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THE DARKER SIDE OF ELECTRIC CARS: HOW TO SOURCE THE LITHIUM TO PRODUCE EV BATTERIES IN A LESS UNSUSTAINABLE WAY

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ABSTRACT
A replacement of cars with conventional internal combustion engines (ICEs) by electric vehicles (EVs) is seen by many as a means to improve local air quality, reduce dependence on fossil fuels and CO_2 emissions. The market for EV is slowly developing with a growing number of (subsidized) manufacturers offering EV models in different market segments to (subsidized) car owners. The number of EVs is still small in most countries, but policymakers and manufacturers see partial or even full replacement of ICEs by EVs as realistic in the coming decade. EV engines are powered by rechargeable lithium-ion batteries. Li-ion is produced from precursors, either liquid (brine metal salt) or solid (hard rocks). Lithium mining is still concentrated in a few countries. Lithium is used for batteries, ceramics, grease and medicine. This reliance comes at a cost, as conventional lithium mining creates several externalities. The following main question will be addressed: How to source a required volume of lithium in a way that reduces the environmental and social-economic impact of mining this resource? To address this question, we will use a combination of relevant literature and a local case study supported by a model-based estimation. The focus is on the Netherlands, an EV user country, but the approach is generic. Technical details (of mining) will be briefly touched upon. An estimated 7,654 million tons of battery-grade lithium is needed for a simulated car fleet of 8 million cars. This would take an estimated 1.67 billion m^3 of brine, 42.1 million m^3 of fresh water and 57.41 million m^3 of desalinated water from mining areas where precipitation is extremely rare. In perspective, around 1.2 billion m^3 of water is used by all activities in the Netherlands yearly. The paper discusses several strategies to address the water depletion and its impacts on source areas.
Keywords: electric cars, batteries, lithium sourcing, environmental impact, mitigating policies.

1 INTRODUCTION

1.1 Background

Conventional cars have internal combustion engines (ICE). ICE exist well over 100 years. At a system level, ICE have hardly changed. The pros and cons of ICE has been widely studied and (partially) addressed by policymakers [1].

1.2 Tailpipe emission abatement

Emission and fuel economy standards were introduced some 50 years ago, starting in the USA with the CAFE regulations in 1975. These regulations stimulated a range of technical innovations [2]. Emissions per car could be reduced until a certain point where it was halted. Car weight increased due to higher safety standards, demand for more luxury (SUV) and more powerful engines [3]. With fuel economy improvement stalled, the European Court of Audit concluded that most European cars emitted the same amount of CO_2 in 2024 as in 2012. Diesel car emissions stayed the same, while petrol engines emitted 4.6% less [4].

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One has to keep in mind that the emission data in official documents is an approximation of reality, using lab tests and actual measurements, which may not be representative of reality. One could envision many scenarios regarding purchase behaviour (SUVs versus regular cars), the car market (new and second hand), actual daily use and driving behaviour (speeding), car maintenance and the manipulation of lab tests, that would lead to different emission figures.

In 2025, more than 1.6 billion cars are in use worldwide [5] and this number is rising, in particular in developing countries where economic and population growth go hand in hand.

1.3 Going electric

Governments in many developed countries offer financial support for car buyers and manufacturers of cars and electric charging facilities. As a result, the number of EV on the road and charging infrastructure is expanding in these countries. Over 42 million EV were in active use globally in 2024 [6]. Compared to the 1.6 billion cars worldwide, this is still a small number, but it is expected to rise even when buyer stimulation ends, as technical development is reducing a key disutility, limited driving range (anxiety), by a combination of extended driving range and investments in (public) charging infrastructure.

In battery EV (BEV) tailpipe emissions are replaced by those from power plants, which varies with the fuel sources of electricity; the energy mix [7]. EV are called green or 'zero emission' mobility. This holds for local emissions like NO_x and C_xH_y, but not for CO_2 or externalities from the sourcing of EV batteries or EV production in general. Such labels should be considered as greenwashing.

1.4 Scope and definitions

The research and the paper were restricted because of practical reasons as follows:

- Only lithium mining was in scope, excluding the sourcing of many other, partially scarce, components and minerals such as cobalt.
- An estimation was made of the soil and water use of lithium mining. No attempt was made towards a full lifecycle analysis, because this very complex activity has already been done by others (e.g., Siwiec et al. [8]).
- Where the word lithium is used, it refers to the battery-ready, synthetic, version of lithium, which in practice is either lithium-carbonate (LiC) or lithium-hydroxide (LiOH) [9].
- Emissions to the air from mining, production and transport of lithium are briefly referred to, but not substantiated.
- The same holds for oil used to produce and transport petrol, diesel and LNG for ICE.
- The term li-ion comes from the electrochemical process in a battery cell, where electrons travel between anode and cathode, as part of a charge and recharge cycle. The loss of an atom is called ionisation, hence the name of the battery;
- LIB are high voltage (HV) multi-cell batteries, exclusively used in EV. They should be distinguished from the low voltage (LV) batteries used in ICE. Battery and car production are out of scope;
- Only fully electric car (BEV) are considered (in Section 3).

1.5 Research questions

The main question addressed in this paper was: How to source a required volume of lithium in a way that reduces the environmental and social-economic impact of mining this resource?

This main question will be addressed via four sub questions:

Sub question 1: What are main negative impacts of lithium mining?
Sub question 2: How much lithium is needed to supply a sample Dutch car fleet?
Sub question 3: What is the environmental and social impact of sourcing this amount of lithium to the car industry?
Sub question 4: What could policymakers do to reduce the environmental and social impact of lithium mining?

1.6 Research approach and gap

Literature was studied to have a generic understanding of the system of lithium mining and the most relevant negative impacts on source countries. With that in mind, the switch was made to an EV user country, the Netherlands, in order to explore the role of the Dutch government and others in mitigating these impacts. While many countries stimulate EV deployment and most of the literature discusses the user or manufacturers perspective, not many, including scholars, address the elaborate problems that Li-ion sourcing poses for source regions and the role EV user countries could play in reducing this impact. By addressing this issue, we therefore help to reduce a perceived gap in the literature.

The research approach shown in Table 1 was chosen.

Table 1: Research approach.

Sub question	**Methods**	**Section**
(1) Externalities of lithium mining	Literature	2
(2) Estimated lithium needed	Literature, modelling	3
(3) Environmental impact	Literature, modelling	3
(4) Mitigating policy options	Literature, policy analysis	4

2 THE SYSTEM AND THE PROBLEM

2.1 Introduction

This section discusses three impacts of lithium mining; its environmental, socio-economic and also political implications, which influence each other in a complex way.

2.2 Brine metal salt mining

Lithium can be sourced via two distinct mining techniques [9], [10]:

- Brine: Extraction of lithium-chloride, which is processed into lithium-carbonate (LiC);
- Hard rock: Extraction of lithium-sulphate (spodumene), from which either lithium-hydroxide or lithium-carbonate can be made.

Graphite is used in the LIB anodes; lithium in the cathodes. LiC has a lower energy density than LiOH and lower production cost. lithium-carbonate can also be processed into lithium-hydroxide, but this additional process makes the lithium more expensive [9].

Brine can be found in Chile, Argentine and Bolivia, the so-called lithium triangle in the Central Andes, an area of around 4,000 km^2. In Chile's Atacama Desert, lithium was discovered in 1969. Production began in 1984. In about 35 years 246,956 metric ton of lithium-chloride was produced. Chile produces about one quarter of all lithium in the world.

Lithium reserves are thought to be massive, but uncertain [11]. The lithium originates from hard rock formations, as in Australia, but they dissolved into (salt) water from the mountains. Pure lithium metal cannot exist due to its reactivity.

In case of the Salar de Atacama desert in Chile (Table 2), an area known for its complex, unique and valuable ecosystem with large salty plateaus, access to sufficient (fresh, clean) water is (ultimately) determining between life and death for all species inhabiting such regions. Lithium processing [12] is a series of mechanical and chemical steps to rise the lithium percentage from 0.17% to 6%, taking up to 2 years [13]. Sulfuric acid and sodium hydroxide are used to isolate and concentrate the lithium. The process remains have to be disposed of as well. In countries and regions with weak governance structures, this usually means that they are shovelled into landfills. The negative impact is also felt in a wider area, as process / runoff water pollutes already scarce water resources and migrate to other areas, especially in elevated terrain. There is an ongoing debate whether brine should be regarded as water, hence its extraction reduces the amount of potable (fresh) water. The high salt content and other minerals distinguish it from fresh water; hence humans, flora and fauna cannot drink it. Since it is part of a complex hydraulic system, its extraction will not be without (indirect) consequences, however [13]. Solid waste may also migrate.

Table 2: Brine and water used in battery-grade lithium mining [14].

Salar de Atacama (Chile)	**Per ton lithium**
Modelling: Cradle to gate	
Li_2CO_3 (87%) + LiOH (13%)	
Brine	217 m^3
Water	5.5 m^3
Desalinated water	7.5 m^3

Further processing can be done in local plants, if available or cost-effective. With local processing, remains are discarded locally. As PR China has major factories for this activity and a heavily subsidized and growing car industry, export is a logical alternative for local processing. In that case China gets waste. Lithium transport by road, rail and ship add to the environmental impact.

2.3 Environmental impact from spodumene mining

Conventional open pit or blast mining converts rock into raw lithium. Again (potable) water is used in the extraction process. The lithium percentage varies with the source material. Granite has the highest concentrations (see Table 3). Spodumene is used as an example. Petalite (Li_2O, Al_2O_3. $8SiO_2$) is a comparable source material with a slightly lower lithium content [15].

Table 3: Lithium concentration found in solid rock mining [15].

Granite rock	**Chemical form**	**Li_2O**
Spodumene	Li_2O, Al_2O_3. $4SiO_2$	8,03% (theoretical
For Li_2CO_3		6–7% (practical)
Average ore		1–2%

Australia is the main producer of spodumene in the world. It lacks processing facilities and a car industry, hence its exports to China. Both in Australia and China, a massive and growing amount of waste is created. In 2020, this already amounted to 200,000 metric ton [16], which has to be discarded of. With growing volumes of extracted minerals, the waste problem and its environmental impact keep growing. There is already resistance from indigenous and other local residents against mining (companies), that has led to public demonstrations and legal action in Australia, a country where the economic benefits of mining seem to major over environmental concerns and rights of indigenous people [17].

Extraction, production and transport of lithium via both technologies consumes also a large amount of diesel fuel, which creates a substantial amount of CO_2 as well (see Roche et al. [13] for the Atacama case).

2.4 Socio-economic impact and political arena

The socio-economic impact of lithium mining can be substantial. Chile was already briefly touched upon. Another example is Argentine [18]. There, water extraction destroys nature areas and makes life for indigenous people and their livestock very difficult. Multinational mining companies are seemingly above the law, supported by a market-oriented government. They pay only 0.3% export tax, which does not compensate either the local communities or the country at large. Weak governance in a vulnerable democratic setting threatens the land and water rights of indigenous people and divides the people, creating social conflict [19]. As a result, only few may benefit economically from this natural resource. In contrast, mining companies pay 40% tax in Chili, which at least gives the option to manage and compensate the negative impact on local communities and the environment if politicians want to do so [13], [18].

These were examples of countries with established production facilities for lithium. The debate about developing mining sites is in full swing in other countries, including the USA and Europe. European countries like Germany, Czechia, Serbia, Spain, Portugal and Austria are thought to have large resources, but protests and conflicts are rising [20], [21]. This is not strange, as contrary to the much poorer and less educated (indigenous) people in current source countries, European protesters are well educated and organised. They can rely on a better functioning governance and legal system and a relatively free press.

To answer sub question one, both widely used lithium mining techniques deplete and pollute large amounts of scarce (potable) water. Use of fossil fuels during production and transport creates emissions to the air. Environmental impacts include loss of land and habitats, destroying life and occupation of local (indigenous) people living in and in proximity of lithium mines. Mining increases social divide and conflicts over land and water rights as well.

3 CASE STUDY

3.1 Introduction

The Netherlands is a small, densely populated country of 31,543 km^2. Its 18 million inhabitants [22] own over 8 million cars, with which they drove 119.6 billion kms in 2023 [23]. The Netherlands does not have a local car industry anymore, but there are car parts suppliers to foreign manufacturers. As a trading country with major seaports, many cars are imported and exported. This economic dependency is linked with political dependency, as decisions about the future car supply are mainly made abroad, by the EU and other trading partners.

3.2 BEV and politics

The focus is on full BEVs. This is because the actual charging behaviour of plug-in hybrid EV (PHEV) owners is unknown. The owners may have bought their car just for the purchase subsidies and reduced road tax. If used in petrol or diesel mode, then laboratory fuel economy and emission estimations cannot be used. Stricter emissions standards for ICE (Euro 6e in the European Union), make PHEV obsolete from a tailpipe emission perspective [2]. With EV sales being on a bandwagon, politicians may argue that subsidies are less needed to direct purchase and use behaviour. The issue of rising cost of such subsidy programs is prevalent, leading to adapted or even abandoned subsidy programs [24]. Public spending on charging networks makes more sense then. If production of new ICE will stop in the EU by 2035, subsidies for EV owners are obsolete. But, without state support EU manufacturers may not be make the transition, as the EV market is flooded by exports from PR China that subsidises its car industry heavily, because of its strategic nature [25].

3.3 Estimated lithium needed for car fleet

The following assumptions were made:

- The Dutch car fleet consists of only one representative car model with average, uniform, LIB properties: a mid-range Volkswagen ID.3 Pure with 45kWh LIB;
- All yearly kms are driven by this car model;
- LIB will last at least as long as an EV itself;
- Car use and charging behaviour are out of scope.

If the entire 119.6 billion car kms of 2023 were driven in this car, a model with an average energy consumption of 0.16 kWh per km, then the national electricity demand for passenger car mobility would be:

$$119.6 \text{ billion km} \times 0.16 \text{ kWh/km} = 19.136 \text{ billion kWh} \quad (1)$$

This is equivalent to 19.14 TWh of stored electrical energy.

The amount of lithium required per kWh of battery capacity varies with battery design. Estimates vary widely, from 5 to 15 kg [26] or even 18 kg (0.4 kg/kWh) if lithium of all components is included [27].

Using the latter source as an upper-bound estimate, the same car fleet batteries would contain

$$19.136 \text{ billion kWh} \times 0.4 \text{ kg/kWh} = 7.654 \text{ million ton of lithium} \quad (2)$$

This figure represents the theoretical lithium requirement if the entire Dutch passenger car fleet were to be electrified using battery packs with 400 g of lithium per kWh.

3.4 Impact on brine processing countries

Suppose that this amount of lithium would be resourced from Atacama region, what would be the local water impact (Table 4)?

A car fleet is neither built nor replaced at once, hence these values are not equivalent to yearly production, but spread out over time. Nonetheless, they are considerable for only 8 million EVs.

Table 4: Brine and water used in battery-grade lithium mining.

Salar de Atacama (Chile)	**Per ton**	**8 million EV**
Li battery-grade		7,654 million ton
Brine	217 m^3	1.67 billion m^3
Water	5.5 m^3	42.1 million m^3
Desalinated water	7.5 m^3	57.41 million m^3
Water consumed in NL 2023 [28]		1.2 billion m^3

The Atacama desert is the most arid place in the world, where an inch of rain represents a few years of rain [29]. The region houses 10% of Chile's population. Chile has a growing drought problem, because of the massive use of water for its mining industries (lithium, copper, gold). Water that evaporates from artificial ponds in desert areas with very limited vegetation is not recuperated, but lost, which makes an already harsh environment even more difficult to exist. Surrounding areas will also be negatively impacted.

If the current 1.6 billion cars on the world's road should become electric, then these numbers should be multiplied by 225, creating an even larger negative impact in Chile.

The figures are in a ballpark, because lithium battery designers may choose different designs and battery components to build an LIB. More detailed information could not be found in the public domain. The 45 kWh LIB example gives a source of direction. With other, less or more powerful batteries and technical development, the amount of lithium and other battery materials such as cobalt, needed will vary. Finally, unless lithium is fully recycled and re-used for the same purpose, then the same amount is needed to replace these cars at end-of-life.

With this elaboration, sub questions 2 and 3 were addressed.

4 POLICY PERSPECTIVES

4.1 Introduction

This is a qualitative exploration into ways to reduce the environmental impact of lithium mining on source countries. It also offers opportunities for further research.

4.2 Less intrusive mining from brine

Direct lithium extraction (DLE) is thought to be more efficient, environmentally friendly with lower water consumption and impact on the landscape [26].

4.3 Sourcing from other areas

Switching lithium sourcing from the Andes to Australia is an alternative. If lithium is processed locally instead of shipped to PR China, then higher value added (profit, tax) would allow to invest in less intrusive mining techniques and much less global transport of raw ore.

4.4 New battery technology

Lithium could (partially) be replaced. Could solid-state batteries be the future [26]? This could also help to reduce the risk of thermal runaway and fires in EVs.

4.5 Lithium recycling

Repair and recycling of LIB could help to reduce the amount of virgin lithium needed. The Netherlands already has a thriving recycling network for cars. New recycling techniques could make recycling more cost-effective and easy [26].

4.6 Supply chain responsibility

Source countries struggle with the powers of large, multinational mining companies. This problem is larger in case of weak governance structures. Introducing supply chain responsibility for car manufacturers could make them responsible for environment-saving lithium sourcing. They buy EV minerals locally, but the contracts are not public. Transparency is not easy, as the clothing and wood industries experience, but the car supply chain might offer different opportunities. The LIB cost/performance ratio is becoming more positive, reducing cost per EV and offering an opportunity for compensatory payment to the local communities as well.

4.7 An ecolabel for EVs

To reduce the amount of greenwashing surrounding EVs, an eco-performance label would make sense. A suggested approach is the one used for energy labels for electrical appliances or houses as practiced in the EU.

4.8 Mobility policy

The direct relation between the number of cars on the road logically means that reducing the number of cars on the road also reduces the amount of lithium needed. A large array of options is available, ranging from improved public transport, shared mobility, stimulation of active modes etc.

5 CONCLUSIONS AND RECOMMENDATIONS

A large amount of water of various qualities is needed to produce lithium-chloride for LIB. Extracting vast amounts of water from already very arid regions exceeds carrying capacity of the environment by a large extent. It is possible to reduce this impact (substantially) as is shown tentatively and qualitatively. To this end, a range of policy suggestions could be explored further by scientists and practitioners.

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