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Early Warning, Emerging Issues and Futures

Challenges for the growth of the electric vehicle market

Background

The Foresight Briefs are published by the United Nations Environment Programme to highlight a hotspot of environmental change, feature an emerging science topic, or discuss a contemporary environmental issue. The public is provided with the opportunity to find out what is happening to their changing environment and the consequences of everyday choices, and to think about future directions for policy.

Abstract

Electric vehicles (EV) can play an important part in the decarbonisation of the traffic sector. This helps in climate mitigation and positively impacts the air quality of cities, due to reduced emissions such as CO_2, NO_x, SO_2 and fine particles. In order to become an eco-friendlier product, however, increased efforts must be made to lighten the environmental and social burdens of the mining of rare earth materials, needed especially for the batteries and engines, and its production process. It must be accompanied by a shift of electricity production to renewable energy sources, while pushing for clear guidelines on re-usage and recycling of the batteries.

Introduction

As CO_2 emissions are on the rise and air quality in cities is deteriorating, the use of electric vehicles is seen as a win-win solution. Alternatives to combustion vehicles (CV) are needed and EVs provide a promising solution as they do not use petrol nor emit CO_2, NO_x and other noxious gases or particles. Although use and growth of public transport and soft mobility should remain the priority for land and city planning, there will still be a need and demand for individual transport, where consumer EVs can play a significant role.

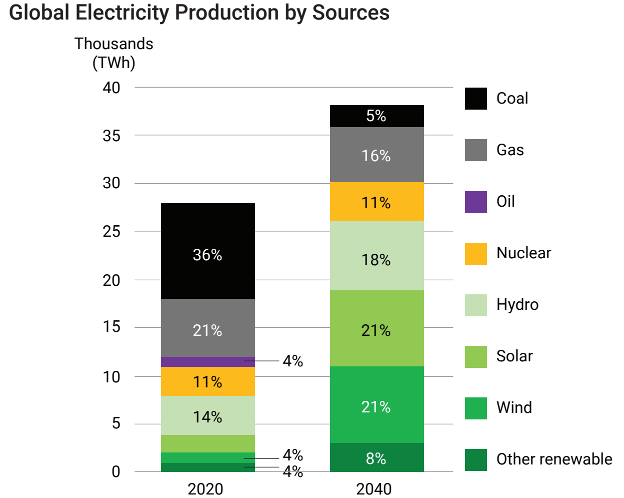


Figure 1: Global electricity energy mixed by sources for 2020 and 2040. Renewable energy is represented in green. An additional 18,000 Terrawatt hours (TWh) will be produced by renewable sources, thus increasing their share from 29% to 68% of total electricity. Electricity from transport will induce a 3,800 TWh increase of electricity demand and will represent 10% of total electricity.[1]

To get the best improvement, the source of electricity to charge the car's batteries has to be based on renewable energy, so that it provides the eco-friendly alternative needed. In 2020, 61 per cent of the global electricity energy mix comes from fossil fuels (coal: 36%, gas: 21%, oil: 4%, Figure 1). A rapid increase of the production of electricity from renewable energy, observed over the last couple of years, is foreseen for the next 20 years. By 2040, 68% of all electricity production will stem from renewable sources. Transportation will account for 10% of its use.[1]

A closer look at all phases of the EVs life cycle shows two "challenges" that require attention to make EVs an even greener option:

1) the production process of batteries and EV engines requires the use of rare earth elements and consumes high amounts of energy; and
2) the need to implement strategies for the reuse, recycling and disposal of the batteries used in EVs at the end of their service life.

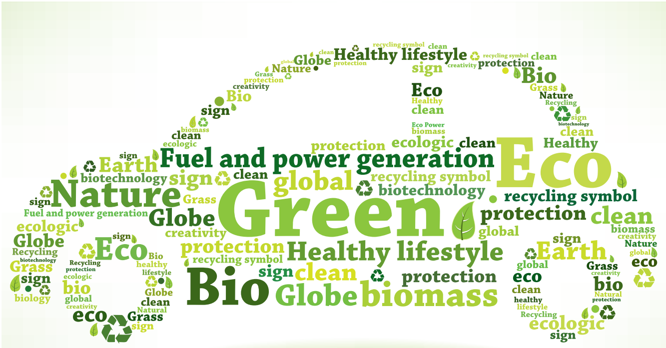
The potential threats and challenges, as well as solutions for the production and use of EVs and their batteries are now considered.

Electric car at charging station

Why is this issue important?

The production of EVs is on a steady and steep rise. While in the year 2013, 400,000 EVs were produced, 5.1 million EVs were shipped to customers in 2018.[2] This growth is expected to continue. The leading car manufacturers plan to produce more than 20 million EVs per year in 2025, and 60 million in 2040.[3] Expected electric vehicles on the road will number 250 million by 2030 (Figure 2).[4] It is, therefore, fundamental that this production and use be as green as possible. Almost half of the electric cars on the road in 2018 were in China. Europe accounted for 24% of the global fleet, and the United States 22%.[4] Despite the current rapid growth, the market penetration of electric cars is still limited to less than 1% of the global car fleet today.[2]

The reasons for the rapid growth stems from the willingness of consumers to move away from petrol, underpinned by governments in many countries with incentives to encourage this shift. Clearly, extraction, transport, refinement and burning of fossil fuels have significant socio-environmental impacts. EVs do not directly emit CO_2, nor Nitrogen oxides, nor dangerous



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particulate matter. They also do not make noise. This helps in improving the air quality of cities and decreasing CO_2 emissions to mitigate climate change. In addition, the EVs' engines are built in a completely different manner, reducing tremendously the amounts of mechanical parts needed; for example, they do not need oil for the engines, filters or spark plugs. This makes EVs very reliable cars. Also, electric engines convert energy into movement much more efficiently, with an 80% efficiency rate for "tank-to-wheel", while combustion engines achieve only a rate of 20%.[5]

Although these positive aspects are of importance for the transition to greener traffic, there remain two challenges: Firstly, EVs will not help in solving today's traffic congestion problems. Reducing mobility needs (e.g. via improved land- planning) and pushing for public transport and soft mobility (such as bicycle or pedestrians) should, therefore, remain the favoured option. These are much more efficient options in terms of energy and emissions per individual and per km. Although electric trains and subways are also electric vehicles, they do not require batteries. Secondly, to become clean transport, this shift to EVs should be done in parallel with a rapid transition to electricity production from renewable energy, a cleaner production of the electric batteries and a well organised reuse and recycling of these batteries.

EVs need precious minerals, for both the battery and the engine. Some of these minerals are so-called 'rare earth elements' (REE), which are not especially scarce resources but are available in only small amounts on the earth's crust. The origin of many of these minerals are concentrated in a few countries, (such as the Democratic Republic of the Congo, Republic of Chile and The People's Republic of China) especially the latter dominating the supply of many critical metals (Figure 3).

Electric Vehicles Stock Scenario

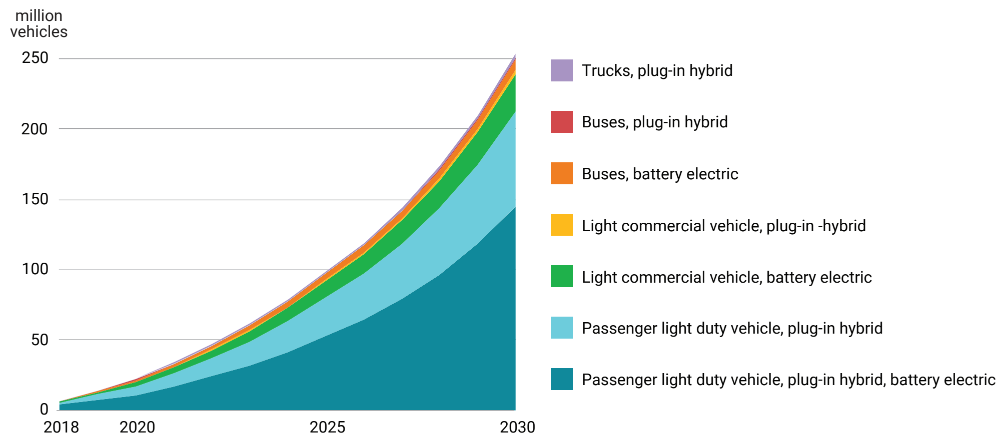


Figure 2: EV sales are on a steady rise. Projected EVs on the road will number 250 million by 2030.[3]

Rare Earth Element Production

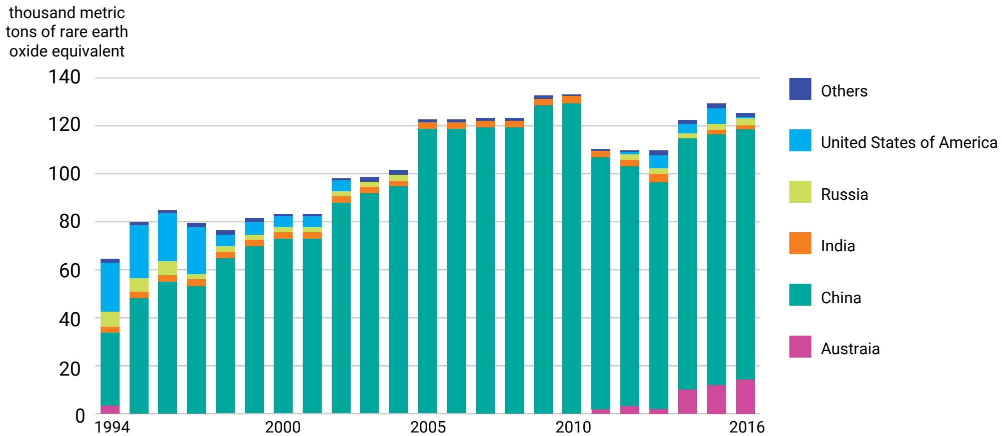


Figure 3: Rare earth element production, dominated by China.[48]

What are the findings?

Carbon footprint

The differences of the carbon footprint between EVs and CVs have been widely studied – with EVs having a clear advantage over CVs, although this positive effect depends mainly on how the energy is generated to produce the car (especially its battery), and what energy source is used to charge the battery. In Germany – where about 40% of the energy mix is produced by coal and 30% by renewables - a midsize electric car must be driven between 125,000-219,000 km, to break even on CO_2 emissions with a diesel car, and 60,000-127,000 km compared to a petrol car.[6,7] The case is similar in the USA, but less pronounced in nuclear-powered France or regenerative energy rich Norway, where for a life time of 150,000 km, a break-even can be reached at 40,000 km for a medium-sized EV. The full life cycle CO_2 emissions sum up in these countries to around 70-80 g CO_2 per km for EVs, which contrasts the 190 g CO_2 per km for Germany.[8] An average European CV emits more than 250 g CO_2 per km, while its EV counterpart achieves under current conditions 130 g CO_2 km – almost half of it (Figure 4). Considering the whole life cycle of cars, recent research found that under current carbon intensities of electricity generation, EVs already produce less emissions than CVs in most of the world.[9]

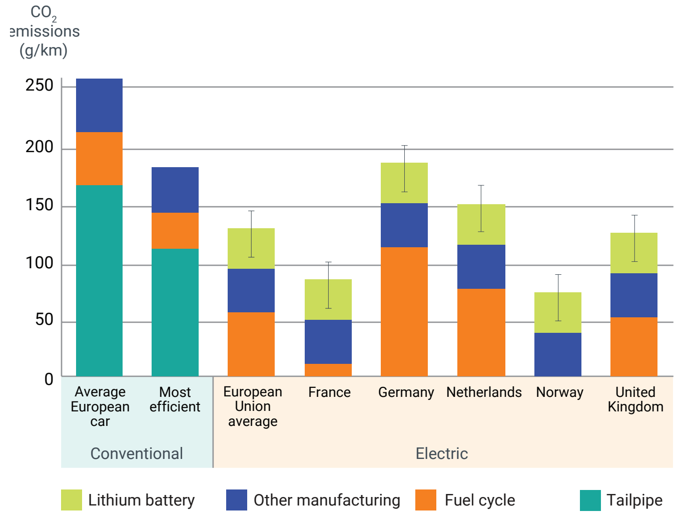
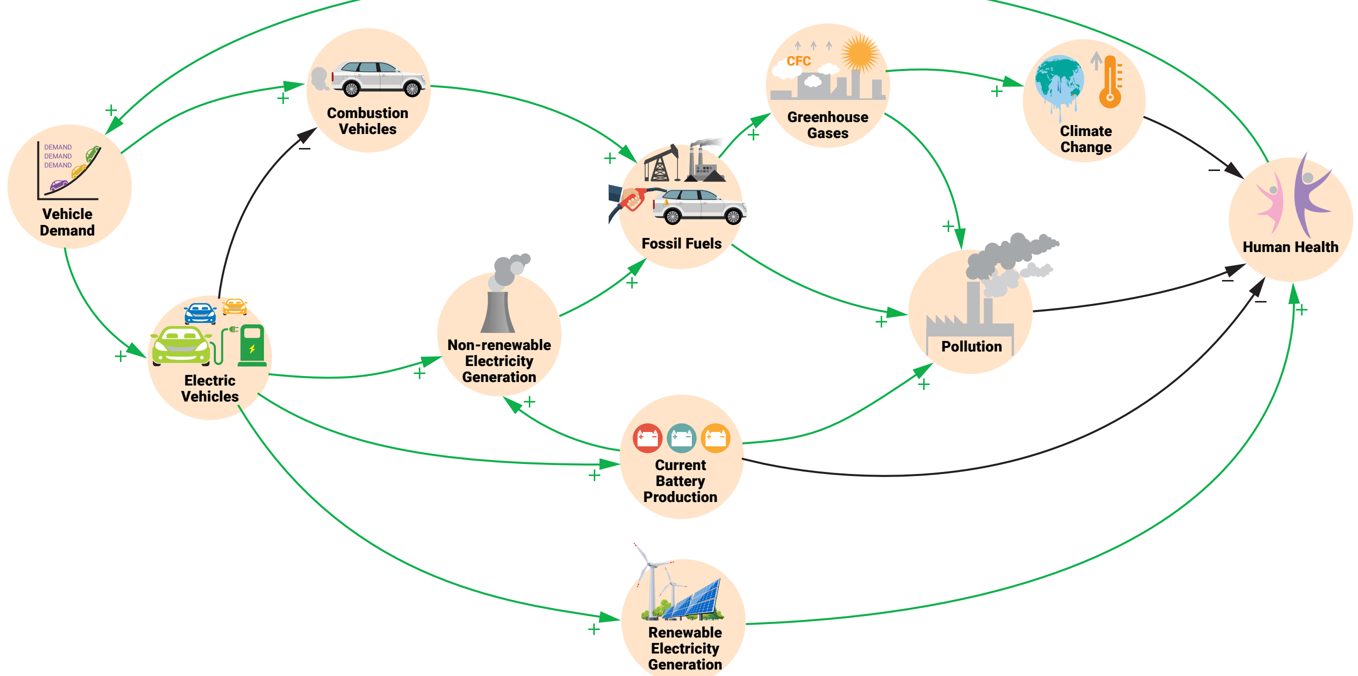


Figure 4: Life-cycle emissions (over 150,000 km) of electric and conventional vehicles in Europe in 2015.[7]

Countries will further improve their share of renewable electricity energy, which will steadily raise the EVs advantage over CVs. This advantage can be further improved if the production of the car and its battery is based on renewable energy and uses recycled materials. Some car manufacturers have already moved in this direction.

A Systems Thinking Perspective



Dominant causal loops in individual vehicle demand and alternatives to consider. Vehicle demand drives production and supply of vehicles. Combustion vehicles use fossil fuels that are polluting and increase greenhouse gases that worsen climate change which in turn adversely impacts human health. Electric vehicles, if built and operated using renewable energy resources and with recyclable components such as batteries, will help improve human health. This approach in turn leads to a more sustainable reinforcement of vehicle demand. (+) Influence is reinforcing and in the Same direction, (-) influence is balancing and in the Opposite direction.

Environmental footprint

Aside the greenhouse gas emissions affecting our climate, there are other environmental footprints of EVs which are reviewed here, keeping in mind that for CVs, impacts through the extraction of oil such as pollution of the environment and its energy consumption for transport and refinery are also major burdens.

- ***Components/Minerals***
  Most of the focus is on lithium, however other elements of batteries, such as cobalt, nickel and graphite also need to be considered. Batteries for small to medium sized consumer cars weight around 200-300 kg and have a capacity of 30-45 kWh. Depending on the battery type, it will consist of 5-80 kg of lithium, 8-20 kg of cobalt, up to 50 kg of graphite and 100 kg of nickel.[3,10,11]

Most electric vehicles use Neodymium-Iron-Boron permanent magnets, which contain up to 1 kg of neodymium[12], and up to 100 g of dysprosium[13] as well as praseodymium. In 2015, half of the global demand for REE originated from these.

- ***Environmental impacts***

Without clear policies and action, the production and use of EVs exhibit the potential for significant increases in human toxicity, freshwater eco-toxicity, freshwater eutrophication and metal depletion impacts. These impacts emanate largely from the vehicle supply chain. Life cycle assessments show that the battery production is the phase mainly responsible for all the impacts considered.[14–17] The type of recycling used plays an important role too. New policies on accelerating research for new types of batteries with a lower footprint should be implemented.

The amount needed for main minerals for EV batteries will increase from around 200,000 tons in 2018 to 7,100,000 tons in 2030 (Figure 5).[18]

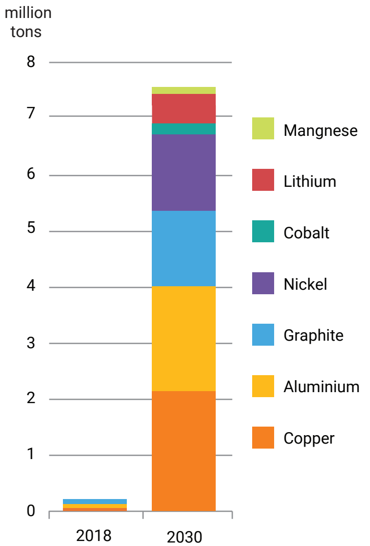


Figure 5: Metals and materials demand from lithium-ion battery packs in passenger EVs.[18]

Intensive mining operations have a definite impact on the surrounding environment such as: acidic mine drainage, water contamination, dam bursts and flooding, waste production, air pollution, soil erosion and contamination, water availability, ecosystem destruction, radioactive radiation, and submarine/riverine tailings disposal.[19] These should be better regulated. There are many reports on the negative impacts of mining minerals for EVs like lithium[20-22], nickel[23,24], cobalt[25,26] [or graphite[27], and which describe the impacts of this mining on the local population and the environment.

Lithium, for example, takes 250 to 750 tons of lithium rich materials to produce one ton of lithium.[28] One report states that '9,600 to 12,000 cubic meters of waste gas - containing dust concentrate, hydrofluoric acid, sulfur dioxide, and sulfuric acid - are released with every ton of rare metals that are mined. Approximately 75 cubic meters of acidic wastewater, plus about a ton of radioactive waste residue are also produced'.[29] The latter is due to an often-found association of radioactive thorium and uranium with those rare earths.

Some metals, are derived from small mine pits, with hardly any environmental protection measures and very poor equipment for the workers, of which some are children.[26] New policies and enforcement of these are needed to protect the health of mining workers and ban child labour.

Extracting the ore from the earth represents only a small portion of REE production. Refining these into marketable products constitutes the major aspect of REE production and its environmental (and associated social) impacts.

- ***Water***

In addition to the common consequences of mining – deposits, dust, toxic waste streams and others, – a major concern in the countries where lithium is exploited is the large amounts of water that is required in its processing.[10] Data from Bolivia and Chile suggests that 5 to 50 m^3 of freshwater are needed per ton of final battery grade lithium carbonate produced.[30] Other sources indicate much higher amounts of up to 2,000 m^3.[22] This extraction is having a significant impact on local farmers.[21] In arid land (e.g. in Atacama desert) the competition for water between mines and farmers is leading to high tensions. Better consideration for water use and new extracting techniques are needed.

- ***Electricity***

The good news here is that the effects of an increased EV fleet on electricity consumption is rather small for the EVs' use phase. In Germany for example, 10 million EVs would imply an increase of additional electricity of 5% or 30 TWh.[31] Or, in an extreme case: if the entire mileage of all passenger cars in Germany were covered by electric cars - in 2015 this was approximately 630 billion km - the electrical energy required for this would correspond to "only" about 20% of the current electricity consumption.

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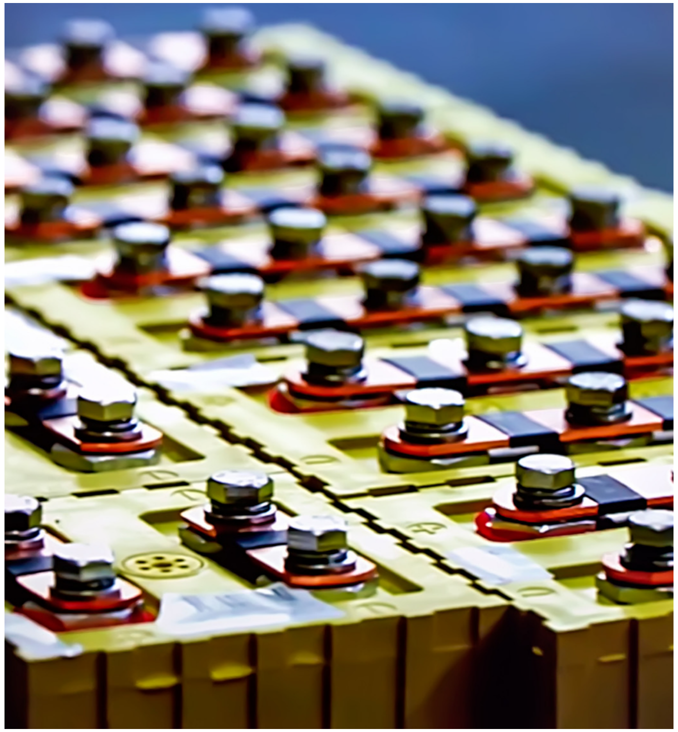
What is being done?

EVs production process

Due to increased awareness of uncontrolled effects on the environment around small illegal mining pits, some countries have closed many of these in recent times.[23,32] Increased pressure from companies and international agreements leads to environmentally and socially improved mining management. As the efficiency of batteries rapidly increases, the input to output ratio of energy and materials decreases proportionally, leading to a continuously decreasing footprint. Many different battery technologies, working with less or no cobalt for example, and using less harmful substances, are being developed around the world, which will steadily improve the environmental footprint of the EVs.



Production of lithium batteries for environmentally friendly electric cars
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Recycling batteries

Up to 2011, only a tiny share, less than 1% of the REE and 5% of lithium-ion batteries used in Europe got recycled[33-36] and most often ended up in landfills[37], resulting in a considerable loss of resources. Although EV batteries will only become obsolete in the coming years, their recycling process should be organized and regulated early enough.

There are several reasons for the limited recycling. For example, batteries are produced by a variety of chemical processes making it difficult to develop standardized recycling, the cost of the recycling, the low value of the metals involved, the limited collection of used lithium batteries, and there is a also a lack of incentives.[38,39] The cost of the recycling process makes it currently five times as expensive to buy recycled lithium, as to purchase new lithium.[39] Corrective measures need to be implemented so that recycling can become the norm. Nevertheless, some companies do recycle lithium-ion batteries, but they only recycle the cobalt and nickel in the batteries, due to their high value[10].

Currently, the most widely used process includes heating the battery to high temperatures (>600°C), which makes it very CO_2-intensive, and achieves only limited and partially low-quality recovery of the minerals.[40-42] Some companies are improving the procedure using mechanical destruction with much higher recycling rates, which will eventually lead the way to a more circular economy model. Prior to going for recycling the batteries can also be reused for energy buffers and storage or backup of mobile masts.

EU regulations, which require battery manufacturers to pay for the costs of collecting, treating and recycling batteries, are in place, although only at minimum standards. For the 11 million tons of spent lithium-ion batteries in need of recycling from now to 2030[35], car manufacturers and recyclers will need to work together in order to make that process as cost effective and efficient as possible.

What are the implications for policy?

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Change in our mobility schemes

Reducing impacts from individual transportation starts by reducing their demand. Looking more holistically at the issue of personal transport, land use and city planning is of utmost importance in order to design a transportation system, which enforces an effective network of public transport and soft mobility. We need whole new mobility concepts, which could be organic (cycles, pedestrians), or electrified (e.g. subway, trains, electric buses, electric bicycles, electric scooters/motos), but not necessarily individual car based.

Governments should focus on reducing individual mobility by cars and implement incentives for individuals to instead use public transport and encourage soft mobility. Successful examples are some cities in the Netherlands or in Tallin of Estonia, where public transport is free. In Copenhagen, 62% of all citizens commute to work, school or university by bicycle[43], and in Switzerland, the use of trains is much more accepted than in other countries.

Rapid shift to renewable energies and material in the car production and use phase

Moving from combustion to electric vehicles need to be done along with a rapid shift toward production of electricity from renewable energy. Such energy should also be used for car production.

Responsible mining

A due diligence process for companies should be introduced for the production of all metals in the manufacturing phase. This already exists in the USA for some conflict minerals such as tin, wolfram and gold. In the EU, comparable regulations exist, but do not include some minerals, for example cobalt.

As a significant share of Europe's mineral imports is assumed to come from poorly managed mining sites that could cause detrimental environmental impacts, there is a need that this situation should be tackled by international, EU and national policies. Countries lacking governance capacities, mining companies needing more resources for environmental management practices and old mining sites with poor technical levels are areas that require improvement in mining. Such environmental protections would not only benefit the environment but also the population most severely affected by mining.

Mining enterprises should sign up to international standards such as the Initiative on Responsible Mining Assurance, which is an independent initiative with the mission to enhance social and economic well-being, strengthen environmental protection and establish fair governance.

Reuse of batteries

The reuse of car batteries is currently tested in the form of electricity storage facilities in buildings. Reduced efficiency, which poses a problem for the distance an EV can travel, plays only a minor role when packing lots of batteries together to store surplus energy from rooftop photovoltaic systems. However, some argue that the high-cobalt-content batteries should be recycled immediately to bolster cobalt supplies and thus avoid extended mining.[44] The supply of used EV batteries will, in time, far exceed the quantity that the second-use market can absorb.[45]

Recycling of batteries

The system in place needs to be rapidly upscaled to handle the large amount of material waste expected from the substantial introduction of EVs in the coming years.[46,47] This transition must be accompanied by designed production, reuse, collection and recycling schemes.

The EU has responded to the environmental challenges from mining waste facilities within the EU through the *Mining Waste Directive* in 2006 and the obligatory *Environmental Impact Assessment* (EIA) for new mining activities. The environmental problems of imported raw materials are addressed by the European *Raw Material Initiative*, which promotes 'sustainable development' without formulating precise targets and policy instruments.[19] The further development of the European Battery Directive is urgently needed, with high recycling quotas for battery manufacturers and EV producers.

It would make sense for each manufacturer to operate recycling plants for its own products, since they would know the structure and composition of their battery packs best. It would be ideal if the recycling plants could be located close to the cell factories in order to enable a closed cycle as far as possible. Tesla has already implemented this concept in its Gigafactory 1 in Nevada.[31] It would further help if the batteries could be standardized and designed for disassembly that allows for easy reuse of parts and recycling of materials.

Promoting research and development of alternative materials

A substitution of the currently used rare materials in powertrain and battery manufacturing can be a good long-term strategy towards a sustainable use of critical metals.[48] Constant research and development into batteries has largely improved their efficiency and reduced costs. Perhaps in the future, new battery technologies will reduce some of the negative footprints of using rare earths materials.

Taxing heavier cars

Reduction of the environmental footprint of cars (both EVs and CVs) also requires reduction in car size and weight. The extent of environmental friendliness depends a lot on the size of the battery and on the weight of the car. Developing heavy cars is not only less beneficial for efficiency, but also creates road safety issues. The presence of heavy cars in the car mix has an influence on how other cars need to be designed (regarding protection in case of accident) thus encouraging heavier cars on average.

Also, EVs should not be used for reducing the average emissions of a car fleet. For example, in EU legislation, from 2021, phased in from 2020, the EU fleet-wide average emission target for new cars will be 95 g CO_2/km. However, car manufacturers are using EVs to lower the average consumption of their whole fleet. What this means is that – unless selecting a brand which does not produce CVs – a consumer who is purchasing an EV is indirectly allowing another consumer to purchase a powerful Sports Utility Vehicle (SUV). Legislation should be improved, to include not only an average, but also a maximum emission target, which is also going down. Regulators should take weight into account by taxing heavier vehicles and creating incentives for smaller models in both electric and traditional vehicles.

Conclusions

EVs can play a significant role in reducing greenhouse gases from individual transport, they also bring the co-benefits of being silent and are helpful in preserving air quality. If the issues presented in this Foresight Brief can be addressed, they will largely improve EVs footprint.

Customers who are purchasing EVs are environmentally aware. Buying a new car is now a decision of what propulsion technology–petrol or electricity–will be used for the lifetime of the car, that is for the next 20 years. When EVs become the norm, car manufacturers that are the most environmentally-friendly will have a marketing advantage and most possibly also have taxation advantages. Currently the taxes are on CVs to lower emissions, next should come legislation favouring the most environmentally friendly EVs.

It is, therefore, also in the interest of the electric vehicle car industry to sell cars with the lowest environmental footprint.

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