Metals for the energy transition

Why we should address a raw materials transition together with the energy transition

PowerShift

Metals for the energy transition – Why we should address a raw materials transition together with the energy transition

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Executive Summary

The paper investigates the role of metals in the energy transition, the impact of various sectors on metal demand, and the need for sector-specific reduction targets to ensure the sustainable supply of metals for renewable energy production.

Key findings related to metal demand, CO_2 emissions, and sector reduction targets include:

1. The metal intensity of renewable energy production is not higher compared to energy production with fossil fuels. The report examined the metal consumption of energy production, including iron, aluminium and copper. Compared to the metal needs in g per MWh the metal intensity is not higher compared to e.g. coal power plants. While some renewable technologies do require critical metals, their overall environmental impact is significantly lower compared to fossil fuel-based energy production.

2. Not surprisingly, the study emphasizes that fossil energy production emits much more CO_2 than renewables, contributing to climate change and environmental degradation. Transitioning to renewable energy sources is a vital step towards reducing greenhouse gas emissions and mitigating the impacts of climate change.

3. The automobile industry and the shift away from combustion engines to battery vehicles has a higher impact on metal demand. The study highlights that a large share of common metal demand projections is on account of the automobile industry. The growing shift towards electric vehicles and the assumption of a 1:1 replacement of combustion engines with electric cars, instead of considering a transformation to alternative mobility systems, significantly increase the need for critical raw materials like lithium and cobalt which only play a minor role in wind, solar and hydro power.

4. The report argues that to secure the metal supply for renewable energy production, there is a need for reduction targets in other sectors with alternative models that are less resource-intensive, such as the mobility and construction sectors. Implementing reduction targets can help manage the demand for critical raw materials, promote the adoption of alternative materials, and support a sustainable energy transition. The energy transition therefore does not contradict the need for reducing primary raw material consumption, but rather supports it.

Renewable Energy and metallic resources – an undifferentiated debate?

Bauxite in Guinea waiting to be exported to Germany, where it will be processed to aluminium.
Photo: Igor Grochev, Unsplash

Many mining companies present themselves as green companies. Their raw materials are, after all, needed for renewable energies or electromobility. The Brazilian mining company Vale for example, presents itself on its website[1] as "*Guardians of the Rainforest*". Yet in December 2021 the company was sentenced to a fine by a Brazilian court for allegedly deforesting 15 hectares of forest, of which a part had protected status. Vale also operates the world's largest iron mine in Brazil's Carajás Mountains. It is located in the middle of the rainforest and has, along with its associated infrastructure, caused massive deforestation. The company is also responsible for the "socio-ecological crime" of Brumadinho, where on 25 January 2019 a reservoir burst, killing 270 people and destroying large parts of the ecosystem of the 540-kilometre-long Paraopeba River.[2]

Vale is the third largest mining company in the world, and not the only one to present itself as "green", a far cry from the truth of its sad reality. The second largest mining company in the world is Australian. Rio Tinto highlights on its website[3] that *"decarbonisation is an urgent priority for us and the world"*. Yet Rio Tinto's activities involve, among others, the expansion of a bauxite mine in Guinea, which has both violated human rights and destroyed the environment.[4]

Unsurprisingly, the world's largest mining company also emphasises: *"At BHP, we're focused on the resources the world needs to develop and decarbonise"* [5] Yet a study by TNI and the London Mining Network shows that the British company has spent over 1.2 billion US dollars on oil production over the last three years, in comparison to only 200 million on copper production.[6]

It is because metals and technological developments are needed in the fight against climate catastrophe that these companies can "*greenwash*" themselves, i.e. give themselves an ecological veneer: Without metals, neither our energy systems (neither fossil nor renewable), nor our mobility, communication or other technologies would function.

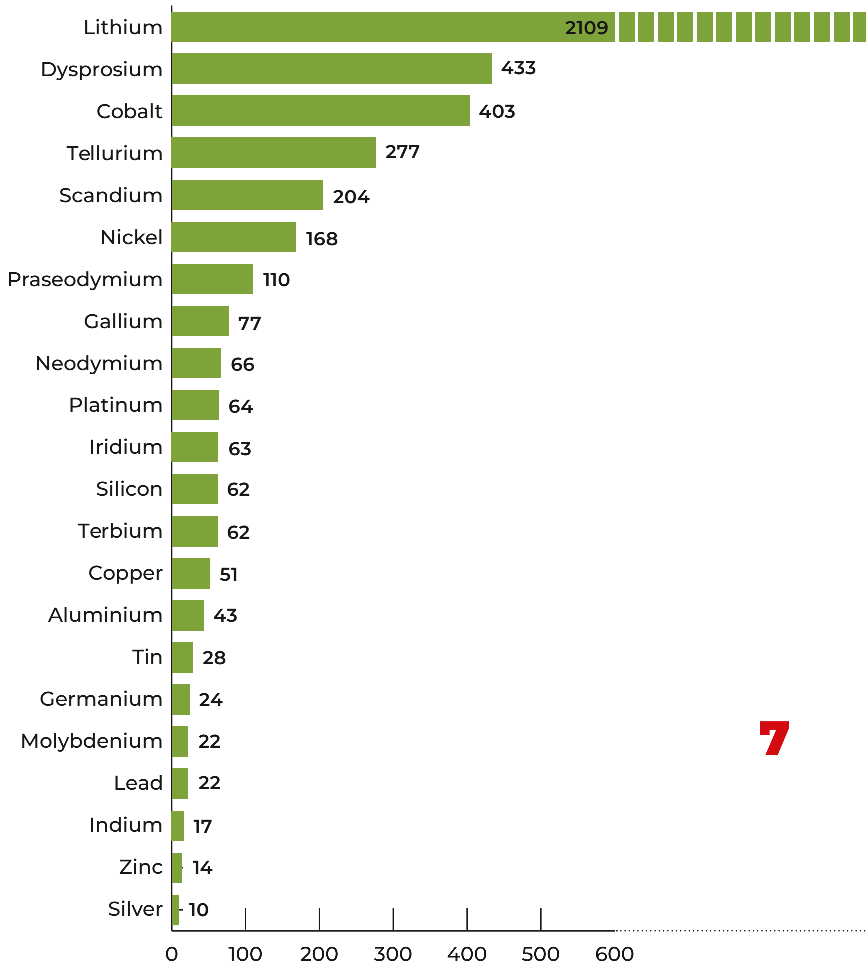
The unsustainable, dirty and in many ways, destructive mining industry is needed both to maintain the status quo and for its transformation. But if planned changes lead to a renewal of the status quo – i.e. mobility continues to be about individual automobility, energy consumption is not about reduction, technologies continue grasping for higher, further, faster – then by 2050 we will need many times more lithium, cobalt, copper and other metals for these so-called green technologies. This is shown in numerous forecasts.[7] But there are often different definitions for what "green technologies" are. While many think first and foremost of wind turbines and solar panels, they can also include battery-powered cars, 3D printers and other technologies, to which there may be more sustainable alternatives.

The essential challenge remains that several economic sectors, especially energy, transport, metals processing, and agriculture, are facing fundamental transformation. The phasing-out of fossil-fuel energy, the main driver of the climate crisis, has top priority. Metals are needed for everything, from e-mobility to wind power and solar plants to digitalisation. The amount of metallic raw materials required has roughly tripled in the last twenty years. In addition, China and India have become important new players in the global market. The supply of metallic raw materials has thus become a key economic policy issue. In 2011 the European Union therefore drew up a strategic list of "*critical raw materials*" for the first time. In this context critical means that the use of a raw material is both essential for European industry, and that its continuous supply to European industry is endangered due to their scarcity or political risk factors. This list is reviewed every three years. In 2020, bauxite, cobalt, lithium, graphite and phosphorus were among the critical raw materials.[8]

Many of these critical raw materials are in fact urgently needed for the energy transition. On behalf of the European Mining Association, the University of Leuven has calculated that the consumption of metals for "clean technologies"[1] will increase massively by 2050 compared to total consumption in 2020 (Figure 1).

The forecast increase in the consumption of metallic raw materials is rarely put into context with the often-negative consequences of mining. In general, much mining of metal takes place in China, Australia and countries of the Global South (see Figure 2). In many of these countries, conflicts arise due to mining, be it over water or land use, or emissions into the air, soil or water. In addition, the mining of raw materials and processing of ores into metals have a major impact on the climate.[9] Firstly, new mining projects contribute to the destruction of rainforests. In Brazil, scientists estimate that ten percent of deforestation

Figure 1 – Forecast percentage increase in consumption for renewable energy technologies and electromobility from 2020 to 2050



Own depiction, Data: **https://eurometaux.eu/media/jsfne00y/final-slides-ku-leuven-study-presentation-25-4.pdf**

from 2005 to 2015 can be attributed to mining activities. Levin Sources, a consultancy which specialises in resources, estimates that international mining is responsible for about seven per cent of global deforestation.[10]

Deforestation largely takes place in regions with tropical forests, not only Brazil but particularly in Southeast Asia and West Africa. The clearing of land for the mining of bauxite in Guinea, gold in Ghana or other raw materials in those regions assumes ever greater proportions.

Secondly, the mining and processing of iron ore/steel (about seven[11] to eleven[12] percent of global CO_2 emissions, bauxite/aluminium (around two[13] to three[14] percent of global CO_2 emissions, copper (0.3 percent of global CO_2 emissions)[15], nickel (0,27 percent of global CO_2 emissions) [16] and the other 90 or so metallic elements together, account for up to 15 percent of global CO_2 emissions. Shockingly, according

1 Clean technologies: In the study this label applies to wind power, solar energy, hydropower, geothermal energy, biomass, hydrogen as well as nuclear power, electromobility and its associated batteries (Gregoir p.10)

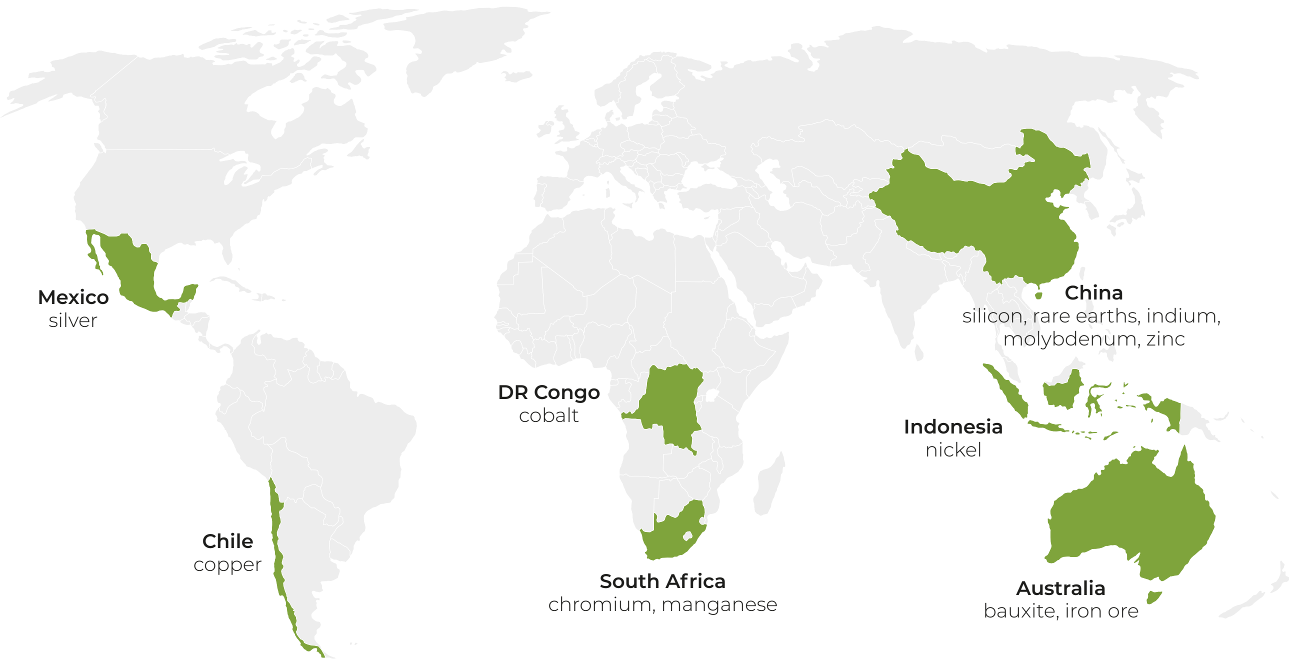
This mine eats itself into the rain forest in the Phillipines.
Photo: Michael Reckordt

to an analysis by Bloomberg Intelligence[17], only eleven out of 46 metal and mining companies have any strategy whatsoever in place to reduce emissions.

A group of researchers led by the Japanese environmental scientist Takuma Watari recently used life cycle assessments and material flow analyses to show that global metal use targets and the growth forecasts of the World Bank, the EU Commission and the German government are not in line with the two-degree climate target.[18]

This raises a number of questions: Is the energy transition and the expansion of renewable energies inconsistent with a raw materials transition and with reduction targets for metals? How many raw materials does this expansion of renewable energies require and how does it relate to total consumption? What other drivers can be identified for the high forecasts for metal consumption?

Figure 2 – Country map showing the most important producers of selected raw materials



Own depiction,
Data: U.S. Geological Survey, 2022, Mineral commodity summaries 2022: U.S. Geological Survey, 202 p., *https://doi.org/10.3133/mcs2022.*

Actual material requirements of renewable energy technologies

There are few holistic assessments of the material requirements for PV and wind power plants. A first publication appeared in 2011 by the WWF[19] and calculated that for the global supply with 100 percent renewable energy (25,000 TWh) in 2050, about 3.2 billion tonnes of steel, 310 million tonnes of aluminium and 40 million tonnes of copper would be needed. Other studies, for example by the World Energy Council, assume that 40,000 TWh of energy will be needed worldwide in 2040[20], which means that the values for material consumption would also have to be adjusted. At the same time, there is a lack of evaluation regarding the extent to which technological change in wind power and PV systems will have a positive effect on the consumption of metallic raw materials. Hans-Josef Fell, former member of parliament for the Green Party and one of the initiators of the Renewable Energy Sources Act, argues that the share of electricity production from wind power must be increased, but not the number of wind turbines. Through technological innovation, the number of wind turbines in Germany could even be decreased *"from the current level of around 30,000 to around 24,000 units"*.[21]

On 11 January 2022, the minister of the Federal Ministry of Economic Affairs and Climate Action (BMWK), Robert Habeck, made it clear in his opening statement on climate protection that 80 percent of electricity should come from renewable sources by 2030. To this end, the BMWK envisages an installed capacity of 130 GW from wind power plants (100 GW on land, 30 GW at sea) and 215 GW from solar plants by 2030. According to the German Mineral Resources Agency (DERA), 63 GW of wind and solar power were installed in Germany by 2020, which produced 132 TWh. 54 GW of photovoltaic capacity were installed, producing 51 TWh. Within the German electricity mix, wind has thus been the most important energy source in recent years. However, photovoltaics rank behind brown coal, nuclear energy and gas.

The German DERA estimates a net addition of 67 GW from wind power plants from 2021 to 2030 – excluding repowering, i.e. the replacement of old wind power plants with more powerful, newer ones.[22] For these increases, several metals and metal products will be needed, as well as cement. DERA assumes a net addition from photovoltaics in the same period – also without repowering – of 161 GW.[23]

By 2030, three times more concrete than steel will be used in wind turbines in Germany..
Photo: LEEROY Agency, Pixabay

For classification purposes, in Figure 3 the cumulative and yearly forecast material requirements to meet this wind and solar expansion are compared with total German consumption of the respective raw materials in 2020.

The table clearly shows that the annual metal demands for steel, aluminium, copper, nickel and zinc required for the expansion of wind power plants only account for a small part of their current total consumption. The demand for rare earth elements is the highest in relative terms, and would account for around nine percent of current annual consumption. Due to expected price increases and China's monopoly on the extraction of rare earths, in the future DERA assumes a reduction in and substitution of rare earth elements in wind turbines for Europe. The Danish wind power company Vestas, for example, already uses turbines with gear boxes in all its models, which reduces the need for rare earths by the factor 4 to 12 depending on the exact model.[24]

PV plants have somewhat larger impact than wind power in terms of aluminium and copper consumption. This is due to the significantly larger GW capacity. The annual demand for silicon would amount to about 32 percent of total consumption of this raw material in 2020, for silver 17 percent. In order to counteract possible bottlenecks and price increases, research is already being conducted on various thin-film photovoltaic modules that require

Figure 3 – Material demand for the expansion of renewable energy compared to total material consumption in 2020 in Germany in tons

Raw material	Material demand for an increase of 67 GW Wind by 2030	Annual material demand for the increase in wind energy	Material demand for an increase of 161 GW solar power by 2030	Annual material demand for the increase in solar power	Material consumption in Germany 2020 (partly estimated)
cement	27.400.000	2.740.000	9.600.000	960.000	30.108.000
steel	9.500.000	950.000	10.700.000	1.070.000	31.200.000
aluminium	100.000	10.000	1.200.000	120.000	2.560.600
copper	160.000	16.000	730.000	73.000	1.046.000
nickel	31.000	3.100	-		50.019
zinc	450.000	4.500	-		377.500
SE	5.500	550	-		4.862
silicon	-		600.000	60.000	189.600
glass	-		730.000	73.000	10.309.000
silver	-		2000	200	1.170

Own depiction, detailed list of sources on p. 25

significantly lower amounts of these two raw materials. At the same time these thin film modules face other bottleneck issues due to the scarcity of indium and tellurium amongst others.

According to DERA, the total global wind power capacity of 95 GW installed in 2020 used 0.6 per cent of global concrete production, 0.6 per cent of global steel production and 1.6 per cent of cast iron production. The share of demand in the raw material markets for wind turbines was highest for zinc (at 3.9 per cent), molybdenum (3.5 per cent) and rare earth elements (3.2 per cent). From these DERA figures it can therefore be seen that the addition of wind turbines does not drive the demand for metals. The globally installed solar energy capacities of 138 GW also only claimed 0.2 per cent of concrete production and 0.5 per cent of global steel production. Larger demand shares for silicon (16.8 per cent), germanium (15.6 per cent), silver (10.0 per cent) and indium (4.6 per cent) also represent a significant amount, but are not yet driving demand in the commodity markets.

Measured in terms of the global material consumption of wind power and solar energy, it becomes clear that renewables are not a driving factor in the high forecasts for future metal consumption. The Oeko-Institut comes to similar conclusions in a study commissioned by several green-party MEPs.[25] According to the study, the expansion of wind power and photovoltaics is not neutral in terms of raw materials. Very high demand shares by green technologies are identified for the raw materials cobalt, lithium, niobium, tantalum and light and heavy rare earth elements. However, a closer look reveals that at least cobalt and lithium play a major role in electromobility and thus distort the result. Lithium, cobalt and tantalum play only a very minor role, if any, in the production of wind power and PV systems.

Material consumption in relation to energy produced

Electricity production from fossil fuels is also very material-intensive, as becomes clear by a look at this old power plant.
Photo: Benita Welter, Pixabay

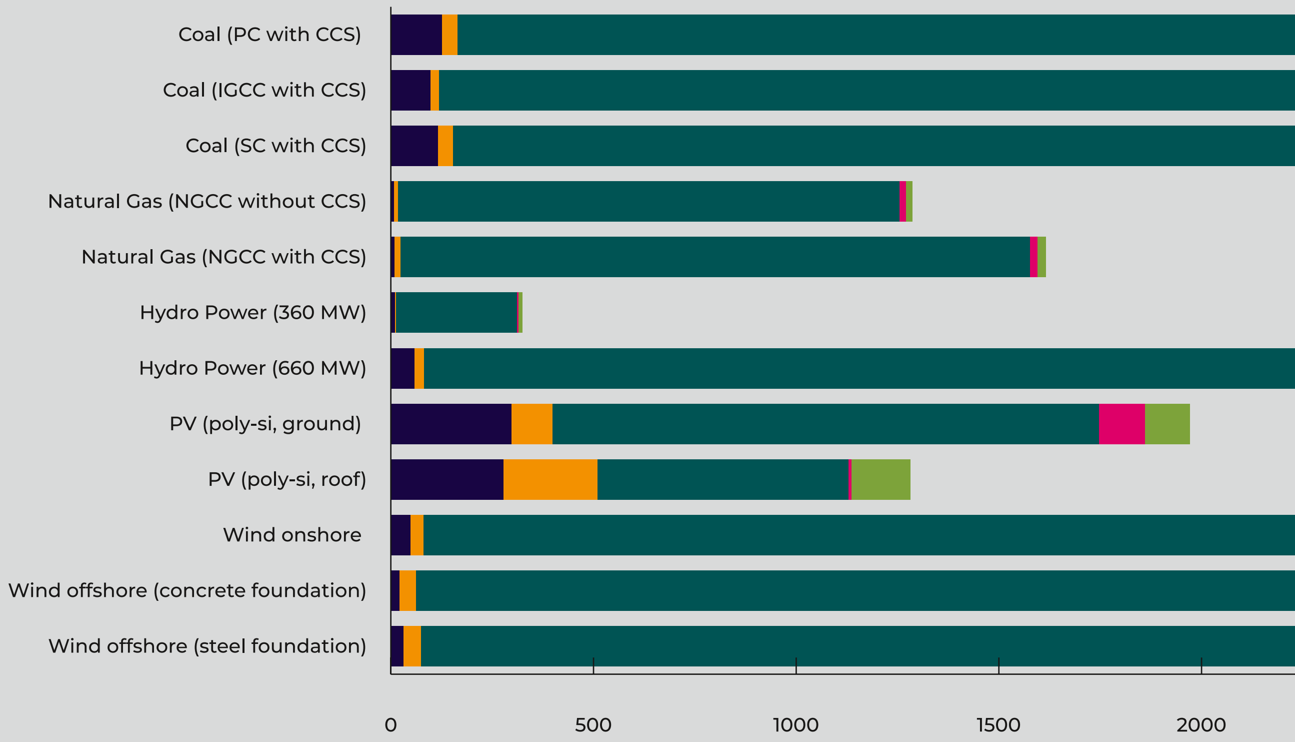
In addition to the question of absolute material requirements, material efficiency is an important indicator for comparing fossil and renewable energy sources. This was investigated by the United Nations Economic Commission for Europe (UNECE) in a life cycle analysis of various energy infrastructures.[26] The results show that the metal requirement per megawatt hour is generally high for all energy production technologies, but that raw materials for batteries, such as lithium and cobalt, are of little significance to wind, solar and hydropower technologies.

Our underlying data comes from the Luxembourg Institute of Science and Technology (LIST), from the UNECE study “Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources”.[27] Within this we have looked at the material requirements for coal power, gas, hydropower, photovoltaics and wind power plants. For this paper, we have not calculated material requirements of coal-fired power plants without CCS (carbon capture and storage) and nuclear power plants[2] in detail, as the political agenda is clearly set against the future construction of such plants. In the case of PV systems, we have also focused on established and market-dominating technologies.

In general, figures 4 and 5 show that iron (and steel) account for the largest share of material demand in all energy technologies. This metal consumption is particularly visible in wind power plants, coal-fired power plants and large hydropower plants. In terms of material requirements per megawatt hour generated, small hydropower, PV and gas power plants are the most economical and their material intensity is significantly lower.

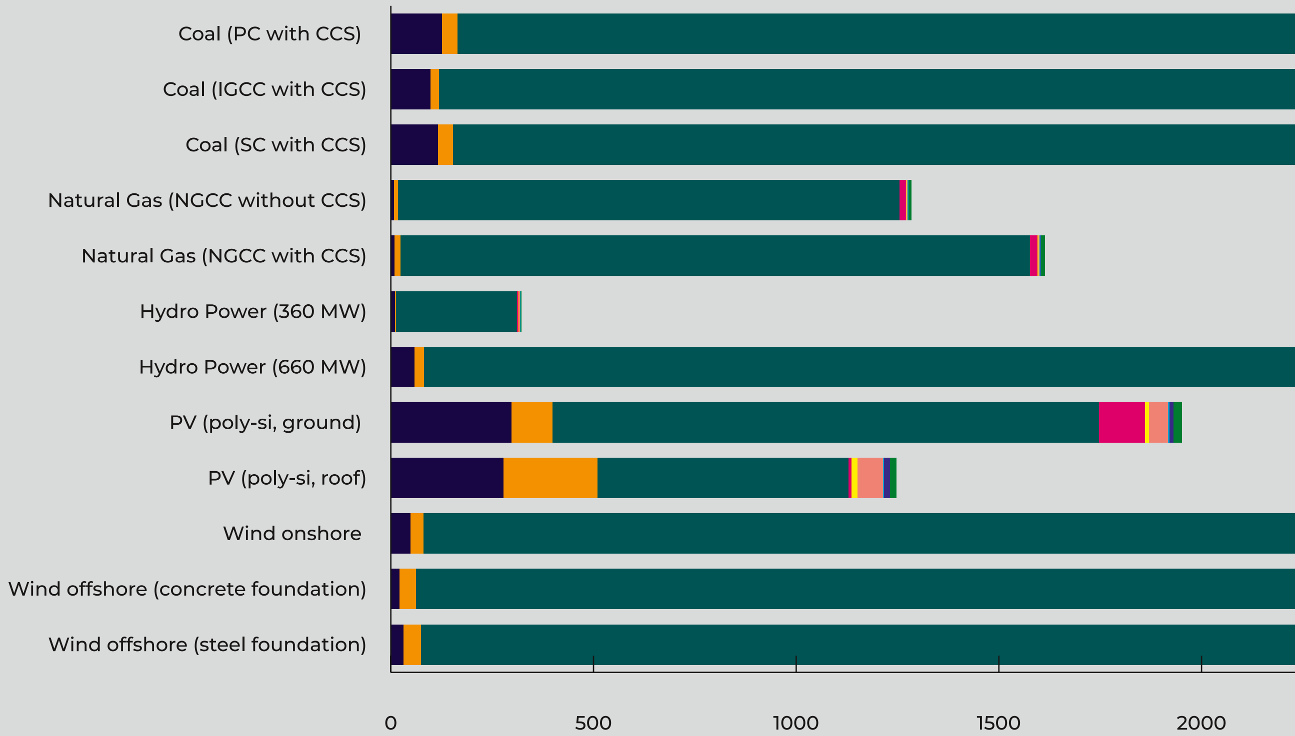
2 Nuclear power is not considered in detail here, as the German government has decided to phase out nuclear power and has by now largely implemented these plans. There are good reasons for this: In contrast to other energy sources, nuclear energy produces radioactive waste, the final disposal of which remains an unresolved issue. Reactor safety issues have become more important with the 2011 nuclear disaster in Fukushima and the Russian invasion of Ukraine, with combat operations and artillery fire in the immediate vicinity of nuclear power plants. In addition, a large part of the nuclear fuel rods is produced in Russia and Kazakhstan, which in turn could create a renewed geo-strategic dependence on Russia. The example of France also shows how problematic cooling and maintenance of the reactors is in the context of advancing global warming, and that nuclear power is anything but a constant and reliable energy supply.

Figure 4 – Metal demand for selected energy technologies in g per MWh



Own depiction,
Data by the Luxembourg Institute of Science and Technology (LIST) on behalf of UNECE (2021):
Life Cycle Assessment of Electricity Generation Options. United Nations Economic Commission for Europe.

Figure 5 – Demand for bullk metals for selected energy technologies in g per MWh



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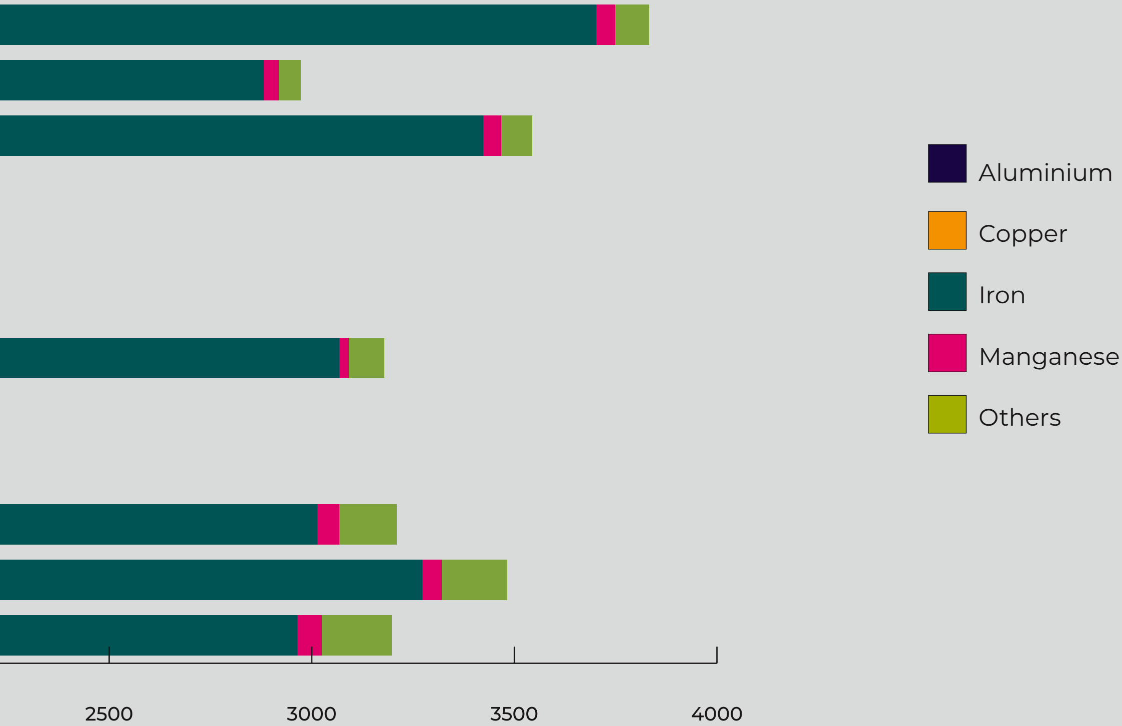
Data by the Luxembourg Institute of Science and Technology (LIST) on behalf of UNECE (2021):
Life Cycle Assessment of Electricity Generation Options. United Nations Economic Commission for Europe.


Aluminium
Copper
Iron
Manganese
Others
2500
3000
3500
4000

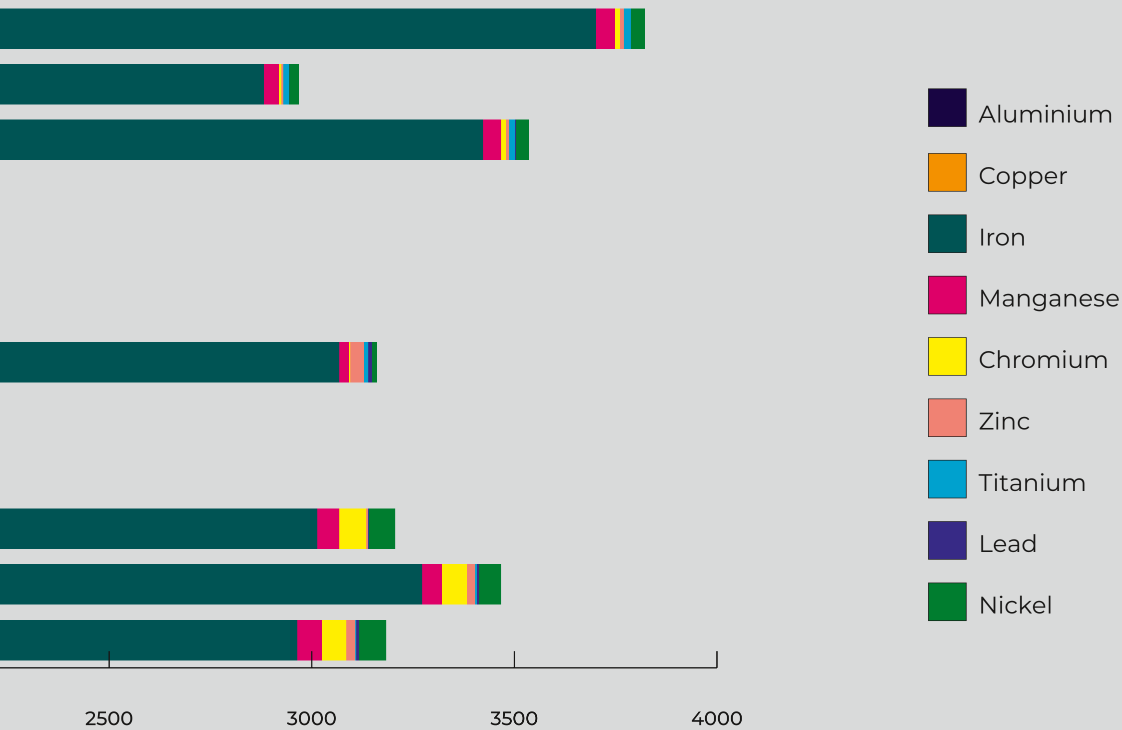
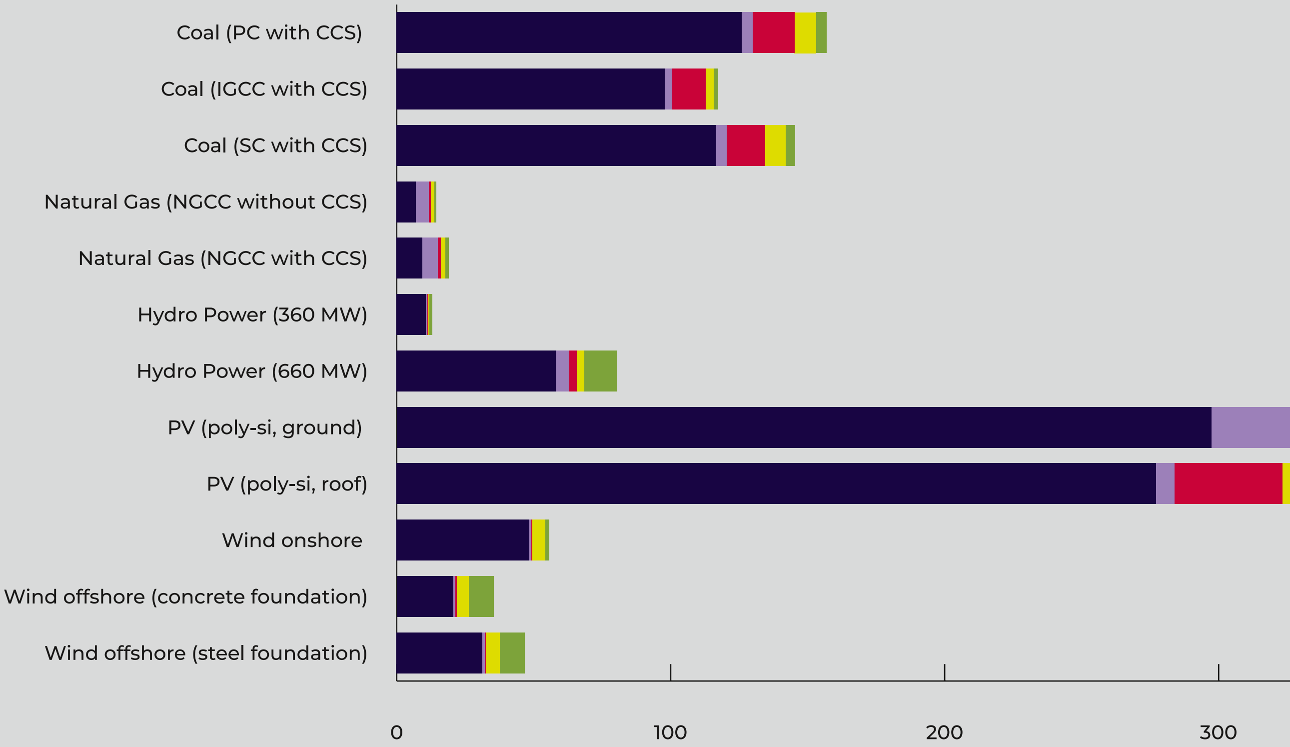
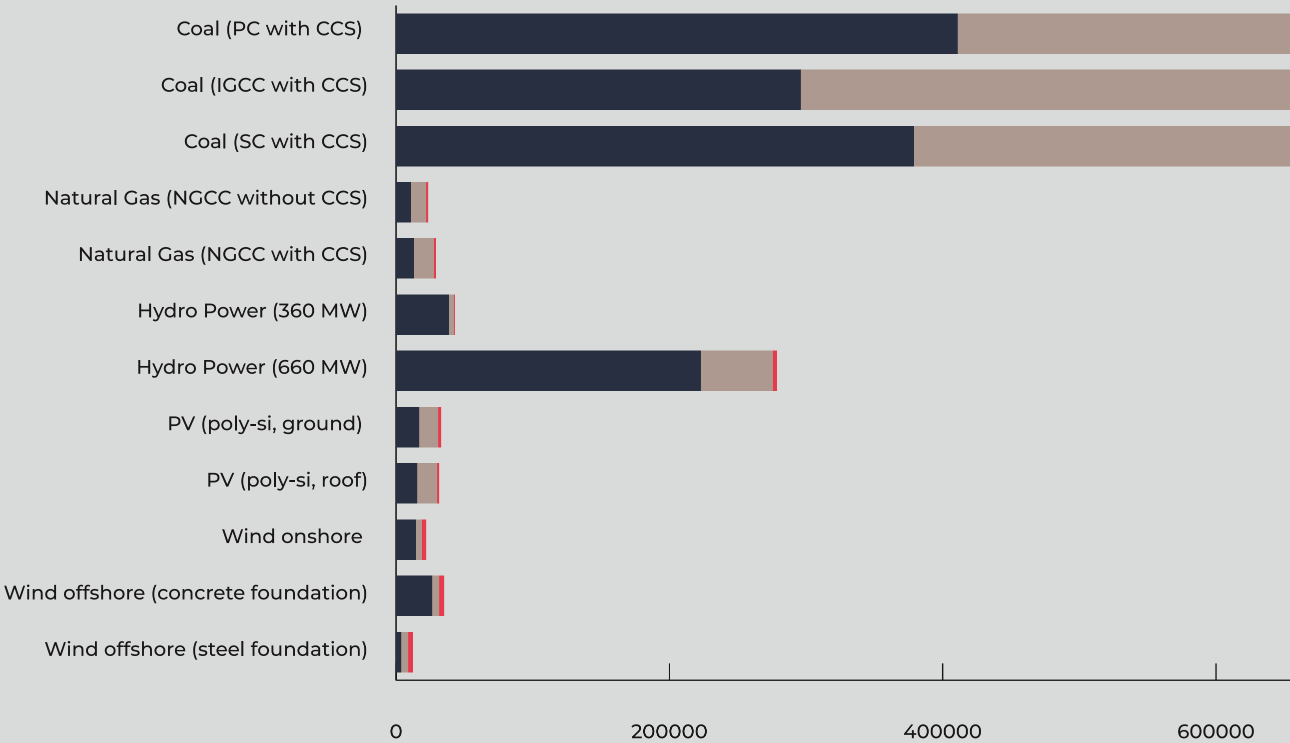

Aluminium
Copper
Iron
Manganese
Chromium
Zinc
Titanium
Lead
Nickel
2500
3000
3500
4000

Figure 6 – Demand for critical raw materials for selected energy technologies in g per MWh

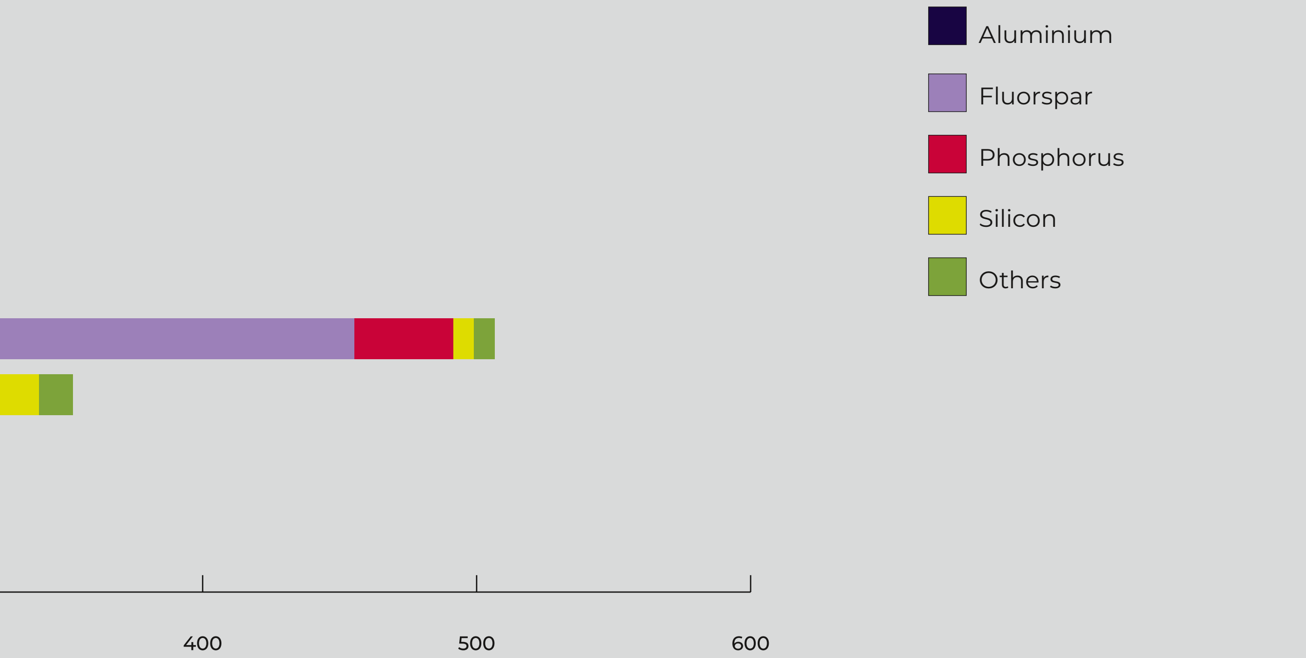


Own depiction,
Data by the Luxembourg Institute of Science and Technology (LIST) on behalf of UNECE (2021):
Life Cycle Assessment of Electricity Generation Options. United Nations Economic Commission for Europe.

Figure 7 – Total raw material demand for selected energy technologies in g per MWh



Own depiction,
Data by the Luxembourg Institute of Science and Technology (LIST) on behalf of UNECE (2021):
Life Cycle Assessment of Electricity Generation Options. United Nations Economic Commission for Europe.


Aluminium
Fluorspar
Phosphorus
Silicon
Others
400
500
600

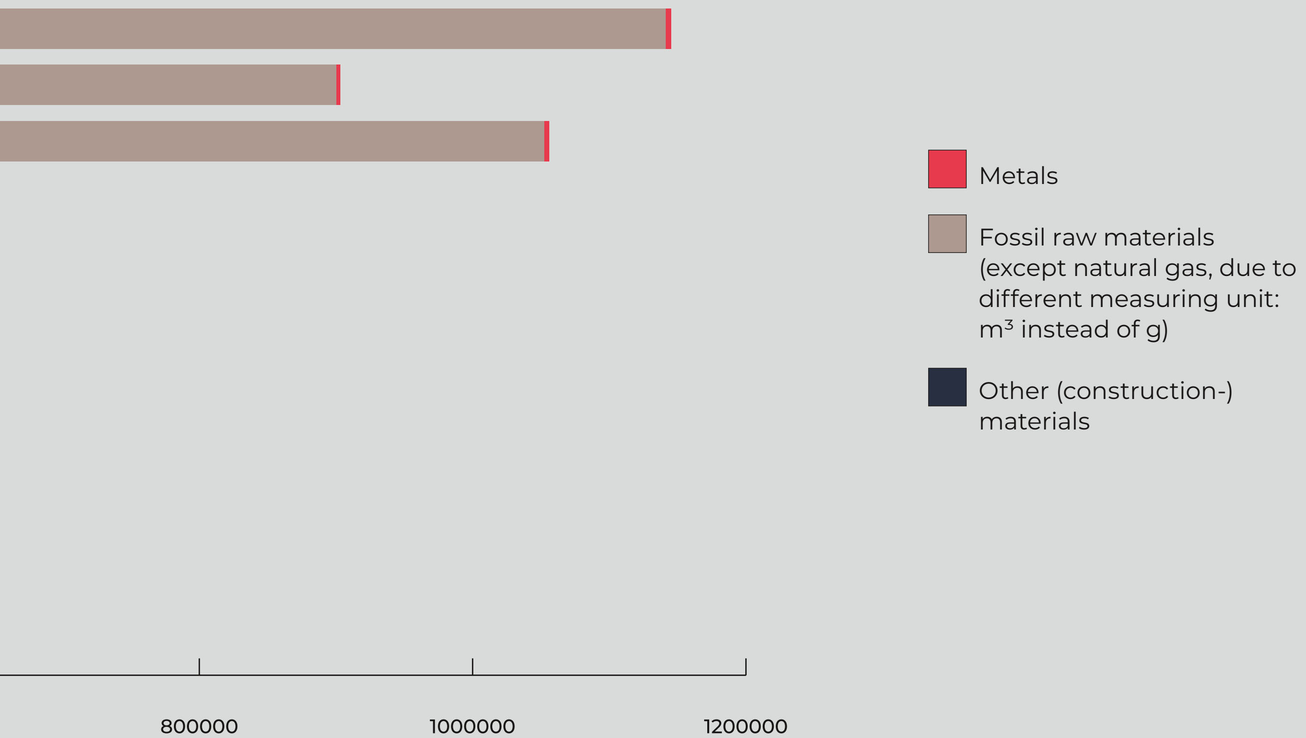
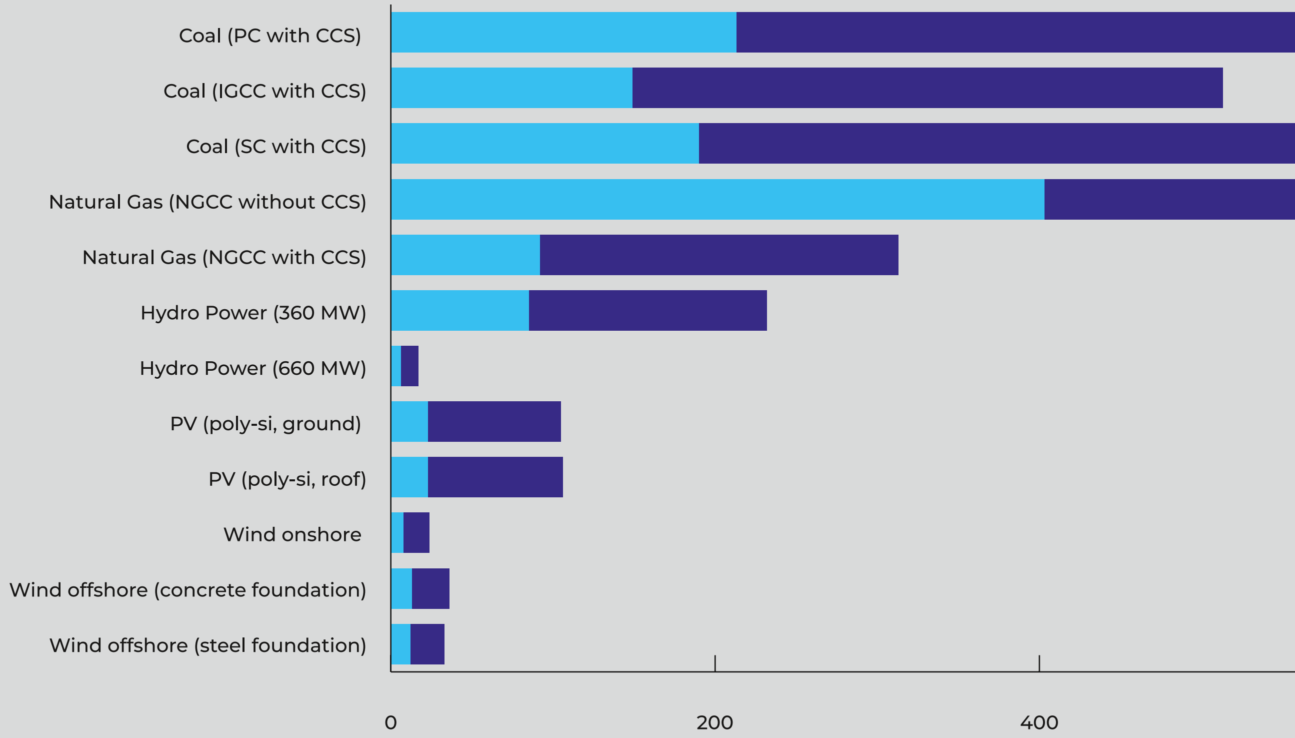
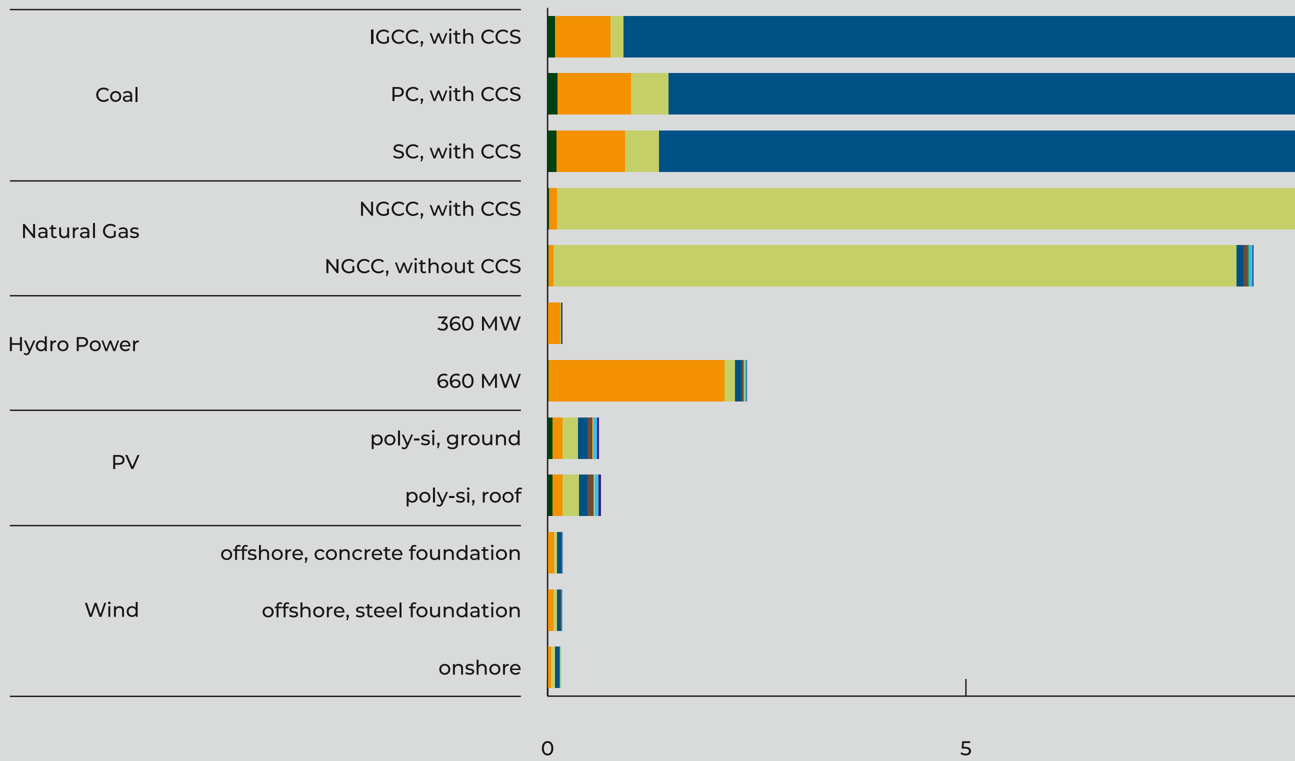

Metals
Fossil raw materials (except natural gas, due to different measuring unit: m³ instead of g)
Other (construction-) materials
800000
1000000
1200000

Figure 8 – Greenhouse gas emissions of selected energy technologies with regional variation in g CO2 equivalents/kWh



Own depiction,
Data by the Luxembourg Institute of Science and Technology (LIST) on behalf of UNECE (2021):
Life Cycle Assessment of Electricity Generation Options. United Nations Economic Commission for Europe.

Figure 9 – Cumulative life cycle energy demand, in MJ/kWh



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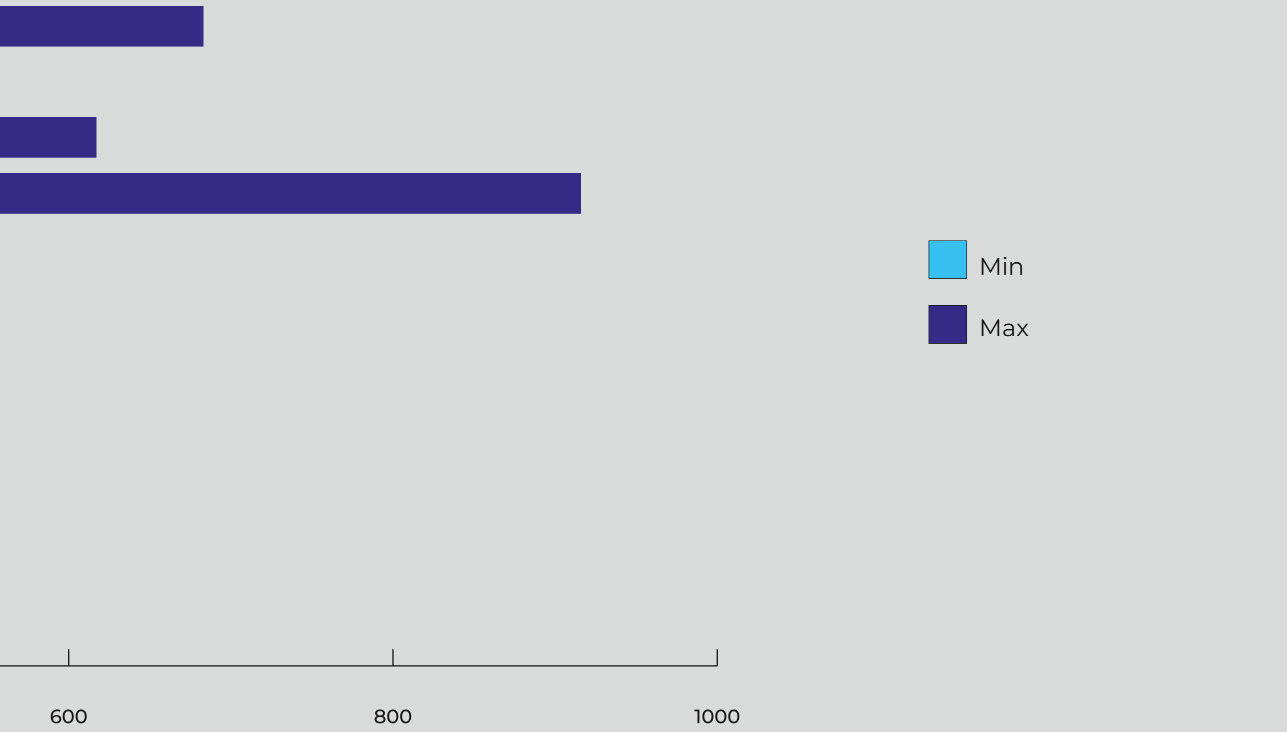
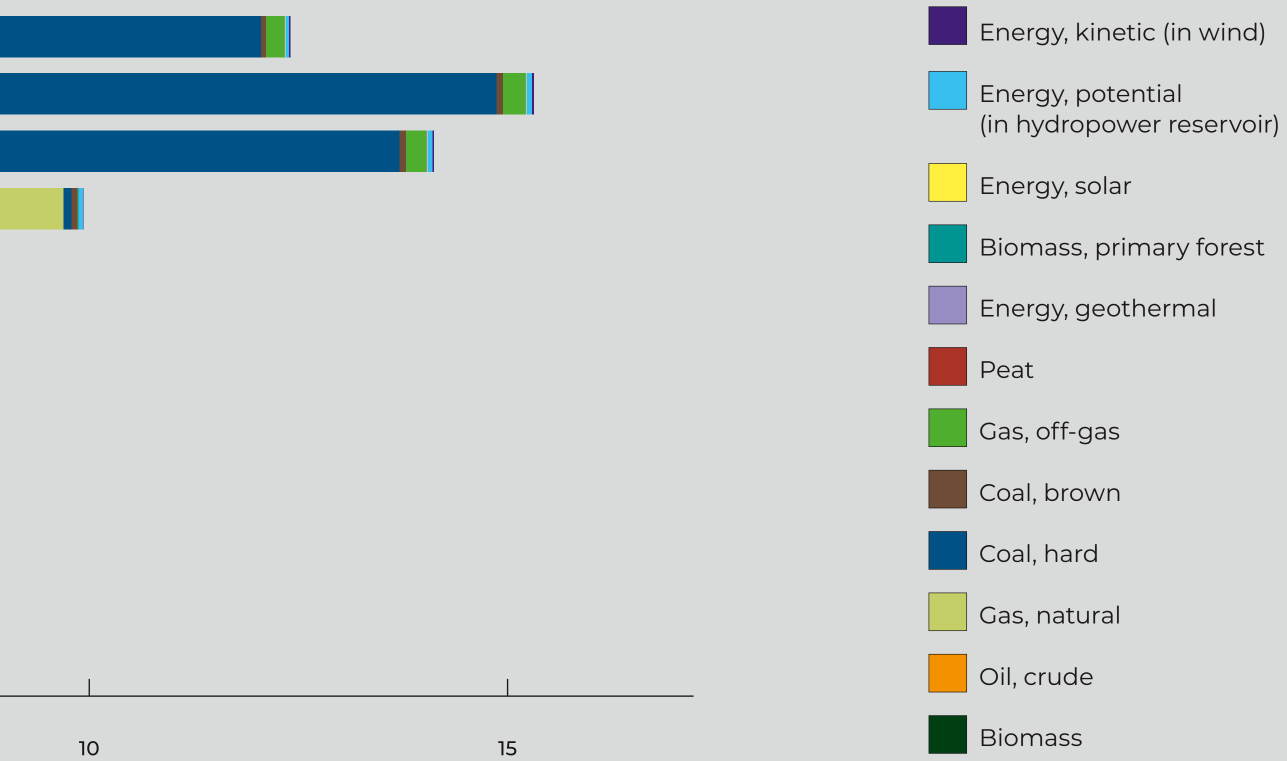

600
800
1000
Min
Max


10
15
Energy, kinetic (in wind)
Energy, potential (in hydropower reservoir)
Energy, solar
Biomass, primary forest
Energy, geothermal
Peat
Gas, off-gas
Coal, brown
Coal, hard
Gas, natural
Oil, crude
Biomass

In the medium term, wind farms must replace coal-fired power plants. Photo: Hans-Jürgen Münzer, Pixabay

If we turn to the discussion about raw materials classified as "*critical*" by the European Union, the weightings change slightly. The current critical raw materials list includes a total of 30 raw materials – including two groups of raw materials, heavy and light rare earths. A look at Figure 6 makes it clear that a number of critical raw materials are needed, especially for solar plants, but also for gas and coal infrastructure. In terms of weight, the metal aluminium, which is produced from bauxite, stands out. While wind power and small hydropower plants require by far the fewest critical metals, the demand from solar plants and large hydropower plants is slightly higher than for fossil energy technologies. However, it should not be forgotten that gas and coal-fired power plants, unlike renewables, require a constant supply of fossil fuel for their operation. Figure 9 shows how enormous this need is, especially for coal-fired power plants. Compared to the use of metals, almost three times the amount of fossil fuel material is required during the life cycle of this type of energy production. This also applies to gas, which does not appear in Figure 7 due to the different measurement unit of m^3 instead of g. However, when looking at the CO_2 emissions in Figure 8, and Figure 9, which shows the cumulative energy demand of the power plants in MJ per kWh, it becomes clear how much lower in emissions and more energy efficient renewable energies are when the entire life cycle is considered.

In summary, it can be stated that the material requirements for renewable energies are not significantly higher than those for fossil energy. On the contrary, wind power mainly requires bulk metals and, so far, some rare earth elements. In terms of raw materials defined as critical by the EU, wind power plants together with small hydropower plants perform best by a wide margin. The production of solar energy, on the other hand, requires significantly more critical raw materials, above all aluminium and silicon. In terms of material intensity for all metals, solar plants together with small hydropower plants score among the best. Although natural gas is somewhat more material efficient than renewable alternatives in terms of bulk metals, it is a driver of CO_2 emissions and has a problematic role as a geopolitical bargaining chip, which has become shockingly evident since the Russian invasion of Ukraine. Rising energy prices and supply insecurity pose growing problems for both industry and citizens. The supply gaps are currently being filled with fracking gas, which has even more devastating socio-ecological consequences than conventional drilling methods.

In addition, the metal requirements of renewable energies are offset by the greenhouse gas emissions of fossil fuels. In 2021, the combustion of natural gas in Germany released 55.8 tonnes of CO_2 per terajoule, for hard coal 93.5 tonnes of CO_2 per terajoule and for brown coal 94.4 tonnes of CO_2 per terajoule, without including emissions from the construction and maintenance of infrastructure, extraction, or transport of fuels.[28] For solar and wind energy, this value is 0. Lucas Gilsbach (BGR) compares the emissions from copper production with the CO_2-saving-potential and explains:

"*For example, a 5 MW offshore wind turbine including infrastructure requires up to 30 t of copper. Assuming 3,066 full load hours per year (utilisation of 35 per cent) and an* *average CO_2 emission of 474 g CO_2/kWh from electricity generation in Germany, each tonne of copper used in a wind turbine thus helps to save about 240 t CO_2 per year, which is about 100 times the emission generated by the production of the copper."*[29]

This analysis of material requirements for electricity generation is in no way intended to deny the challenges and potential social and environmental impacts, as well as the global injustices of the high demand for metals by renewable energy infrastructure. The raw materials for solar and wind energy must be mined at the highest possible environmental and social standards. Development policy concerns must also be taken into account, especially as many of the mining regions are located in countries of the Global South.

The fact is: for a globally just energy transition we need to use raw materials modestly. This requires a circular economy and the absolute reduction of consumption in other industrial sectors. It also becomes clear that it is not renewable energy technologies themselves that are the problem, but power generation in general. While we mainly talk about the dimension of fossil raw materials in the case of coal and gas power plants, it is completely forgotten that these types of fossil power plants also require large quantities of metals for the infrastructure. This is no less material-intensive when comparing the megawatt hours of electricity generated.

A side note on carbon capture and storage

Included in the raw material requirements for coal- and gas-fired power plants is the planned capture and storage of CO_2 (CCS) in order to mitigate climate change. CCS is supposed to be used to capture the CO_2 produced in the production or combustion process and make it transportable. It is then moved by lorry, train or ship from the point of origin to an often underground storage facility. Depleted oil and gas reservoirs can be used for this purpose. Beforehand, these must be sealed from the inside, so that the CO_2 cannot escape afterwards. The fossil fuel industry promises a CO_2 neutral operation of plants and in this way lobbies to protect fossil infrastructure from a green transition. However, CCS is highly controversial. On the one hand, the plants are very expensive and would require lavish subsidies paid with public money. On the other hand, there are safety risks. If CO_2 were to escape from underground storage sites, both air and groundwater would be poisoned. For this reason, there have already been civil protests at planned storage sites, similar to those against nuclear repositories.

Furthermore, according to the IEA (International Energy Agency), 70 to 100 plants would have to be built every year to limit global warming to two degrees. After more than 50 years of research, to date only 26 CCS plants are in operation around the world. Existing and planned capacities are particularly needed for energy-intensive steel and cement production, as there are no low-emission alternatives to date, unlike in energy production.[30] It therefore seems more than dubious to use the already lacking capacities for new fossil fuel projects. Nevertheless, for transparency we have included coal-fired power plants with CCS in the comparison.

Emissions in relation to energy generated

The balance of power between electricity from wind power and electricity from fossil fuel power plants will have to change quickly. Photo: S. Hermann/F. Richter , Pixabay

In order to categorise substantial differences in emissions, which make a switch to renewable energies necessary in the first place, we also looked at pollutant emissions during the entire life cycle of energy technologies in relation to the energy generated.

Figure 8 clearly shows that the greenhouse gas emissions of gas and coal-fired power plants are many times higher than those of renewables, even with the use of CCS. Wind energy in particular produces hardly any emissions, while there are major regional differences in solar energy. Even the highest emissions value for solar energy is still below the lowest existing value for fossil energy, in this case, gas with CCS.

Other studies have come to similar conclusions. Sven Ullrich, for example, calculated that even when accounting for the production of the solar energy systems, including installation, emits significantly less CO_2 than fossil-fuelled power plants. According to his calculation, the CO_2 equivalent per kilowatt hour of electricity from a PV system with monocrystalline solar modules is between 43 and 63 grams.

In comparison: A lignite power plant emits a whopping 1,140 grams of CO_2 equivalents for every kilowatt hour of electricity produced. A gas-fired power plant emits less CO_2, but at 490 grams of CO_2 equivalents per kilowatt hour, the emissions are still more than ten times higher than the greenhouse gas pollution of a solar plant at a good location in Germany using Chinese-produced monocrystalline modules.[30]

Electricity production with wind turbines has an even lower CO_2 impact, despite the high overheads and large amount of material that goes into such a plant. The higher electricity yields however make up for this effort. The emissions caused by production, installation and maintenance are so low that the electricity produced by an offshore wind turbine only emits between 5.4 and 11.8 grams of CO_2 equivalents per kilowatt hour. At a good onshore wind site, the CO_2 equivalents per kilowatt hour of electricity produced are 6.1 to 11.2 grams. At a location with less wind, they are between 5.2 and 15.6 grams of CO_2 equivalents per kilowatt hour.[31]

Material intensity – The role of mobility

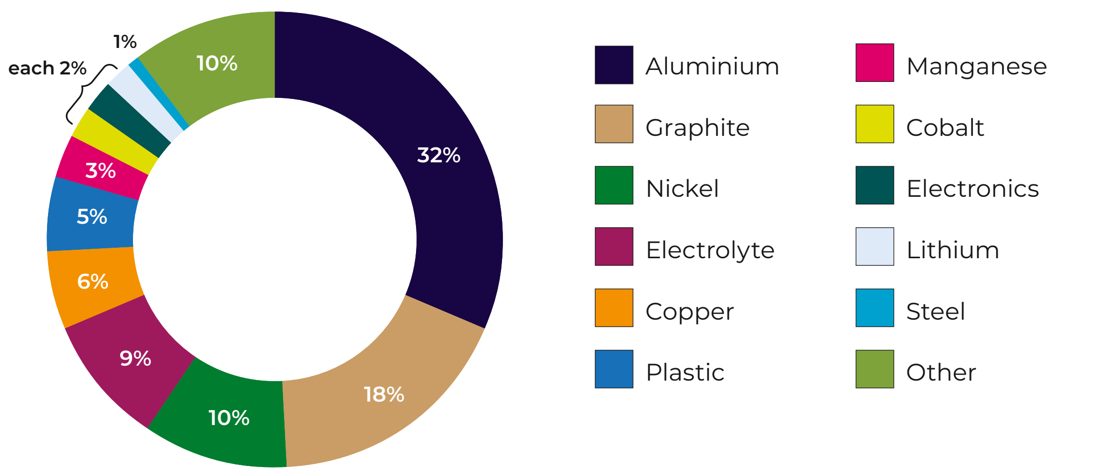
As we were able to show using data from the Luxembourg Institute of Science and Technology, renewable energy technologies are not significantly more material-intensive than fossil energy technologies. Therefore, renewable energies are not the driver for the very high, partly unrealistic forecasts for material consumption. A closer look at widespread scenarios and forecasts reveals that the high consumption of lithium, cobalt and nickel is primarily due to (electric) mobility and, to individual, electrified automobility. In the presentation of the study by the University of Leuven for the European mining association Eurometaux, the author Liesbet Gregoir emphasises that 60 per cent of the forecast raw material consumption flows solely into the transport sector.[32] This is hardly surprising if one looks at an example. Volkswagen gives the material composition of a 400-kilogram battery (as shown in Figure 10). Aluminium accounts for the largest share of the weight at 32 per cent.[33]

The VW group announced that by 2030, 70 per cent of the vehicles it sells will be battery-powered. In 2020 and 2021, VW sold nine million vehicles per year. Without taking into account changes in the sales figures, the material composition and the weight of the batteries, this would mean, as things stand today, that in 2030 alone, Volkswagen would need almost 800,000 tonnes of aluminium, 250,000 tonnes of nickel and more than 130,000 tonnes of copper for batteries. Since the average car registered in Germany currently weighs 1.6 tonnes, this would mean that three times that amount of additional raw materials would be needed – above all aluminium, iron/steel and copper.

Compared to the material requirements of the wind power expansion targets as calculated by DERA, this means that the batteries for the electric Volkswagens alone could require around 8 times as much aluminium and nickel in 2030 as the entire planned expansion of wind power plants in Germany. The copper demand for VW's electromobility is also very high; for the batteries alone it corresponds to the same amount as required for the expansion of wind power by 2030.

Under these conditions, future supply gaps in the metals market can be expected. If the car industry pushes ahead with its goal of a 1:1 replacement of combustion engines with electric cars, it will be in competition with the energy industry for the sought-after metals. Prices will skyrocket, making the energy transition significantly more expensive. In addition, there will be social and ecological damage caused by increased mining, especially in the Global South.[34]

Figure 10 – Material components of a 400 kg Volkswagen battery



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Conclusion and outlook

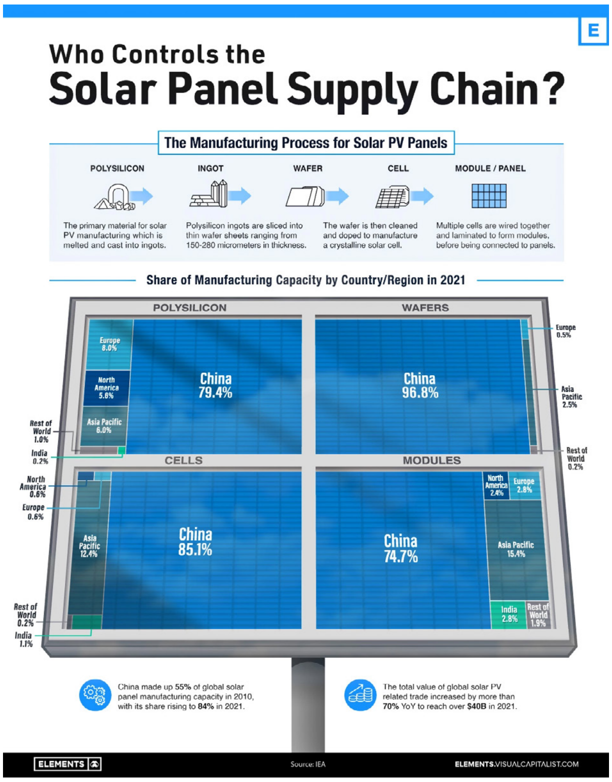

Figure 11 – Percentage of market share along the PV supply chain by country

Source: Visual Capitalist, August 30, 2022 by Niccolo Conte, Graphics / Design Sam Parker, Clayton Wadsworth
https://www.visualcapitalist.com/visualizing-chinas-dominance-in-the-solar-panel-supply-chain/

Energy production, whether fossil or renewable, requires large quantities of metals. In order to effectively counteract climate change, a shift away from fossil fuels is unavoidable due to the greenhouse gas emissions that have been identified. We will need metals for the expansion of renewable energies, but compared to (electric) automobility, they are not a driver for new mining projects. The supply of metals for the energy transition does not therefore contradict a fundamental debate about reducing the consumption of primary raw materials. On the contrary, the predicted higher electricity consumption would also make an expansion of fossil energy infrastructure necessary and would require metals to a comparable extent.

In order to reduce the ecological, social and climate consequences of metal consumption in the medium and long term, a raw material transition is needed. The goal of the raw material transition is to reduce demand for metal. Sector-specific targets are an important lever. Here, the energy sector is challenged in a different way than the mobility sector, for example: there is no alternative to the expansion of renewable energies, which must be given priority, while in the mobility sector we need a rapid shift away from motorised individual transport in addition to a conversion to electric engines. A new car in Germany weighs 1.6 tonnes on average and car production requires many times more raw materials than wind power and PV plants. There is no way around reducing metal consumption in the mobility sector by drastically reducing the number and size of cars. A first step would be to abolish company car privileges, which currently subsidise large and heavy cars.[35]

A further step would be the expansion of circular economy approaches, with product design based on durability, repairability, and recyclability. For better circularity, there is a need to expand the data capture, collection, and sorting structures for end-of-life plants. A framework is also needed here for the production of photovoltaic and wind power plants. The high scrap volumes expected in the coming years illustrate the urgency. This also affects the solar and wind power industry.

Last but not least, raw material requirements for renewable energy technologies must not come at the expense of people living in the extraction regions. Compulsory regulations for human rights and environmental due diligence, the extension of value chains and the creation of jobs in regions rich in raw materials, and the highest possible human and labour rights protections and environmental standards in the extraction and processing of raw materials should apply to the materials essential for our energy transition. Development policy concerns must be given special consideration in the extraction of many raw materials. Countries such as Indonesia (for nickel) or Mexico and Bolivia (both for lithium) have tried in recent years to extend the value chains in their countries and thus profit from the wealth of raw materials. This would also help to reduce dependence on China, not only for raw materials but also for intermediate products and, for example, solar cells (see Figure 11). This extension of value creation could also be an important building block for advancing the energy transition in countries of the Global South.

Tables attached to Figure 2

Figure 2 – Most relevant producers of selected raw materials

Metal	Country	Production Volume 2021 in kilotonnes (estimate by USGS)	% of countries total share in global production	Renewable energy technologies that use material (e.g., wind power, PV and/or hydropower plants)
Iron ore (Usable ore)	Australia	900.000	34,6%	EET
	Brazil	380.000	14,6%	EET
	China	360.000	13,8%	EET
	India	240.000	9,2%	EET
Bauxite	Australia	110.000	28,2%	EET
	China	86.000	22,1%	EET
	Guinea	85.000	21,8%	EET
	Brazil	32.000	8,2%	EET
Copper	Chile	5.600	26,7%	EET
	Peru	2.200	10,5%	EET
	DR Congo	1.800	8,6%	EET
	China	1.800	8,6%	EET
Silicon	China	6.000	70,6%	Photovoltaic
	Russia	580	6,8%	Photovoltaic
	Brazil	390	4,6%	Photovoltaic
	Norway	350	4,1%	Photovoltaic
Silver	Mexico	5.600	23,3%	Photovoltaic
	China	3.400	14,2%	Photovoltaic
	Peru	3.000	12,5%	Photovoltaic
	Chile	1.600	6,7%	Photovoltaic
Indium	China	530	57,6%	Photovoltaic
	South Korea	200	21,7%	Photovoltaic
	Japan	60	6,5%	Photovoltaic
	Belgium	60	6,5%	Photovoltaic
Rare Earth Elements	China	168.000	60,0%	Wind power
	USA	43.000	15,4%	Wind power
	Myanmar	26.000	9,3%	Wind power
	Australia	22.000	7,9%	Wind power
Cobalt	DR Congo	120.000	70,6%	Wind power
	Russia	7.600	4,5%	Wind power
	Australia	5.600	3,3%	Wind power
	Philippines	4.500	2,6%	Wind power
Molybdenum	China	130.000	43,3%	Wind power
	Chile	51.000	17,0%	Wind power
	USA	48.000	16,0%	Wind power
	Peru	32.000	10,7%	Wind power

Metal	Country	**Production Volume 2021 in kilotonnes** (estimate by USGS)	**% of countries total share in global production**	**Renewable energy technologies that use material** (e.g., wind power, PV and/or hydropower plants)
Zinc	China	4.200	32,3%	Wind power
	Peru	1.600	12,3%	Wind power
	Australia	1.300	10,0%	Wind power
	India	810	6,2%	Wind power
Nickel	Indonesia	1.000.000	37,0%	Wind power
	Philippines	370.000	13,7%	Wind power
	Russia	250.000	9,3%	Wind power
	New Caledonia	190.000	7,0%	Wind power
Chromium	South Africa	18.000	43,9%	Wind power
	Turkey	7.000	17,1%	Wind power
	Kazakhstan	7.000	17,1%	Wind power
	India	3.000	7,3%	Wind power
Manganese	South Africa	7.400	37,0%	Wind power
	Gabun	3.600	18,0%	Wind power
	Australia	3.300	16,5%	Wind power
	China	1.300	6,5%	Wind power

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Own depiction, Data: https://eurometaux.eu/media/jsfne00y/final-slides-ku-leuven-study-presentation-25-4.pdf

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p. 12/13 Figure 4
Metal demand for selected energy technologies in g per MWh, Own depiction, Data by the Luxembourg Institute of Science and Technology (LIST) im Auftrag von UNECE (2021):
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Data by the Luxembourg Institute of Science and Technology (LIST) on behalf of UNECE (2021):
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Data by the Luxembourg Institute of Science and Technology (LIST)on behalf of UNECE (2021):
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Data: https://www.volkswagen-newsroom.com/en/publications/more/battery-recycling-facts-and-figures-about-the-pilot-plant-in-salzgitter-605

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