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METAL DEMAND FOR ELECTRIC VEHICLES

Recommendations for fair, resilient, and circular transport systems | Netherlands perspective

FOREWORD

The global shift away from fossil fuels presents us with an opportunity. In redesigning systems to mitigate climate change, we have a chance to rethink the way we interact with natural resources as a whole, and prioritise systems that improve the quality of human life.

This study focuses on rethinking mobility. In the race towards a carbon-free economy, electric vehicles offer a promising solution for cleaner passenger transport that can be powered by renewable energy. As a result, governments and automotive producers are strongly focusing on electric vehicles.

However, research from the Netherlands reveals limitations in the supply of critical metals needed to produce efficient and high-performing electric vehicles. Production of some of these metals, such as nickel, praseodymium, neodymium, cobalt, dysprosium and lithium, would have to scale threefold in the coming ten years to meet projected global electric vehicle demand.

As we design low-carbon passenger transport with these complex metal supply chains in mind, we must understand where large shifts create new dependencies and navigate potential trade-offs. This may mean creating entirely new systems that offer the most future-proof pathway.

A sustainable, fair, and resilient transport sector involves reducing our dependence on privately owned vehicles, through promotion of new mobility concepts that make more effective use of existing vehicles, and improved public transport infrastructure. Also critical is the development of a circular economy within the industry, enabling maximum resource efficiency.

Originally released at the Springtij Forum in September 2019, the report has since been expanded upon, with further recommendations to illustrate clear pathways to action. Our recommendations are based on the Dutch and European settings, however many of these can be transferred and applied to other contexts.

This is the second in a series of studies on the metal demand for our new, carbon-free economy. It follows an earlier study on the critical metal demand for solar panels and wind turbines. The aim of these studies is to understand the new dependencies arising from a carbon-free economy, and what we can do to move, rapidly and safely, towards this new economy with both societal needs and critical raw materials in mind.

SUMMARY

To meet Paris Climate Agreement targets, a rapid roll-out of renewable energy technologies is needed. Among these are electric vehicles - a promising solution for cleaner, more efficient passenger transport. Yet calculations from the Netherlands show that current global production of some critical metals will need to be scaled up drastically to support a large-scale transition to electric transport.

Our research finds that supply could become constrained for several metals crucial to the production of electric vehicles, namely nickel, praseodymium, neodymium, cobalt, dysprosium and lithium. When looking at future prospects, the worldwide demand for some of these metals, as a result of electric transport, is forecasted to exceed current annual global production by three times in 2030. These metals are also needed for many other applications, such as energy production, consumer electronics, and many industrial applications.

Although both production and recycling of these metals can be expected to increase over this period, the size and speed of the required increase is cause for concern. Since the Netherlands is front runner in the electric vehicle transition, it will have a proportionally higher global share of electric vehicle metal demands. However, the anticipated pace of the Dutch transition is in line with Paris Climate Agreement targets, meaning that other committed countries could soon follow suit.

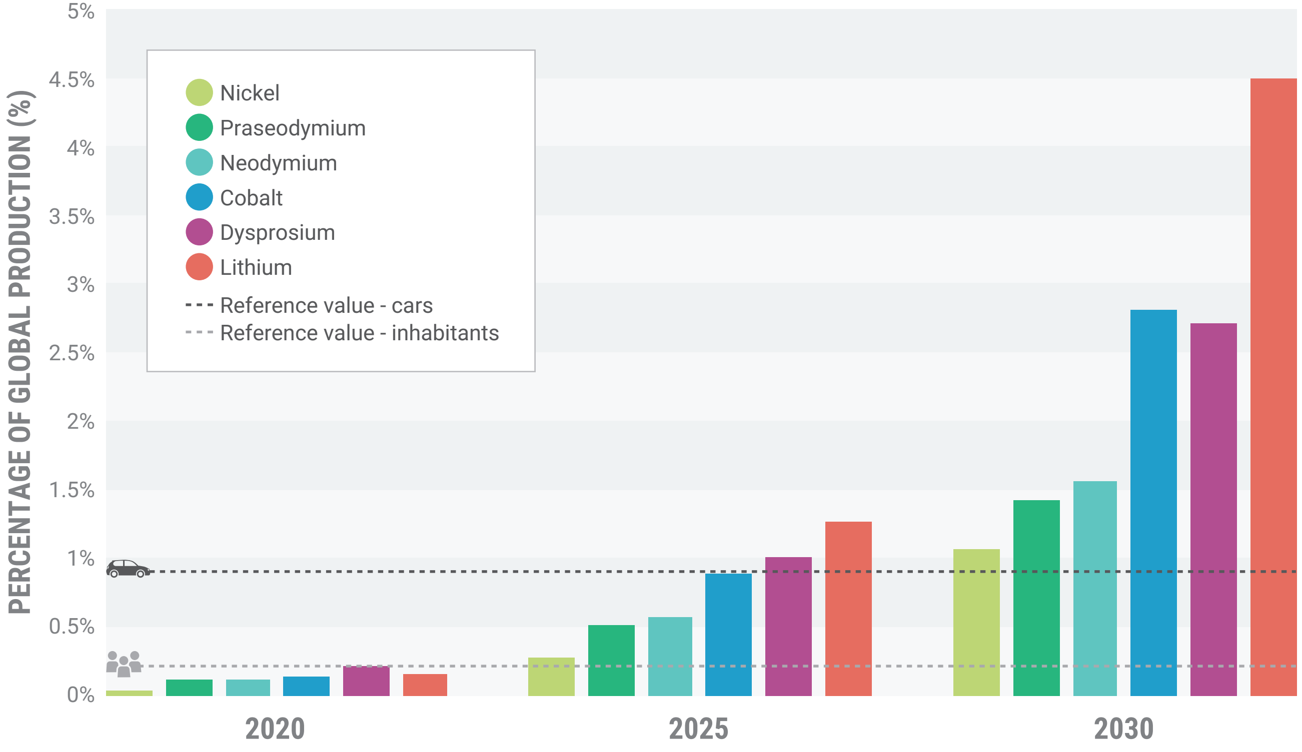


Fig. 1 **Critical metals required for electric vehicles in the Netherlands, as factor of annual global production of these metals.**

CRITICAL METAL CHAINS ARE COMPLEX

Production chains for critical metals are long and complex. Scaling up production requires significant investment, and investments need to start today in order to have a mine in operation ten years from now. Critical metals are also used as leverage to exert geopolitical influence. Moreover, mining activities are sometimes related to human rights violations and frequently cause significant environmental damage.

Unless a consistent climate policy - supportive of expanding the supply of critical materials in a sustainable manner - is implemented, these metals will likely become supply constrained. With growing worldwide demand for critical metals, the risk of geopolitical conflicts increases as well. Supply constraints or temporary disruptions could delay the large scale deployment of sustainable energy technologies (such as electric transport). This we cannot afford in light of the challenges we face in combating climate change.

SUSTAINABLE EXPANSION OF MINING PRODUCTION IS ESSENTIAL

Given the increasing demand for metals, increased mining production can be expected. This expansion can lead to severe local environmental and social issues, making it imperative that mining is done as sustainable and fair a manner as possible. Due to the many different drivers that influence mining production, this report only takes the current production into account.

THREE POSSIBLE SOLUTIONS

To achieve Paris climate policy targets, it is important to phase out fossil fuel-driven vehicles. Hydrogen cars are not realistic at scale in the coming ten years, as the currently limited supply of sustainable hydrogen is required for other critical applications. Therefore, taking electric cars as a starting point, we explore three possible solutions for limiting critical metals demand.

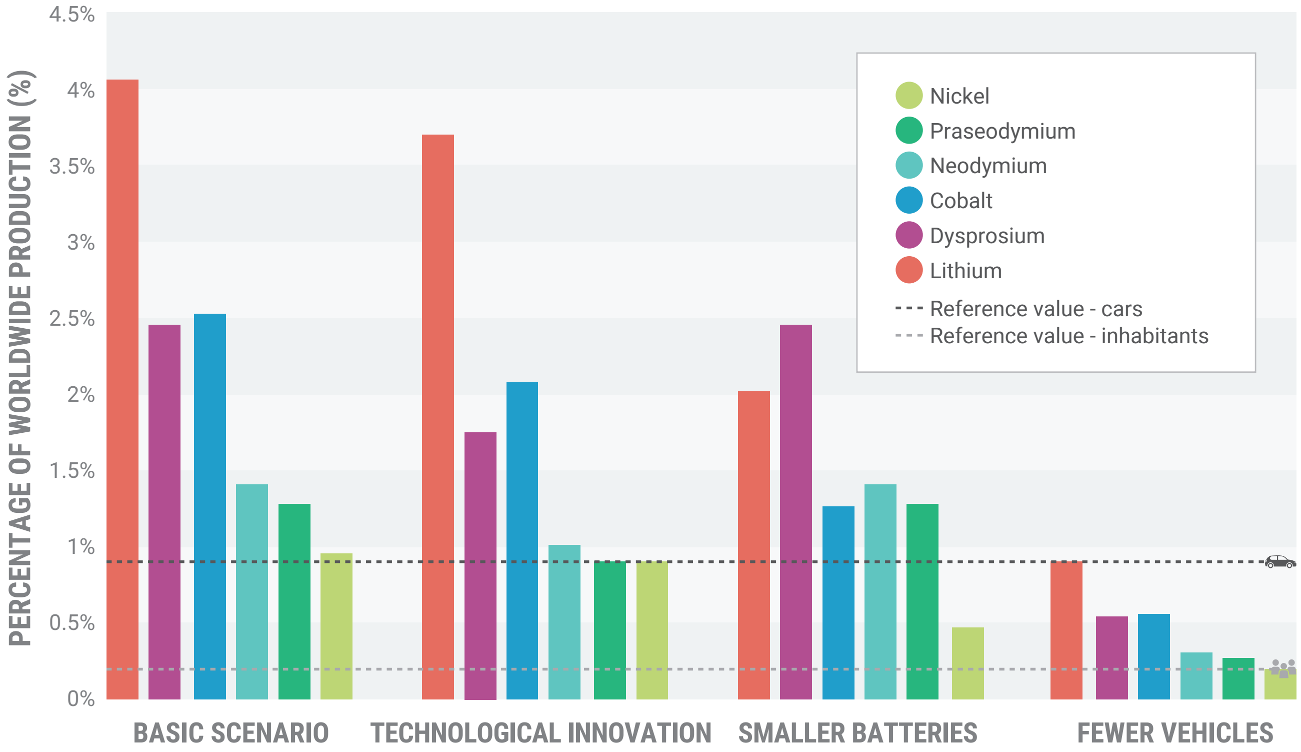


Fig. 2 Three scenarios for limiting the metal demand for electric transport in the Netherlands.

01 Innovation

The dependence on specific metals can be mitigated by substituting critical metals with other metals. This appears to be the easiest solution from a societal perspective, but is challenging and could reduce performance and efficiency.

02 Smaller batteries

Having smaller vehicles with shorter ranges will lead to a reduction in demand for metals. However, the metal demand for the electric motor will remain, which means the effectiveness of this option is limited to those metals required for batteries.

03 Fewer vehicles

By making more effective use of our vehicles (e.g. car sharing), the number of vehicles could be reduced significantly. This is by far the most effective solution for reducing metals demand, but the most complex in societal terms.

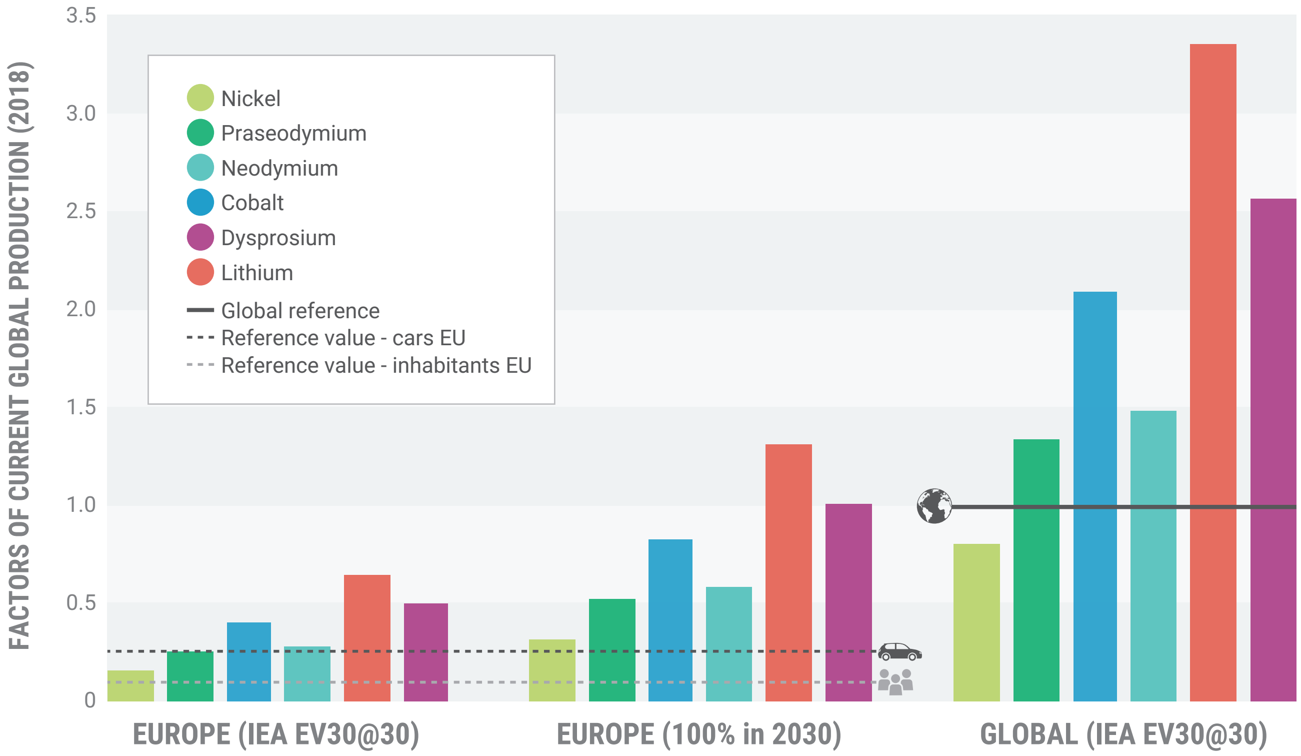


Fig. 3 **Basic scenario for the volume of critical metals required annually for electric passenger transport in 2030, as a factor of the current annual global production (2018).**

METAL DEMAND IN EUROPE AND THE WORLD

In addition to the Netherlands, we have also reviewed the development of the annual metal demand for electric passenger cars at the European and global level. In the International Energy Agency's EV30@30-scenario, Europe is projected to need between 15% and 70% of the current global production of critical metals in 2030. In its scenario in which all new cars sold in Europe in 2030 are electric, Europe will need as much as 1.5 times the annual global production of lithium (see graph) in 2030. In the global EV30@30 scenario, up to three times the current annual global production will be needed to produce sufficient electric cars in 2030.

RECOMMENDATIONS

To achieve 2030 climate targets – both national and international – exponential growth in the number of electric cars will be needed. Even when all fossil fuel vehicles have been replaced, new electric cars will still be needed to replace the cars that have reached the ends of their life cycles. Consequently, demand for critical metals is expected to increase rapidly. We make eight recommendations for creating a mobility system based on electric vehicles, which is also future-proof from the perspective of materials: five recommendations for the Netherlands, which can also be applied at national level in other countries – and three for Europe.

Recommendations for the Netherlands (national level)

RECOMMENDATION 1 **Promote new mobility concepts with fewer vehicles**

RECOMMENDATION 2 **Promote electric vehicles with small batteries for regional solutions**

RECOMMENDATION 3 **Invest in a future-proof infrastructure**

RECOMMENDATION 4 **Avoid unnecessary investment in existing infrastructure**

RECOMMENDATION 5 **Develop a second-hand market for batteries**

Recommendations for Europe

RECOMMENDATION 6 **Support sustainable initiatives in the mining industry to minimise the impact on people and the environment**

RECOMMENDATION 7 **Ontwikkel een Europese recycling-industrie voor kritieke metalen**

RECOMMENDATION 8 **Develop a European recycling industry for critical metals**

CONTENTS

01 INTRODUCTION

In 2015 the signatories of the Paris Climate Agreement agreed that the increase in the global average temperature must be kept below 2° Celsius. In June 2019, the Dutch government unveiled a national Climate Agreement for the Netherlands, in which a range of public and private parties undertook to reduce national CO_2 emissions by 95% by 2050.[1] Emissions from traffic and transport, one of the issues covered in the Paris agreement, was also one of the five key pillars of the Dutch Climate Agreement.

In the domain of mobility, electric cars are often seen as a promising solution for passenger transport. They are cleaner, more efficient and can run on sustainable electricity. And the market for electric vehicles is growing steadily: all of the major automotive companies now produce an electric model and almost 2,500 electric cars are sold every month in the Netherlands alone.[2] Together with countries like Norway, the Netherlands is a global leader in the roll-out of electric transport.

Critical metals, such as cobalt, are used in the production of electric cars, for the motor and batteries for example. In the last few years, there has been a lot of media attention on the growing worldwide concerns about the increasing dependence on these critical metals.[3] The trade war between the United States and China, for example, has highlighted dependence on China's production of metals, such as the rare-earth metal praseodymium.[4] An end to exports of critical metals could have serious repercussions, including making it impossible to manufacture certain products, not only electric cars, but also solar panels and industrial equipment.

At the moment, this issue is receiving relatively little attention, but it needs to be addressed, particularly as it relates to electric vehicles. What metals are needed to meet the targets for the Netherlands, Europe and the world, and in what quantities? Where will these metals come from? And how can we organise the recycling of these metals in order to reduce our future dependence on imports? In this study, we endeavour to provide answers to these questions and so contribute to the creation of a genuinely future-proof mobility system.

SCOPE OF THE STUDY: CRITICAL METALS IN CARS AND THE CHARGING INFRASTRUCTURE

In this study, we analyse the demand for critical metals for electric cars (battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)) and the associated charging infrastructure in the Netherlands. The study does not cover light electric vehicles for urban distribution because it is difficult to predict what

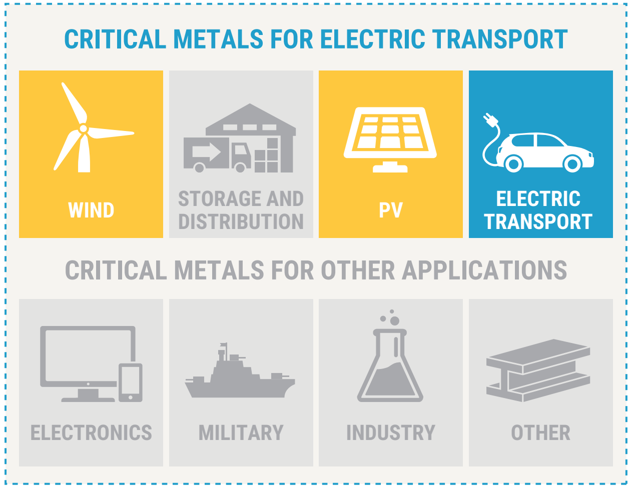


Fig. 4 This study focuses on the metal demand for electric transport and supplements earlier research into the metal demand for wind turbines and solar panels.

developments will occur in this regard. Heavy goods vehicles and buses also fall outside the scope of this study, because there are likely to be more suitable technologies for freight transport and because there are relatively few buses on the road (± 5,200).[5] Finally, we ignore the potential increase in demand for critical metals because of the need to expand the capacity of the electricity grid, since that will be affected by many other factors (for example, the electrification of the heat supply in the built environment).

THE NETHERLANDS AS THE STARTING POINT

The starting point for this study is the situation in the Netherlands. Our scenarios are therefore based on Dutch policies and the targets in the national Climate Agreement. The findings are then extrapolated to the European and global scale on the basis of estimates from the International Energy Agency (IEA).

THE NEXT PIECE OF THE PUZZLE

In September 2018, we published the report entitled *Metal Demand for the Energy Transition*.[6] That study showed that to meet the targets for the production of sustainable electricity laid down in the national Climate Agreement, the Netherlands would require, relative to its size, a substantial share of the annual global production of critical metals. With this report, we add another piece of the complex puzzle surrounding our use of critical metals: the metal demand for electric transport.

02
CONTEXT & DEVELOPMENTS

Achieving the global objectives for sustainability presents major challenges. The European Union (EU) and the Netherlands have both formulated targets for the climate and the circular economy. By 2050, the Netherlands wants to have reduced CO_2 emissions by 95% compared with 1990. Emissions should be between 49% and 55% lower by 2030, depending in part on the targets set elsewhere in the EU.[1]

In addition to the climate targets, the Netherlands and the EU are both striving to create a circular economy. Driving forces behind this strategy are the growing dependence on scarce raw materials, as well as the explosive growth in the consumption of natural resources and the accompanying environmental impact.[7] The Netherlands has also adopted policies in this domain, with the aim of reducing our use of primary raw materials by 50% by 2030 and completing the transition to a fully circular economy by 2050.

The EU wants to be in the vanguard of electric transport development. The Netherlands first declared its ambition to be a leader in this field in 2009,[8] and countries such as Norway, Sweden and Germany are also very progressive. The Netherlands' pioneering role is reflected in the fact that the government already started financing the roll-out of a charging infrastructure when electric cars were still in their infancy. The country also has a favourable tax regime for electric cars, although this will be gradually phased out from January 2020. Finally, the government has strongly facilitated tests with self-driving electric cars in recent years.

DUTCH POLICY: CLIMATE

One of the measures announced in the Dutch Climate Agreement is an expansion of electric transport in order to reduce national CO_2 emissions. The agreement refers to electric cars as a building block for the mobility system of the future, in combination with hydrogen-powered vehicles for heavier transport and improvements in public transport. The original target was to reduce emissions from transport by 7.3 Mton CO_2 (over 20%) in 2030, which should bring emissions down to no more than 25 Mton.[1] The targets for the number of electric cars in the coming years are shown in table 1. The interim targets in the Climate Agreement are in fact lower than the figures in earlier policy documents,[9] and are now 166,228 in 2020 and 589,355 in 2025.

Table 1 **The targets for electric transport, on the basis of the Climate Agreement.**[2]

TARGETS FOR ELECTRIC DRIVING

YEAR	CARS (BEV + PHEV)	CHARGING POINTS	*(OF WHICH HIGH-SPEED CHARGING POINTS)*
2020	**166,228**	**222,840**	*1,322*
2025	**589,355**	**678,657**	*3,699*
2030	**1,947,946**	**1,741,500**	*9,740*

Crucial changes in mobility system

The Dutch Climate Agreement gives two main reasons why it will not be feasible to replace every one of the existing petrol- and diesel-fuelled cars with electric cars. The first is the traffic congestion due to the absolute number of vehicles: the number of traffic jams and delays is expected to increase further in the coming years.[10] Second, fewer fossil-fuel-driven cars will signify a substantial decline in tax revenues, since the government derives more than half of the income it earns from mobility (around €8 billion in 2018)[11] from excise duties on fuels.

The Dutch Climate Agreement therefore sketches three crucial system changes, which were also recommended in outline by the Council for Infrastructure and the Environment (#1 and #2),[12] and have been endorsed by the Mobility Alliance (#3)[13]:

1. Transform the Infrastructure Fund into a Mobility Fund, so that financial resources are allocated according to what is needed to enhance mobility rather than by type of infrastructure (road, rail and waterway).
2. Draft regional mobility plans, in which each region formulates the best solution for improving accessibility in consultation with relevant transport services.
3. Establish an alternative system of taxation based on 'payment for use', possibly broken down according to a vehicle's emissions and the location and/or time it is used.

DUTCH POLICY: CIRCULAR ECONOMY

The Netherlands' stated ambition is to create a circular economy by 2050, with an interim target of reducing the consumption of primary raw materials by half in 2030, compared with 2015. A circular economy will reduce the country's dependence on critical metals; the EU has to import 90% of the 54 critical metals that are used.[7] And as the Circular Economy Transition Agenda for Manufacturing Industry notes, cars are becoming 'smarter' and therefore more efficient.[14] Consequently, fewer vehicles, and hence fewer raw materials, will be needed.

EUROPEAN POLICY: CRITICAL METALS

Every three years, the European Commission publishes a list of the raw materials that are critical for the EU. This list has expanded steadily since it was first published in 2011: from 14 materials (2011) to 20 (2014) and 27 (2017). The elements cobalt, neodymium, dysprosium and praseodymium – which are required for the batteries and the motors in electric cars – are on this list. The European Commission has developed its own framework for determining whether a material is 'critical',[15] and this continuous process illustrates how seriously the Commission takes the issue of import-dependence on other countries for the supply of critical metals. Several non-EU countries with significant import-dependence also publish regular reviews of which materials are critical to their economy, including the USA and Japan.

The EU has also instituted a major programme for research into batteries (European Battery Alliance), while the European Institute of Innovation and Technology has formed EIT Raw Materials, the world's largest consortium in the raw materials sector. Also, critical materials feature prominently in the Horizon2020 research programme. The World Economic Forum hosts the Global Battery Alliance, where NGO's and companies work together towards a sustainable battery supply chain.

In addition to the research effort, European legislation governing the metals tin, tantalum, tungsten and gold (also known as the 3TG metals) will enter into force on 1 January 2021. Since these metals are sometimes mined in the same regions as cobalt, this Conflict Minerals Regulation is also likely to affect the production of cobalt in conflict zones.[16] The legislation is expected to have an impact on between 600 and 1,000 companies in the EU and the vast majority of 3TG producers outside the EU. The Regulation is modelled on the Dodd-Frank Act (2010) in the United States, which regulates the mining of these metals in a similar manner. The US regulation has not in fact been entirely successful. Rather than instituting a difficult and uncertain programme of reforms, Western companies simply abandoned the regions concerned, causing the local economy around mining locations to collapse. As a result, child mortality in nearby villages more than doubled, and rather than declining, violence increased.[17]

DUTCH POLICY: ELECTRIC TRANSPORT

The Netherlands has been an international pioneer in the promotion of electric transport for years. However, although various plans have been adopted to flesh out the policy on electric transport with targets and policy instruments designed to increase the number of electric cars on the road, they devoted scarcely any attention to the role of critical metals. The key points of the most relevant policy documents are as follows:

- In the *Electric Mobility Action Plan* (2009), the Dutch government presented an initial outline of the future of electric transport. The targets were 20,000 electric cars in 2015, 200,000 in 2020 and 1,000,000 in 2025.[8]
- *Electric Mobility Gets Up to Speed* (2011) confirmed those targets and announced that the roll-out of the

charging infrastructure would be concentrated in 'focus areas', tax breaks for buyers of electric cars (for example, a reduction of the *bijtelling* (the new-car value that is added to a person's annual taxable income for income tax purposes) to 0% for zero-emission vehicles, and a uniform system for plug-and-pay services.[9]

- *Mobility 2040: safer, robust, sustainable* – the most recent vision document on the future of mobility in the Netherlands – lists eight priority areas for the further development of mobility. One of them is sustainability. However, it devotes little attention to the roll-out of electric passenger transport and scarcely mentions the future of transport modes other than cars.[18]
- The *National Charging Infrastructure Agenda* sets out a strategy for the installation of a charging infrastructure and mentions the goal of 1.7 million charging stations by 2030. It also calls for the promotion of innovations, including smart charging, new mobility services and autonomous driving.[19]
- The *Multi-annual Mission-driven Innovation Programme (MMIP)* for Sustainable Mobility, which emerged from the discussions on the theme of mobility ahead of the Dutch Climate Agreement, offers pointers to aspects where innovation is needed, including vehicle propulsion systems and the use of sustainable energy carriers, as well as efficient transport for people and goods.[20]

Further developments

Other non-policy developments also affect the roll-out of electric transport. Primarily, it has been agreed that measures will be taken to ensure that all new passenger cars sold in 2030 are emission-free.[21] A growing number of cities are also creating environmental zones: the frontrunners, Utrecht and Amsterdam, have now been followed by Arnhem, Nijmegen and Rotterdam. In 2011, the 'Beter Benutten' [Optimising Use] programme was launched to reduce traffic congestion, and ultimately the total number of vehicles on the road.[22]

Finally, the national government is preparing a National Battery Strategy to address important issues such as the technological innovation that is required, the growing geopolitical dependence with regard to critical metals and the organisation of collection and recycling systems for used batteries, as well as social dilemmas such as fire safety and the toxicity of batteries.

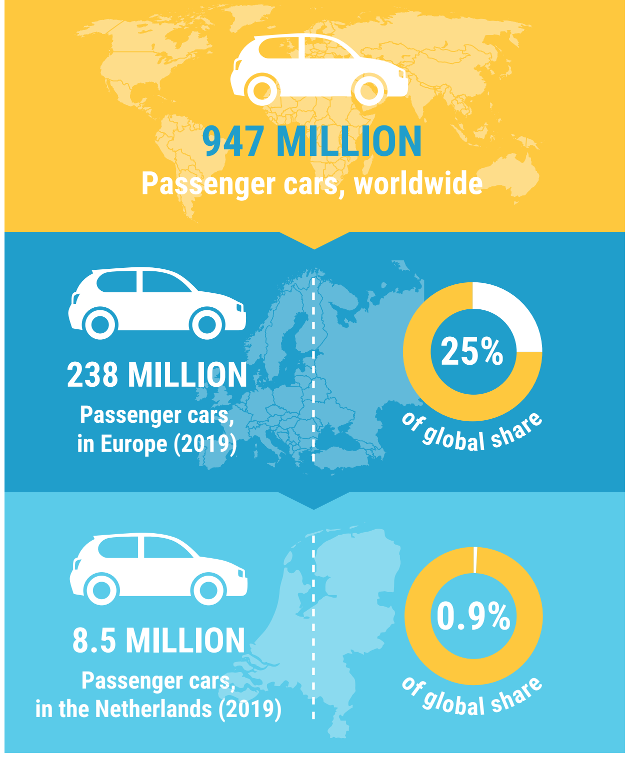


Fig. 5 Key figures for the Dutch and European car fleet, in relation to the rest of the world.[23,24]

TRENDS & FIGURES FOR THE NETHERLANDS

The entire Dutch vehicle fleet is still growing, and it is not confined to electric vehicles. At the beginning of 2019, there were 12.7 million road vehicles in the Netherlands.[23] Of these, 8.5 million were passenger cars, which represents 0.9% of the world's total.[24] Electric cars only accounted for a small proportion of the total expansion of the vehicle fleet in the Netherlands in 2018. Their number increased by 20,000, compared with a total increase of approximately 160,000 (1.9%). Figure 5 presents some key figures for the Dutch vehicle fleet; key figures for electric transport are shown in table 2.

Table 2 Key figures for electric transport in the Netherlands, end of 2018.[2]

	2017	2018	GROWTH
BEV	21,115	44,984	+ 23,869 (+ 113%)
PHEV	98,217	97,702	- 515 (- 0.5%)
TOTAL	119,332	142,686	+ 23,354 (+ 20%)
REGULAR CHARGING POINTS	32,875	35,861	+2,986 (+ 9%)
HIGH-SPEED CHARGING POINTS	755	1,116	+ 361 (+ 48%)
TOTAL	33,630	36,977	+ 3,347 (+ 10%)

HYDROGEN CARS: A LIMITED ROLE

Hydrogen is regularly mentioned as an energy carrier of the future, for passenger transport as well as other types of mobility. Battery- and hydrogen-propelled cars both featured prominently in a survey of industry trends among CEOs in the automotive sector.[25] The technology certainly exists for hydrogen cars, and a number of car makers have already launched models, including recently the Toyota Mirai and the Hyundai Nexo.

Some say the hydrogen-propelled car will beat the battery-driven electric car, others say it won't.[26] The most important arguments in favour of the hydrogen car are the rapid technological advances in fuel cells, the energy density and the speed with which it can be filled. The main arguments against it are that it consumes more energy per kilometre than a battery-propelled car, and the absence of a transport infrastructure for hydrogen. In fact, both hydrogen-driven and battery-driven cars are currently propelled mainly by fossil energy: hydrogen is currently recovered mainly from natural gas ('grey' hydrogen), and electric cars are often charged with fossil-based electricity.[27]

Hydrogen is needed for various applications

An important consideration when discussing the use of hydrogen in the future energy system is that passenger transport is only one of its applications. Furthermore, there are few, if any, alternatives to hydrogen for some of those applications, such as its use as fuel for high-temperature heat for industry, as a raw material for artificial fertiliser, in the chemical industry (for products such as packaging materials, medicines and clothing) or as fuel for planes and ships.[28,29]

Fig. 6 **Indicative ladder of priorities for the use of hydrogen, based on the 'ladder of hydrogen'[28] and the supportive document for the Dutch Climate Agreement.[29]**

Insufficient production capacity for sustainable hydrogen

Practically no 'green' hydrogen (from renewable energy) or 'blue' hydrogen (from natural gas, with carbon capture and storage (CCS)) is produced in the Netherlands, while the annual consumption is around 100 PJ. To make the switch to sustainable hydrogen, there first has to be the capacity to produce this basic demand sustainably and it then has to be scaled up to 200 or even 300 PJ by 2030.[26]

Hydrogen cars are not a priority

Given its limited availability, decisions will have to be made on how sustainable hydrogen should be used, and there is no consensus among scientists at the moment. At least until 2030, hydrogen will be needed more urgently for functions other than passenger transport, particularly because there are no real alternatives to hydrogen for those functions. Passenger cars are low on the ladder of priorities for the application of hydrogen (figure 6). If hydrogen-powered cars are introduced, their number is likely to be relatively small compared with the number of emission-free cars that are needed. For this study, we have therefore ignored hydrogen-fuelled cars in our analysis of future passenger transport by car.

CO_2 gains of driving electric

CO_2 emissions from electric cars are substantially lower than from cars powered by fossil fuels. The IEA recently published an overview on the basis of which we can assert – for the Dutch situation – that over its entire lifecycle an electric car causes 50% fewer CO_2 emissions than a comparable petrol-driven car. CO_2 savings could rise to 70% if the Dutch energy mix is further decarbonised, and could improve even more if batteries are produced more cleanly and their life cycle is extended.[30]

However, the sustainability of electric vehicles is a regular subject of debate. One would expect different LCA studies to produce roughly the same results, but that is not the case. Why is this?

LCAs include many variables, such as the impact of the car's production and the carbon intensity of the electricity used for charging. The above figure of 50% savings in CO_2 emissions is based on an electric car battery with a relatively large capacity (58 kWh), the Dutch energy mix in 2017, and an average assumption for environmental damage caused by battery production. However, choices can be made in these variables. Here are two examples:

- **Battery:** a car with a relatively small battery has roughly a 10% lower impact than a car with a relatively large battery.[30] However, this model does not take into account that a larger battery will on average not be discharged as deeply, resulting in a longer life-time for the battery with an accompanying lower overall environmental impact. The IEA model shows that clean battery production reduces the impact of an EV 35-40% across the entire life cycle, compared to a calculation based on the most polluting production process. This model does not include significant recycling of the battery, which would reduce impact even further.[31]
- **Energy mix:** with a clean energy mix, the emissions of an electric car are significantly lower than with a more polluting energy mix. In the Netherlands, the CO_2-intensity of the energy mix declined from 550 gram/kWh to 450 gram/kWh between 2000 and 2017. A further sharp decline in the CO_2-intensity is expected in the future, partly due to the large volume of wind energy (which has a CO_2-intensity 12 gram/kWh) entering the Dutch grid.[32]

These types of methodological choices are important for the interpretation of the results of an LCA, but are often lost in the public debate.

03

METAL BUDGET FOR ELECTRIC TRANSPORT

In the present discussions on electric vehicles, the assumption seems to be that the demand for electric vehicles will always be met. It simply has to, if we want to achieve our climate goals. Reality is likely to be more unruly: the present supply of critical metals with today's mining production is simply limited. This chapter presents a basic scenario for the metal demand for the country's electric cars based on the targets in the Dutch Climate Agreement (for the Netherlands) and the IEA scenarios (for Europe and the world). Additionally, an indication of the metal demand for the charging infrastructure is provided.

BASIC SCENARIO (NETHERLANDS)

Structure of the basic scenario: growth in the number of electric cars

In 2018, there were just over 142,000 electric cars (BEV + PHEV) on the road in the Netherlands, 23,000 more than the year before.[2] While the number of PHEVs fell slightly in 2018 (-0.5%), the number of BEVs grew by 113%. The size of the challenge becomes clearer, however, when we compare those figures with the total number of cars sold in 2018: 447,000.[33] Significantly more new electric cars will have to be sold in the coming years.

In light of the targets in the Climate Agreement (for 2020, 2025 and 2030) and the current number of electric cars, we have modelled a scenario with exponential growth in the number of new electric cars. In this scenario, the number of new electric cars sold annually increases from almost 29,000 in 2020 to 131,000 in 2025 and 414,000 in 2030. Because of the rapid growth in the number of BEVs, we assume that 90% of the new EV sales will consist of fully electric cars and only 10% of hybrids in 2030. The sources for the scenario are explained further in the chapter on the research method.

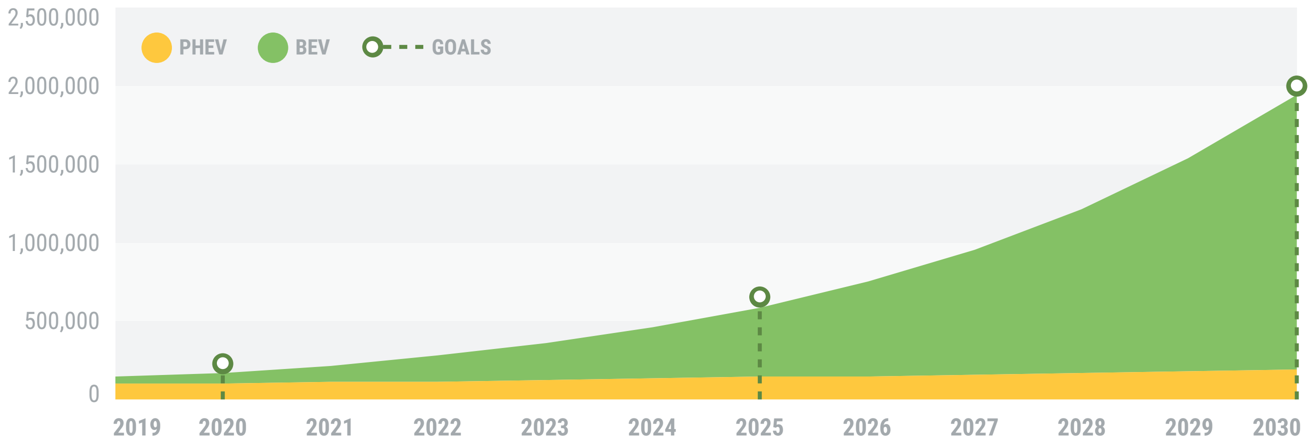


Fig. 7 **The number of electric cars in the Netherlands up to 2030, including the ratio of BEVs to PHEVs. The dots are the target in the Dutch Climate Agreement.**

BASIC SCENARIO: ANNUAL METAL DEMAND FOR EVS IN THE NETHERLANDS

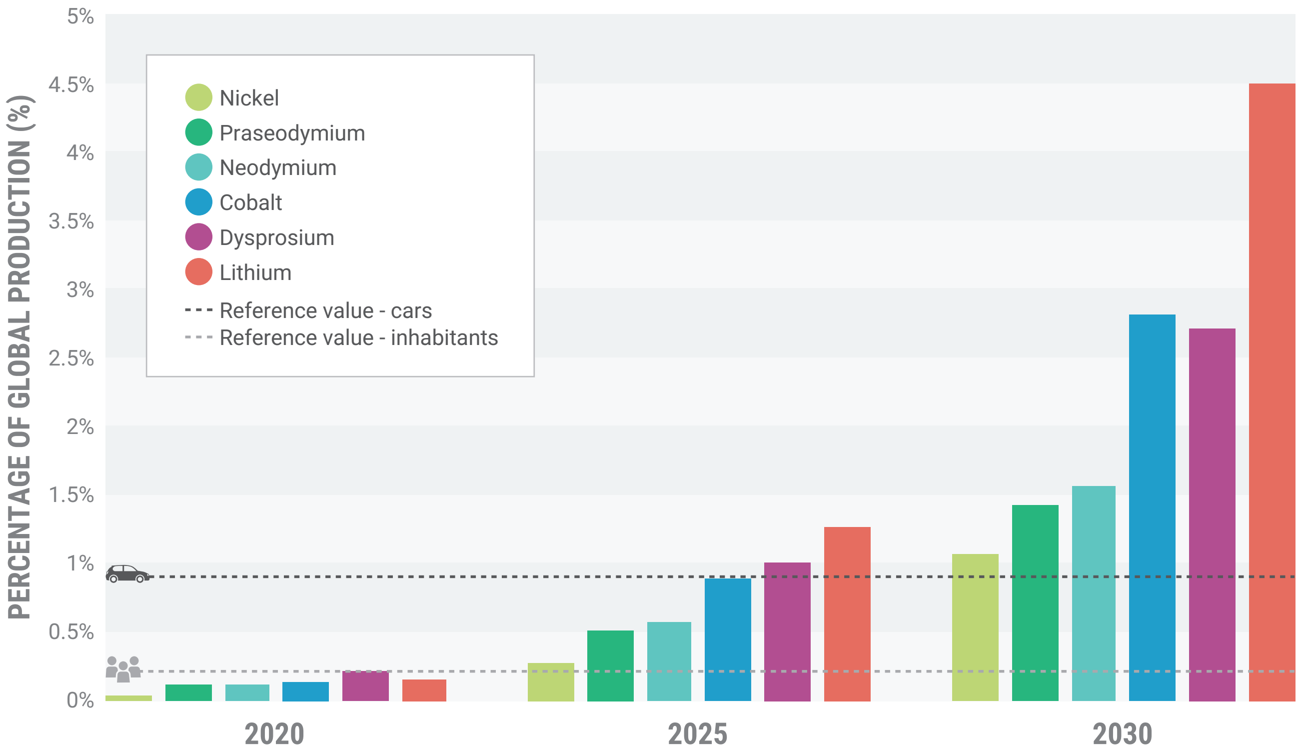


Fig. 8 **Basic scenario for the volume of critical metals required annually between 2020 and 2030 for electric passenger transport in the Netherlands, as a factor of the current worldwide annual production (2018).**

This figure shows the anticipated annual demand for a number of the critical metals required to meet the targets for the number of electric cars. The volumes are expressed as a percentage of the current worldwide annual production of those metals. The graph shows the demand for 2020, 2025 and 2030, when the annual increase in the number of new electric cars will be approximately 414,000.

CONCLUSIONS

- For five metals, the Netherlands will need significantly more than 1% of the current global annual production to produce its electric vehicles in 2030. This is more than the Dutch share of the worldwide car fleet (0.9%) and the Dutch share of the global population (0.2%).
- The elements neodymium, dysprosium and praseodymium – which are needed for the motors in electric cars – are also needed to produce wind turbines. The scarcity of these elements will create tensions between different sustainable technologies.

METHOD

- We base our projection on the growth of electric vehicles according to Dutch policy, as shown in Figure 7.
- We forecast that the capacity of an electric car's battery will improve from 58 kWh to 75 kWh (for BEVs) and from 10 kWh to 12.5 kWh (for plug-ins) between 2019 and 2030, on the basis of IEA projections.[34]
- To determine the metal demand per vehicle (battery + motor), we forecast developments in battery technology on the basis of projections by McKinsey in 2018,[35] which correspond with forecasts by *Benchmark Mineral Intelligence*.[36] According to those projections, 77% of new cars will be fitted with nickel-manganese-cobalt batteries (NMC811), which contain significantly less cobalt per kWh than the existing technology.
- For the electric motor, we assume a substitution rate of neodymium, dysprosium and praseodymium which equals the cobalt substitution rate for batteries. Consequently, the amount of critical metals per vehicles lowers by 30% in 2030, compared to 2020.
- Figures for metal production are derived from data from the United States Geological Survey (USGS).[37] The current level of production is intentionally used because the rate of production growth is difficult to predict for most metals.

BASIC SCENARIO: 2030 EV METAL DEMAND FOR EUROPE AND THE WORLD

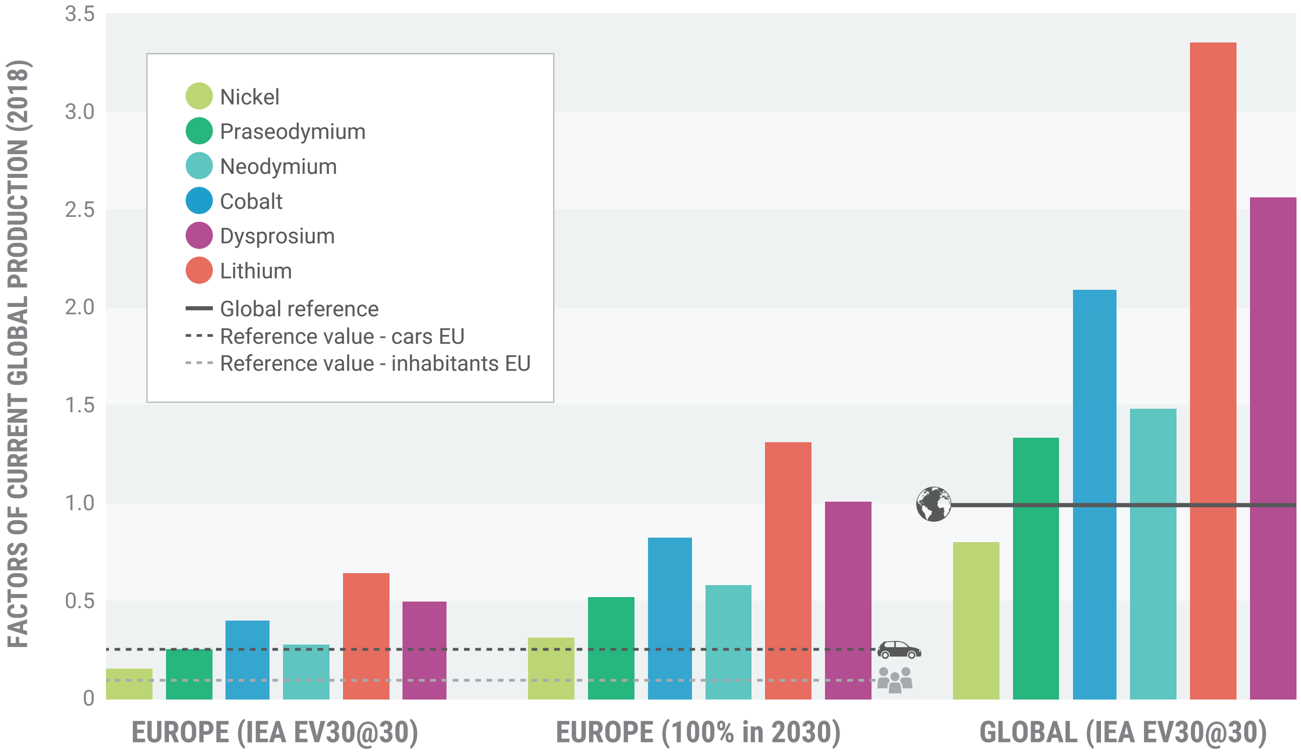


Fig. 9 Basic scenario for the volume of critical metals required annually in 2030 for electric passenger cars in Europe, as a factor of annual global production (2018).This is shown for Europe on the basis of the IEA's EV30@30 scenario (left), for Europe on the basis of the Netherlands' level of ambition (centre), and for the world on the basis of the IEA's EV30@30 scenario (right).

We also surveyed the annual metal demand for electric passenger cars at the European and global level in addition to the Netherlands. In the Global EV Outlook,[34] the IEA uses a number of scenarios to map trends in the electric-car market. For the annual sales figures, we have used the EV30@30 scenario (2019). In that scenario, 30% of new cars sold worldwide in 2030 will be electric. The figure for Europe is just over half of all new cars.

We also produced a second European scenario in which all new passenger cars sold in Europe in 2030 are entirely electric. Europe would then be following pioneers such as the Netherlands, Norway, Slovenia, Ireland, and Denmark, which will outlaw the sale of fossil fuel-powered cars with effect from 2030.

CONCLUSIONS

- In the EV30@30 scenario for Europe, 15% to 70% of current global production of critical metals will be needed in 2030. For five of the six metals, this is more than the European share of the worldwide vehicle fleet (25%) and significantly more than the European share of the global population (9.4%).
- In the ambitious scenario, Europe will need more than the current annual global production for dysprosium and lithium. The demand for the other metals significantly overshoots the reference value for cars.
- In the EV30@30 global scenario, for some metals over two times the current global production will be needed to produce sufficient electric cars in 2030.

METHOD

- We base the European and global scenarios on the same technological developments, the same advances in battery capacity and the same current production figures for metals as in the scenario for the Netherlands.
- The figures for sales of electric cars in 2030 are taken from the growth projections in the EV30@30 scenario in the Global EV Outlook.[27]
- In the European scenario based on the Netherlands' ambitions, it is assumed that all new cars sold in 2030 will be electric (BEV or PHEV). This represents around 18 million cars in 2030.

ORIGIN OF METALS: APPLICATION AND SHARE OF WORLDWIDE PRODUCTION

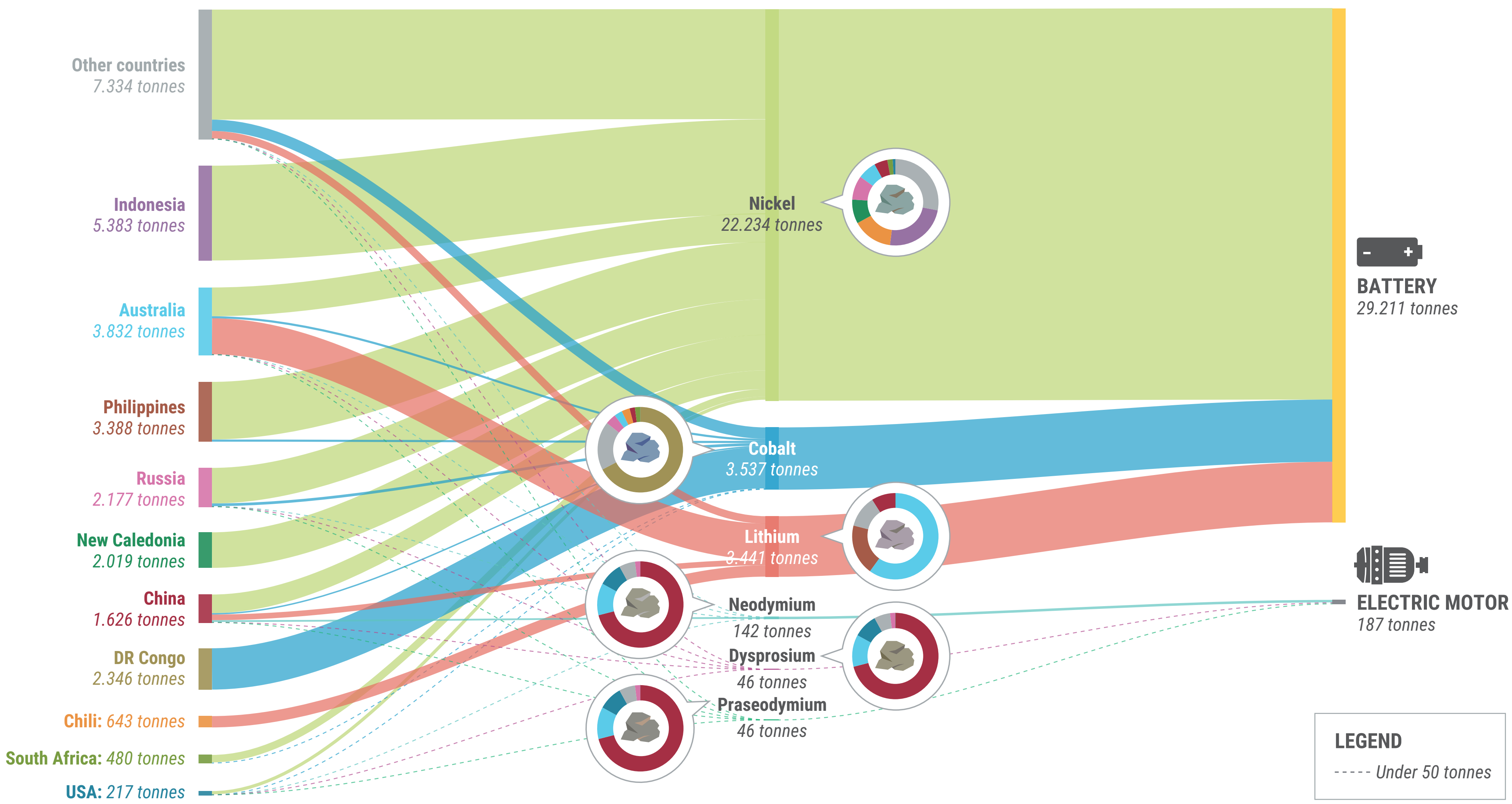


Fig. 10 The origin of critical metals in the basic scenario, based on the metal demand in 2030 and the annual global production in 2018.[34] The flowchart shows the origin of the metals (on the left) and their application (on the right). The pie charts (in the centre) show the relative production volumes of these metals in the various countries.

We have analysed where the six critical metals focused on in this study are currently extracted. Most of the ores are mined in just a few countries. Scarcely any of the raw materials for batteries and electric motors are presently mined in Europe. It is important to note that after they have been mined the ores have to be processed into components and products, which can also create dependency.

CONCLUSIONS

- Currently, eleven countries together account for 72% to 94% of the current global production of the six critical metals. This means that the supply of these metals is vulnerable to geopolitical developments.
- In absolute terms (mass), nickel is the metal that is required most. In relative terms (percentage of global production), nickel is however far less critical. Also, nickel production is spread across various countries.
- China controls 71% of the global production of neodymium, praseodymium and dysprosium. Although cobalt is mined primarily in the Democratic Republic of the Congo, 80-90% of the worldwide refining takes place in China. China also controls almost half of the worldwide lithium production[38] and is therefore a dominant player.

METHOD

- The production data were taken from the United States Geological Survey (USGS).[37] In view of the difficulty of scaling up or even predicting the growth of the production capacity of these critical metals, the production figures for 2018 are used as a baseline.
- The quantities of metals required by each country (left-hand side of the figure) were then determined on the basis of their shares of annual global production.
- The pie charts show the proportion of each metal produced by the individual countries (also in 2018).

Construction of a Nickel Mine in New Caledonia. Credit: Barsamuphe wikipedia.org

Metal demand for charging infrastructure

This report does not cover the metal demand for the charging infrastructure, charging stations and any grid reinforcement that might be required to connect the charging stations volume of critical metals required is relatively small when compared with the metals in electric cars. The composition of charging stations varies and depends on factors such as the type of connection, the number of charging points and the supplier. Most charging stations consist of at least the following components:

- Housing (often aluminium)
- Control and operating system
- Main switch and fuses
- An electricity meter (internal or external)

It is difficult to make a precise estimate of the quantity of metals required for the charging stations in the Netherlands. This is due in part to the growing diversity in charging stations, the wide variety of metals in their components, and the differences in the number of charging points ('sockets') in each station. To illustrate this point: even the precise metals composition of an electricity meter is almost impossible to determine and there is just one in each charging station.[39]

The electrical components of a charging station contain a small quantities of critical metals. Given the average weight of a (semi-)public charging station, which ranges from 30 to 80 kilograms, we assume that the volume of critical metals in each one is negligible in proportion to the volume in an electric car. For example, the total volume of copper – the most common metal in a charging station – used in the roughly 41,000 charging stations in the Netherlands is approximately 147,000 kilograms[40], or around 3.5 kilograms per station.

At the moment, there are roughly as many (semi-) public charging points in the Netherlands as there are electric cars.[2] The ratio is expected to change from 1:1 (charging points : cars) to 1:2.[19] Accordingly, the charging stations' relative demand for metals will decline further.

04

CONTEXT: A COMPLEX CHAIN

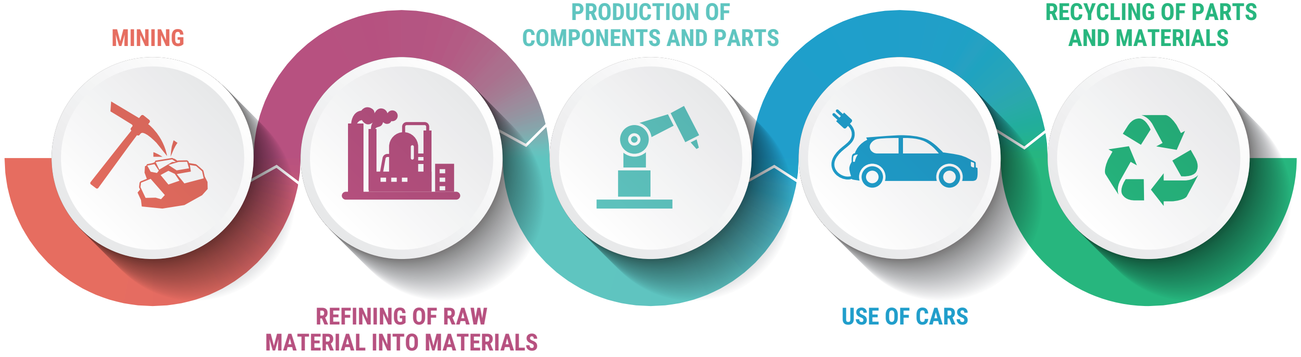


Fig. 11 **The production chain of a metal, from mining to recycling.**

There are significant uncertainties surrounding the available supply of critical metals. This is due to a number of factors, including uncertainty about the reserves of metals, the relationship with other metals in the mineral ores, the complexity surrounding substitution, and numerous social and geopolitical aspects.

A frequently asked question about the availability of critical metals concerns the size of the reserves. The identified reserves are often more than sufficient to supply demand for the foreseeable future. However, availability is limited by scaling of the production capacity, which is constrained by technical limits (what can be mined with the current technology?), economic limits (what can be extracted profitably?) and social limits (what is the social and environmental impact?).

Scaling up production locations and opening new mines are often a lengthy and expensive processes. Because of time-consuming activities such as surveying, licensing and the construction of infrastructure, it can take around 10-20 years to open a new mine. The length of time involved implies that substantial private investment needs to be made, at significant risks for mining companies. This factor alone makes a significant growth in global mining production in the upcoming ten years challenging. In the next paragraphs, we discuss a number of other aspects related to mining.

Various definitions of reserves

Four definitions are in use concerning the availability of metals:[41]

- ***Reserves:*** the ore that can be recovered under current market conditions.
- ***Reserve base:*** all of the ore that could be mined with existing technologies, including ores for which mining is unprofitable or only marginally profitable.
- ***Identified reserves:*** all known ores, including ores that cannot currently be mined profitably. This category also includes estimated reserves of unprofitable ores that probably exist but have not been proved for certain.
- ***Crustal abundance:*** the statistical average quantity of an element in the earth's entire crust, including in non-extractable rock, such as granite.

News reports mentioning metal scarcity often base themselves on reserves or reserve base: the technically or economically recoverable reserves. However, these estimates do not provide an accurate assessment of the quantity of a metal that can still be mined. Growing demand will lead to higher prices, and hence an increase in the reserves. Furthermore, for economic reasons, mining companies will usually stop actively developing new reserves once they identify sufficient ore to support production for another ten to twenty years. Finally, the reserve base regularly increases as a result of innovative mining techniques.

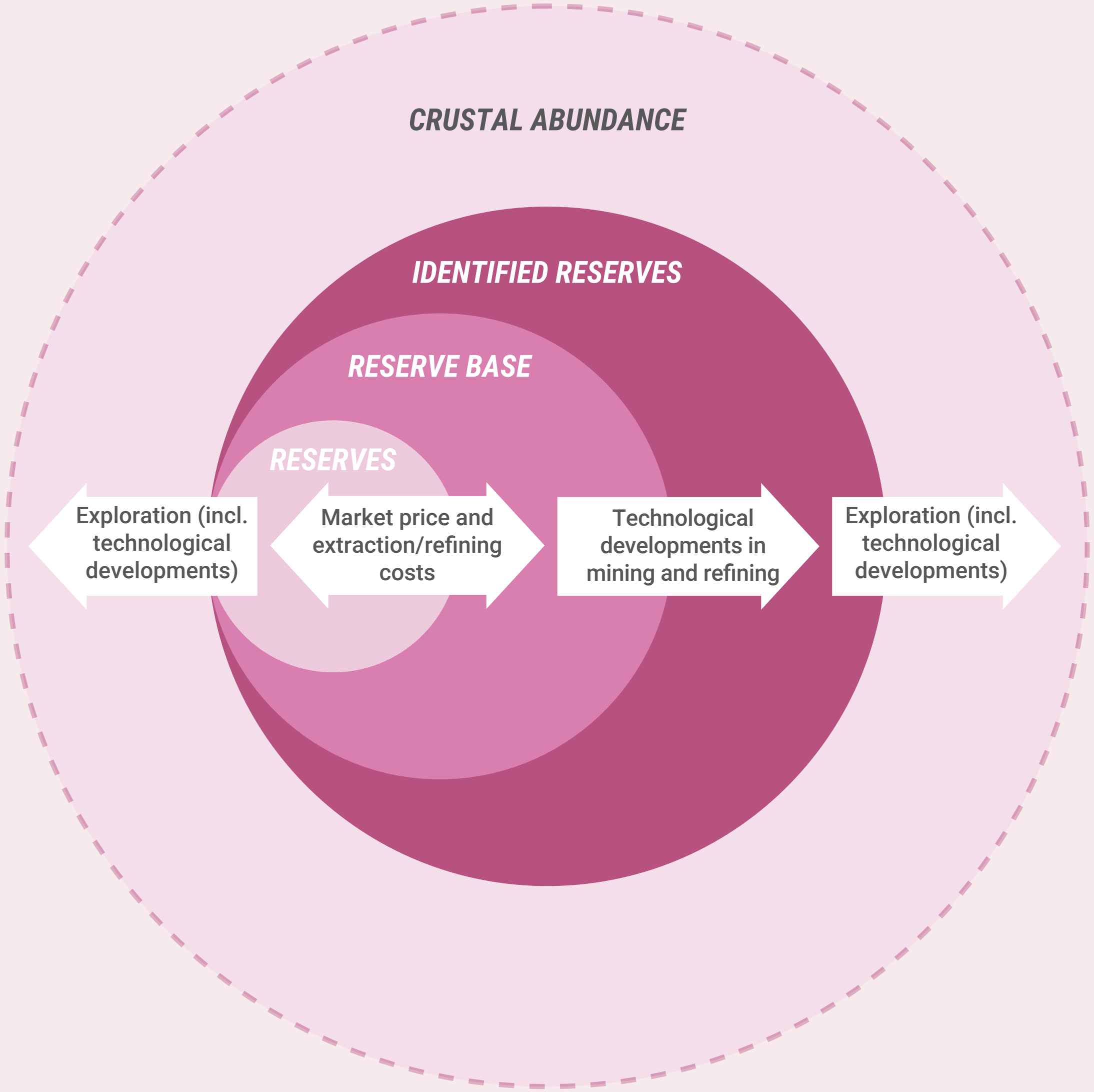


Fig. 12 **Four perspectives of the availability of metals: from reserves to the abundance in the earth's crust.**

MINING

Co-production of metals

Critical metals are often not extracted alone. They are often so-called *companion metals*, a by-product of the mining of so-called *major metals* such as copper, iron and zinc. To illustrate: in the first quarter of 2018, Glencore's Katanga mine produced 1 ton of cobalt for every 55 tonnes of copper, and over 90% of Cobalt is produced as a by-product.[42]

The rise in the price of a *companion metal* would have to be extreme before it makes sense to over-produce the main product for a small additional quantity of the by-product. On the other hand, the price of a *companion metal* is sometimes so low that a mining company does not bother to recover all the *companion metal*. In this case, if demand for *a companion metal* rises, production can initially be increased relatively easily. However, once this spare production capacity is fully utilised, it will suddenly become much more difficult to scale-up, leading to a discontinuity in the price-elasticity of the *companion metal*. There is little information available about unutilised production capacity, making it very difficult to predict price levels of *companion metals*.

Of the critical metals covered in this report, lithium and nickel are not *companion metals*, and usually mined as the primary product. Rare earth metals (REE) and cobalt are often a by-product, but not always. For example, the Chinese Bayan Obo mine, which accounts for a large proportion of global REE production, was originally an iron mine that co-produced REEs. Because of the sharp rise in the price of REEs and the decline in the concentration of iron in the ore, Bayan Obo turned into a mine that produced mainly REEs, with iron as a by-product.

Geopolitical, ecological and social impact

There are a number of complexities when mining deposits of critical metals. Three important factors are:

- **Protectionism:** Some countries are dominant players in the supply chains of critical metals. One well known example is that China has restricted its exports of unprocessed rare earths, in order to attract more industry higher up in the value-chain. Indonesia banned export of nickel containing ores for similar reasons.
- **Environmental factors:** Mining has a major environmental impact in the areas where it occurs. Legal standards for health and the environment increase the costs for producers, and can make mining impossible. Differences in environmental legislation can therefore lead to variations in production. For example, China is practically a monopolist in the production of rare-earth elements (REEs). Efforts are regularly made to break China's monopoly. However, Mountain Pass in California, which was formerly the largest REE mine outside China and had been closed for environmental reasons, was reopened with a Chinese owner, which further reinforced that country's monopoly. Another important production location for REEs, operated by Lynas in Malaysia, is under fire from the local population because of alleged environmental problems.[43] Also in China, smaller REE mines are regularly shut down because of the environmental harm they cause.
- **Forced labour:** An important issue in the critical metals chain is the working conditions under which the metals are mined. Artisanal mining operations often employ child labour and have poor working conditions, violence and corruption. However, large mining companies are not immune. Recent research has shown that these situations have occurred at 20 of the 23 largest mining companies in the last ten years – including companies specifically mining for cobalt and lithium.[44] Mining companies seem to become more sensitive on this issue.

REFINING

Geopolitical dominance of China

Analyses of geopolitical dependence often consider only the location of the mine. Cobalt is mined mainly in the Democratic Republic of the Congo (more than 50%), which means that the dependence begins there. However, the entire chain is important. A study by *Benchmark Mineral Intelligence*[36] found that China accounts for 68% of the production of Li-ion batteries (compared with 6.7% in Europe), as well as ~80% of the other individual steps in the production process. Europe is thus dependent on both DRC as well as on China.

COMPONENTS PRODUCTION

Complexity and consequences of substitution

Sudden increases in the prices of materials draw a lot of attention to the need to open new mines. However, these new mines often come too late to resolve acute supply problems. In the event of a disruption of supply, the industry therefore resorts mainly to substitution. Substitution can take place at the level of materials (for example, replacement of cobalt with nickel in lithium-ion batteries) or at the level of a technology (for example, replacing neodymium-based magnetic motors with copper-based induction motors). Up to now, substitution has often been reactive.

However, substitution is often subject to legal constraints. In the domain of consumer electronics, substitution can be implemented very quickly because the safety rules are relatively flexible. In the automotive industry, it can often take five years before a new component can be used; that period can be up to ten years in the defence and aviation industries.[45]

RECYCLING

Potential

Once there is a sufficient quantity of a metal circulating in an economy, recycling can contribute to meeting demand for that metal. An indicative calculation (Figure 13) shows that metals from recycling EVs will only become

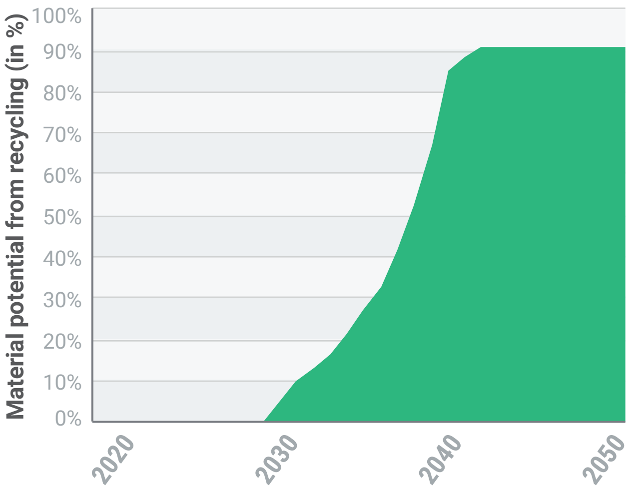


Fig. 13 **Indicative supply of reusable critical metals from electric vehicles, with a theoretical recycling rate of 90% and a life cycle (of both cars and batteries) of 15 years.**

available in 2030, and not account for a significant share of the total demand until 2040. Additionally, this share will only become significant if recycling rates are high enough: this estimation assumes 90%. Because of the rapid growth in the volume of metals required in the time-frame of this study, even 100% recycling will not be sufficient to meet demand. For the time being, the dependence on mining metals will remain.

Recycling is absolutely critical for a sustainable long-term EV strategy. Unfortunately, current recycling rates for several of the critical metals are still below 1%. Nickel actually has one of the highest recycling rates, but this also only reaches 68%.[47] These low recycling rates have several causes. Sometimes, the concentration of a metal in a product is too low for recycling. Secondly, products are stored instead of recycled (for example, mobile phones). Thirdly, materials in some applications are mixed in such a way that pure recovery is not possible any more.

Substitution potential

Substitution is needed to facilitate rapid innovation (scenario 1). Substitution can occur at two levels:[46]

- **Material level:** For a specific application, a metal can often be replaced by another metal. Stainless steel can be made with nickel, chrome or vanadium. Cobalt is partially being replaced by nickel in the lithium-ion battery of near-future EVs. Companies often have alternatives readily available. However, there are limits to this type of substitution: in a catalytic converter, platinum can be replaced by palladium but not by a metal such as iron or copper. If large-scale substitution is required, there could be shortages of the alternative materials.
- **Technological level:** The motors of electric vehicles often use large quantities of rare earths, due to the greater efficiency of neodymium-magnet based electric motors. However, not every EV uses these motors. Tesla, for example, uses copper-based induction motors in its Model S, but uses neodymium-magnetic motors in its Model 3. Wind turbines have a similar dynamic: direct-drive models have large neodymium magnets, others have a mechanical gearbox. New technologies such as Li-Air are very promising for increasing the energy density of batteries, and hence reducing the metal demand. As these technologies are only expected to emerge after 2030 they are not discussed in this study.

CURRENT SITUATION WITH THE MOST IMPORTANT METALS

Lithium

Lithium is mined mainly in Australia (from the rocky material spodumene) and Chile and Argentina (from salt lakes). Lithium is also recycled from existing Li-ion batteries. How much is uncertain, with recycling rates cited between 5%-50%. Almost half of the worldwide lithium production is controlled by China, even if most mines are not located in China.[48]

Australia can significantly expand its current production, with limited environmental impact. Expanded production from South American salt lakes requires a lot of water, leading to conflicts between local populations and mining companies. Furthermore, the landscape of the salt lakes is severely damaged because of the need for lithium evaporation baths.[49] Recovering lithium from seawater is often mentioned as a future solution. However, this process is highly energy intensive.

Cobalt

Over 60% of the world's cobalt is produced in the Democratic Republic of the Congo. It's mining sector is notorious for poor working conditions, child labour, corruption and conflict.[50] This is challenging to avoid. Even FairPhone, which aims to use only cobalt that is produced free of conflict or child labour, has difficulty creating transparency in this chain.[51]

In the DRC, cobalt is mostly a by-product of mining for copper and nickel. In principle there is room for expanding supply, but mining companies are wary of making further investments in additional cobalt production because the costs would make it difficult to compete with cobalt from Africa. This can lead to price volatility and temporary supply constraints.

Nickel

Nickel is extracted and used on a large scale, for example in stainless steel. Nickel ore contains relatively large quantities of companion metals, the availability of which depends on the demand for nickel. Nickel is mostly problematic because its production can be accompanied by serious environmental damage.

In 2017,[23] mines – mainly nickel mines – in the Philippines were closed because of the damage they caused to the environment.[53]

Although due to historical - not current - production, it is still illustrative that Norilsk, the home city of one of the world's largest nickel producers (Norilsk Nickel), is by some measures the world's most polluted city.[52] More recently, in 2017, 23 mines – mainly nickel mines – in the Philippines were closed because of the damage they caused to the environment.[53]

Rare earth metals: Neodymium, Dysprosium, Praseodymium

The majority of the rare earth metals neodymium, dysprosium and praseodymium is mined in China (around 70% in 2018), and to a lesser extent in Australia. China controls most of the production chain, from mining to refining, and increasingly also the fabrication of components that contain these metals.[6]


The Salar de Uyuni salt flat contains much of the world's lithium reserves.

05

THREE SCENARIO'S FOR ELECTRIC TRANSPORT IN THE NETHERLANDS

Climate change is a global challenge that does not just affect the Netherlands. Also, the Netherlands is not the only country that will have to make the transition from cars fuelled by fossil fuels to electric vehicles. To provide an indication on an understandable scale, we have taken the situation in the Netherlands as the point of departure for our scenarios. If the Netherlands wants to take the lead in the transition towards fossil-free mobility while limiting its dependence on these metals, alternative solutions are required rather than replacement of all existing cars with electric alternatives. This also avoids the risk that in case of a sudden supply chain disruption or limited growth in mining production, the roll-out of EVs can get pressured.

There appear to be three directions in which we could look for a solution, and we have sketched a scenario for each one.

THREE POSSIBLE SOLUTIONS

SCENARIO 01

FAST TECHNOLOGICAL DEVELOPMENT

Technological innovation

Using alternative metals would reduce the demand for the critical metals that are commonly used at present. This ‘substitution’ is regarded as the most desirable solution in societal terms, but is challenging from a technological perspective – because the properties of the metals that are currently used are often better than those of the metals that would replace them. However, it will also be necessary to look for solutions in this direction. This option is fleshed out in the scenario ‘technological innovation’.

SCENARIO 02

EVERYONE A SMALL ELECTRIC VEHICLE

Smaller batteries

Suppliers are already working hard on this development. There is room for further improvement in terms of the efficient use of metals, but the potential gains are probably limited. One option is to reduce the battery capacity of cars. This option is fleshed out in the scenario ‘smaller batteries’.

SCENARIO 03

NEW MOBILITY CONCEPTS

Fewer vehicles

Reducing the number of vehicles on our roads by making more effective use of vehicles already in circulation is the simplest option technologically, but the most complex in societal terms. The volume of critical metals that we need will decline most rapidly. There are also various positive side-effects, such as improved living conditions in cities and fewer traffic jams. This option is fleshed out in the ‘fewer vehicles’.

Fig. 14 **Three future scenario’s for scaling electric mobility in the Netherlands.**

SCENARIO 01

TECHNOLOGICAL INNOVATION

The first scenario is based on the idea that 'technology will save us'. It is the most straightforward scenario because no change of behaviour or lifestyle is required. For electric transport, it implies a heavy emphasis on developing new battery technology to reduce the quantity of critical materials required.

Various types of batteries are used in electric cars. Most cars have nickel-manganese-cobalt (NMC) batteries, with a cathode composed of these three metals. NMC batteries have a high energy density and are therefore suitable for mobility. Newer NMC batteries coming onto the market in the coming years will generally contain less cobalt and lithium. Our basic scenario incorporates these developments, but here we simulate an accelerated transition to these new NMC batteries. We assume that the low-cobalt NMC 811 will be used in 90% of new BEVs (compared to 75% in the basic scenario). We further assume that silicon anode materials (see text box on the next page) will be used in half of all batteries, which will increase the energy density by 15%.

We also assume an accelerated substitution of REE in the electric engine. Previous research showed that it takes the automotive industry at least one year to replace an essential part of the engine, even if the technology is already there.[54] In the event of a severe disruption - such as an export restriction by China - a maximum of 10% of the REE was substituted in the market. In this scenario, we assume an average reduction of REE per vehicle of 50% in 2030.

SCENARIO 02

SMALLER BATTERIES

In the second scenario we look at the effect of reducing the average capacity of batteries. The basic scenario is based on an average capacity of 75 kWh for BEVs and 12.5 kWh for PHEVs. With that capacity, a BEV would be able to travel over 500 kilometres on a fully charged battery. Much of the traffic in the Netherlands is for shorter distances to work, sport and local recreation, however.

In scenario 2, we assume a halving of the average battery capacity. With a battery capacity of 37.5 kWh, the action radius is still around 250 kilometres. In addition to cars with smaller batteries for shorter distances in areas with many charging stations, there are still BEVs with batteries in excess of 80 kWh for individuals who have to travel long distances for their work or to go on holiday. Sharing concepts could help in allowing motorists to alternate the size of the battery in accordance with their needs.

This scenario has a partial effect. The demand for cobalt, nickel and lithium will be halved. It has however no effect on the volume of critical metals used in the electric motor. The volume of metals per electric motor is roughly the same for every electric car: in other words, the electric motor of a Volkswagen E-Up contains about the same quantity of critical metals as a Tesla Model X.[55]

SCENARIO 03

FEWER VEHICLES

For the third scenario, we explored ways of reducing the demand for all metals to less than 0.9% of the current annual production by 2030, focusing entirely on new mobility concepts such as self-driving cars. In this scenario, we would use the fewest possible vehicles, all of them with the maximum action radius. From the broader perspective of material demand – also accounting for the rest of the car and the necessary infrastructure – there is a positive effect on the volume of materials required.

Limiting the number of cars in this way implies a different sort of mobility system, one involving intensive use of electric, self-driving shared cars. This scenario would require substantial investment in both social aspects (behavioural change and acceptance) and technology (self-driving cars and digital platforms to provide mobility services). Long-term gains will arise in the form of lower transportation costs due to the more efficient use of vehicles.

In this scenario, there are a million electric cars in 2030. This is almost half fewer than the target of 1.9 million in the Climate Agreement (and the basic scenario). In this scenario, 92,000 electric cars will be sold in 2030, compared with the estimated 414,000 needed to meet the targets.

The benefit in this scenario is that – due to the smaller number of cars – the quantity of critical metals required for both the batteries and the electric motors will decline.

SCENARIOS ASSUMPTIONS

In drafting these scenario's, which are based on Dutch figures, we adopted three basic principles:

1. We assume that there will eventually be no fossil fuel-driven cars - in the Netherlands and Europe.

2. In scenarios 1 and 2, we aim to approach the Dutch reference value of the annual global production of critical metals: 0.9%.

3. In scenario 3, we take the Dutch reference value of the annual global production as a fixed limit, within which we determine the maximum number of vehicles.

Note: the use of raw materials for other products – such as wind turbines and industrial applications – falls outside the 'budget' in this calculation.

EFFECT OF THREE FUTURE SCENARIOS ON DUTCH METAL DEMAND

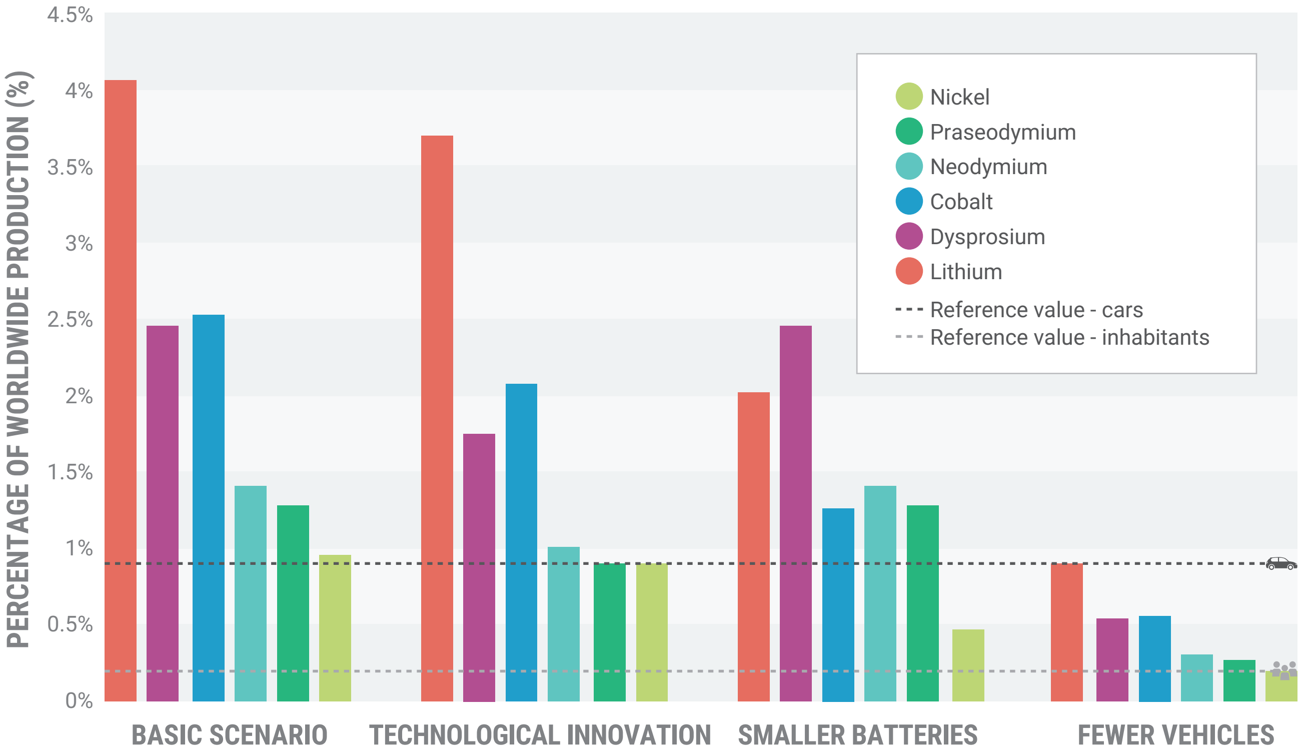
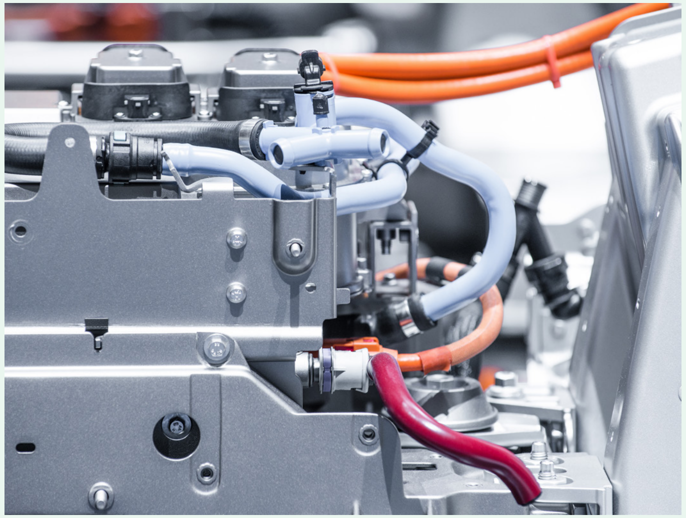


Fig. 17 The annual volume of critical metals required (in 2030) for electric passenger cars in the Netherlands, as a factor of the current annual global production (2018) under different scenarios.

Future battery developments

In addition to the anticipated improvements in existing battery technology, there are alternatives that contain even fewer critical metals, or even use totally different materials. They include two possibly promising technologies, which are not yet commercially available but could make a difference in the longer term:

- **Silicon anode material:** The battery innovation that is currently closest to being ready to market is the (partial) replacement of the graphite anode with an anode material based on silicon. This would reduce the demand for graphite, while also increasing the battery's energy density. Estimates range from 10% improvement to as much as 40%.[55,56] Sila Nanotechnologies, Enevate, and Enovix are some of the companies working on this development.
- **Solid state** batteries have a significant potential in the longer term. In a solid state battery, the liquid electrolyte is replaced by glass or a polymer, for example. These batteries could potentially store two to three times as much energy as existing batteries. However, this technology is currently still in the laboratory stage and will most likely not be commercially available within the next ten years.



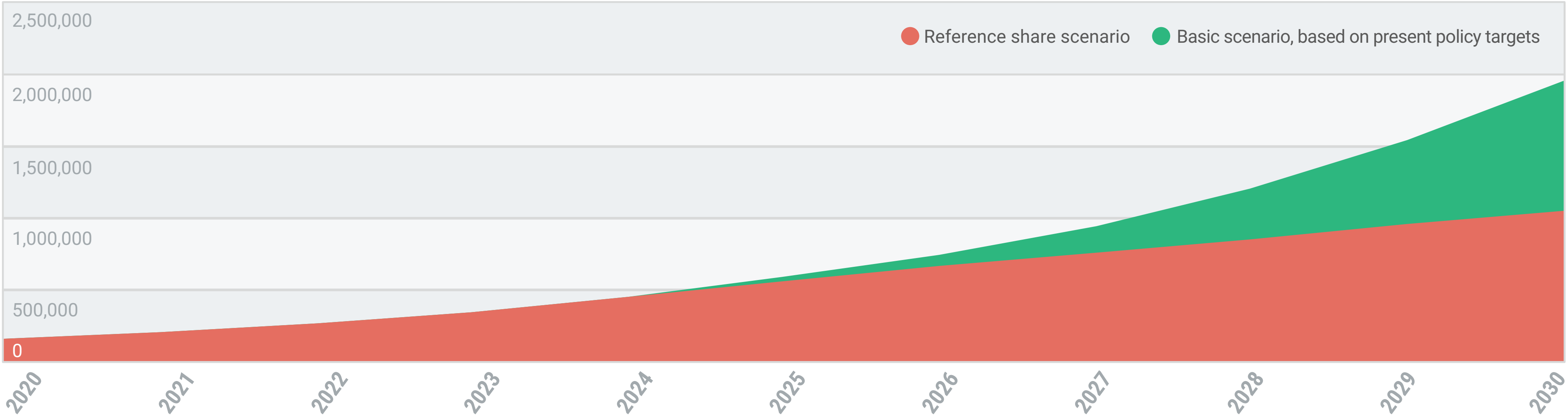


Fig. 15 **The growth in electric vehicles in the Netherlands for the basic scenario (green) and scenario 3 with a limited number of EVs (red).**

Aggregate metal demand for sustainable electricity production and electric transport

It is not only electric vehicles that create a demand for critical metals: they are also required for solar panels and wind turbines. The report *Metal Demand for the Dutch Energy Transition* showed that a few percent of the current annual global production of a number of critical metals will already be required to generate renewable electricity. Some of these metals are also required for electric vehicles.

In both reports, a reference value of the annual global production is used. The Dutch reference value for electricity was 0.5%: the Netherlands' value of the final electricity consumption. The figure for electric cars is 0.9%: the Netherlands' share of the number of cars worldwide. If we were to look at a global share per capita, the reference value of the Netherlands' use of critical metals would be 0.2% of the global production.

Aggregating the two results gives a more complete picture of the metal demand for solar panels, wind turbines and electric transport. The combined amount is significantly larger than the various Dutch reference values. The use of neodymium, dysprosium and praseodymium is particularly critical. Figure 16 shows the total demand for the relevant metals for the Netherlands and the world in 2030.

When we look at the global picture, we see that the metal demand for five specific metals in 2030 will be a number of factors above the 2018 production.

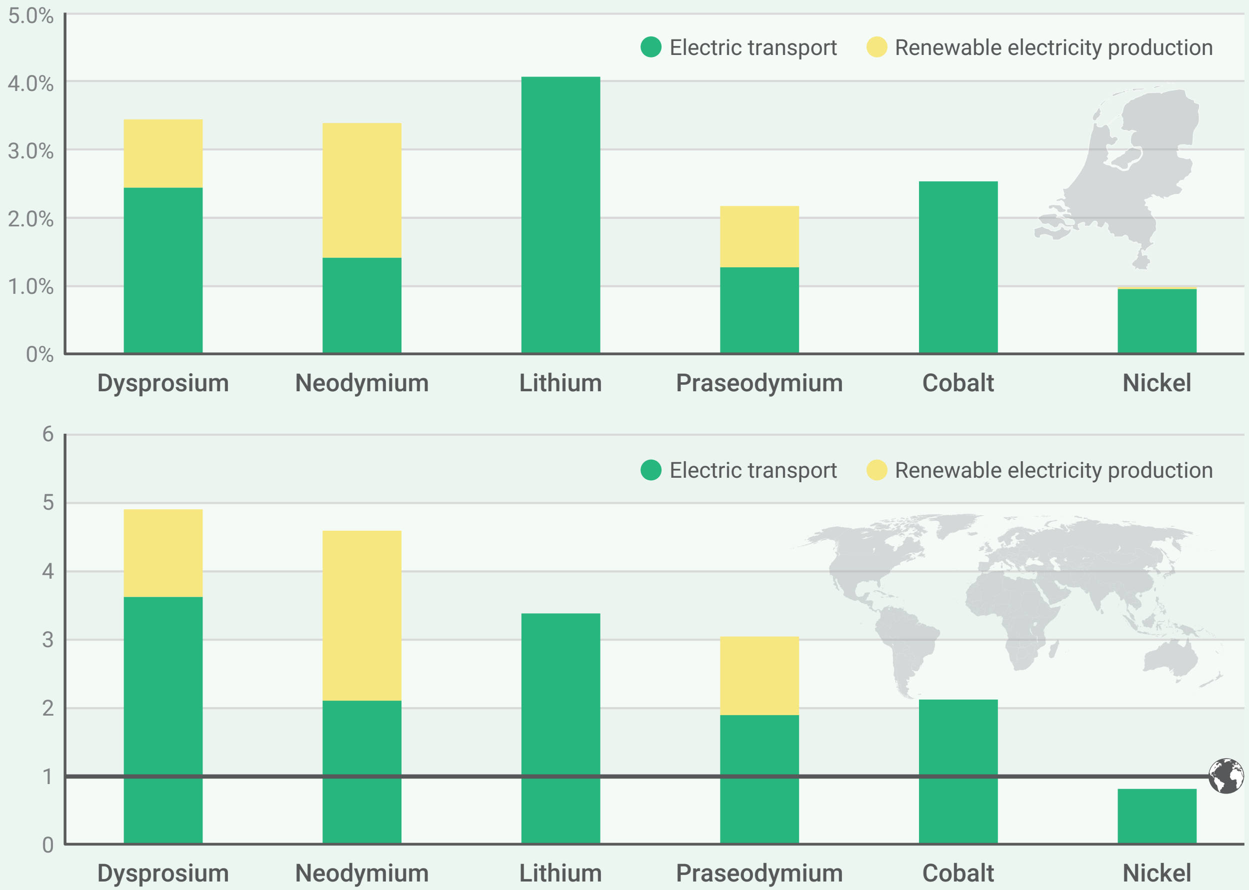


Fig. 16 **The aggregate metal demand for electric transport and renewable electricity in 2030 in the Netherlands (top) and the world (bottom), as a factor of the current annual global production.**

06 RECOMMENDA-TIONS

A substantial quantity of critical metals will be needed to achieve the Dutch Climate Agreement, which contains the policy target of 1,900,000 electric vehicles (EVs) in 2030. For six metals, that target represents between 1.5% and 2.5% of the current annual global production of those metals, well above the 0.9% that could be defined as a reference value on the basis of the size of the current Dutch car fleet. For Europe, the figure is up to 1.5 times current global production compared with a reference value of 25%. Mining production will grow, but the required speed of growth seems challenging. Assuming a future without fossil fuel-powered cars and without the large-scale use of hydrogen cars before 2030, expanding the option space beyond simply replacing current fossil fuel cars with equivalent EVs is desirable.

The future scenarios in Chapter 5 outline three possible solutions. Each will demand greater changes than is generally anticipated. Despite this, a combination of the three solutions seems reasonable: we will have to focus on substitution by developing different types of batteries; on matching different types of electric cars to the specific needs of users; and on promoting car sharing at the expense of car ownership.

Measures need to be taken to support these various solutions, through both government policy on mobility and sustainability and the commercial strategies of car manufacturers and recycling companies. The eight recommendations we make suggest steps that can be taken towards a sustainable, fair and future-proof mobility system: five are to be taken at the national level and three at the European level.

RECOMMENDATIONS ON A NATIONAL LEVEL (THE NETHERLANDS)

Most policies relating to mobility and climate are formulated at a national level. That is therefore the most relevant scale for developing a sustainable mobility system. The recommendations could be applied by both the Netherlands and other countries.

RECOMMENDATION 1 Promote new mobility concepts with fewer vehicles

The most effective way of reducing the demand for critical metals is by substantially reducing the number of electric vehicles that are needed. If replacing fossil fuel-driven vehicles remains the point of departure, new mobility concepts based on far fewer vehicles will be required. On the basis of the scenarios, we propose a target for the Netherlands is at least 900,000 fewer vehicles (11% of the current vehicle fleet) by 2030.

Reducing the number of vehicles will require a major extra effort to find other mobility solutions. These alternative solutions should include making more effective use of existing vehicles (for example, car sharing), a shift to other modalities (bicycle, rail) and developing new technologies (such as self-driving cars) and the accompanying regulatory changes and digital infrastructure.

Developments in car sharing and rail transport

In the Netherlands, there are already various initiatives to promote car sharing, both public and private. However, the currently projected growth in the number of business-to-consumer shared cars (up to 80,000 in 2030[1]) seems insufficient to achieve the necessary reduction in the number of vehicles.

Inaddition, the Dutch rail authority ProRail already anticipates problems regarding the growth in passenger numbers on the railways.[58] A further shift towards more rail passengers will require substantial policy support to cope with growing passenger numbers.

Credit: autodelen.info

RECOMMENDATION 2 Promote electric vehicles with small batteries for regional solutions

Batteries with a smaller capacity contain proportionally fewer critical metals than larger batteries with a larger action radius. Currently, electric cars are often bought on the basis of their range and therefore their battery capacity. Indeed, the average action radius of the cars that are sold is steadily increasing. Many buyers feel that it must be possible to use their car anywhere, also for that once-a-year road trip or holiday. However, many journeys only cover relatively short distances, for which a vehicle with a smaller battery is perfectly suitable. Furthermore, a significant share of the households in the Netherlands own a second car, which are easier to replace for cars with a smaller reach.

With the ageing population – and older people being less inclined to travel long distances – the expectation is that there will be greater demand for short journeys by car. Cars with a small battery are perfectly suited to that trend. The promotion of EVs should therefore also be geared to encouraging diversity in the types of car: not just vehicles with a large action radius, but also cars with a smaller range and therefore a smaller battery.

RECOMMENDATION 3 Invest in future-proof infrastructure

Scaling up new mobility concepts based on fewer vehicles also imposes new demands on infrastructure. For example, locations where self-driving cars can be automatically charged, or motorways with induction zones where cars are charged as they drive. Smart investments in the infrastructure of the future, rather than that of the past, are needed to match the changing nature of personal transportation.

RECOMMENDATION 4 Avoid unnecessary investment in existing infrastructure

A significant amount of public spending is currently assigned to constructing new roads and maintaining existing roads. In a future with fewer vehicles, the need for additional car infrastructure will decline. At a national level, that relates to the construction and widening of motorways; at a local level, it concerns the creation of parking spaces in new residential estates in municipalities where a high parking standard often still applies.

More roads and more parking spaces lead to more vehicles using them. It will be easier to make the gradual transition to a system with fewer vehicles if that infrastructure is not expanded. At the same time, the money saved can be invested in new mobility concepts (recommendation 1) or new future-proof infrastructure (recommendation 3).

RECOMMENDATION 5 Develop a market for second-hand batteries

There is significant potential in the use of second-hand EV batteries to store electricity from the grid. The potential demand for this application is enormous. For example, the Netherlands between 1.5 and 3 million dwellings are forecasted to switch to all-electric heating.[59] That will potentially lead to significant additional demand for batteries. Currently, demand for stationary storage is often met with new batteries (for example, the Tesla Power Wall), partly because there are not enough second-hand batteries from electric cars available.

To avoid a future situation where new batteries are produced for stationary storage purpose, while EV batteries are recycled at material level, it is important to develop a market in second-hand batteries in which old batteries from electric cars can be used in a second-life application.

Declining battery performance

The longer a battery is used (undergoes more charging cycles), the more its performance declines. For batteries in an electric car, this means that the more often the battery is used, the shorter the car's action radius becomes. The batteries will eventually have to be replaced when the car's range becomes too limited. However, these batteries can still be used in the built environment, where the weight of the batteries is not a factor. One example of this can be found in the Amsterdam Johan Cruyff football stadium, where a 3MW test location for energy storage has been constructed, using 148 batteries from electric vehicles.[60]

Credit: Johan Cruijff Arena

RECOMMENDATIONS FOR EUROPE

At an international level, the most important success factor for both the development of electric transport and the necessary expansion of critical metals supply, is a stable and uniform climate policy. Although a lot of attention is given to both the climate and critical metals at EU level, policy on both topics is neither stable nor uniform. Given the urgency of the climate crisis, it is important for the European Union to take action. The following three recommendations are indicative of the course that the EU could adopt.

RECOMMENDATION 6 Support sustainable mining initiatives to minimise social and environmental impact

Regardless of reductions made in the material intensity of electric vehicles and the wider economy, the coming decades will probably see a significant expansion of mining. Consistent climate policy is important to provide mining companies with the certainty they need to invest in expanding production. However, the substantial increase in demand for metals will put significant pressure on the ecological and social contexts of (prospective) mining sites. Environmentally and socially friendly mining is possible, but requires a shift in attitude on the part of the mining industry and improved cooperation along the supply chain.

In Europe, there are strict laws and regulations for new mining locations. Responsible sourcing is not expected to be a problem. Major challenges arise with new mining locations in developing countries, where a strong government to maintain oversight of compliance with social and ecological laws and regulations might be lacking. There are several positive developments. In 2021, European legislation will enter into force requiring companies to show the origin of several metals that are associated with conflict. The World Bank is also involved in improving the sustainability of mining, through their *Climate-Smart Mining* initiative.

RECOMMENDATION 7 Develop a European recycling industry for critical metals

It is important for batteries to be recycled in order to keep future European demand for critical metals in check. There is room for several of these recycling plants in Europe. Belgium's Umicore is the best positioned in the Benelux region: it already invests to meet the growing supply of recyclable critical metals. A recycling facility in the Netherlands therefore seems less necessary from the perspective of volumes, but might be interesting from an economic perspective. For optimal recycling of the materials that are released in 2030, this recycling capacity will have to be in place before then.

To illustrate the volumes involved: in 2030 around 7,400 tonnes of batteries are forecasted to be recovered from around 20,000 cars (± 370 kilograms per car). Umicore's current capacity is around 7,000 tonnes per year.[61] Besides batteries from EVs, significant attention should also be focussed on recovering batteries from other applications such as consumer electronics. *Urban mining* is a concept that should be supported in this context.

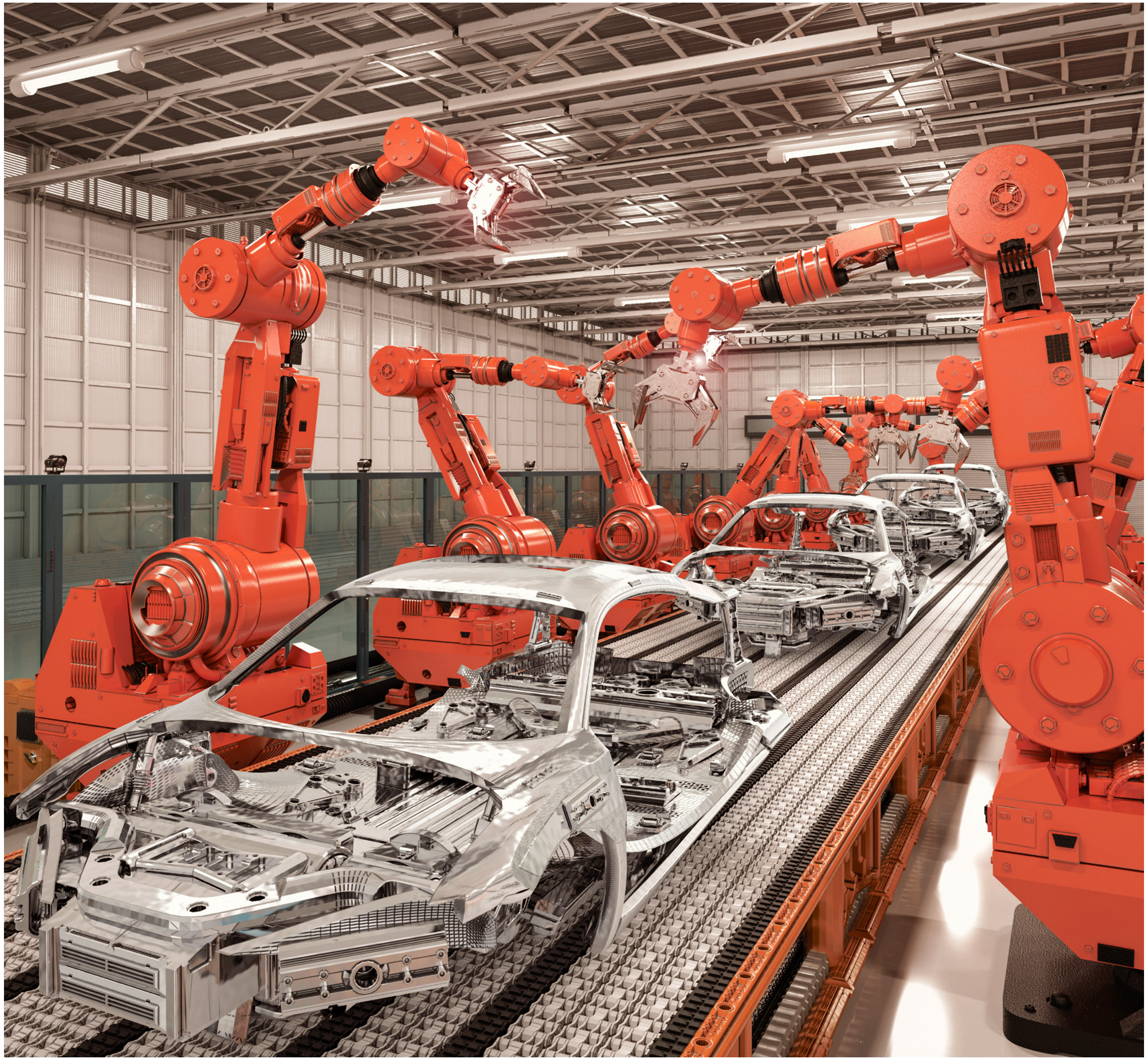
Recycling plant in Lelystad

Battery Safety Solutions will be opening a recycling plant in Lelystad next year, where used batteries from end-of-life cars will be separated into their individual materials. With a process involving the use of a solution of sulphuric acid it will be able to recover far more lithium, for example, than with the regular heating process. With this process, batteries that are not fit for a second life in the Netherlands can be recycled. The plant will have an annual capacity of around 5,000 tonnes. The company may build a second plant at another location if the demand requires it.

RECOMMENDATION 8 Support development of new types of batteries

The development of new battery technologies based on non-critical metals is often mentioned as a possible solution. Numerous developments are already underway, with the emphasis on reducing the volume of cobalt used. For example, Li-Air is seen as a very promising technology, but it will probably only be available commercially after 2030.[62]

In general, few commercially scalable technological breakthroughs are expected in the period up to 2030, because developing new battery plants at scale is an expensive and time-consuming process. Moreover, new types of battery can also create new types of risk, both technological and in terms of the availability of other metals that might be used. We therefore recommend to continue research into new types of batteries, so that alternatives are available if needed.



07 RESEARCH METHOD

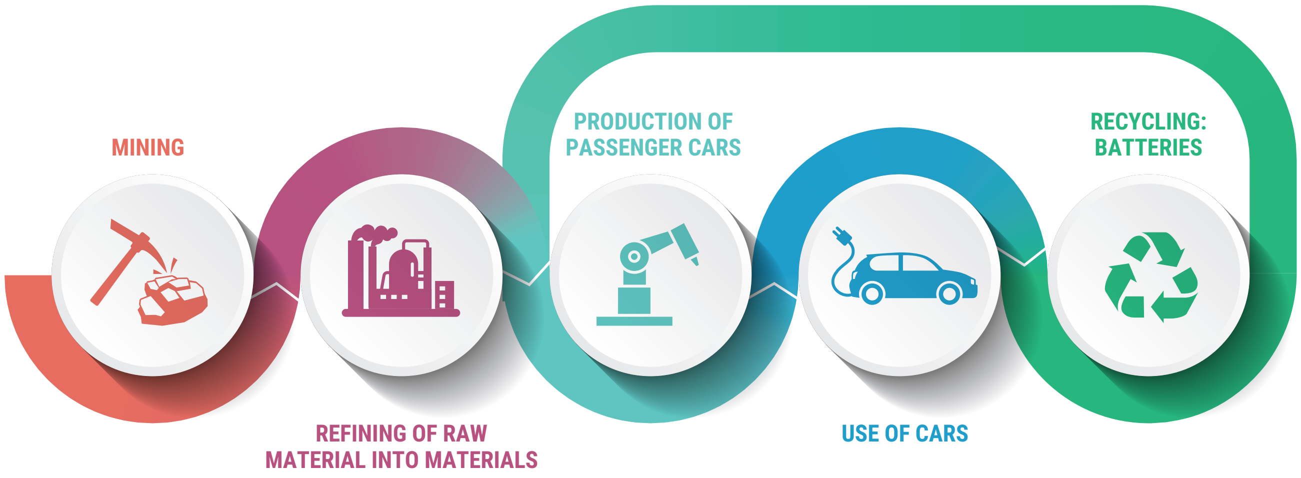


Fig. 18 Limits of the system studied, from mining up to and including the use of the cars.

This study was initiated and carried out by Metabolic, Copper8 and Leiden University's Institute of Environmental Sciences, with the aim of showing the influence the growth of electric transport in the Netherlands will have on the demand for critical metals. This chapter explains the research method.

SYSTEM BOUNDARIES

For this study we looked exclusively at electric passenger cars: both battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). In identifying the relevant critical metals, we considered the entire chain, from mining via refining and production up to and including the use and recycling of a car at the end of its life cycle. The system limits are summarised in Figure 18.

Calculations and assumptions were made for three aspects of this study. They related to:

- Scenarios for growth in the number of electric cars
- Metal demand for the technology in electric cars
- The definitions used

SCENARIOS FOR GROWTH IN THE NUMBER OF ELECTRIC CARS

The scenarios for the growth in the number of electric cars are based on the target in the Dutch Climate Agreement: 1.9 million electric cars in 2030. For this aspect, our growth scenario starts from the current number of electric cars (as of January 2019).

Table 3 Assumed number of electric cars (BEVs and PHEVs) sold annually up to the end of 2030.

	2020	2025	2030
BEV	17,217	123,146	402,414
PHEV	6,325	8,655	11,844
TOTAL	23,542	131,801	414,258

METAL DEMAND FOR THE TECHNOLOGY IN ELECTRIC CARS

For the metal demand of electric cars we looked exclusively at the metals that are needed for the batteries and the electric motors. For all other metals, the demand does not differ from a regular fossil fuel-powered car. We also focused exclusively on critical metals, not on critical *materials* (for example, rubber).

Metal demand for batteries

Various types of batteries are used in electric cars. Most use nickel-manganese-cobalt (NMC) batteries, with a cathode comprised of those three metals. More modern NMC batteries generally contain less cobalt and lithium. The expected metal demand for each type of battery is shown in table 4.

Table 4 Metal demand for each type of battery, in kg/kWh.[63]

	Lithium	Cobalt	Nickel	Manganese	Carbon
LCO	0.113	0.959	0	0	1.2
NCA	0.112	0.143	0.759	0	1.2
NMC-622	0.126	0.214	0.641	0.2	1.2
NMC-811	0.111	0.094	0.75	0.088	1.2

In scenario 1, we assume further technological development of batteries. In that case, new cars will be fitted with modern batteries (such as the NMC 811) which contain less cobalt and lithium per kWh. The following table shows the expected ratios of these technologies in the coming years.

Table 5 Expected development in the share of battery types in electric cars that are sold.[64]

	2019	2025	2030
LCO	2%	0	0
NCA	26%	16%	7%
NMC-622	40%	28%	16%
NMC-811	32%	56%	77%

Metal demand for electric motors

Electric motors contain a strong permanent magnet in which various critical metals are used. In contrast to batteries, the quantity of critical metals does not depend on the car's characteristics. In other words, the Tesla's electric motor contains the same quantity of neodymium as that of a hybrid Toyota Prius. The metal demand for an electric motor is shown in table 6.

Table 6 Metal demand for an electric motor, in kg / vehicle.[57]

METAL	DEMAND (KG / VEHICLE)
Neodymium	0.34
Dysprosium	0.11
Praseodymium	0.11

Table 7 Summary of all the assumptions for each of the scenarios.

ASSUMPTIONS FOR THE SCENARIO FOR THE NETHERLANDS				
	BASIC SCENARIO	SCENARIO 1: TECHNOLOGICAL INNOVATION	SCENARIO 2: SMALLER BATTERIES	SCENARIO 3: FEWER VEHICLES
TOTAL NUMBER OF ELECTRIC CARS IN 2030				
BEV	1,753,151	1,753,151	1,753,151	884,036
PHEV	194,795	194,795	194,795	160,994
NUMBER OF ELECTRIC CARS SOLD IN 2030				
BEV	402,414	402,414	402,414	89,470
PHEV	11,844	11,844	11,844	2,633
BATTERY CAPACITY IN 2030				
BEV	75 KWH	75 KWH	37.5 KWH	75 KWH
PHEV	12.5 KWH	12.5 KWH	6.25 KWH	12.5 KWH
SHARES OF BATTERY TECHNOLOGIES IN 2030				
NCA	7%	3%*	7%	7%
NMC-622	17%	7%*	17%	17%
NMC-811	77%	90%*	77%	77%

We assume that in 2030, 50% of the batteries will have silicon anodes, which improves the energy density by 15%.

ASSUMPTIONS FOR EUROPEAN AND GLOBAL SCENARIOS

For the metal demand for Europe and the world we explored three scenarios. Two scenarios are based on the IEA's EV30@30 scenario: one for Europe, and one for the world. For Europe, we also included a second, more ambitious scenario, in which all new passenger cars sold in 2030 are electric. Further scenario parameters are found in Table 8.

Table 8 Overview of the number of electric cars sold in 2030 for the three European and global scenarios.

	EUROPE IEA EV30@30	EUROPE 100% IN 2030	GLOBAL IEA EV30@30
NUMBER OF ELECTRIC CARS SOLD IN 2030			
BEV	6,079,198	12,391,430	31,524,640
PHEV	2,260,950	4,608,570	11,724,516

Furthermore, we assume similar developments regarding technology and average battery capacity as in the basic scenario for the Netherlands (table 7).

DEFINITIONS

Metals are divided into many different categories, primarily on the basis of their chemical properties, but also on the basis of price and universal availability. For this study, we chose to use the term **critical metals** (which are not to be confused with rare earth elements): this is not a distinct group but a collective name for metals that are difficult to find or extract.[65] Figure 19 shows which metals were investigated and the group they belong to.

Rare Earth Elements (REE)

The term 'rare earth elements' is a collective name used for a group of elements with similar properties (shown in pink in Figure 19). This category encompasses both 'light' REEs (LREEs) and 'heavy' REEs (HREEs). The elements are mined in oxidised form and when they are extracted they are called 'rare earth oxides' (REOs). During the refining process, these elements are converted into their pure form: a metal. In this report, no distinction is made between LREEs and HREEs.

INVOLVEMENT OF EXPERTS

To validate this study, many external experts were consulted, from both the scientific and business communities. The issues discussed included the research method, the assumptions and the recommendations. The experts included scientists, policymakers, representatives of research institutes and a number of relevant private parties. We would like to express our sincere gratitude to these experts.

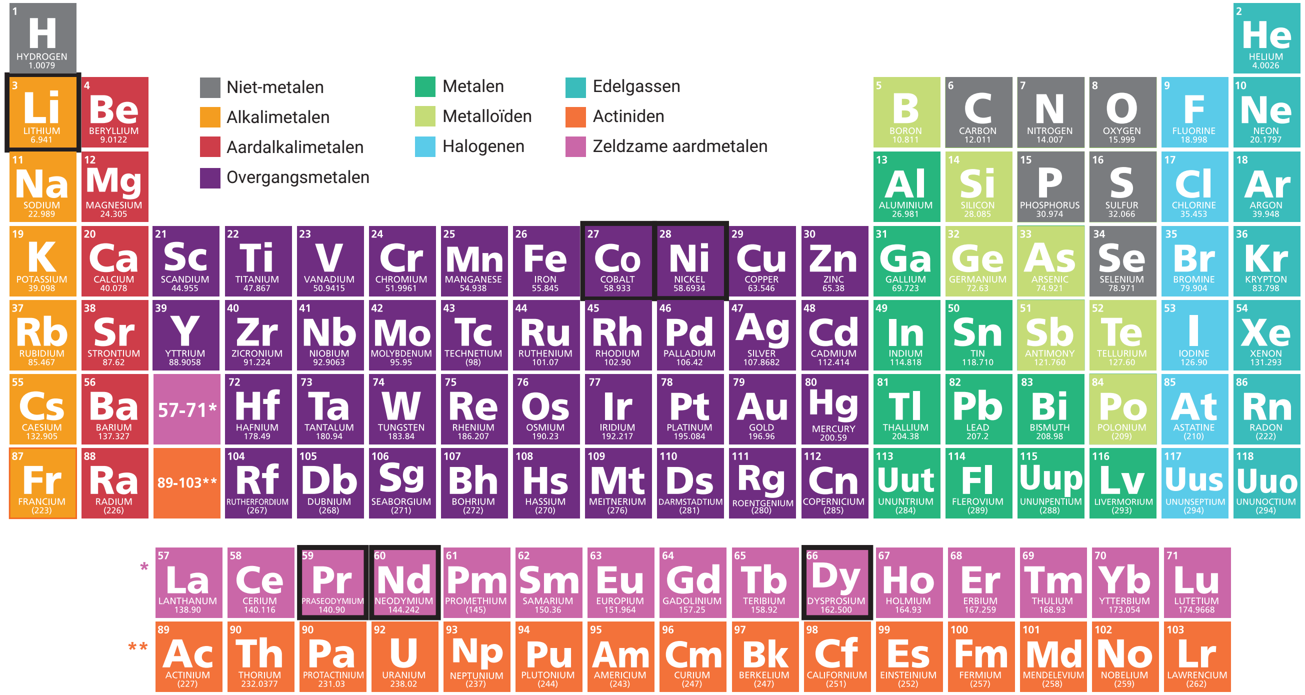


Fig. 19 Periodic system of elements: the elements framed in black were included in the study.

07

APPENDIX

Properties Of Electric Cars

CURRENT TOP-10 ELECTRIC CARS IN THE NETHERLANDS (BEV)					
MAKE OF CAR	TOTAL 2018[2]	NUMBER SOLD IN 2018[2]	BATTERY CAPACITY[66]	RANGE[67]	PRICE FROM[67]
TESLA MODEL S	12,990	4,962	100 KWH	510 KM	€ 87,020
NISSAN LEAF	5,398	3,275	40.0 KWH	230 KM	€ 36,990
TESLA MODEL X	4,625	2,956	100 KWH	460 KM	€ 98,070
RENAULT ZOE	3,586	1,282	44.1 KWH	260 KM	€ 27,190
VOLKSWAGEN E-GOLF	3,516	2,296	35.8 KWH	190 KM	€ 39,680
JAGUAR I-PACE	3,501	3,501	90.0 KWH	380 KM	€ 80,330
BMW I3	3,433	1,657	42.2 KWH	235 KM	€ 41,995
HYUNDAI IONIQ ELECTRIC	2,415	1,422	38.3 KWH	265 KM	€ 33,995
OPEL AMPERA-E	1,111	882	60.0 KWH	345 KM	€ 46,699
SMART FORTWO ELECTRIC DRIVE	615	149	17.6 KWH	105 KM	€ 23,669

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