has one important disadvantage. CO2 emissions are a key contributor to the greenhouse effect, trapping heat in the atmosphere and causing catastrophic climate change. Even while electricity accounts for only 20% of our total energy consumption, it accounts for 40% of energy-related CO2 emissions.

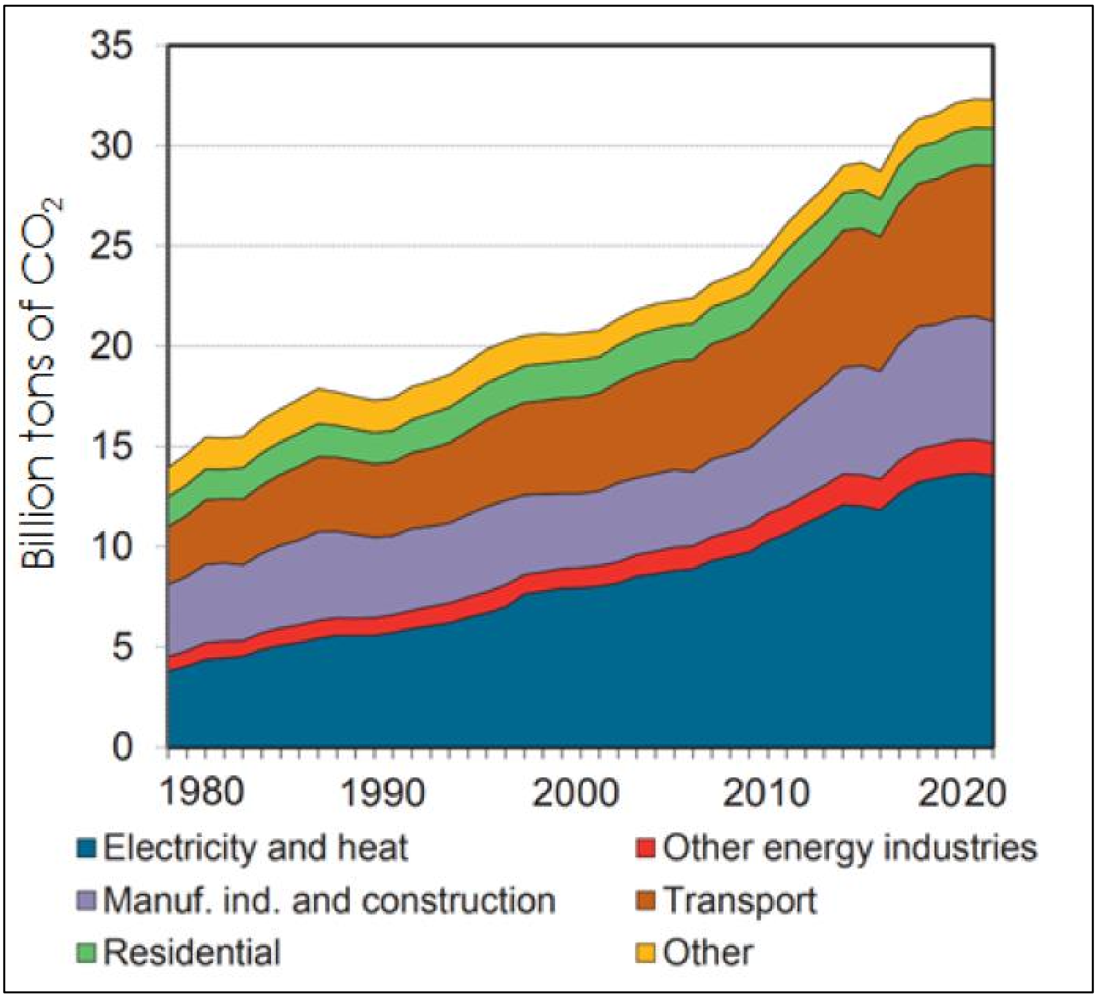

Fig. 19. CO_2 emissions by sector (1980 - 2020) [29]

This percentage may increase in the future. According to the International Energy Agency, China will bring online extra energy generation comparable to the existing US market over the next 25 years. India will add the equivalent of the European Union's current electrical generation during the same time span.

These countries still rely heavily on coal for producing electricity, 67% of the generation mix in China, 76% in India. Expanding the power production with the same resources will make it impossible to maintain temperatures in line with the Paris Agreement objective.

In additional detail, coal releases around 1 ton of CO2-equivalent every megawatt-hour generated, which is almost twice the amount emitted by natural gas. As a result, we must urgently decarbonize our power generating mix, either by transitioning to less carbon-intensive modes of production, such as nuclear or renewables, or by incorporating carbon capture and storage technology into carbon-emitting facilities.

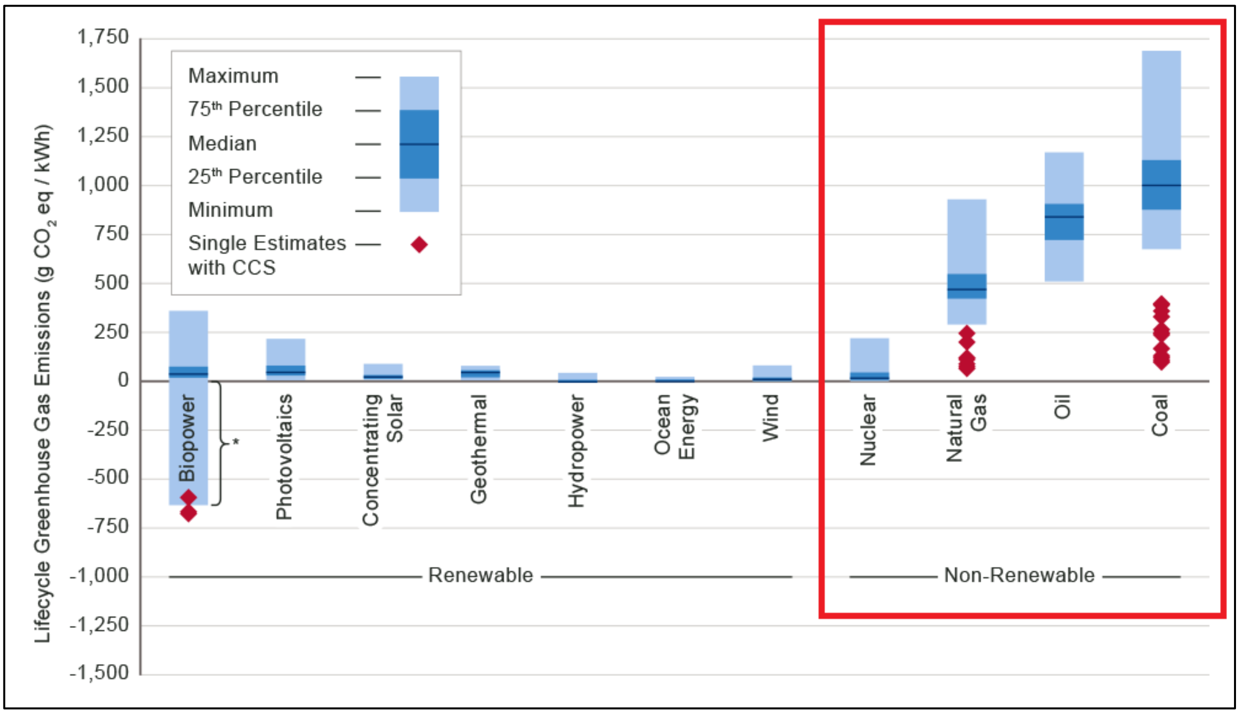

Fig. 20. Life-cycle emissions of non-renewable generation resources [30]

The challenge is daunting: according to the IEA projections only for OECD economies, the average CO_2 intensity of electricity needs to fall from 400 grams per kilowatt hour in 2020 to 15 grams/kWh by 2050 to achieve the goal of limiting the global increase in temperatures to 2°C.

To summarize, electricity is a critical energy transporter in many applications. However, electricity is CO2 demanding; it accounts for 20% of our energy use but accounts for 40% of CO2 emissions. Furthermore, future power usage is predicted to rise: Today, 1 billion people still lack access to modern energy, and worldwide electricity demand is increasing. As a result, decarbonizing the electrical mix is critical for mitigating the danger of climate change.

4.3. The levelized cost of electricity

When we compare different means of power generation, one useful tool economists frequently use is what is called the “levelized cost of electricity” or LCOE.

This LCOE reflects a unit cost for a given technology or a specific power plant: it is generally expressed in dollars per megawatt-hour of electricity produced. In the numerator of the formula, “I_t” reflects the initial investment of the installation (or what we usually call capital expenditures), “M_t” corresponds to the operation and maintenance spending throughout the lifetime of the plant (also known as OPEX), while “F_t” stands for fuel. All of these costs are divided by the total electricity output of the asset over its lifetime, which is the term “E_t” in the formula. [31]

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t : investment expenditures in the year t

M_t : operations and maintenance expenditures in the year t

F_t : fuel expenditures in the year t

E_t : electrical energy generated in the year t

r : discount rate

n : expected lifetime of system or power station

Fig. 20. Levelized cost of electricity formula [31]

However, because various power plants incur expenses at different points in their working lifetime and produce energy differently depending on the technology or location, the LCOE discounts all costs and megawatt-hours in current value. Simply said, it matters not just how much the power plant will cost, but also when these expenditures will arise.

So, what makes the difference from one installation to another?

Well, for renewable sources, LCOE will vary from one site to another depending on each site’s resource availability: for instance, a solar plant installed in a location with higher solar irradiance will generate more electricity compared with the exact same plant set up in a place where there is less sun. More electricity production, with the same costs, means a lower cost of production per MWh.

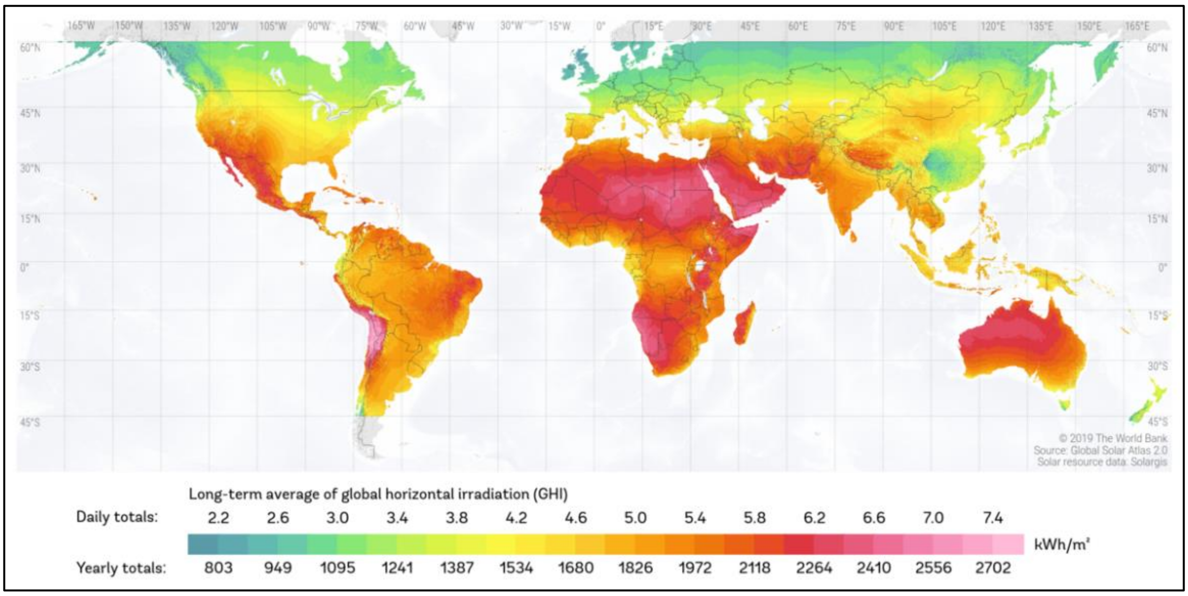

Fig. 21. Solar resource map: global solar irradiation [32]

A developer can potentially tolerate greater capital expenses if they anticipate increased energy generation during the power plant's lifetime. This is the rationale for offshore wind farms, for example. Installing turbines at sea takes far more investment and more difficult technology than installing turbines on land; nevertheless, the plant will catch a greater wind resource and will likely produce more power during the facility's lifetime.

Will the LCOE be lower in the end? It depends on each project, because many other factors have an impact on the costs throughout a plant’s lifetime.

Two other elements have played a key role in reducing the LCOE of renewables in recent years: economies of scale, and learning effects. Economies of scale are cost reductions obtained by a technology due to a larger scale of operation. This is quite evident in the case of solar PV: for instance, from a 10 MW to 100 MW PV power plant installed in the United States, the CAPEX per unit will be reduced by 20%. This is due the fact that the project will benefit from bulk purchasing, lower labor-cost per watt installed due to learning improvements for larger systems and a lower developer cost per unit.

Learning effects, on the other hand, are built into any produced product, like as wind turbines or solar panels. These impacts are frequently quantified using learning curves, a notion used to forecast how the costs of a product or process may change based on previous trends. Manufacturers improve their efficiency in manufacturing an item or providing a service through time, resulting in cost savings.

Latest learning curve for solar PV modules, by BloombergNEF, shows a record learning rate: 28.5% reduction in cost per Watt for every doubling of cumulative capacity, 1976-2018. Includes the spectacular 35% drop, forecast for this year. [33] [34] [35]

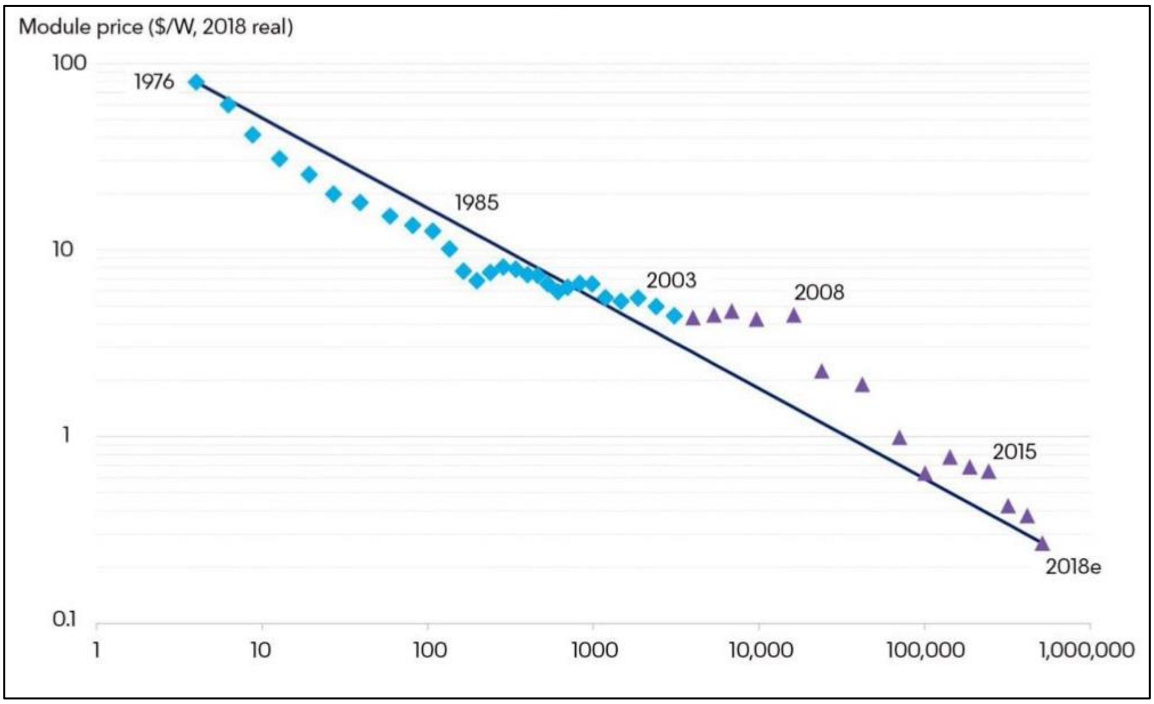

Fig. 22. Total industry cumulative production, MW [35]

This learning effect is a major driver of popular support for renewables. Policymakers decided to pay a higher price for solar PV or wind projects in the early years since they knew it would result in lower costs afterwards.

This bet is about to pay off in several countries, as wind and solar costs have fallen dramatically in recent years and are now competitive with traditional power generation methods in many cases. Indeed, if we look at the graph, which shows average LCOE statistics for various generating technologies, we can see that solar PV and wind are becoming increasingly competitive with fossil-fueled generation methods.

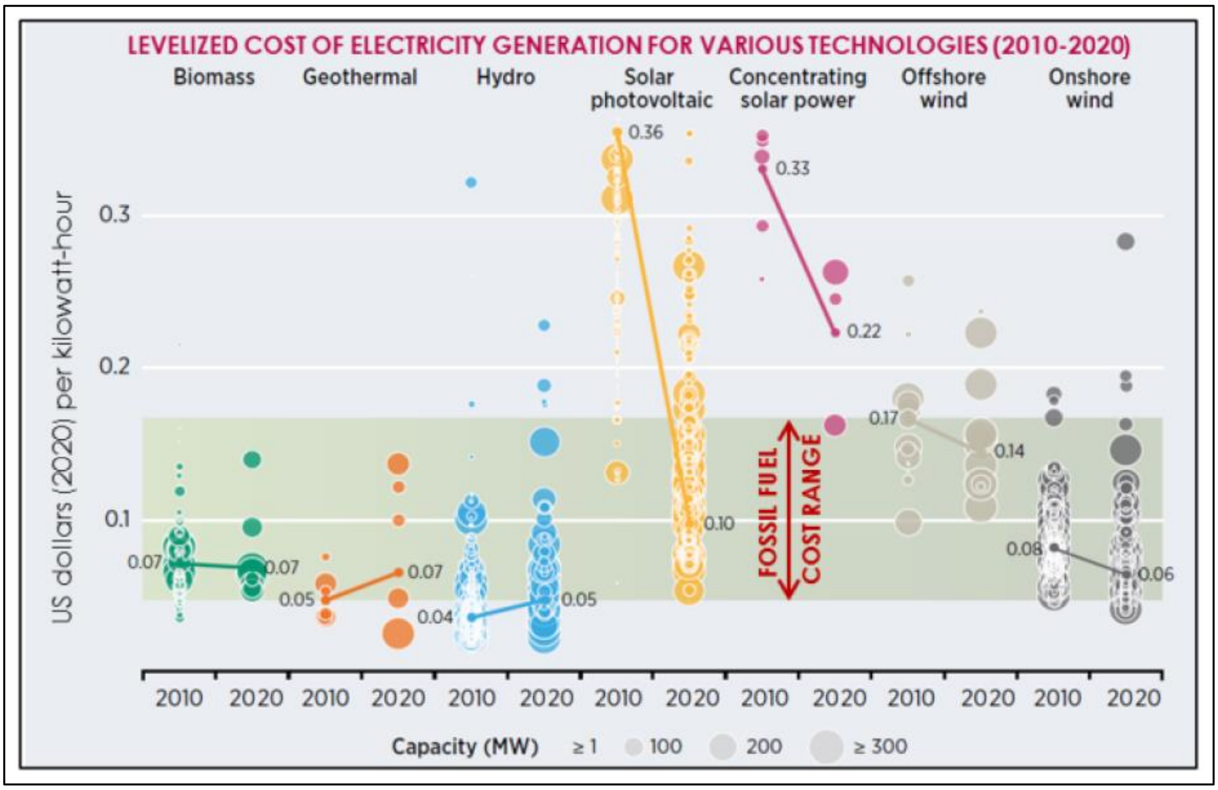

Fig. 23. Cost of electricity generation for various technologies (2010 - 2020) [13]

In conclusion, LCOE varies from project to project. However, both solar and wind systems are becoming more affordable. When these technologies attain grid parity, the power market will be in a very new economic setting.

To summarize: LCOE is a good tool to compare different ways of electricity generation. This LCOE is the ratio of discounted costs to discounted energy output throughout the power plant's whole lifespan. The LCOE for each technology varies from site to site, owing primarily to resource availability and capital costs.

The recent cost drop for solar and wind is due to two factors: economies of scale (the larger the project, the lower the cost per unit) and learning effects (getting better at producing panels and turbines through time). Wind and solar are already competitive with traditional power generating methods, and this is likely to spark an electrical revolution.

5. Mineral Demand

5.1. Importance of mineral resources for energy transition

Renewable energy is generated from natural resources such as wind and sunlight, which are technically limitless. Nonetheless, these energies are dependent on technologies that consume a significant number of mineral resources, which are not infinite on Earth. This is also true of all low-carbon technology.

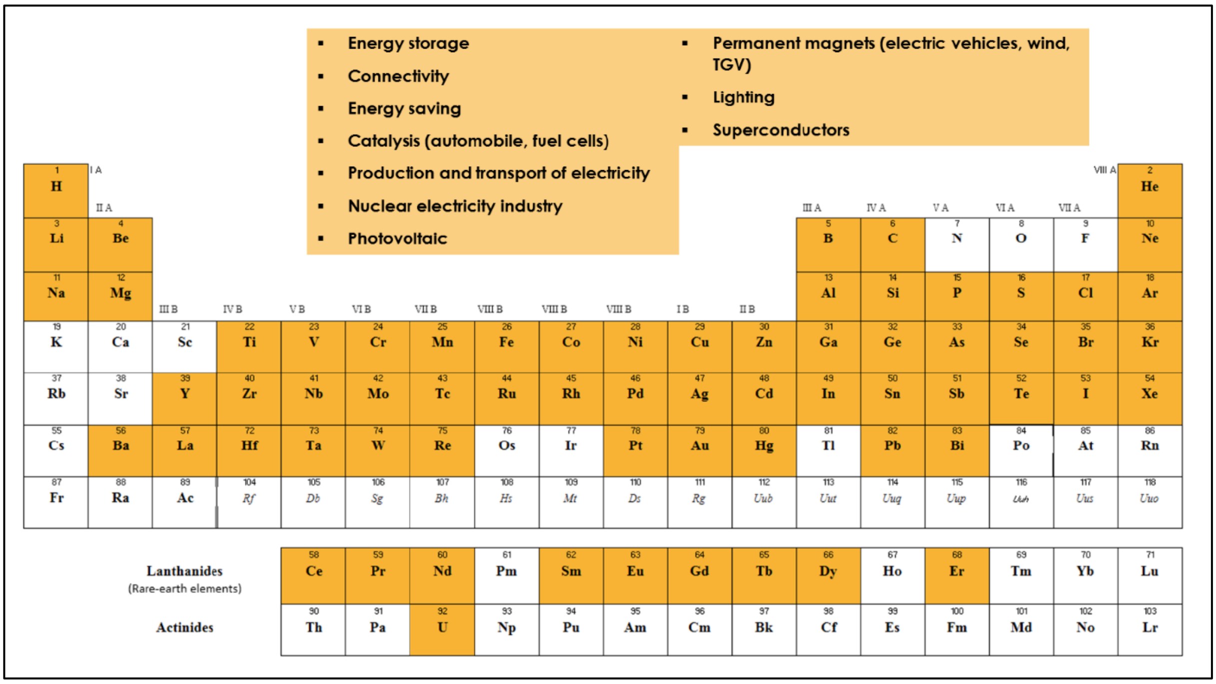

Fig. 29. Chemical elements and their usage [36]

Wind turbines require neodymium and dysprosium; solar panels require silica, cadmium, and indium; fuel cells require titanium; and electric batteries require lithium, cobalt, and other elements. Catalytic converters in thermal vehicles, for example, consume platinum, rhodium, palladium, and other metals. Nowadays, another rapidly growing area is also one of the first consumers: the digital sector, with its electronic components such as semiconductors. All information and communication technologies consume a lot of metal, and their influence on the world is far from insignificant.

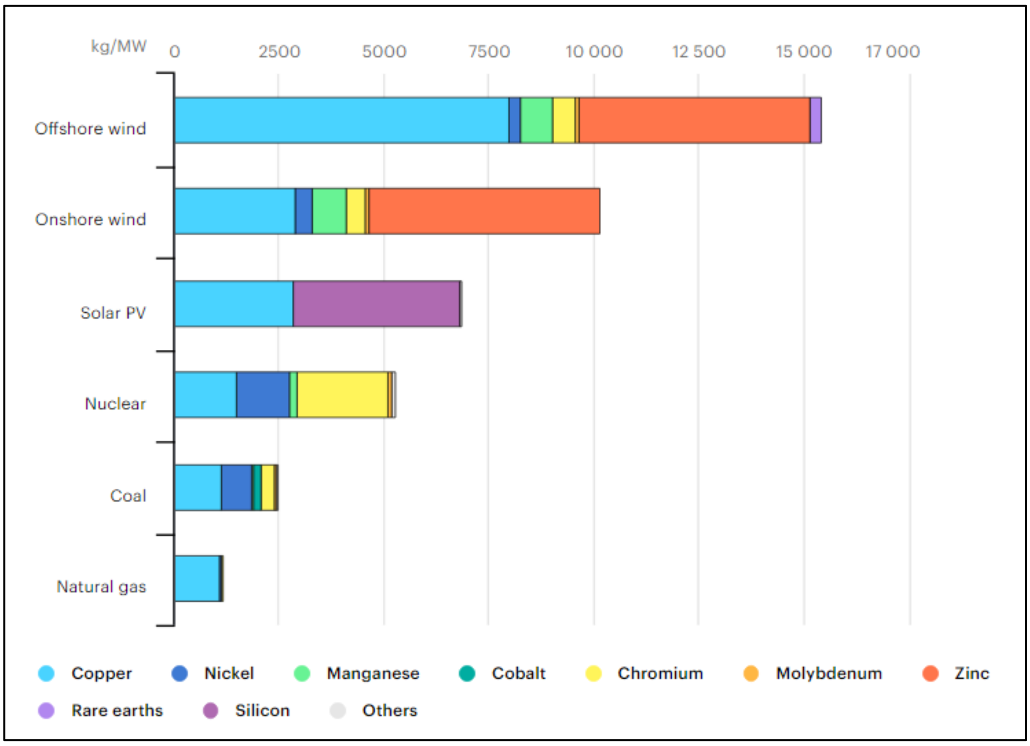

Fig. 30. Minerals in renewable technologies compared to other power generation sources [37]

An energy system driven by green technologies and an energy system powered by traditional resources differ deeply. Solar or PV plants, wind stations and electric vehicles usually require more minerals to function than fossil fuel-based machines. A standard electric car demands 6 times the mineral inputs of a conventional car. As well as an onshore wind farm demands 9 times more minerals than a gas-fired station. Since 2010 the average amount of minerals required for a new block of power generation capacity has risen by half as the share of renewables in new investment has increased.

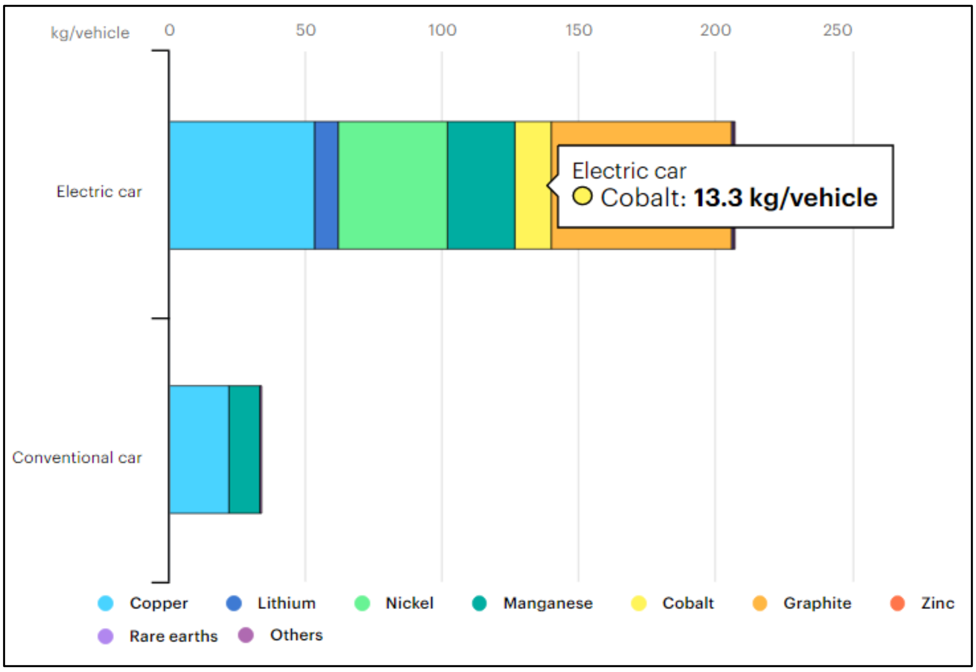

Fig. 31. Minerals used in electric cars compared to conventional cars [37]

If we consider that we are moving to a 9 billion human society by 2050, it is hard to conceive a decreasing demand in the short or medium term for all of the metal of the energy transition.

Is the signal that we are shifting from an economy essentially dependent on Oil & Gas to a new era where the mineral resources used for the energy transition will take this place? We can also ask if this new dependency can be a limiting factor for the deployment of low-carbon technologies.

5.2. Geopolitical, Economic and Environmental and Social issues

First of all, as seen on the map, the countries holding the resources necessary for the energy transition are different from the oil producing countries. Some resources are geographically very concentrated. The top three producers of lithium, cobalt, and rare earth elements (REEs) account for about three-quarters of worldwide output. In other circumstances, a single country accounts for over half of global manufacturing. South Africa and the Democratic Republic of the Congo accounted for 70% of world platinum and cobalt production, respectively, and China accounted for 60% of global rare elements output. Copper and nickel have a little more diversified picture, but the top three producing nations still account for over half of world production. There is therefore a strong chance that new major players will emerge and change the existing global governance of energy today. The Covid-19 crisis has effectively illustrated that effects of breakdown in one part of the supply chain can impact drastically on the projects and businesses in other parts.

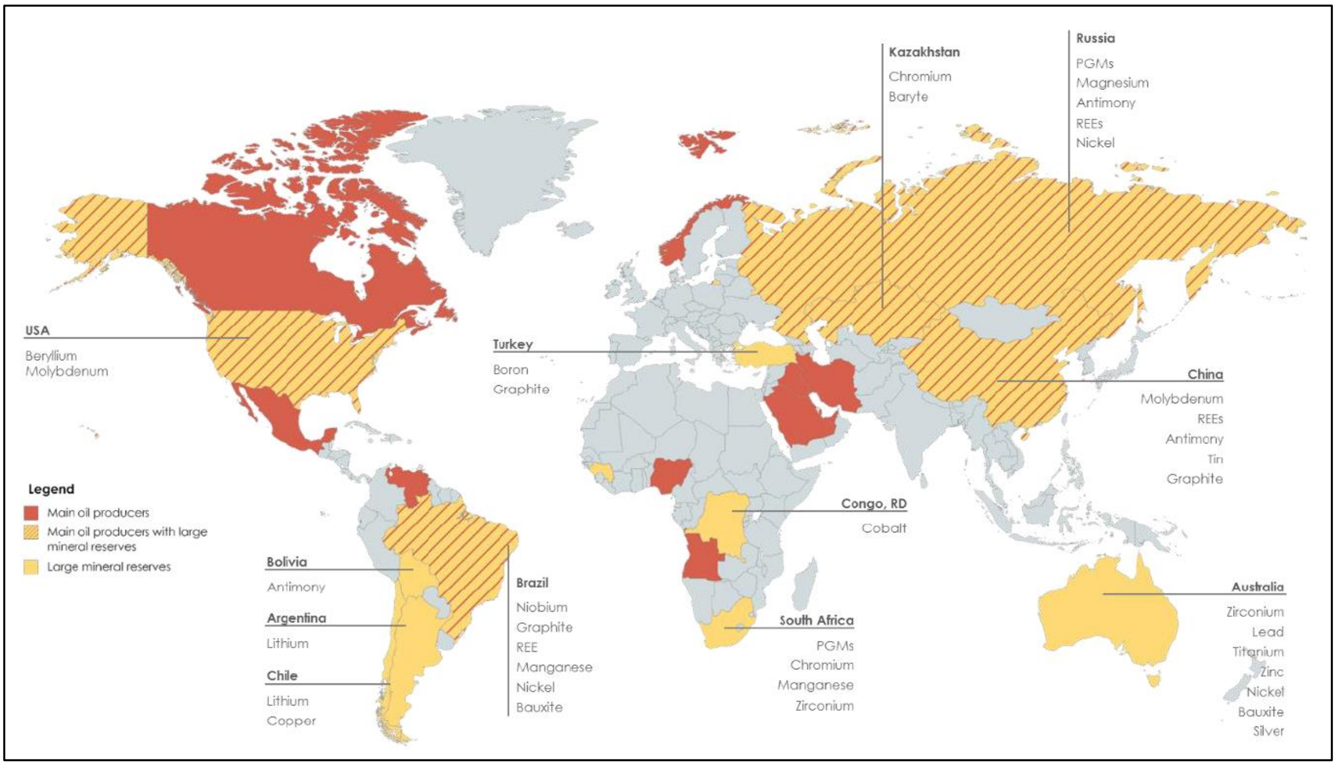

Fig. 32. Earth element map [39]

In addition, like oil-producing countries, these countries may have national strategies that can constrain supply and affect the price of raw materials. This was the case, for example, for the rare earth market in 2010 when China threatened an embargo on Japanese markets. This crisis has raised awareness of the geopolitical issues related to supply. In 2014, Indonesia, one of the main suppliers of nickel, decided to ban direct shipping ore in order to capture more added value through nickel refining. This decision forced the market to find other sources of supply.

In addition to these geopolitical risks, there are also risks related to economic availability. This is particularly the case for many products that are only extracted as a co-product.

The Indium for example. 95% of indium supply comes from zinc mine operation. Its availability and ultimately its price are therefore dependent on the zinc market.

One way often mentioned to overcome a lack of metals is recycling. However, as indicated in the table below, many materials are nowadays very poorly recycled. Recycling processes for small metals, which are embedded in complex matrices, are often difficult and require a lot of energy, so they are not cost-effective. Consequently, it is cheaper to exploit resources directly from the ground.

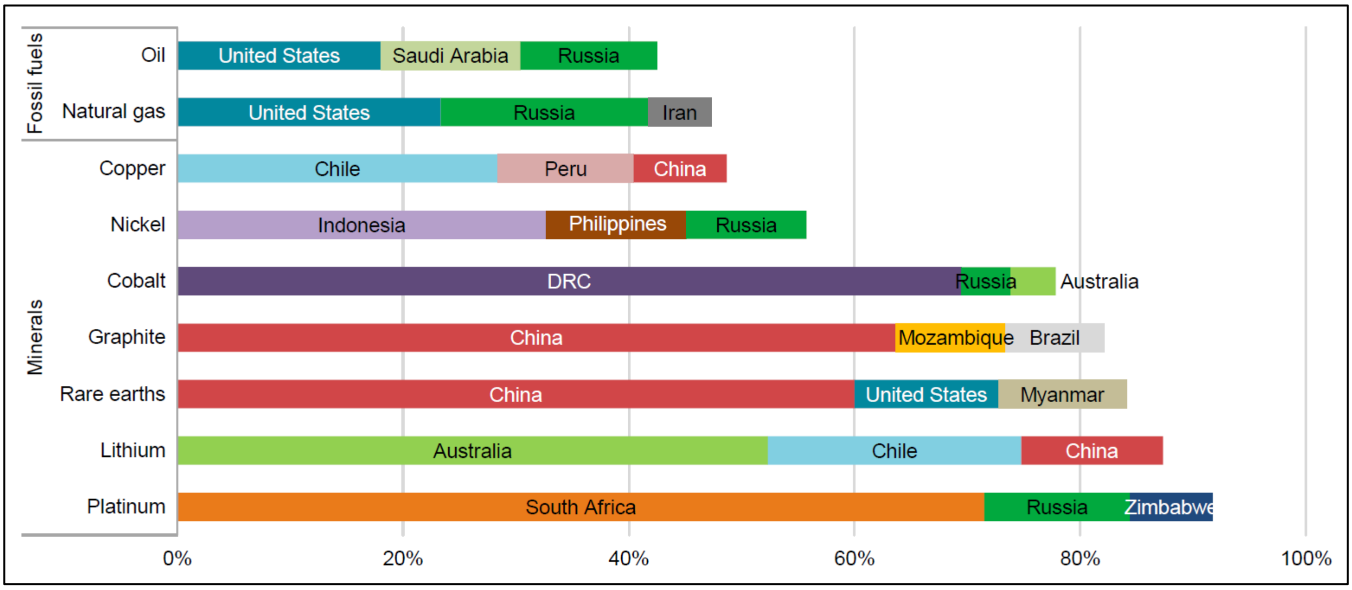

Fig. 33. Share of top three producing countries in total production for selected minerals and fossil fuels, 2019 [37]

An increasingly significant risk is also related to the environmental impact of extraction processes and the acceptability to society. For example, lithium mining in Chile is a major water user, while the region is known to be regularly under water stress. There are regular public demonstrations for greater consideration of these factors and more responsible exploitation.

Criticality of a mineral resource is not only geological, but also and above all, as with oil, it is an economic and geopolitical issue. To obtain a global vision of the criticality of a raw material, it is therefore necessary to take these different risks into account and quantify them in order to determine the criticality of the raw material studied.

Areas of risks		Description
Environment	Climate change	• With higher greenhouse gas emission intensities than bulk metals, production of energy transition minerals can be a significant source of emissions as demand rises • Changing patterns of demand and types of resource targeted for development pose upward pressure
	Land use	• Mining brings major changes in land cover that can have adverse impacts on biodiversity • Changes in land use can result in the displacement of communities and the loss of habitats that are home to endangered species
	Water management	• Mining and mineral processing require large volumes of water for their operations and pose contamination risks through acid mine drainage, wastewater discharge and the disposal of tailings • Water scarcity is a major barrier to the development of mineral resources: around half of global lithium and copper production are concentrated in areas of high water stress
	Waste	• Declining ore quality can lead to a major increase in mining waste (e.g. tailings, waste rocks); tailings dam failure can cause large-scale environmental disasters (e.g. Brumadinho dam collapse in Brazil) • Mining and mineral processing generate hazardous waste (e.g. heavy metals, radioactive material)
Social	Governance	• Mineral revenues in resource-rich countries have not always been used to support economic and industrial growth and are often diverted to finance armed conflict or for private gain • Corruption and bribery pose major liability risks for companies
	Health and safety	• Workers face poor working conditions and workplace hazards (e.g. accidents, exposure to toxic chemicals) • Workers at artisanal and small-scale mine (ASM) sites often work in unstable underground mines without access to safety equipment
	Human rights	• Mineral exploitation may lead to adverse impacts on the local population such as child or forced labour (e.g. children have been found to be present at about 30% of cobalt ASM sites in the DRC) • Changes in the community associated with mining may also have an unequal impact on women

Fig. 34. Environmental and social challenges related to energy transition minerals [37]

Finally, to succeed in the energy transition, it is essential to have a systemic vision concerning the various aspects involved, including the demand for mineral resources. Only in this way can the most relevant choices be made for the benefit of society.

<u>As a consequence, following challenges and vulnerabilities were distinguished such as</u>:

1) High geographical concentration of production: In reality, the concentration of mineral resources is more dramatic than for fossil fuels. For example, The Democratic Republic of the Congo (DRC) and China keep about 70% of global production of cobalt and rare earth elements respectively. In the sector of processing, it is even more concentrated: China has huge presence in refining of some of top 5 most demanded minerals and invests in number of mineral projects around the world. In recent years it could lead to potential economical as well as social issues.

2) Long project development lead times: Usually mining companies don't want to dive quickly into the mining processing. Often, they wait for 15 years to start production. Thus, this uncertainty has no positive effect on the mining industry in general.

3) Declining resource quality: As far as mining companies don't hurry up with the production of minerals, often, they have a tendency to fall in quality. And this problem even more actual than quantity.

4) Growing research of environmental and social productivity: mineral extraction can lead to a series of environmental and social problems. And this can harm local nations. Thus, this is socially responsible to produce important minerals using sustainable ways.

5) Higher exposure to climate risks: Mining properties are vulnerable to climate changes. Several mining deposits are exposed to water presence whereas other reserves are under extreme conditions such as heat and waterflooding. [37]

These challenges are going to be actual for several years to come. And from governments and big enterprises it will be defined which issues will be still critical and which will disappear or successfully solved.

5.3. States of mineral market

Besides the Covid-19 pandemic and the following economic crisis have changed the global image on the energy scene, resulting in falling the global energy-related CO2 emissions by 6% in 2020, the world is far from observing a crucial decline – CO2 emissions in December 2020 were already higher than their pre-pandemic level one year before.

Analyzing the path of the Paris Agreement, a lot of things should to be done such as: the annual installation of solar photovoltaic cells, wind turbines and electricity networks need to grow by 3 times by 2040 from today's levels, electric cars sales need to increase 25 times over the same period. To achieve "below 2 °C temperature" globally by 2050, even more drastic rise in the development of clean energy technologies is demanded over the same timeframe. [40]

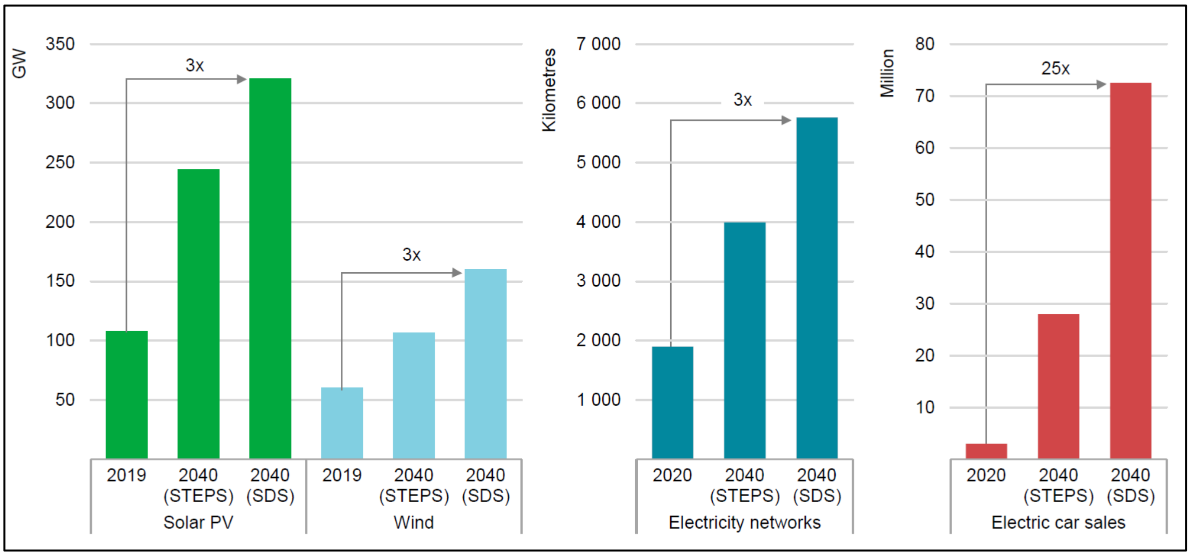

Fig. 34. Annual deployment of clean energy technologies by scenario [37]

One of the fundamental contrasts between oil and minerals is that minerals and metals may be reused and recycled indefinitely with the correct infrastructure and technology in place. As a result, this provides an extra lever for ensuring consistent mineral supply by maintaining them in circulation for as long as feasible.

The level of recycling is typically measured by two indicators:

1) End-of-life (EOL) recycling rates: captures the amount of (secondary) materials recovered and functionally recycled at end-of-life compared to the overall waste quantities generated.

2) Recycling input rates (also called recycled content rates): assess the share of secondary sources in total supply.

EOL recycling rates vary greatly depending on the metal. Copper, nickel, and aluminium, which are utilized in huge quantities, have significant EOL recycling rates. Due to very high worldwide prices, precious metals such as platinum, palladium and gold have also attained greater rates of recycling. Lithium, on the other hand, has essentially no worldwide recycling possibilities due to restricted collection and technological restrictions, and REEs are in a similar situation.

Recycling does not negate the necessity for ongoing investment in basic mineral supplies. Even if EOL recycling rates reach 100% by 2050, according to a World Bank estimate, significant investment in primary supplies would be required. However, at a time when demand is on the rise, recycling can help alleviate the strain on primary supply from primary materials. [41]

Mineral and metal companies are becoming the vital chain between underground resources and the energy technologies that consumers need today. As a result, mining and refining industries have a lot of room to contribute to smooth clean energy transitions by assuring enough mineral supply.

We already have a lot of mining companies already engaged in the energy sector, as coal producers. For such companies the energy transition therefore is represented as an issue, as well as a possibility. Some of these enterprises are already moving away from coal as it was with Rio Tinto, which entirely came out the coal production in recent years and other companies are following the same route, mostly through decreasing thermal coal production. However, there are still significant uncertainties about the timing and magnitude of demand growth, as well as the complexity of establishing high-quality projects.

As governments have issued stronger signals about their net-zero intentions, and price signals for particular minerals gave increased incentive, the situation is starting to alter. In the second half of the decade, new project investment increased. Although the potential of boom-and-bust cycles is always there for commodities with long lead-times from project development to production, this trend would need to be sustained in order to support enough supply.

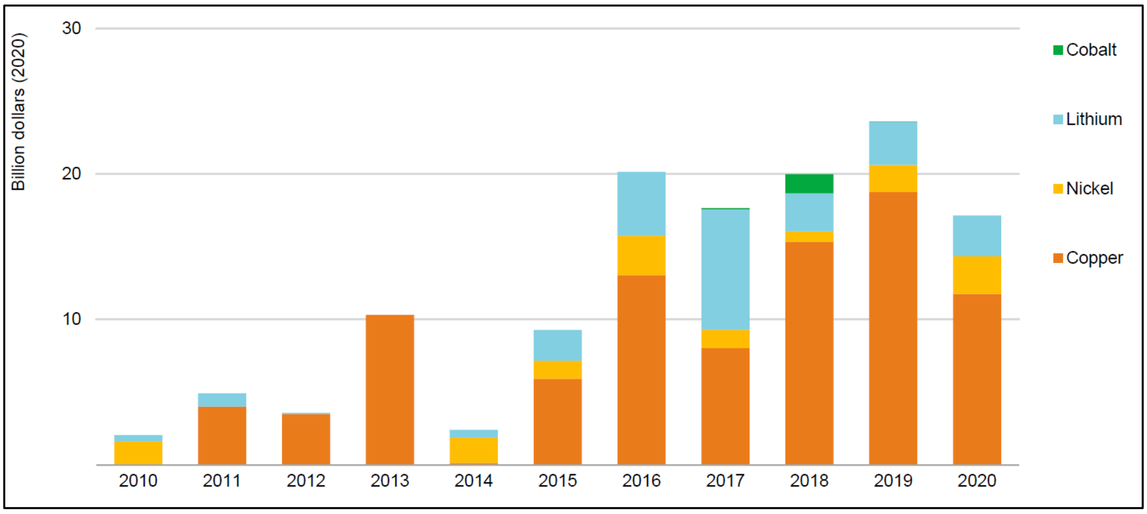

Fig. 35. Announced capital cost for greenfield projects for selected minerals [37]

Mineral prices are more volatile than traditional hydrocarbon prices, owing to a mismatch between demand patterns and new project development, as well as supply chain opacity. Prices for lithium and cobalt rose dramatically in a short period in the late 2010s as the adoption of electric vehicles began to pick up steam. Despite prices have since fallen, this has served as a warning about potential supply and market imbalances. This gives policymakers even more cause to be concerned about this important part of a clean energy future.

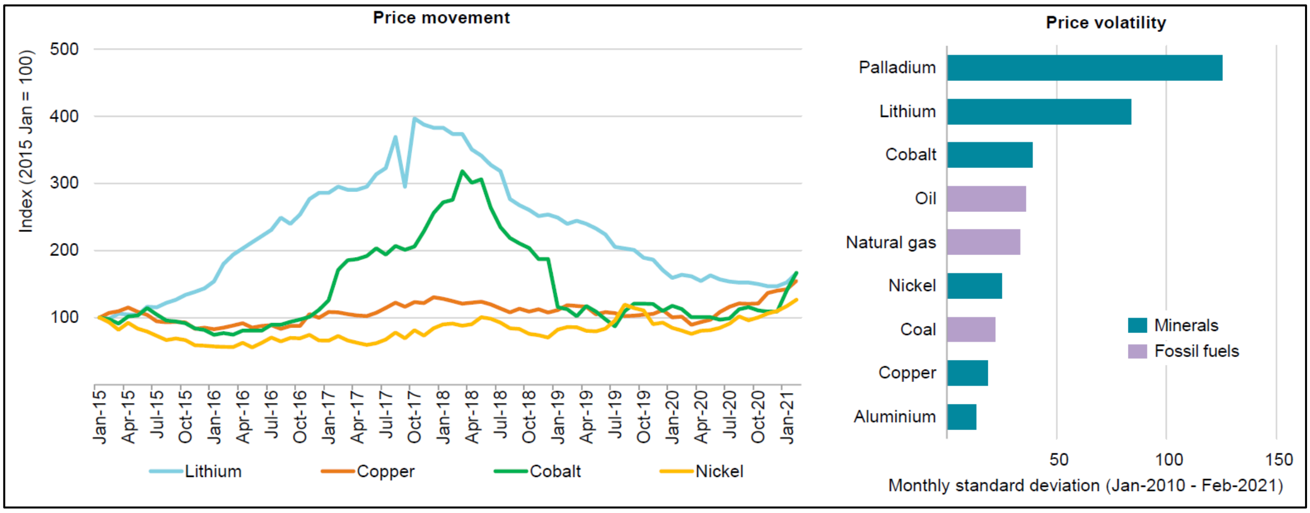

Fig. 36. Price movement and volatility of selected minerals [37]

5. 4. Mineral requirements for clean energy transitions

Minerals and metals have been crucial in the development of today's clean energy technologies, from wind turbines and solar PV panels to electric cars and battery storage. The energy sector is becoming an increasingly important aspect of the minerals and metals business as clean energy technology is deployed. Mineral-energy ties are expected to strengthen as renewable energy transitions take place.

However, this begs the issue of whether there will be enough sustainable and sustainably produced minerals to support the pace of energy transitions. Understanding the possible mineral requirements coming from sustainable energy transitions is the first step in addressing this.

Mineral demand projections are susceptible to a lot of uncertainty. It is heavily reliant on the severity of climate policy (as seen by the difference between the STEPS and SDS), as well as diverse technological development paths.

Over the next 20 years, global renewable energy transitions will have far-reaching implications for mineral demand. In the STEPS, overall mineral demand from clean energy technologies will double by 2040, while in the SDS, it will quadruple.

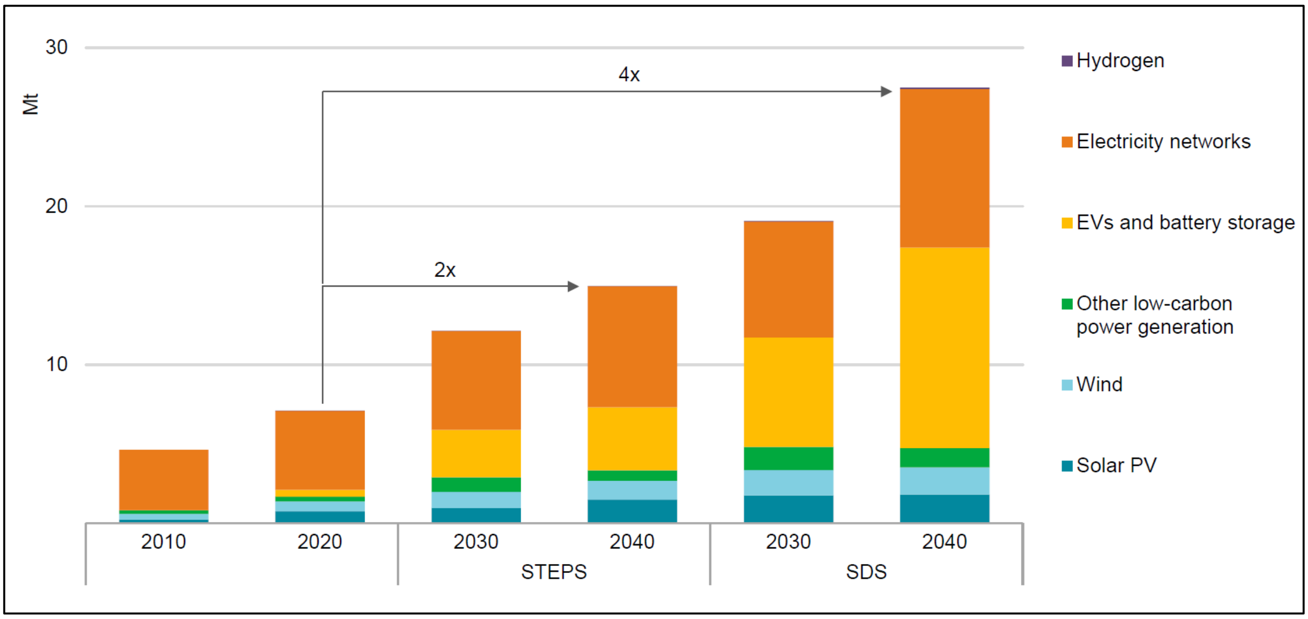

Fig. 37. Total mineral demand for clean energy technologies by scenario [37]

EVs and battery storage are expected to account for over half of the mineral demand increases from sustainable energy technologies over the next two decades, owing to increased need for battery materials. Over the timeframe 2040, mineral demand for use in EVs and battery storage climbs approximately tenfold in the STEPS and around 30 times in the SDS. Copper, graphite, and nickel will dominate mineral demand in 2040 by weight. Lithium has the highest rate of increase, with demand increasing by more than 40 times in the SDS. The change to lower cobalt chemistries for batteries serves to curb cobalt growth, which has been supplanted by nickel growth. Another key driving force is electricity networks. They contribute for 70% of today's mineral demand from the energy technologies studied, however their proportion is decreasing as other technologies, most notably electric vehicles and storage, rise rapidly.

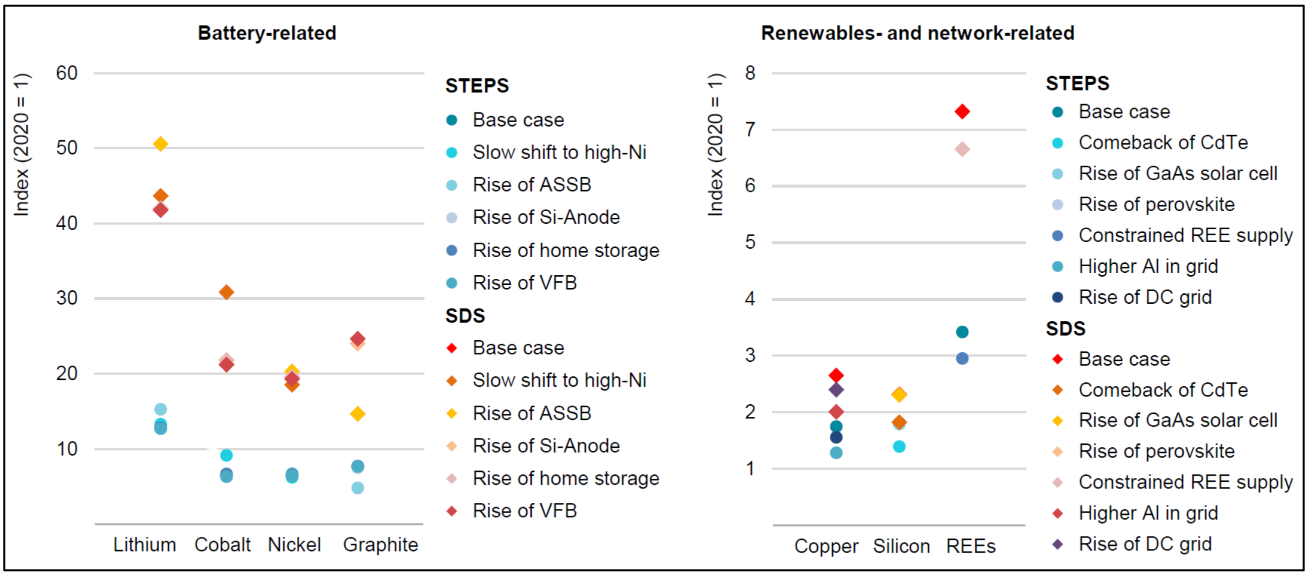

Fig. 38. Mineral demand from clean energy technologies in 2040 relative to 2020 under different scenarios and technology evolution trends [37]

Greater uncertainty about the future may stymie business investment choices, resulting in a supply-demand mismatch in the coming years. Despite excellent demand growth expectations, mining and processing industries may be hesitant to spend extensively due to the vast number of demand channels available. However, it does not depend on technology. It goes from the ambiguity of pending climate ambitions – whether green energy development and following mineral demand tracks STEPS or SDS paths. In this case governments may help reduce uncertainty by giving signals about their climate aims and enacting concrete measures to achieve these long-term objectives. The efforts must be complemented by a variety of steps to temper the rapid development in primary supply requirements, such as boosting technology innovation for material efficiency or replacement, scaling up recycling, and improving the upkeep of existing assets to extend their lifetime.

5.5. Mineral supply

Before the epidemic, demand and supply for particular minerals were tightly balanced, and supply instabilities were expected to occur in the future years. While demand cutbacks prompted by Covid reduced some of these constraints, questions about the sufficiency and cost of future supply remain as the globe emerges from the crisis, and several governments place renewables and batteries at the center of their economic packages. Although price rises were not necessarily related to physical market balances, the price rallies in late 2020 and early 2021 may have offered a glimpse of what may happen if the globe advances on a decarbonization path.

Looking on the pathway, the market will react to supply constraints by lowering demand, substituting, or boosting supply. However, this is frequently accompanied by price volatility, long time delays, or a reduction in performance or efficiency. In the case of renewable energy transitions, a lack of minerals might make them more expensive, take longer, or be less efficient. Given the urgent need to reduce emissions, this is a risk the world cannot afford.

Despite the demand on the main minerals such as copper, lithium, nickel, cobalt and rare earth elements will increase every year, there are several vulnerabilities that could interfere sufficient supply and drive to high price volatilities. Moreover, each of these elements have they own certain challenges that should be considered by mineral producers and society in general. The way policy makers and government choose for the mineral supply will definitely determine the energy transition and the green energy future.

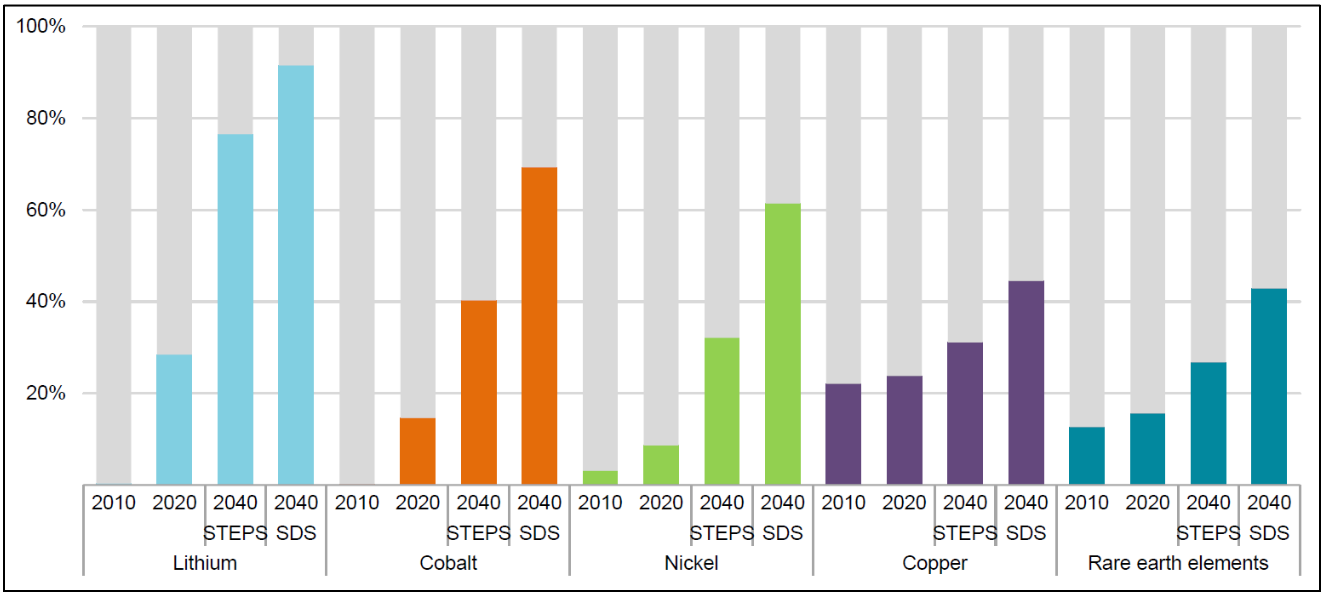

Fig. 39. Share of clean energy technologies in total demand for selected minerals [37]

5.5.1. Copper

Despite an ever-increasing demand for copper, there is more of the metal available today than at any other time in history. This, together with the ability to infinitely recycle copper, means that society is extremely unlikely to deplete the copper supply, and copper will continue to contribute to global initiatives, like the SDGs and clean energy.

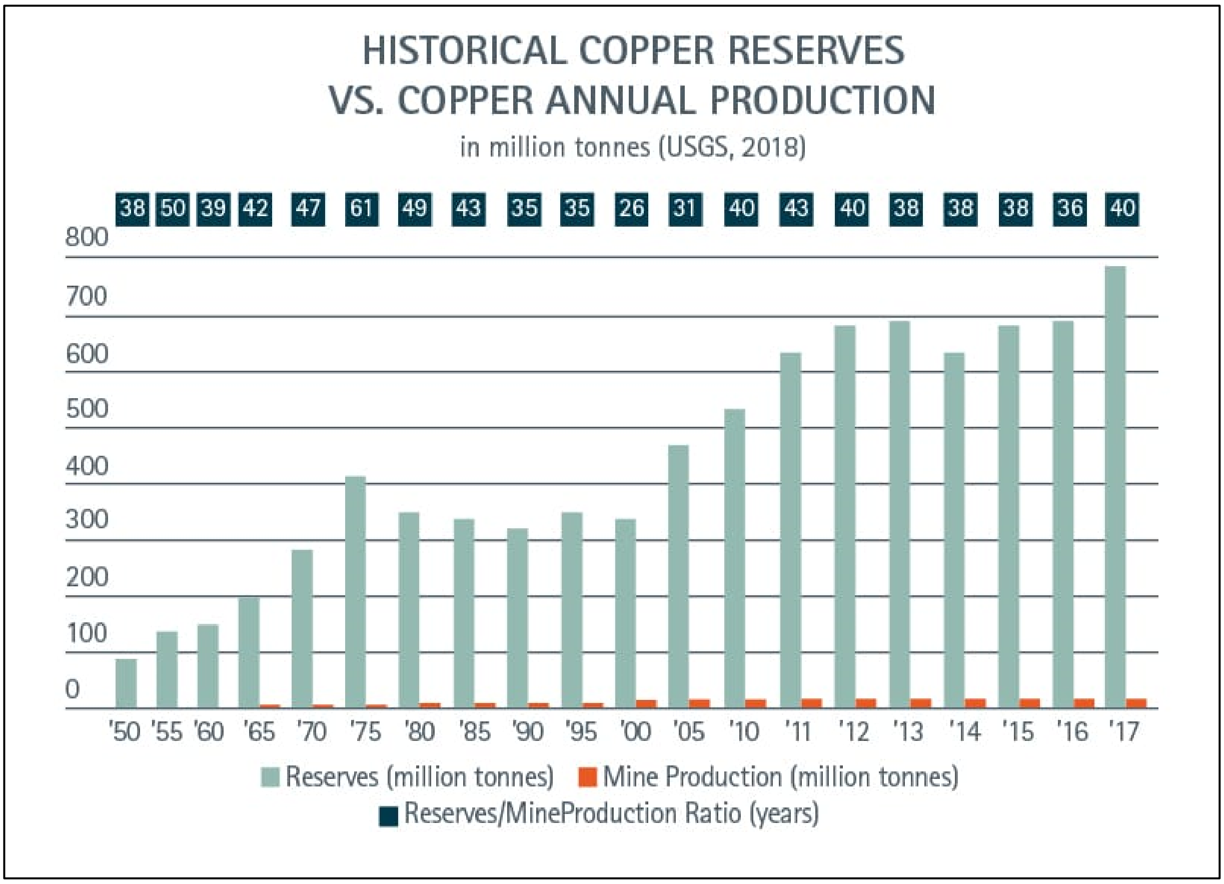

Fig. 39. Historical copper reserves vs. copper annual production [43]

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). The green energy transition is anticipated to significantly increase demand for copper because of its uses in expanding electricity networks and clean energy technologies, such as electric vehicles. [44]

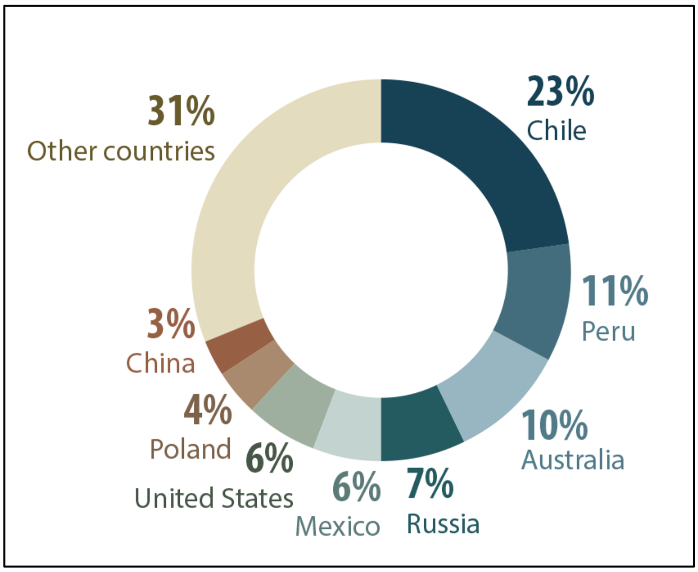

Fig. 40. World reserves of copper [45]

This circular chart shows the estimated percentages of world reserves of copper by country in 2020. Chile had the largest share with 23%, followed by Peru (11%), Australia (10%), Russia (7%), Mexico (6%), the United States (6%), Poland (4%), and China (3%). All other countries combined accounted for 31%.

Two types of copper ore exist:

1) Copper sulfide (80% of production)

2) Copper oxide (20%)

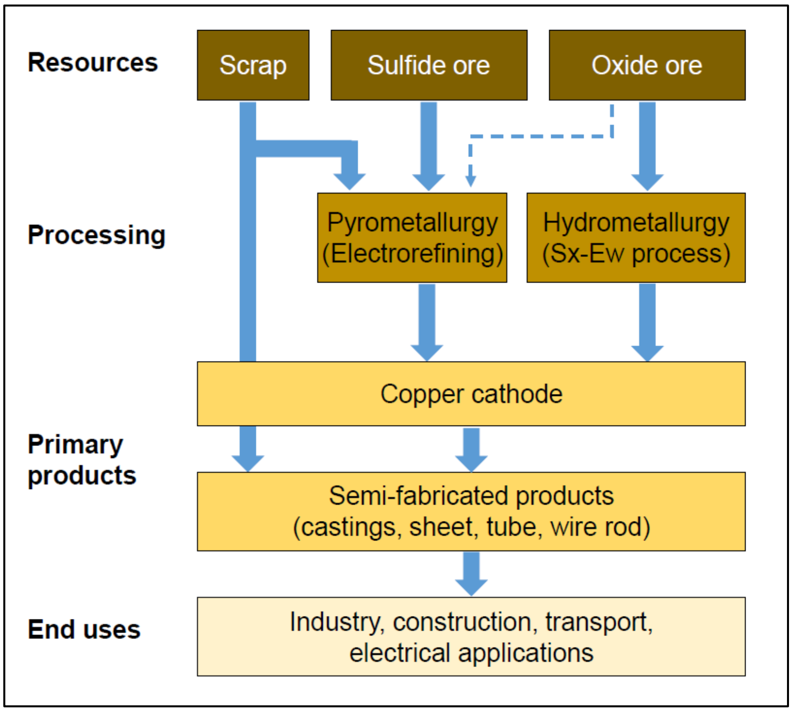

Fig. 41. Copper supply chain [37]

Sulfide ore is processed through a pyrometallurgical (smelting) process; the ore is crushed and ground, then transformed into concentrates, which are then exported to China and other countries for electrorefining to produce refined copper.

Oxide ore is processed using the Sx-Ew (solvent extraction and electrowinning) hydrometallurgical process, which extracts copper from the ore into a solvent and then electrowins the copper cathode from the solvent. Sx-Ew procedures are commonly carried out near mines. [46]

With a market share of over 40%, China is the largest copper refining country, followed by Chile, Japan, and Russia. China, however, imports refined copper goods from other countries since it accounts for 50% of world consumption.

Copper is still in high demand for renewable energy technology, both in terms of weight and dollar worth. Copper consumption is also expanding at a rapid pace in the clean energy sector. In the STEPS, their percentage of total copper consumption climbs from 24% currently to 30% by 2040, and in the SDS, it rises to 45 percent.

Despite the fact that copper supply has been quickly growing in recent decades to meet rising demand induced by strong economic development in emerging and developing nations, historical trends may not be a fair predictor of what will happen in the next decades. Due to decreasing ore quality and reserve depletion, production at most copper mines is going to be peaked. As it is in case of Escondida in Chile, the largest copper ore, which is being exhausted by 2025.

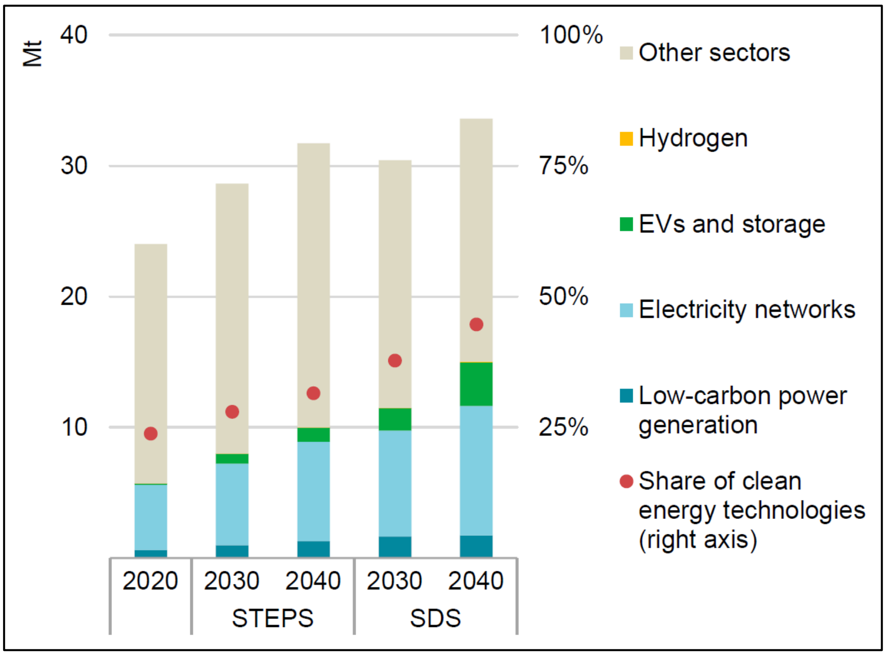

Fig. 42. Total copper demand by sector and scenario [37]

Nevertheless, new investments appear as the energy transition becoming more actual. Prospect projects, such as Quellaveco in Peru, Oyu Tolgoi in Mongolia and Kamoa-Kakula in the DRC are currently in development. These and other projects in progress could bring significant supply in case of success.

While Chile and Peru will continue to be the top producers until 2025, the picture is expected to grow more diversified, with the DRC and Indonesia expanding output. In terms of processing, China is likely to maintain its dominance in the short term, with capacity expansions through 2025 accounting for over half of all planned worldwide capacity additions. As China's processing share rises (but not its mining share), the nation will have more control over intermediate product trade and price.

Despite there is no scarcity of resources, due to deteriorating ore grade in key producing locations, establishing new projects has become difficult. Some big mines' resources are dwindling, and development is shifting to the outskirts of exploited deposits. Extra expense and energy are required to extract metal content from lower-grade ores. Furthermore, the deeper the industrial location, the more expensive and energy-intensive it is.

While cost increases are a key concern for the copper sector, the effects of resource depletion can be mitigated by technological advancements. Continued technological innovation is critical to maintaining inexpensive copper supply.

Another story is environmental issues. Water shortage is a problem in major copper-producing regions in South America. Furthermore, in the copper sector, toxic substances such as arsenic are a major worry. Deteriorating ore grades result in an increase in contaminant levels, especially arsenic, which can lead to major water and air pollution. [37]

5.5.2. Lithium

Lithium is a light metal belonging to the alkali metal group. It is the least dense of all known solid elements. It has half the weight of water, is silver-gray and relatively soft. Lithium products derived from brine operations can be used directly in end-markets, but hard rock lithium concentrates must be further processed before they can be used in value-added applications like lithium-ion batteries. [47]

Lithium is extracted from lithium minerals found in igneous rocks composed of large crystals (spodumene) or in water with a high concentration of lithium carbonate (brine). Historically global lithium supply was dominated by hard-rock mineral sources. Today, the world’s lithium production is split evenly between hard rock and brine. [48]

The industry distinguishes three basic types or qualities of lithium compounds:

1. “Industrial grade”

2. “Technical grade”

3. “Battery grade”

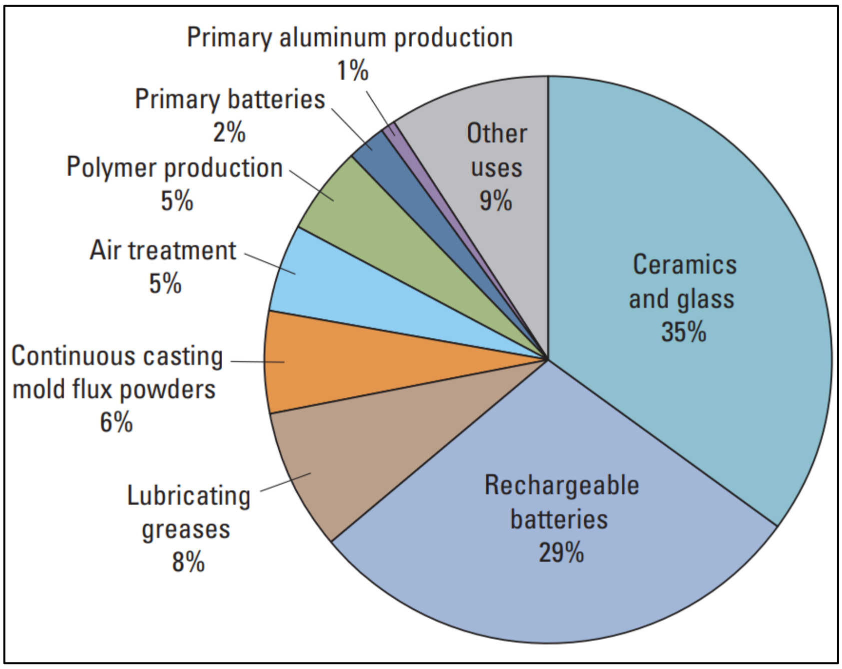

Fig. 43. Pie chart showing major end uses of lithium as a percentage of world consumption [49]

Lithium has many uses. Worldwide lithium consumption in 2020 by end use was estimated to be as on the pie chart: ceramics and glass, 35 percent; rechargeable batteries, 29 percent; lubricating greases, 8 percent; continuous casting mold flux powders, 6 percent; air treatment, 5 percent; and polymer production, 5 percent; primary batteries, 2 percent; primary aluminum production, 1 percent; and other uses, 9 percent. [50]

A) Ceramics and glass: For years to come, ceramics and glass are likely to be the dominant end applications for lithium. Lithium reduces the melting temperature and viscosity of glass, making the process more cost-effective. Where typical window glass would shatter, lithium-bearing glass can endure high temperature changes and rigorous use, making it a frequent application in glass stovetops. Lithium is used to manufacture porcelain enamels, glazes, and tiles in the ceramics industry.

B) Rechargeable batteries: As the production of electric and hybrid cars rises, the production of rechargeable batteries, which presently ranks second among lithium's end applications, is expected to rise in the coming years. Battery production has the most growth potential of any lithium industrial area, with many major automotive manufacturers researching lithium-ion batteries. For usage in cellular phones, cordless tools, MP3 players, portable computers and tablets, the demand for rechargeable lithium batteries has now surpassed that for rechargeable nonlithium batteries. Calculators, cameras, and watches all require non-rechargeable lithium batteries.

C) Aerospace: Lead, copper, silver, magnesium, silicon, and aluminum are just a few of the metals that lithium may combine with. Lithium aluminum alloys having 1-3 weight percent lithium are the most widely utilized in modern aerospace applications. The NASA space shuttles' fuel tanks, for example, were made of an aluminum-lithium alloy.

D) Lubricants: Lithium is frequently utilized as a high-performance lubricant in automotive, aerospace, industrial, marine, and military applications as lithium stearate or related compounds. Lithium was found in 60 percent of all industrial lubricants in 1993, often at amounts of 1 to 2%. Because lithium chloride and bromide are two of the most effective chemicals for absorbing water, they are utilized in air conditioning systems to reduce humidity while chilling the air. [50]

With 8 million tons, Chile has the world's largest known lithium reserves. This puts the South American country ahead of Australia (2.7 million tons), Argentina (2 million tons) and China (1 million tons). Within Europe, Portugal has smaller quantities of the valuable raw material. The total global reserves are estimated at 14 million tons. This corresponds to 165 times the production volume in 2018. [51]

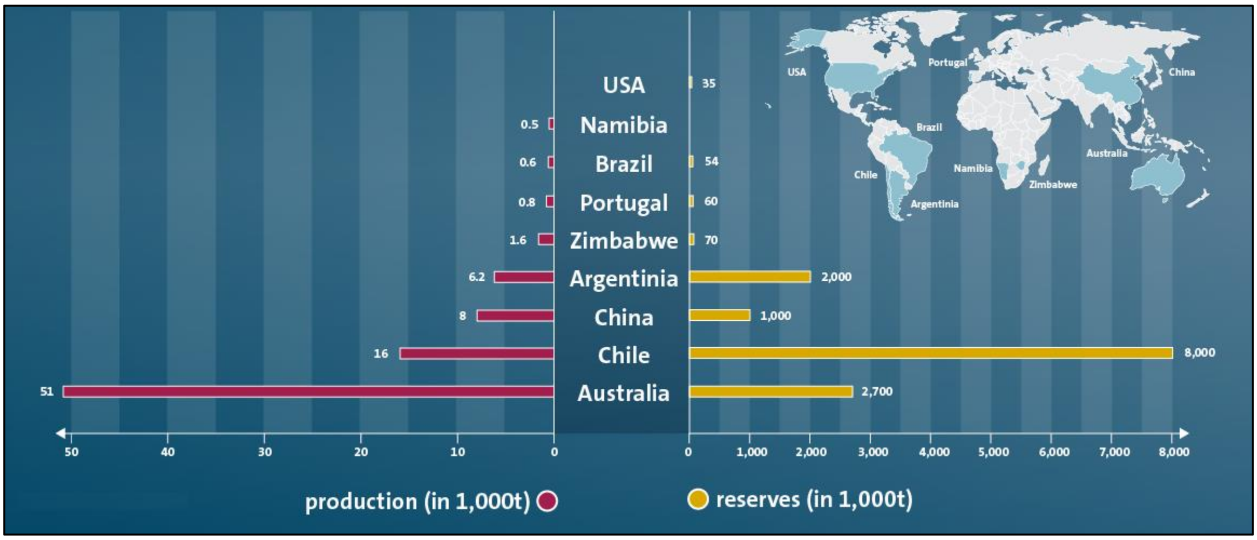

Fig. 44. Countries with major Lithium production and reserves. [51]

Mines and brine water are two main sources of lithium. About 87 percent of the world's lithium comes from the latter sources. Briny lakes (salars), which is type of brine water sources, offer the highest concentration of lithium (from 1000 to 3000 parts per million). Brines with high lithium (about 0.3%) concentration are located in Salars of Chile, Bolivia, and Argentina. Salars with lower lithium concentration are located in the United States and the Tibetan Plateau. [52] [53] [54]

1) Brine extraction. In order to extract lithium from brines, the salt-rich waters must first be pumped to the surface into a series of evaporation ponds where solar evaporation occurs over a number of months. Because salar brines occur naturally at high altitudes solar evaporation is an ideal and cost-effective method for precipitating salts. When the lithium chloride in the evaporation ponds reaches an optimum concentration, the solution is pumped to a recovery plant where extraction and filtering remove any unwanted boron or magnesium. It is then treated with sodium carbonate (soda ash), thereby precipitating lithium carbonate. The lithium carbonate is filtered, dried and ready for delivery. Excess residual brines are pumped back into the salar. Lithium carbonate is a stable white powder which is a key intermediary in the lithium market because it can be converted into specific industrial salts and chemicals — or processed into lithium metal. [55] [56]

2) Spodumene extraction. While accounting for a relatively small share of the world's lithium production, mineral ore deposits yield nearly 20 tons of lithium annually. Well over 100 different minerals contain some amount of lithium, however, only five are actively mined for lithium production. These include spodumene, which is the most common by far. Extracting lithium from hard rock is much more difficult and involves a number of hydrometallurgical processes. There are different ways of getting to the lithium, including crushing and heating the ore to allow the lithium to be displaced by sodium. Due to the added energy consumption, chemicals, and materials involved in extracting lithium from mineral ore, the process can run twice the cost of brine recovery, a factor that has contributed to its smaller market share. In general, the process entails removing the mineral from the ground then heating and pulverizing it. The crushed mineral powder is combined with chemical reactants, such as sulfuric acid, and then the slurry is heated, filtered, and concentrated through an evaporation process to form saleable lithium carbonate, while the resulting wastewater is treated for reuse. [57] [58] [59]

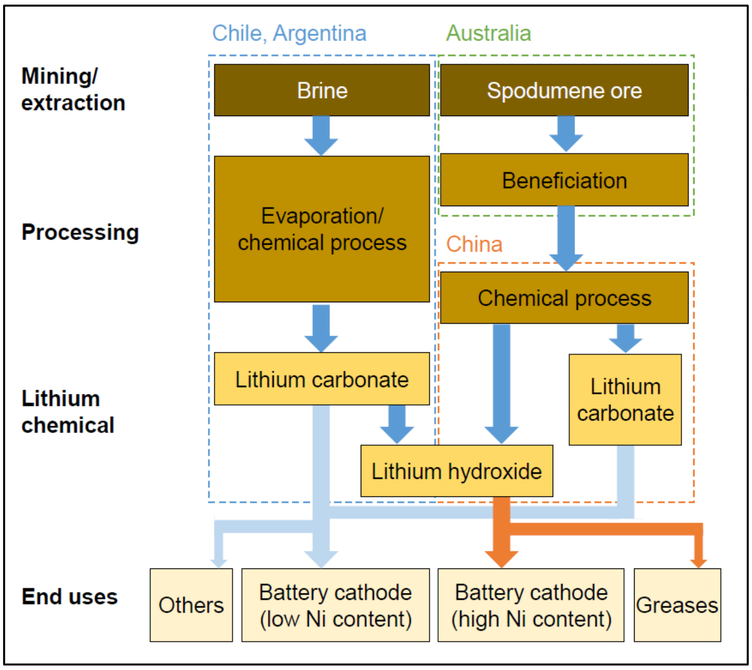

Fig. 45. Lithium supply chain [37]

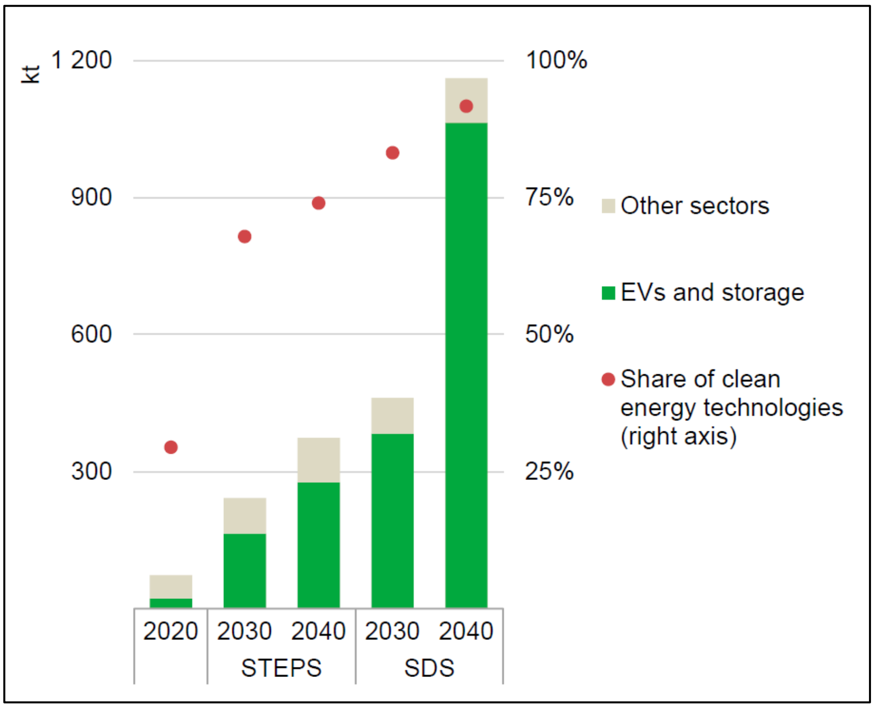

Fig. 46. Total lithium demand by sector and scenario [37]

Lithium demand for clean energy technology is expanding at the quickest rate among key minerals, mainly to the rapid adoption of electric vehicles. While other minerals used in electric vehicles are vulnerable to chemical changes, lithium demand is essentially unaffected, with extra benefits if all-solid-state batteries become widely utilized. Clean energy technologies now account for around 30% of total lithium demand (up from a negligible share in 2010), and the rapid adoption of electric vehicles (EVs) will raise this share to around 75% in the STEPS and over 90% in the SDS by 2040. While lithium carbonate is now the most common chemical product used in electric vehicles, lithium hydroxide is likely to overtake it because it is better suited to high-nickel battery cathodes.

As industry of electric vehicles started to develop in the mid-2010s, rise of supply investments occurred in Australia and other areas, which led to the price drop. Additional production powers are tuned to operate after 2020s such as Greenbushes in Australia and Salar de Atacama in Chile. Moreover, about seven large projects are going to operate by 2026. Volumes of output expected seem able to cope with STEPS trajectory, but not sufficient for the SDS. Following SDS requires additional investigations. Fortunately, new technologies and approaches, such as recovering lithium from non-traditional resources, could potentially solve these issues in several decades.

Rather of evaporating all of the water and chemically eliminating all of the contaminants, this technique separates the lithium straight from an unconcentrated brine that may be processed to lithium compounds without the need of evaporation ponds. This has the potential to cut costs and save time because a brine ore accumulates for long and accounts for a significant portion of a brine project's capital consumption. Some producers are concentrating on lithium extraction technologies from petroleum-origin water and geothermal brine. These innovative technologies, when combined, have the potential to expand the window of future supply of lithium.

Technology	Mechanism	Developer
Unconventional resources		
Sedimentary rocks	Lithium production from hectorite (clay mineral), lepidolite and searlesite	Lithium Americas, Lepidico, Lithium Australia, ioneer
Waste rocks	Lithium production from waste of borate production	Rio Tinto
Direct lithium extraction (Brine/oil and gas produced water/geothermal water)		
Phosphate precipitation	Lithium phosphate precipitated upon addition of phosphoric acid	POSCO
Ion exchange	Lithium ions intercalated into layers of metal hydroxide or oxide	Dow, FMC, Simbol, Eramet, JOGMEC, Neometals
Solvent extraction	Selectively recover lithium from diluted water using solvent	Tenova
Nano filtration	Lithium ions concentrated by membrane	MGX
Others	Utilising subsurface technology expertise, etc.	NeoLith Energy (Schlumberger)

Fig. 47. New technologies for lithium production [37]

Lithium will probably be on the high demand in recent years to come, but main constrains will appear on the stages of middle production that transforms raw materials into lithium products. Not every lithium company able to produce a high-quality product: most of them are the huge enterprises, contributing more than 70 % of the overall production. And an obvious question is: how they will be able to sustain the growth lithium demand, taking into account the low prices on the market some years ago.

Another challenge is a geopolitical issue. China dominates the world lithium market due to the country's massive output of goods manufactured with lithium -- including batteries, glass, grease, air conditioning equipment, and synthetic rubber. China is expected to register the world's strongest yearly increases in lithium demand, boosted by a nearly threefold expansion in the country's rechargeable battery segment. Nevertheless, other major suppliers of Li-Ion batteries in the Asia/Pacific region, including South Korea and Japan, are also projected to see robust increases in lithium demand. Strong market gains in India will be driven by ongoing expansion in the country's manufacturing sector. Among other regions, North America is projected to post the fastest gains in lithium demand, buoyed by strong growth in the production of Li-Ion batteries in the US. Li-Ion battery output is also forecast to expand in Western Europe, particularly in Germany.

As with copper, rising water stress offers a new problem for lithium raw material producers in drought-prone areas such as South America and Australia. In the case of brine resources, production operations may have a negative influence on the region's water balance. Recent research has discovered a negative relationship between the constant extension of lithium production activities and the soil moisture index, which serves as a proxy for drought conditions. New direct lithium extraction technologies may be able to reduce some of the pressures associated with water supply. [60]

5.5.3. Nickel

Nickel plays a part in a range of applications designed to lead to energy transition and tackle global warming. Right now, we have a lot of different powers such as a massive battery storing wind energy in South Australia, a large-scale carbon capture initiative in Canada, the potential of geothermal energy in Iceland. How nickel-containing stainless steel is helping reduce CO_2 emissions in India, and more. Each of these approaches represent steps towards achieving the Paris targets. To meet the goal of energy transition and to achieve lower greenhouse gas emissions plus increased energy efficiency, nickel is a vital part of the equation.

Nickel provides a major cathode material in lithium-ion batteries. In nickel-containing stainless steel, nickel provides toughness, strength and enhanced corrosion resistance, significantly increasing the end product’s life. It also leads to lower maintenance costs and as a consequence shows that the use of nickel creates win-win situations from both an environmental and economic perspective. It is also necessary in nuclear energy technologies as well as carbon capture and storage.

The reduction of greenhouse gases gained during use of these technologies outweighs by far the energy intensity of nickel during production. And as nickel-enabled greener energy becomes more available, the carbon footprint of nickel production will in turn be reduced.

And importantly, nickel is highly recyclable, contributing to a circular economy. Nickel and nickel-containing alloys can be returned to their original state or converted to a different, but still valuable, form. In the future, more nickel will come back for recycling and will lead to further reductions of the carbon footprint as recycling is often less energy intensive than producing it initially. [61]

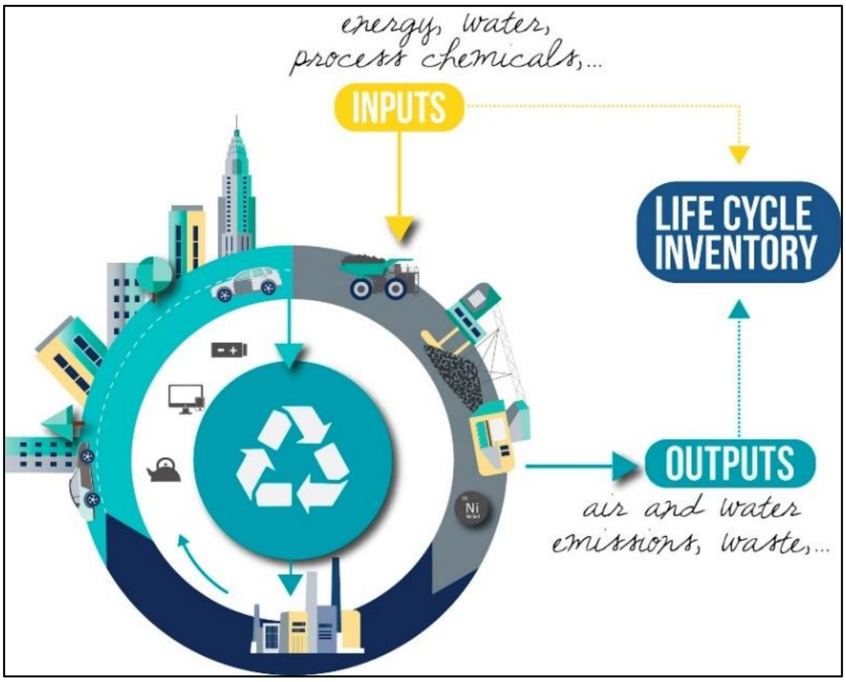

Fig. 48. Reliable and transparent life-cycle of nickel [62]

Nickel products are split into two categories depending on purity.

1) Class 1 Nickel has a nickel content greater than or equal to 99.98% and generally comes from sulphide deposits. Therefore, it has a high level of purity and a high production cost. Powders, briquettes, cathodes or even granules belong to this category. Class 1 nickel is the only nickel suitable to produce nickel sulphates used in the manufacture of batteries. Approximately 55% of global primary nickel production is Class 1 Nickel.

2) Class 2 Nickel, from laterite deposits, has a lower level of purity, and is mainly used in the stainless-steel industry. [63]

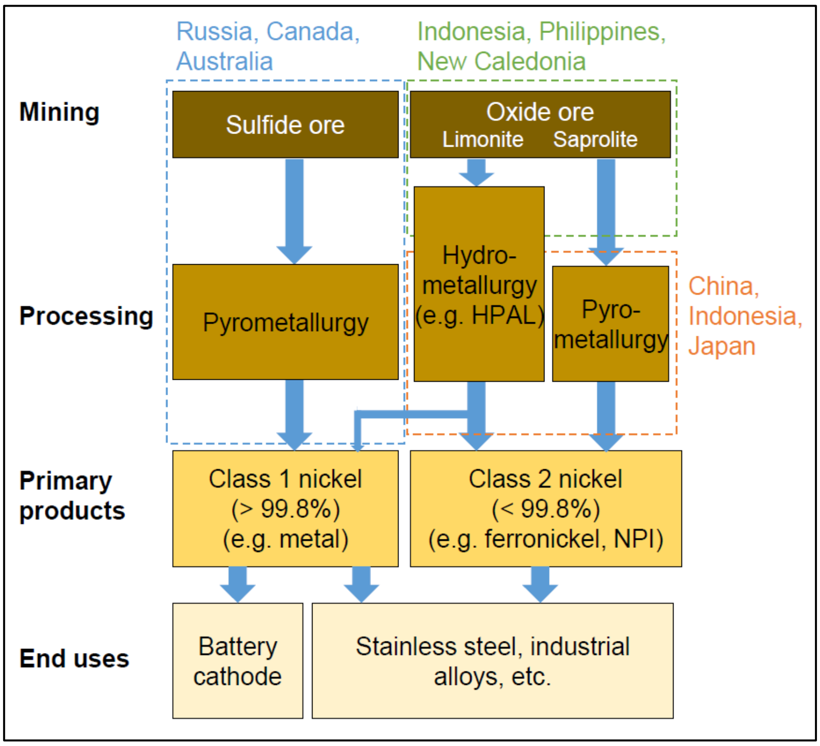

Fig. 49. Nickel supply chain [37]

Nickel is quite common throughout the world, with estimated land resources of 300 million tons, 40 percent to sulphide deposits (South Africa, Canada, Russia) and 60 percent of which correspond to laterite deposits (mostly in Southeast Asia). [64]

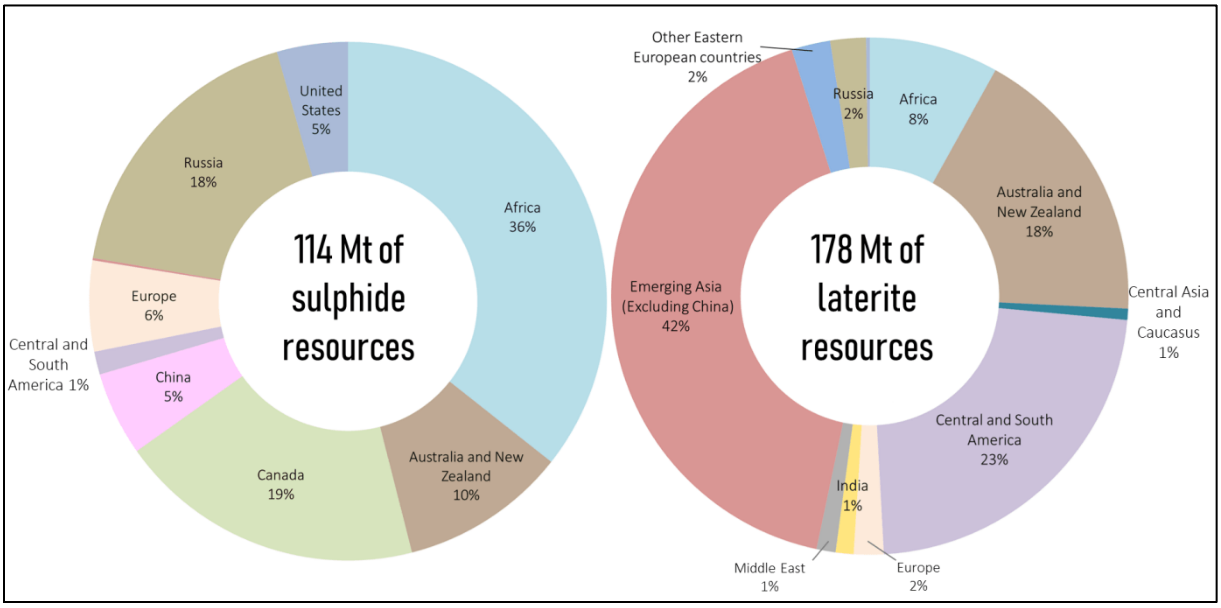

Fig. 50. Global nickel resources [65]

Australia is the only nation with large reserves of these two kinds with 10% and 18% respectively. Laterites are less difficult to process and, as a result, were first favoured for the design of nickel-based good. Nickel deposits are estimated to be 94 million tons, with the majority of them situated in Indonesia

(22.4 percent), Australia (21.3 percent), Brazil (17 percent), Russia (7.3%), Cuba (5.9%), and the Philippines (5.1 percent).

Indonesia and the Philippines are developing nickel projects and for now they represent 45% of global output recent days. These countries are considered as a reason for global nickel production rise by 20% over the past 5 years.

Their dominance in nickel production is likely to expand in the future years, since they account for almost 70% of world production growth through 2025. Indonesia alone is responsible for almost half of the growth. In the long run, other initiatives outside of Indonesia are planned, including the Kabanga project in Tanzania and the Wingellina project in Australia.

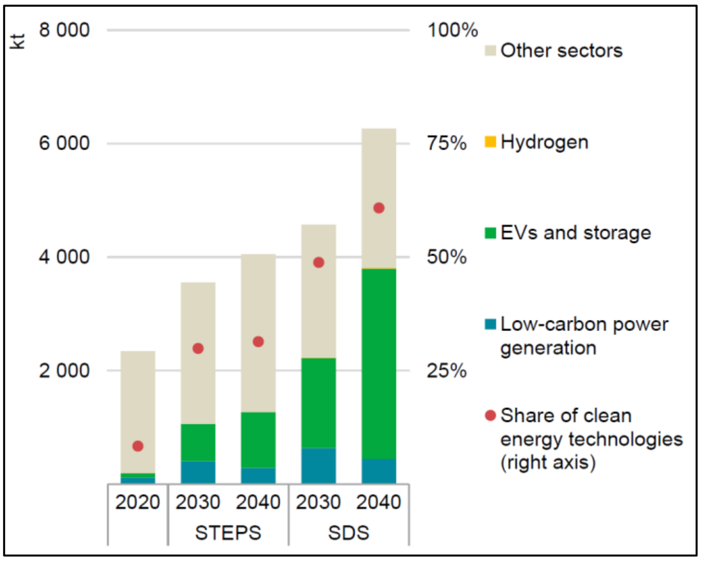

Fig. 51. Total nickel demand by sector and scenario [37]

Around 10% of nickel demand is employed in clean energy technologies, either as a cathode material for batteries or as alloys for renewables and hydrogen. By 2040, clean energy technologies' proportion of total nickel demand will have risen to more than 30% in the STEPS and about 60% in the SDS. According to the SDS, batteries will surpass stainless steel as the top user of nickel by 2040.

Nickel supply prospects are ambiguous. The general nickel market is expected to remain adequately supplied, but the situation changes dramatically for battery-grade Class 1 items. Class 1 nickel is now in minor excess, but the rapid growth in demand from batteries is projected to transform this to shortfalls in the near future. Sulfide resources, in general, are a suitable fit for manufacturing battery-grade Class 1 nickel. However, the majority of future production growth is expected to come from locations with abundant laterite resources, such as Indonesia and the Philippines, which are typically more appropriate for Class 2 goods. [66]

There are certain environmental concerns that must be addressed, such as increased CO2 emissions from the usage of coal-based energy and tailings disposal. While land-based tailings storage facilities are common around the world, deep-sea tailings placement is being examined in Indonesia due to the country's unique geographical characteristics and reduced cost. However, the placement of deep-sea tailings is raising concerns about the marine ecology.

5.5.4. Cobalt

Cobalt's applications are as diverse as they are long-lasting. Since its discovery as a metal in 1739, cobalt has been the foundation of numerous critical uses, ranging from alloys used in jet turbines, hard metals, and orthopedic implants to clean fuels, inks, and colours used in pottery, enamel, and glass. It is also an active ingredient of vitamin B12, making it necessary for human and animal health and vigor. However, as the world develops more sustainable energy sources, the most major application of cobalt may be as a raw ingredient in rechargeable batteries.

More than half of the cobalt produced today is found in rechargeable batteries, which are utilized in portable electronics, stationary applications, and e-mobility. As electric vehicles become more popular, the demand for battery resources such as lithium-ion and cobalt is expected to rise, raising questions about whether there will be enough available. [67] [68]

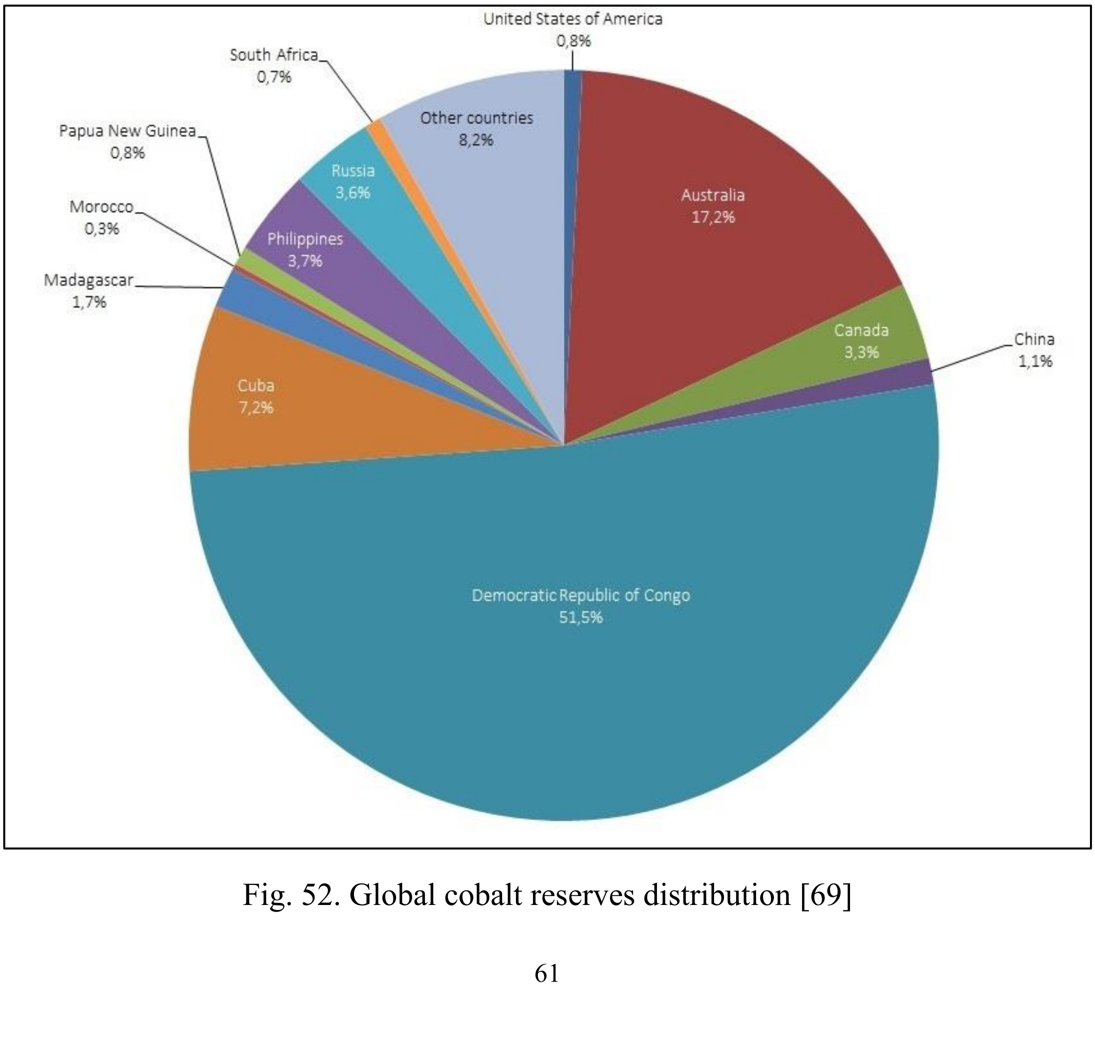

Fig. 52. Global cobalt reserves distribution [69]

Cobalt resources on Earth total 25 million tons (USGS, 2020). The majority of these resources are concentrated in the Copperbelt, a mining region that encompasses a portion of the Democratic Republic of the Congo's Kantanga Province (DRC). Australia, Cuba, Canada, Russia, and the United States have the majority of the remaining resources. Another 120 million tons of cobalt might be discovered at the bottom of the Atlantic, Indian, and Pacific Oceans. However, because to considerable scientific, economic, and regulatory constraints, their extraction is not yet viable.

The direction of cobalt demand is heavily reliant on the evolution of battery cathode chemistries. The composition of cathode chemistries is gradually changing toward ones with a high nickel concentration, which may put a damper on cobalt demand. Even under our default assumptions, if this trend continues, the high penetration of EVs supports a sevenfold increase in cobalt demand for clean energy technology in the STEPS and a more than twenty-fold increase in the SDS through 2040. This increases the percentage of clean energy technologies in overall demand from 15% currently to 40% by 2040 in the STEPS and to more than two-thirds in the SDS.

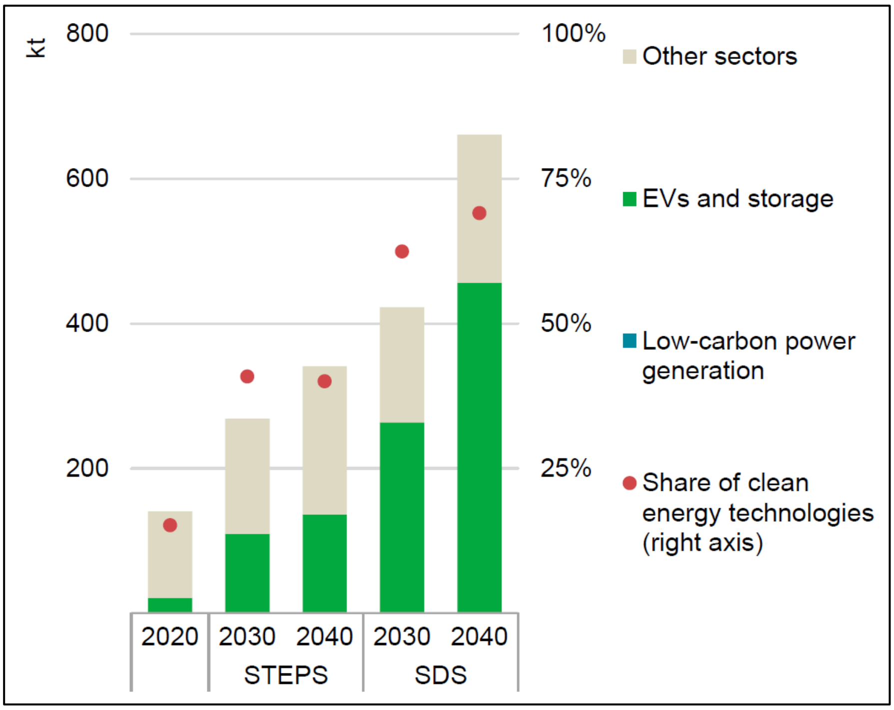

Fig. 53. Total cobalt demand by sector and scenario [37]

Cobalt mining and processing industries are primarily concentrated in two nations, the Democratic Republic of the Congo and China, which have a tight relationship. Regional occurrences on the trade route or legislative changes in these nations might thus have a significant impact on cobalt supply chains. Furthermore, through foreign direct investment, China has control over various assets in the DRC. One-third of China's imported intermediate goods are anticipated to come from mines or smelters in which it has an interest.

Artisanal and small-scale mining (ASM) in the DRC is another topic of discussion. From one point of view ASM extraction have a sufficient contribution into the global cobalt markets. From another, it has a lot of economic, environmental and social issues starting from Covid-19 pandemic impact to unsafe workers conditions and child labour. But intervention probably won't solve the problems, they are not so unambiguous, so, fixing one problem, others may appear. [70]

Another issue is that cobalt is often created as a byproduct of copper and nickel production. This means that investment choices for new project development or capacity expansion are less dependent on cobalt market dynamics and more subject to copper and nickel market circumstances. While this raises concerns about future availability, attempts to adopt processing methods that maximize cobalt recovery can help to mitigate hazards. For example, Kamoto Copper Company in the Democratic Republic of the Congo has used a novel leaching technology called whole ore leach, which increases cobalt recovery rates from 34% to 65%. If extensively used, these methods have the potential to yield significant by-product volumes while also relieving supply-side strain.

5.5.5. Rare earth elements

Rare earth elements are a group of 17 metals that play a critical role to our national security, energy independence, environmental future, and economic growth. Additionally, they commonly used for their optical and magnetic properties in, for example, lighting, medical radiographs and catalytic converters and many more. [71]

To meet the goals of the Paris Agreement, the European Commission has highlighted the substantial amounts of neodymium and dysprosium, alongside metals such as graphite and nickel, needed for renewables and e-mobility by 2050, its target date for net zero emissions in the block.

Because of the transition to low-carbon technologies, demand for rare earths is expected to shoot up. More and more, rare earth metals are being used in sustainable energy applications such as wind power generation and electric vehicles, via permanent magnets containing the metals.

Mining production of rare elements almost tripled in 25 years from 80,000 tons in 1995 to 213,000 tons in 2019. China generously dominates production (62 %), followed by the United States (12.2 %) and Myanmar (10.3 %). [72] [73]

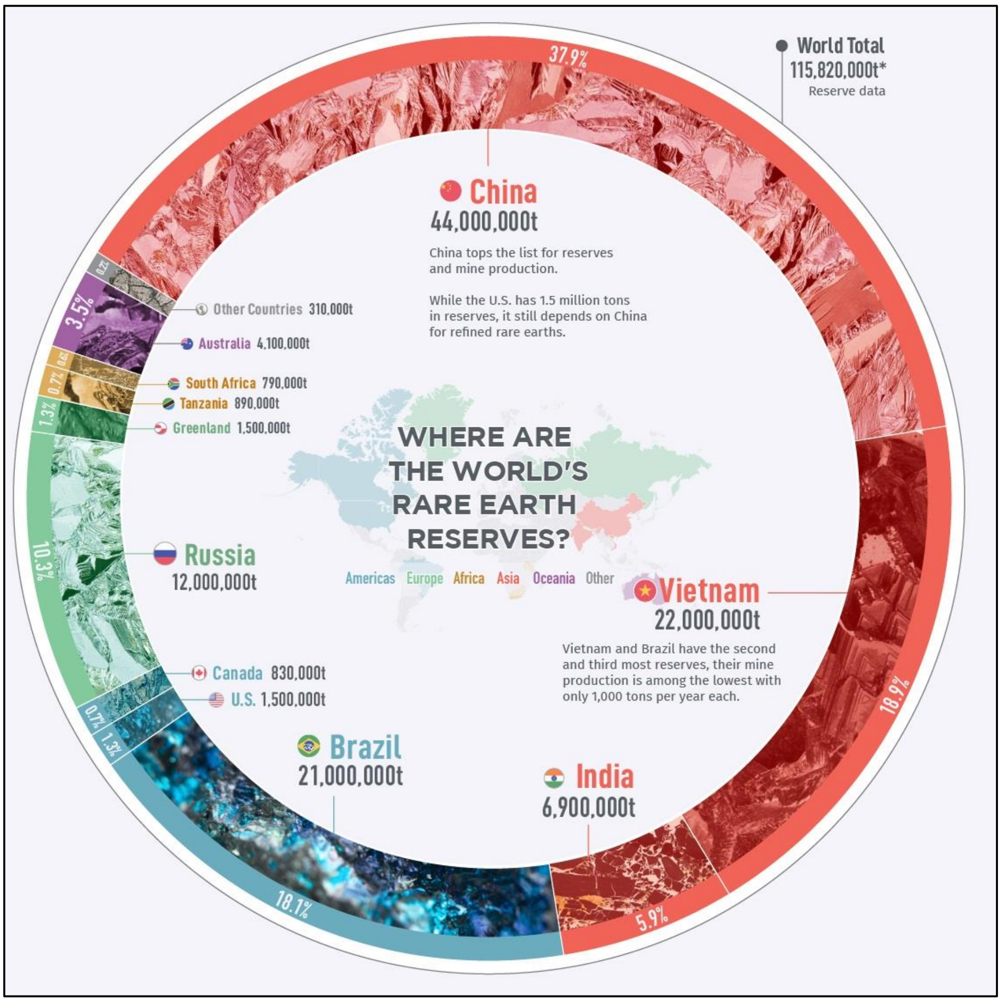

Fig. 54. World's rare earth reserves [74]

With the exception of China, the leading positions do not represent the distribution of reserves (about 116 million tons) which are more than 74 % belong to three countries – Vietnam, China and Brazil. Significant reserves are also recorded in Russia and India.

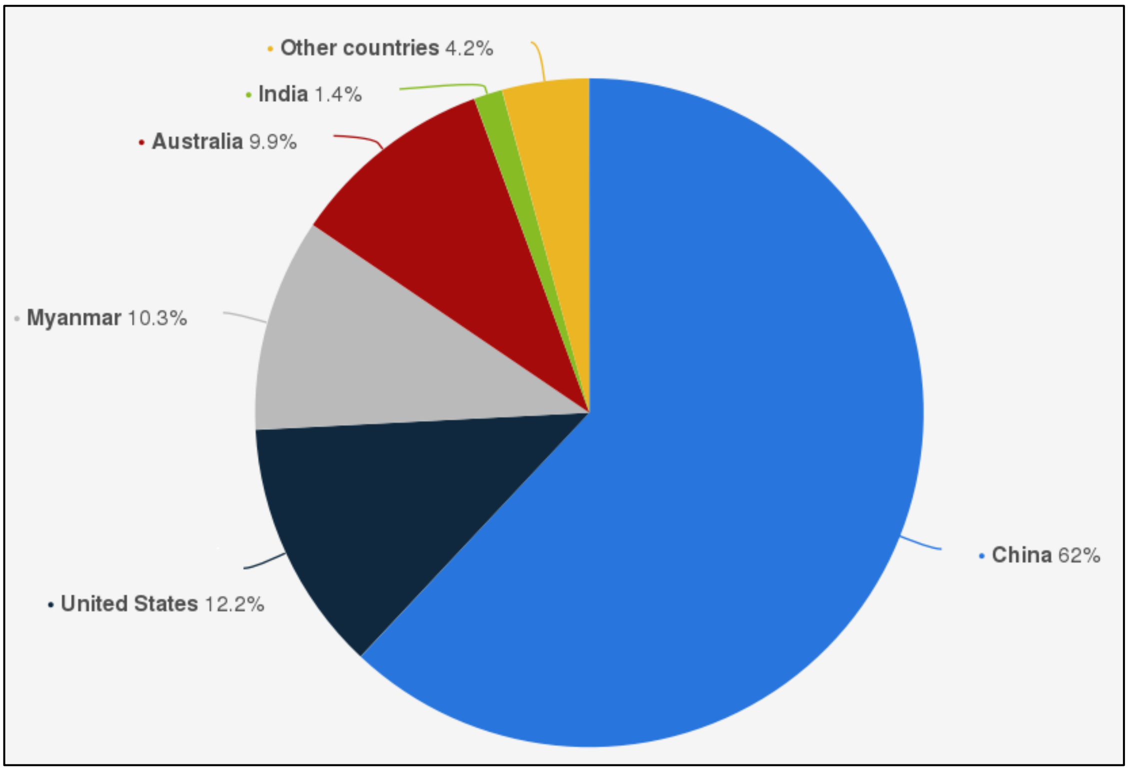

Fig. 55. Distribution of rare earth element production worldwide [75]

The sector has seen significant transformation in recent years. This was made feasible, in part, by the resumption of exploration programs in the early 2010s, during a period when a global scarcity of rare earths was expected. In Canada, Greenland, and four African nations, resources comprising 98 million tons of rare earth oxide equivalent have been found (Kenya, Tanzania, Malawi, South Africa). Other nations (Canada, Vietnam, Kenya, and Brazil) contribute just minimally, if at all, to this market despite considerable reserves.

Several electronic gadgets, including computer memory, DVDs, rechargeable batteries, mobile phones, LED lights, and solar panels, have seen an increase in the use of REE and its alloys during the last three decades. These metals are being used in this manner at an unprecedented rate for a number of applications. Because they are essential components of all high-tech devices. [76]

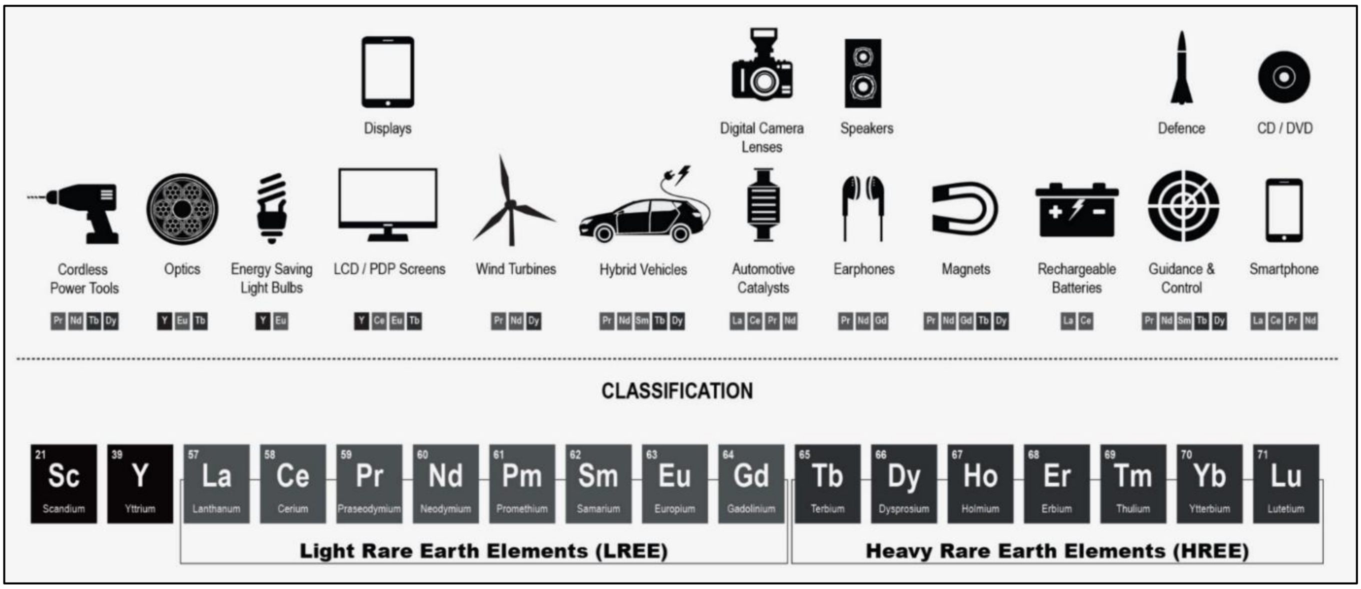

Fig. 56. Rare Earths applications [77]

Several REE compounds are found in smart batteries, which power all electric and hybrid automobiles. Because of their distinct physical, chemical, magnetic, and luminous properties, these elements contribute to a variety of technological advantages such as lower energy consumption, increased efficiency, miniaturization, speed, durability, and thermal stability. In recent years, there has been a surge in demand for energy-efficient devices (green technology) that are quicker, lighter, smaller, and more efficient.

The rising worldwide demand for these elements is piquing the interest of exploratory geochemists as well as technology developers, owing to their critical role in green applications such as hybrid automobiles, electric car batteries, and wind turbines in the face of climate change and global warming.

While rare earth end products will help reduce greenhouse gas emissions through cleaner energy production and usage, there are environmental and social challenges to be addressed. One of these is the uneven geographical distribution of extraction sites. They are presently concentrated primarily in China. China is by far the top producer of rare earth metals, producing more than 6 times more than Australia, the runner-up. It is also the largest consumer and owner of the largest reserve storage. Because of this prominent position, the European Commission has drafted a list of raw commodities most vulnerable to supply chain risk, with rare earth elements at the top. [78] [79]

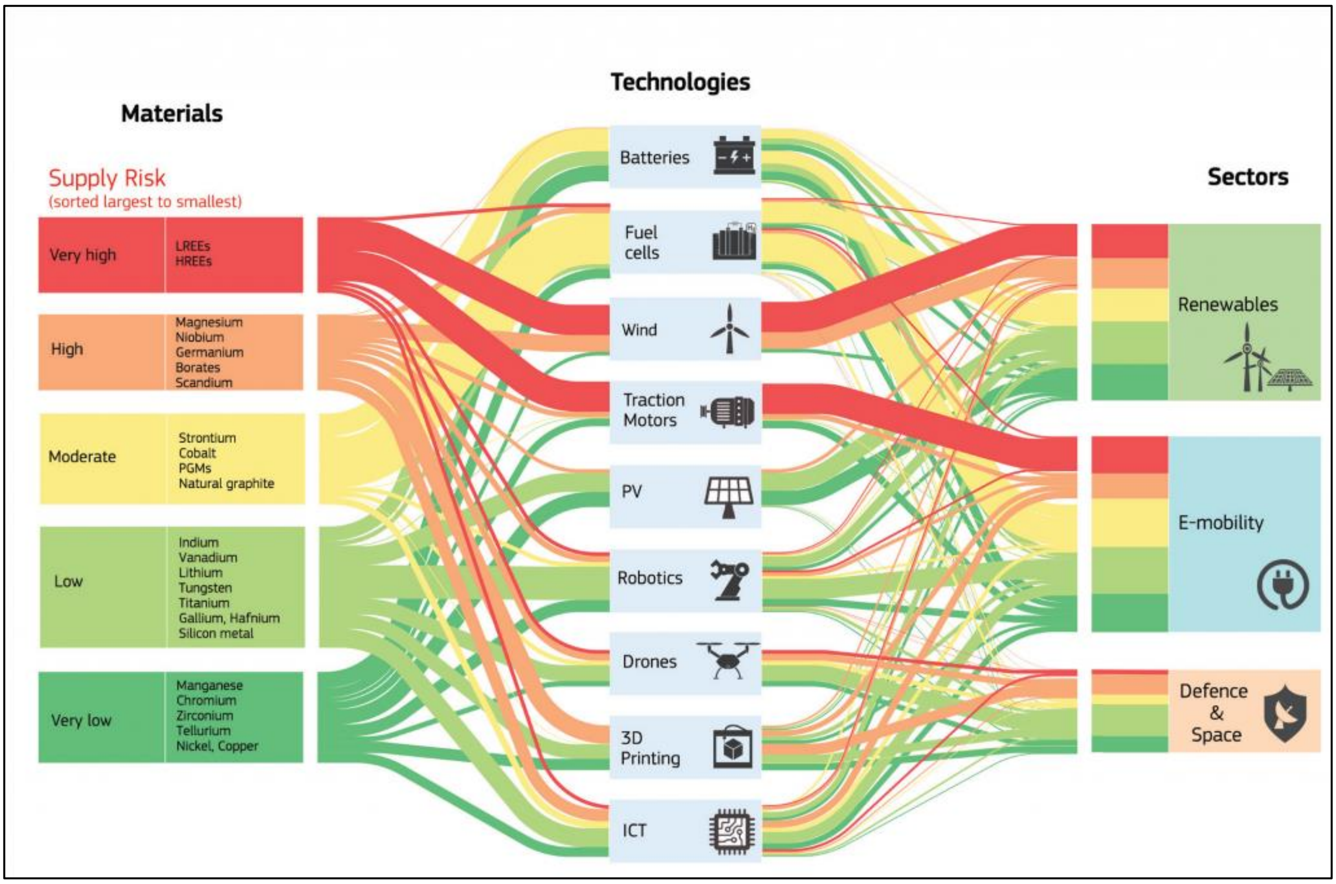

Fig. 57. Flows of materials and their current supply risks [80]

There are also environmental problems. Because many rare earth mineral sources include radioactive elements, extraction and processing are hazardous to land, water, and human health. Furthermore, the chemicals used to extract metals from topsoil or in mines pollute the air and can leak into groundwater.

Concerns like these have driven the quest for alternatives. Researchers are looking towards extraction methods that employ less toxic chemicals, microorganisms, and other non-chemical materials. The use of rare earth metals can be reduced by replacing, decreasing, or recycling them. There are alternatives in the wind sector, such as superconducting generators. These employ a fraction of the rare earth used in common PM turbines.

Due to the difficulties of extracting these elements from existing alloys, less than 1% of rare earth elements are presently recycled. We should keep in mind that rising demand will restrict recycled rare earths' capacity to satisfy predicted near and medium-term demands.

Japan just discovered a massive source of rare earth elements, but there's a catch: it's underwater. Deep-sea mining is being investigated as another means of diversifying supplies, although environmentalists fear that even low-impact extraction methods might create long-term damage.

According to research on the EV and wind turbine supply chains, the present pace of use of rare earth elements in the EV sector is unsustainable. The wind turbine industry, on the other hand, is less vulnerable to supply risk. This is mostly because the wind industry's annual growth rate of 9.2 percent is far slower than that of electric cars, which surpasses 30 percent, and the market share of PM producers is less.

Given the anticipated significance of electric cars in carbon reduction, the EV industry's high susceptibility may cast question on the viability of decarbonization initiatives. These metals are employed in important industries such as defense (drones, for example) and digital technology in addition to EVs and wind turbines. The pervasiveness of digital technology may increase the world economy's reliance on these vital metals. Addressing this is a task on par with obtaining sustainable energy for the net-zero transition. [81] [82]

5.5.6. Comparison and key challenges of critical minerals

The following table demonstrates the comparison of different critical minerals according to several indicators:

	Criticality for Energy Transition	Concentration of reserves	Difficulty to extract	Social and environmental issues
Copper	● high	● low	● high	● moderate
Lithium	● high	● high	● moderate	● moderate
Nickel	● high	● moderate	● high	● low
Cobalt	● moderate	● high	● moderate	● moderate
Rare Elements	● moderate	● high	● low	● high

Grade: ● - high ● - moderate ● - low

Fig. 58. Pivot table for critical minerals [37]

As a consequence, we can distinguish the following key issues and challenges connected to the critical minerals.

	Challenges
Copper	- Challenging to substitute due to superior performance in electrical applications - Mines currently in operation are nearing their peak due to declining ore quality and reserves exhaustion - Declining ore quality exerts upward pressure on production costs, emissions and waste volumes - Mines in South America and Australia are exposed to high levels of climate and water stress
Lithium	- Possible bottleneck in lithium production as smaller producers are financially constrained after years of depressed prices - Lithium chemical production is highly concentrated with China accounting for 60% of global production - Mines in South America and Australia are exposed to high levels of climate and water stress
Nickel	- Possible tightening of battery-grade Class 1 supply, with high reliance on HPAL projects in Indonesia (HPAL projects have track records of delays and cost overruns) - Alternative Class 1 supply options are either cost-prohibitive or emissions-intensive - Growing environmental concerns around higher CO2 emissions and tailings disposal
Cobalt	- High reliance on the DRC for production and China for refining (both around 70%) set to persist, as only a few projects are under development outside these countries - Significance on artisanal small-scale mining makes the supply vulnerable to social pressures - New supply is subjected to nickel and copper markets as 90% of cobalt is produced as a by-product of these minerals
Rare Elements	- Dominance of China across the value chain from mining to processing and magnet production - Negative environmental credentials of processing operations - Differences in demand outlooks for individual elements bring risk of price spikes for those in high demand and slumps for those in low demand

Fig. 59. Key challenges of critical minerals [37]

6. Sustainable development of minerals

The development of mineral supply has a great impact on the green energy transition, as well as, in case of responsible usage, holds big promises to increase the level of GDP for several poor countries. But, if ineffectively regulated, mineral extension can have a range of negative results such as:

- Considerable greenhouse gas emissions from mining and processing activities.
- Environmental problems (land use change, water depletion and pollution, waste-related contamination, and air pollution all contribute to biodiversity loss and societal upheaval).
- Social issues (corruption and misuse of state resources, fatalities and injuries to workers, human inequalities such as child labour, oppression to women)

Furthermore, these concerns may result in supply interruption, slowing the speed of sustainable energy transitions. As a result, both firms and governments must manage the environmental and social implications of mineral production.

Governments have an essential role in encouraging environmental and social performance improvements. As supply chains grow increasingly global, international cooperation to apply suitable standards will be vital to ensure that mineral extraction and trade are done ethically and sustainably, and that the supply of energy transition materials continues uninterrupted. [83]

6.1. Impact of mineral development on climate change

The production of numerous commodities, such as fossil fuels and steel, contributes significantly to world emissions. Because of their low production volumes, emissions from the manufacturing of minerals essential for renewable energy technologies are now quite negligible. These minerals, however, need significantly more energy to manufacture per unit of product, resulting in greater emissions intensity than other commodities. Emissions from creating a ton of lithium carbonate and Class 1 nickel, for example, are three and ten times greater, respectively, than those from making a ton of steel.

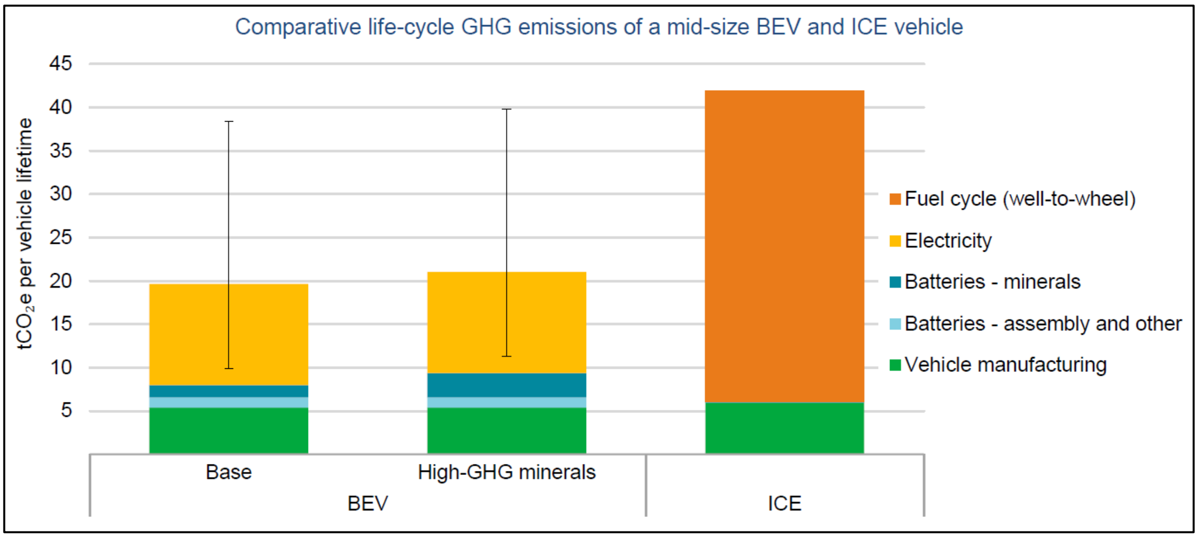

Fig. 60. Comparative life-cycle GHG emissions of a mid-size BEV and ICE vehicle [37]

Mineral development emissions may be greatly decreased by changing fuel sources and adopting low-carbon energy. A simulation of an illustrative refined copper manufacturing plant under various energy consumption profiles demonstrates a substantial variation in emissions intensity depending on the kind of fuel used and the intensity of grid-supplied power. Switching to natural gas would lower emissions by 10%, while utilizing renewable energy would reduce CO2 intensity by around two-thirds. Additional savings might be realized by electrifying fuel usage. When coupled, electrification and renewable energy have the potential to cut emissions intensity by over 80%. Similar tendencies may be seen in nickel production.

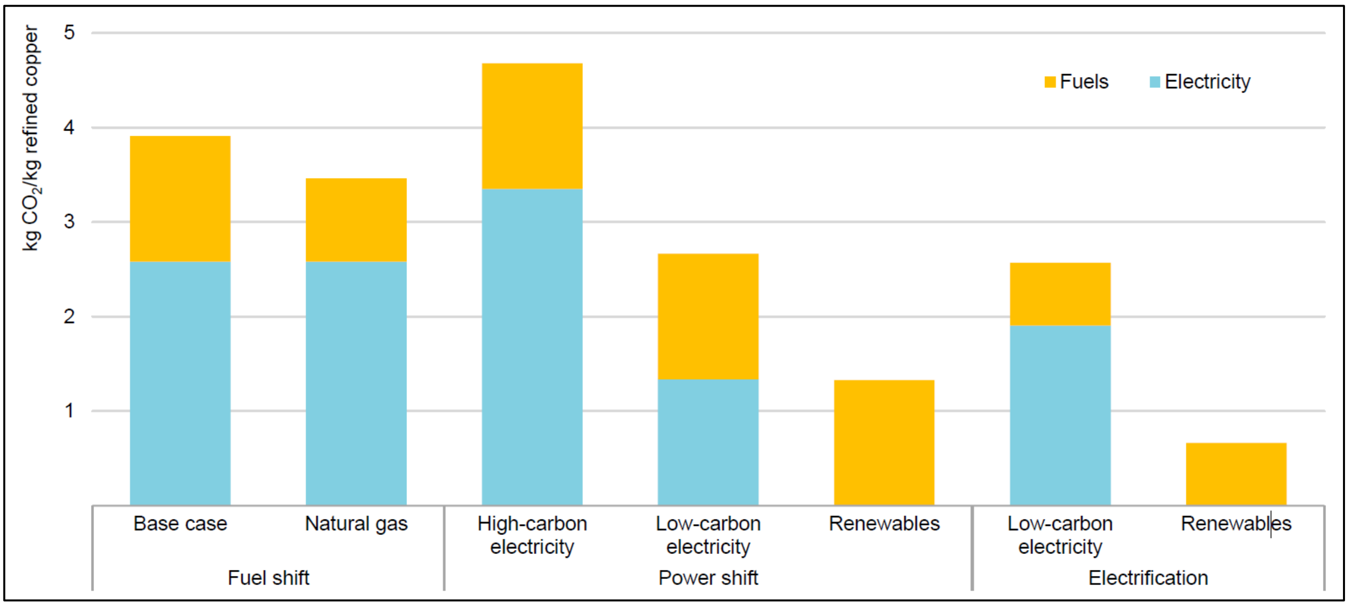

Fig. 61. Emissions intensity for a copper production under different energy consumption scenarios [37]

Short-term solutions for reducing energy-related emissions include increasing the proportion of low-carbon power, improving energy efficiency, and transitioning to cleaner fuels. Electricity emissions can be reduced by using low-carbon electricity through corporate power purchase agreements (PPAs) or onsite renewable generation. A Power Purchase Agreement (PPA) is a long-term contract under which a business agrees to purchase electricity directly from a renewable energy generator. Power Purchase Agreements provide financial certainty to customer and the project developer, which removes a significant roadblock to building new renewable facilities. PPAs therefore help to deliver more renewable energy, saving CO2. Additional emission reductions can be accomplished through energy efficiency investments, such as digitization, automated process management, and technology advancements. [84]

In the mid-term, lowering or replacing diesel consumption in vehicles is a critical component of many businesses' activities. Options include improving material handling techniques, employing other modes of transportation, or transitioning to electric vehicles. Some businesses are also investigating the use of hydrogen.

Companies are also considering alternatives to polluting fuels (coal), such as employing low-carbon fuels for shipping and collaborating with customers to co-invest in emission reduction initiatives. Another strategy for lowering emissions is to increase secondary output.

With rising pressure from investors, governments, and other stakeholders, the sector is becoming more conscious of its environmental impact. However, fewer firms assess the efficiency of emission-control measures, and even fewer take action in response to such assessments.

Mineral supply can also help other industries move to renewable energy. It can serve as an anchor consumer for renewable energy, assist with demand response, and export residual energy to adjacent customers. Furthermore, many electricity-intensive plants in the refining sector ensure services to the power grid by giving for brief interruptions of power supply or demand reduction in times of low supply. Automated process management aided in the competitiveness of these services in several nations.

To meet net-zero objectives, mining firms must address all gas emission sources in their value chain, even those that are difficult to mitigate. Carbon offsets may supplement direct emission reduction strategies in this case. To be effective, mining firms must demonstrate that offsets result in permanent, extra, meaningful, and verifiable carbon reductions.

It is critical to discourage the use of fossil fuels in order to reduce the buildup of heat-trapping greenhouse gases in the atmosphere. Carbon pricing offers universal incentives to reduce energy use and switch to cleaner fuels, and it is an important price signal for diverting future investment to clean technology. [85]

Carbon pricing has the potential to become a significant component of both national and international climate policy. Carbon taxes and carbon trading systems may be a useful instrument for pushing emissions reductions. However, differences in coverage and protection in carbon pricing policies will have an unequal influence on national sector competitiveness, despite the fact that these policies attempt to reduce competitiveness distortions and the danger of carbon leakage. The cumulative impact of these and other policies obscures the influence on relative competitiveness.

New systems are being discussed in a number of countries including China, India and Brazil. While more countries taking carbon pricing measures may help pave the way to a global pricing regime in the future, it currently creates further complexity for linking and ensuring comparable carbon costs among international competitors.

Because of the sector's diversity and the differences in how it is classified, certain actions may be considered compensable in certain systems but not in others. Furthermore, some systems will assign different degrees of protection to certain metals activities. [86]

6.2. Social issues of mineral development

Mineral deposits are considered public resources in most nations, and the government is responsible for managing them in a way that benefits the public. The potential for these public resources to contribute to economic growth and achieve equitable results for national governments, corporations, and communities grows as demand for energy transition minerals develops. Unfortunately, there are other situations when resource development has not resulted in long-term economic progress or has resulted in equal societal suffering.

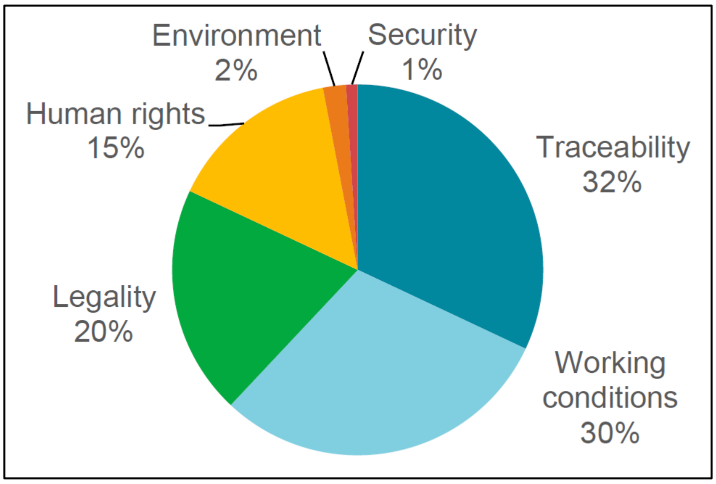

Fig. 62. Incidents at mine sites in the DR of Congo categorized by type of risk [37]

Although mineral production contributes to economic growth in a variety of ways, tax and royalty money is the most direct. This revenue stream may be important in many nations. However, converting mining money into economic success may be a difficult undertaking without skilled management. Volatile commodity prices frequently lead to procyclical public expenditures, undermining government spending's efficacy in encouraging economic growth. Furthermore, a heavy reliance on resource export earnings may lead to underinvestment in other sectors, leaving the economy more sensitive to swings in global commodity prices.

While mining generates a lot of money, its contribution to labor demand may be minor and fluctuate during the project's life cycle. Governments have employed a variety of tactics to clarify expectations for business-community relationships and to encourage "links" to other sectors of the domestic economy, such as the creation of a local supplier industry to assist mine operators.

Clear expectations for each phase of the project will serve to ensure a long-term connection between the project developer and the local community, as well as prepare the community for projected shifts in economic activity. Furthermore, if the economic contribution remains consistent throughout these phases, the enterprise is more likely to obtain a social license to operate.

Because of its technological complexity, relationships between the commercial and governmental sectors, and substantial earnings, the mining sector is particularly prone to corruption threats. Mitigation measures must be implemented in order to mitigate corruption concerns in the industry. However, effective risk reduction requires the accurate identification and assessment of corruption concerns. When awarding mining contracts, good practices in corruption risk mitigation include ensuring transparency in contract negotiation and licensing processes, transparency of beneficial ownership, promoting business integrity, having adequate regulatory frameworks, and preventing illicit influence and conflict of interests. [87]

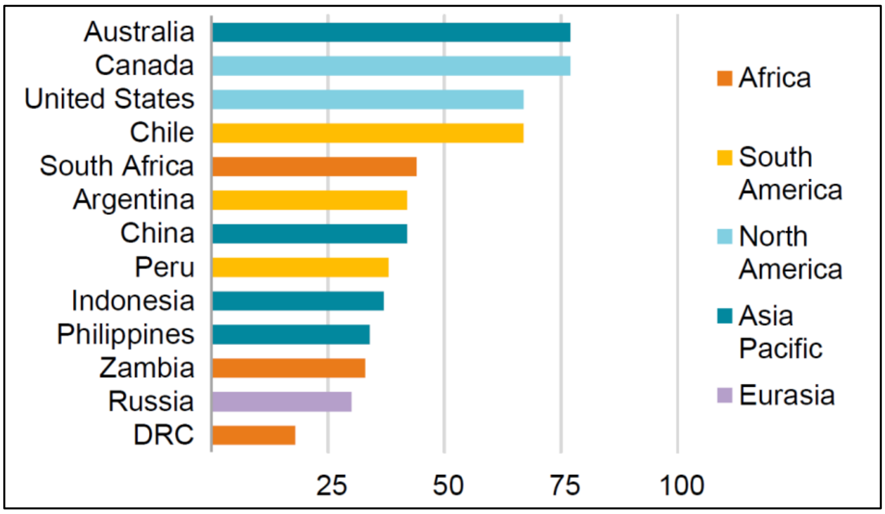

Fig. 63. Corruption Perceptions Index (100 – very clean, 0 – highly corrupt) [37]

Most businesses demonstrate a commitment to providing safe and healthy working conditions. However, only two-thirds of these organizations back up their commitment with resources, such as staff or financial capital. Furthermore, only a few companies collaborate with workers' representatives to identify occupational health and safety issues, and only a few have mechanisms in place to ensure their operations supply gender-appropriate safety equipment.

Adopting explicit risk management rules can assist businesses in reducing possible harm to workers and the general public. Risk is proportional to the frequency of an incident and the degree of its possible repercussions, and policy may influence both of these variables. Policies, on the other hand, can assist to limit the repercussions of an event by enforcing personal protective equipment and drafting and practicing emergency response plans.

Large-scale mine, smelter, and refinery operators are often subject to occupational and public health and safety rules, and data suggests that successful regulation can contribute to a reduction in worker risks from accidents and other unpleasant working conditions. Many international labor standards and voluntary codes of practice have been created by the International Labour Organization to decrease the dangers to employees in these activities.

To some extent, businesses can be expected to address safety hazards by voluntary action in order to avoid accidents that may result in expenses from lost production, civil liability, and public relations harm. Companies may make a stronger effort to comply to such voluntary safety requirements if they pay more attention to preserving a social license to operate. However, industry may not be capable of self-regulating for all forms of safety risk – notably where large-scale hazards are involved or if investor pressure is lacking. [88]

Conditions are frequently worse if regulatory safeguards are weak or non-existent. The issue is especially significant in ASM (artisanal and small-scale mining), where employees are often compensated solely for what they produce and may not have access to health care or compensation in the case of an accident. Situation in DR Congo is a prime example. Public discourse around cobalt mining has predominantly been negative. Human rights groups and the media have brought attention to the frequency of human rights violations and bad working conditions at ASM sites in the Lualaba Province, which contribute for an estimated 20,000 metric tons of cobalt, equivalent to 20% of national output in 2019. This presents a paradox: a key to a clean, carbon-free future is being generated in conditions that put human rights at risk. [89]

According to the International Labour Organization, nearly a million youngsters labor in mines and quarries. Child labour in mining is most commonly found in artisanal and small-scale mines (ASM). Even if produced in small quantities at a mine site, cumulatively, the quantity of minerals coming from ASM is significant: ASM accounts for about 20 percent of global gold supply, 80 percent of global sapphire supply and 20 percent of global diamond supply, 26 percent of global tantalum production and 25 percent of tin. It is also a major source of employment: some 40 million people work in ASM — a number that has doubled in recent years — as compared with 7 million in industrial mining. [90]

Companies can do more to combat the most heinous types of child labor in the mineral supply chain. Adopting blanket "ASM-free" regulations as a mitigation method is not always a smart idea since full disengagement may worsen the causes of child labor. Companies can also aim to engage in formalized ASM and collaborate with multi-stakeholder groups to encourage formalization.

Historically, women have been largely excluded from large-scale mining. Women’s participation may be greater at ASM sites, as some estimates place women at around 30% of the workforce. However, women are most often employed in less lucrative activities at these sites due to cultural barriers and gendered assumptions that mining is “man’s work”. Women also may lack access to finance to invest in equipment and often remain fully responsible for domestic responsibilities, which limits the time and energy they have available for work.

The sector can do more to foster an inclusive workplace for women, both in its operations and in stakeholder dialogues about community implications and working conditions. Companies might begin by conducting focused assessments of the impact of their actions on women and working to enhance gender disaggregated data. Additionally, investments in minerals supply chains that promote women's rights can yield higher and more sustainable returns in terms of mineral production, poverty reduction and broader development effects.

Governments, companies and financial institutions can apply pressure and assist upstream suppliers active in the extraction, transport and trade of minerals to execute gender impact assessments to ensure their projects minimise harm and play a positive role in addressing gender inequality. Moreover, governments can get the data and use them. There is a growing body of evidence on gender inequality and women's rights violations in extraction, transport and trade of minerals. They could support gender research and strengthen the evidence base as well as ensure that the organization collects data sensitively on the gender dimensions of serious abuses. [91]

6.3. International cooperation

Rising demand for energy transition minerals necessitates the extension of supply chains, as well as a rise in environmental and social hazards for both upstream and downstream firms. Identifying and mitigating hazards across nations with disparate legal frameworks and local circumstances is technically difficult and time-consuming. However, neglecting supply chain risks is becoming increasingly costly as a result of consumer, investor, and regulatory pressure.

Improving traceability, accountability, audits, and other techniques that allow organizations to examine their supply chains is a key risk-mitigation approach. International due diligence frameworks assist these efforts. Through industry standards, the operationalization of these frameworks may be adapted to individual supply chains. The development of an entire industry to meet the demands of firms wishing to apply these frameworks attests to their widespread adoption.

The broadening scope of due diligence frameworks and legislation reflects a broader trend in which investors, consumers, and civil society are increasingly urging companies to examine their supply chains more closely and reduce environmental and social harms through proactive engagement, rather than "de-risking" by exiting risky supply chains entirely.

Tariffs, subsidies, and other trade obstacles have been reduced as a result of the global trade and investment system, allowing corporations to weave worldwide supply chains to fulfill market demands. At the same time, this system may be viewed as restricting governments' policy options for addressing environmental and socioeconomic challenges.

Governments are consequently striving to alter their trade policies to meet the aspirations of civil society while also balancing supply stability and national security concerns. Export limits, subsidies to state-owned firms in the mining and processing industries, and carbon border fees might all cause trade distortions. Such policies indicate the possible conflict between international trade disciplines and the integration of environmental and social considerations.

Although international commerce clearly contributes to the stability of energy transition resource supplies, governments must accomplish both security and a fair transition. Fortunately, ethical and sustainable procurement of energy transition minerals is increasingly seen as a cornerstone of supply security, rather than an unavoidable trade-off. As a result, rather than relying on these criteria to create new trade barriers, trade policy should reflect them.

Because experience and capability differ widely between nations, capacity building and knowledge transfer may be a particularly successful area of cooperation. Australia, Canada, and the

United States, all of which have well-developed regulatory systems addressing environmental and social concerns, are increasingly providing technical support to developing nations.

The IGF provides a forum for over 75 member nations to debate mineral resource governance challenges and promote sustainable mining practices. Through its Mining Policy Framework, it, in particular, offers technical capacity building and discusses best practices. These high-level efforts may assist establish continuous contacts with all key ministries in resource-rich nations, as well as ensure that concerns receive appropriate degrees of attention. To realize this potential, synergies across projects should be better leveraged, and new avenues for knowledge exchange outside mining frameworks may be explored.

A high-level coordination conference might be critical in standardizing environmental and social norms and coordinating efforts on supply security. Coordination of competing efforts has been successful in some cases, but mainly on specific areas, such as due diligence processes through the OECD Guidance. In the past, generalized organizations such as the G7 and G20 have also served this function. Whether new or established, such as the Climate Smart Mining Initiative or the IGF, may also play a significant role in channeling discussion and cooperation on energy transition minerals.

Despite rising levels of global adherence to environmental and social norms, they often provide limited opportunities for states to work together. Policy integration through the European Union or other regional blocs is likewise insufficient to maintain global uniformity. As a result, a systematic strategy is required to guarantee that governments act not only in historically troubled supply chains or in specific areas, but also for all minerals that underlie the energy transition and across jurisdictions.

A mineral governance framework should give governments the tools they need to manage greenhouse gas emissions, local and regional environmental consequences, and social and human rights hazards. It may eventually help to provide a consistent supply of minerals required for the energy transition. And this is definitely one of the methods for international minerals governance to develop sustainable and responsible supply chains that contribute to a low-carbon economy through data exchange, coordination systems, and collective activities.

In managing the mining industry and resource earnings, developing countries confront several obstacles. In reality, typically only a tiny portion of the population benefits from resource riches, while corruption and mismanagement may negate the beneficial impacts of higher income, and in the worst-case scenario, earnings may be used to fuel ongoing hostilities. A high reliance on resource exports entails additional risks, such as sensitivity to unpredictable pricing. Mismanagement in the sector can also pose serious environmental and health risks.

In order to achieve sustainable development, resource-rich developing nations must address unequal income distribution and corruption, as well as implement effective extractive industry regulation and oversight based on openness and accountability. They must also lessen the negative environmental, socioeconomic, and health implications of resource exploitation, reduce their reliance on individual resources, and diversify their economies by investing in the added-value chain and other productive sectors. [92]

7. Future of mineral industry

Understanding future mineral availability necessitates a global perspective. Mineral and metal demand is being driven by global industrialization, urbanization, and population increase. Renewable, clean energy, and even some conventional energy consumption is predicted to rise dramatically in the next decades, emphasizing supply, security, and environmental effect concerns.

Mineral rivalry will heat up as the focus shifts back to renewable energy and electric car technology. It is critical to understand the location of deposits, the technology required for production, and the costs of creating and delivering the goods to customers. As mining corporations seek to retain or grow their operational capacities and mineral resource bases, the search for commodities extends beyond developed terrestrial parts of the world to include marine resources. Finding trained people, constructing infrastructure, upgrading recovery technologies, and adopting sustainable development are all operational issues in these places. [93]

So what can mining executives do today to prepare for such an uncertain tomorrow? What strategic decisions need to be thought through and made now, to ensure your company will be thriving 5, 10 or 20 years down the track?

To help us answer these questions these four scenarios were developed. They give an insight into the types of challenges and opportunities miners (and indeed today's non-miners) might need to deal with, and what they can do to win. It discusses not only the kinds of strategies required but the shift in mindset needed to make those strategies work.

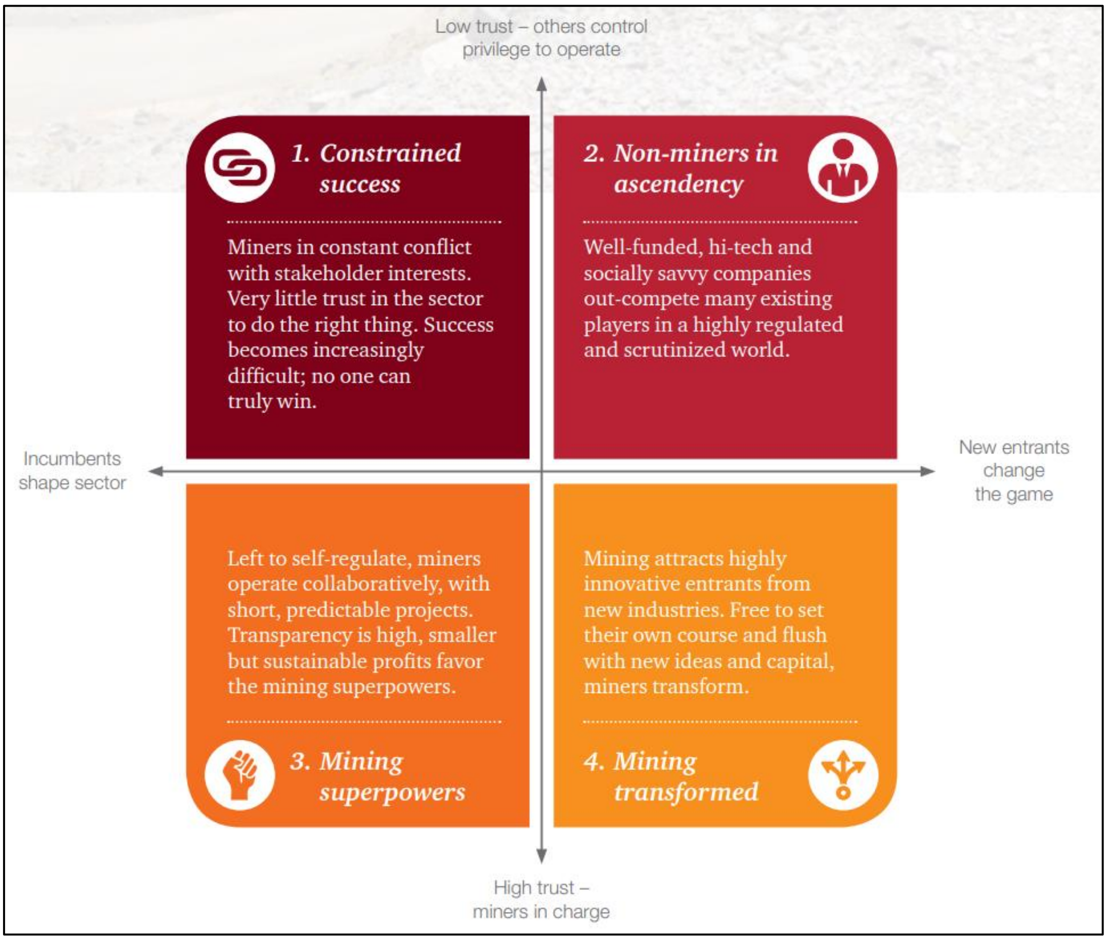

Fig. 64. Four scenarios for future of mining [94]

1.Constrained success

In this circumstance, faith in the mining industry has almost completely vanished. A miner's operating permit is no longer a permanent entitlement, but rather a shaky permission slip that may be revoked at any time by a variety of regulatory 'guardians.' Those who own this privilege see it as their most precious possession, more valuable than mining deposits. While the high cost of compliance hinders outside competition, profiting is exceedingly difficult. Only policy aware operators will thrive, those that grasp the need of sustainable growth and comprehend the importance of mutual results.

2.Non-miners in ascendancy

In this case, miners have lost trust and no longer have control over their operating privileges. Instead than focusing on growth and shareholder returns, time, energy, and resources are spent responding to higher levels of inspection. This offers perfect circumstances for new entrants, particularly those with a track record of success in highly regulated areas, to prosper.

3.Mining superpowers

Trust is strong in this setting, but fresh recruits are few. And, despite the sector's strength, there have been several casualties. The high cost of earning trust, paired with limited access to outside funds or fresh ideas, benefits the extremely wealthy or the really inventive. To survive, mid-tier players use their agility and cheap cost of doing business to concentrate in smaller, specialty product operations.

4.Mining reinvented

Miners in this context have completely recreated themselves. They've opened their doors, cleaned up their act, and restored public and regulatory trust. Simultaneously, a flood of new entrants has resulted in an explosion of new ideas, technologies, processes, and cash. There is no room for also-rans in this transparent, diversified, and highly competitive future. Only the best of the breed thrive. [94]

We can not say exactly which scenario will be dominated in recent years, but several governments and companies predict how organizations around the world will mine for innovation:

- The arms race for rare earths will heat up as geopolitical tensions disrupt global commerce and countries compete to lead in manufacturing and technological innovation.
- Secondary education will be a thing of the past. Alternative financing methods, which decrease the load on mining firms' balance sheets, will gain appeal, putting pressure on stock markets.
- Because of investor demand to establish their social license to operate, miners will become an open book. Miners will confirm their activities using blockchain technology.
- Artificial intelligence will become prevalent in mining operations as miners utilize it to understand data from smart sensors and machine connectivity, as well as to increase operational safety and efficiency through unmanned, AI-enabled technology. This will make mining one of the safest jobs available. [95]

But mining is now faced with many significant challenges, many of which we've never seen. Change is being pushed in mining, like in many other sectors, by technology, innovations, better processes, societal expectations, and even new possibilities. Four pathways may hold the key to tomorrow's prosperity as we dust off our crystal ball and investigate what the future holds for the mining sector.

a. Digital transformation: the "smart" mine

Digitalization is the catalyst that helps mining operations become "smarter" by leveraging digital tools and processes that make operations instrumented, interconnected and intelligent. With dynamic information early on through interconnected digital systems and software, quick course corrections can be made before problems surface. Advanced digital process and control systems enable continuous monitoring and virtual simulations, among other cutting-edge capabilities.

In the future, the digital mine will leverage many of today's emerging and evolving digital technologies. Industrial internet of things (IIoT) is a digital technology that can be particularly transformative for mining. Strategically placed sensors connected to the internet can enable mines to collect huge amounts of data in real time. Best of all, the data from IIoT sensors is highly actionable, helping managers to make smart decisions that can improve efficiency, increase safety, cut costs and more.

The move to the cloud has already transformed every major industry, and mining is no different. Leveraging the cloud allows for real-time enterprise-level views of operations in a mine using an integrated IT cloud-enabled platform. Workers can be better connected real-time via cloud-enabled devices, allowing for a level of collaboration that can boost safety and productivity in any mining operation. Plus, security and infrastructure services can be moved to the cloud, cutting costs while increasing capabilities.

Every mining operation involves numerous vital decisions every day. Artificial intelligence (AI) technology offers decision-making and problem-solving support based on massive amounts of data from numerous mining and work equipment, as well as databases. Best of all, AI leverages superior computer processing power and a level of inter-connectivity with many different mining systems, IIoT sensors, robotics, and data sources for a holistic view of operations in real time. That offers decision-makers the information they need to make well-informed choices for safer and more productive mining operations.

While each of these digital technologies offers mining operations unique capabilities and advantages, it is their interconnectivity that can allow mines to operate at new performance levels. With true digital transformation, IIoT, data analytics, cloud platforms, blockchain, AI and a host of digital innovations all work together to make mining operations smarter than ever.

b. Mining technology and tools: Robots, machines and drones

While digital transformation focuses on making mines smarter, new technologies and tools on the hardware, transportation, and equipment side bring unprecedented brains and brawn to all major operations. Best of all, these new technologies can connect seamlessly with digital transformation efforts, integrating data analytics, AI, and machine learning with a smart mine's unified systems.

Drone technology is already being used throughout the mining industry to help increase safety by going in areas that may be hazardous to humans. Drone analysis of mine slopes avoids the dangerous prospect of sending a geologist or geotechnical engineer into highly dangerous situations. Other drone uses for mines have included inspecting various areas of the mind unsafe for human inspections, clearing blast areas, leveraging 3D imaging and scanning, and streaming live video and real-time data feeds.

Robotics and automation in mining is a particularly exciting proposition since it connects directly to innovation with AI and machine learning technology. Robotics can be particularly advantageous in replacing traditional shovel and extraction processes used by humans. The concept of a continuous robotic mining system will evolve as technology replaces manual processes and computer-controlled and powerful machines extract the most minerals in the shortest amount of time.

Like drones, mine robots can also be used to replace humans in performing radiological, inspection, and survey tasks, especially in small areas or an inhospitable environment, such as abandoned mines. In the near future, abandoned mines with previously inaccessible minerals can be reopened with robots successfully doing extraction that just wasn't possible before.

Fig. 65. A drone on the mining site [97]

c. Sustainability and environmentalism drive future trends

Environment accords, like the Paris Climate Agreement, along with an increasingly global awareness of the value of our natural resources is putting more and more pressure on mining companies to address sustainability. Fortunately, many of the technological innovations we've already discussed reduce fuel consumption, emissions, waste, and water use in mining operations. Even the rehabilitation of mining sites through new biological and chemical solutions for environmentally-friendly waste management and acid mine drainage can allow ecosystems to recover.

Today's shift toward Corporate Social Responsibility (CSR) sets the stage for concepts like "green mines" or "zero-waste mining" to become increasingly popular. The goal of "greening mining" is to reduce the environmental impact of mineral and metal extraction and processing, with a focus on new technologies, smarter mining operations and processes, and sustainability best practices. The good news for mining companies is that "going green" can have its financial benefits. The Green Mining Initiative cites one project in Ontario, Canada that resulted in a 40 percent reduction of energy consumption with an annual savings of up to $4 million.

With billions of tons of inorganic waste or by-products generated by mines every year, "zero-waste mining" might seem beyond reach. It's a lofty goal, but more mines are taking a hard look at their waste output and embracing new technologies to help reduce it. Extraction technologies, including ways to extract valuable minerals from red mud, or smelting red mud to recover iron, are being tested.

When we look at the mining industry's potential contribution to renewable energy and a sustainable world, the script flips to some significant ways that the industry can help lead the way toward a green future. According to the International Energy Agency, renewables will be the leading sources of new energy supply through 2040. It's estimated that renewables will pass coal as the largest source of electrical generation by 2030. According to the World Economic Forum (WEF), the mining industry is "uniquely positioned to contribute to the transition to a sustainable world."

Fig. 66. Volunteers Green Forests Work have planted millions of trees to restore more than 4,000 acres of formerly mined land in Appalachia [98]

d. New frontiers: deep sea, space and rediscovery

As the industry looks further into the future for tomorrow's opportunities, several key areas emerge as the front runners. For example, deep sea mining is a relatively new concept in mining, and undersea technologies are just beginning to scratch the surface of what's possible.

The prospect for significant extraction opportunities lies right on sea floors, especially considering that we've only explored five percent of the deep ocean. The deep sea has created formation with highly valued metals that can be mined. Polymetallic modules — softball-sized formations that litter the sea bed — are rich sources of nickel, cobalt, copper and magnesium. Polymetallic sulfides form when hot water from the earth's crust meets cold water, resulting in smokestack formations rich in iron, silver and gold. Underwater crust formations and mountains (mostly in the Pacific) are rich in rare earth metals, like cobalt, vanadium, molybdenum, platinum and tellurium.

All of these deep-sea formations present massive future opportunities and equally impressive challenges. Enormous capital investments in equipment specifically designed for harsh, deep waters are needed. While some deep-sea mining companies are at the forefront of this new frontier, the technology is yet to be proven on a large scale. Finally, many environmentalists are rightly concerned about the impact of mining on a fragile ocean ecosystem.

Space mining might seem like a frontier that may not be too far off. Some experts contend that asteroid mining may be a reality by 2025. Why asteroids and not Mars first? Beside containing valuable minerals like platinum and palladium, reaching an asteroid that's near to earth requires far less energy than reaching a far-away planet like Mars.

Even though Mars is a much further destination, the red planet is estimated to be rich in ore and other valuable minerals. Also, if colonization is the end goal, mining activities on a planet like Mars may allow colonies to be self-sustainable. NASA continues to tap into fresh minds in academia in brainstorming new mining robotics designed for celestial surfaces like Mars.

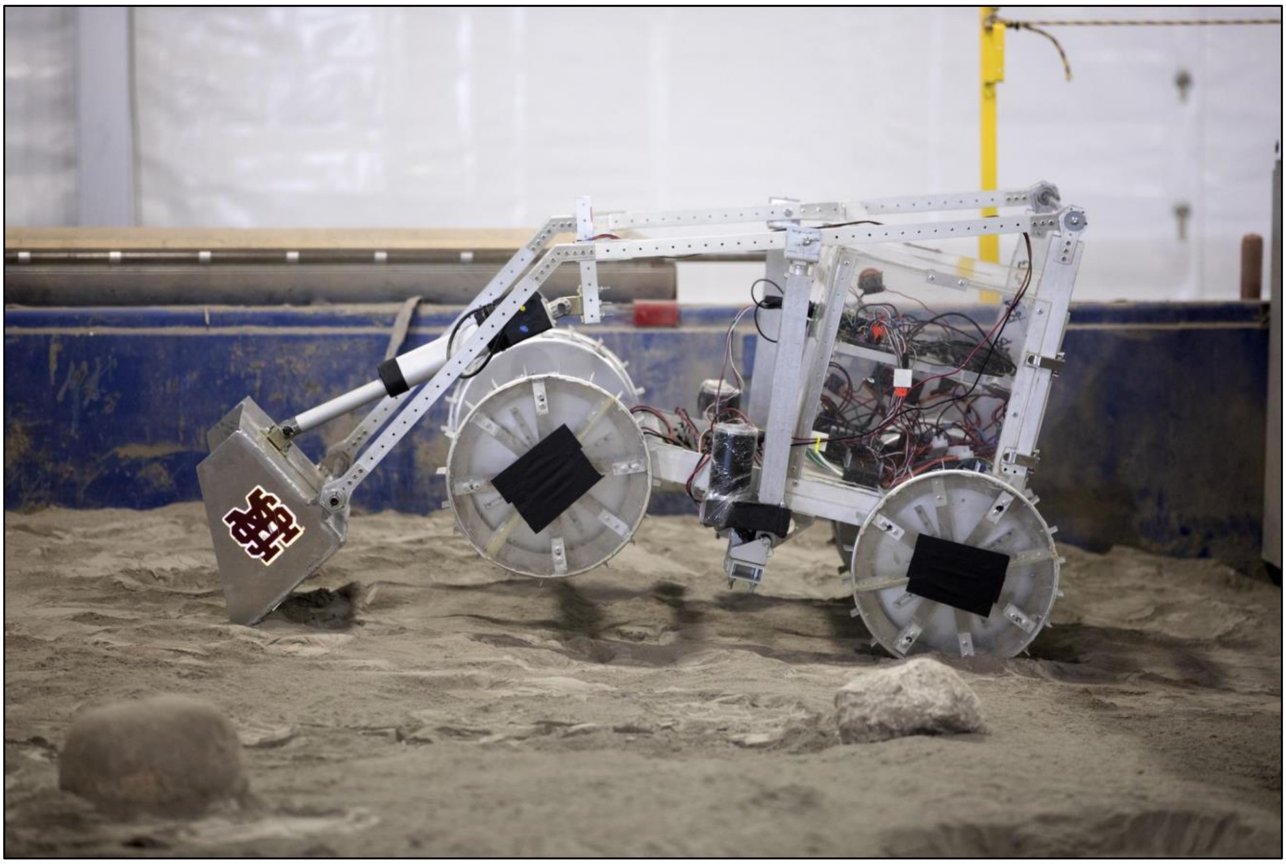

Fig. 67. Students Build Robots to Help NASA Mine the Moon [99]

The moon is another celestial body much closer to us that offers mining potential as well. The European Space Agency is planning to start mining there by 2025 for resources that can help sustain more extended lunar stays and research. The moon's surface is rich in iron oxide, and scientists say that it may be possible to extract deep pockets of oxygen from lunar soil.

Back down to earth, robotics may help the industry to rediscover opportunities to reopen abandoned mines. As mentioned earlier, automated technologies, as well as underwater gear, offer opportunities to reopen old mines for new excavations projects, even when they've been flooded.

Robotic systems have already been developed to enter areas that are off-limits to human, helping to map abandoned mines for potential reopening or to search for valuable minerals. With the thousands of shuttered or flooded sites throughout the world, high-tech robots and machines could help create significant new sources of mining revenues from old mines.

There's no doubt the mining industry faces some significant challenges. The increasing demand for minerals and metals coupled with the pressure to increase output cost-effectively puts many mining operations in a tough spot.

Fortunately, digital transformation and new technologies offer mining companies golden opportunities to become more efficient, boost production, and cut costs while making the work environment safer. And, although the push for sustainability and environmentalism may have headwinds, mining operations are becoming increasingly “green” and also benefiting from the push for materials to build electric cars and renewable fuel sources of energy. Finally, future opportunities for mining in the deep sea, space, and abandoned mines mean the industry has more frontiers to conquer.

Conclusion

Energy transition plans provide a vehicle for navigating a fast-changing environment, identifying trade-offs, and creating measures that satisfy larger sustainable development and climate goals. Governments must discover methods to use the technological, economic, social, and environmental knowledge available across society while also ensuring cohesiveness and unity of purpose. True solutions need wisdom and a comprehensive perspective, in addition to nuts-and-bolts technical knowledge.

While rising demand for minerals and metals creates economic possibilities for resource-rich developing nations and private sector organizations alike, considerable barriers are inevitable if the climate-driven clean energy transition is not handled responsibly and sustainably. As a consequence, international collaboration is essential for drawing on the expertise and resources of governments worldwide, ensuring that lessons and solutions are shared, and ensuring that no area, country, or community falls behind.

Our society should meet and solve a lot of challenges. The future of mineral supply and development will be dependent on how successfully we will be able to cope with these challenges. To succeed in it several recommendations are proposed such as:

1) Ensure adequate investment in diversified sources of new supply

2) Promote technology innovation at all points along the value chain

3) Scale up recycling

4) Ensure reliable supply of critical minerals and metals

5) Mainstream higher environmental, social and governance standards for critical minerals

6) Strengthen international collaboration between producers and consumers

Renewables have transformed our energy systems over the last decade and shown to be beneficial in many wealthy countries. However, in order for the energy transition to be effective, development of mining industry, especially in the sphere of critical minerals, should be successful. Moreover, it must take place internationally — in both developed and developing countries.

The coming decade will be a watershed moment in global decarbonization. If the project is successful, electrification will increase and renewables will become mainstream in emerging countries. The financial burden will undoubtedly rest on rich countries to support this shift.

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