SIZE MATTERS: THE ECONOMIC AND ENVIRONMENTAL IMPACT OF SMALLER EV BATTERIES

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Facing up to the lithium supply challenge

Overview

Conventional thinking about the future of battery electric vehicles (BEVs), and the lithium-ion batteries (LIBs) that power them, is founded on two broad expectations:

- Annual global passenger BEV sales will grow dramatically, to approximately 30-40 million vehicles in 2030 [1, 2]
- Range anxiety is the limiting factor behind consumer BEV adoption, meaning that the average size of BEV battery packs must (and will) continue to grow, to increase BEV range to mainstream-acceptable levels

There's just one snag: the rapid growth of BEV sales, which are widely expected to account for about 80% of total lithium carbonate equivalent (LCE) demand in 2030, is leading to a growing imbalance in lithium supply/demand. The lithium extraction industry expects the market to be in undersupply from 2022 through 2030 (**Figure 1**), and by the end of the decade the mean annual deficit is expected to increase to 0.9 million tonnes of LCE. In other words, lithium supply will be just 65% of mean expected demand [3, 4, 5].

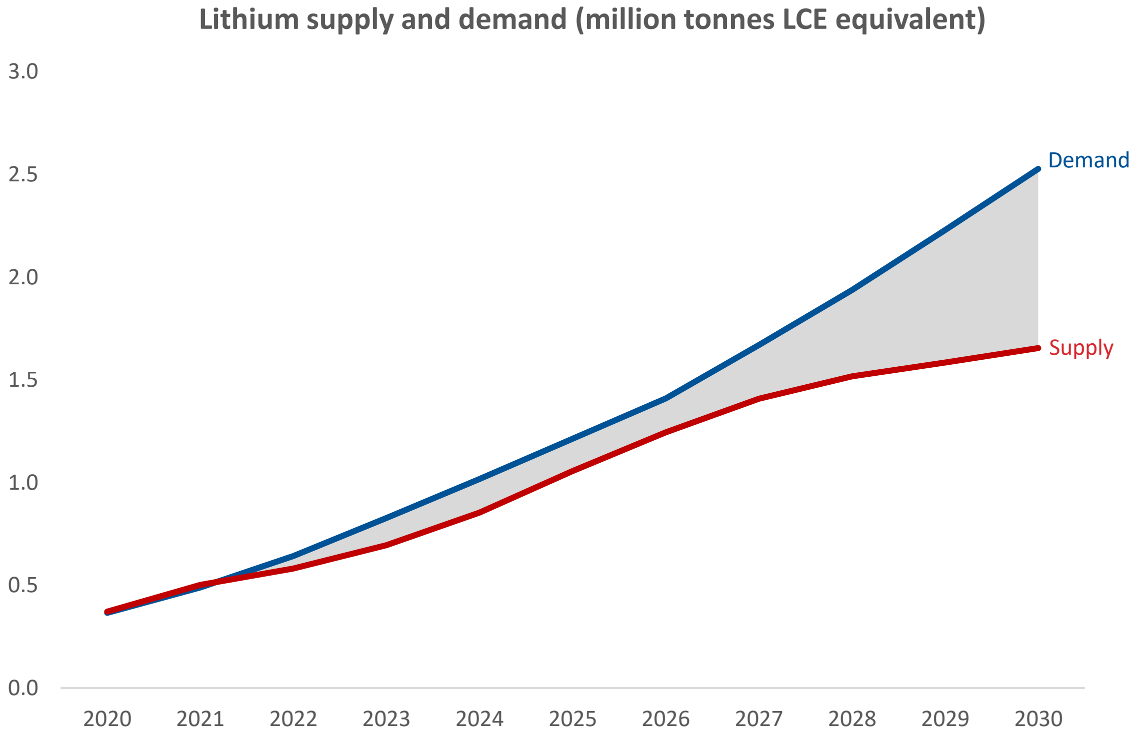

Figure 1: Forecast of lithium-ion battery supply and demand deficit (grey) to 2030. Source: Exawatt calculations, based on data from Albemarle, Orocobre and AMG Lithium [3, 4, 5]

It's therefore highly unlikely that enough lithium will be processed to enable expectations of BEV sales growth **and** also for large pack sizes to be satisfied. Something has to give.

If pack size continues to increase or even flatline, the BEV industry faces the prospect of a significant shortfall in vehicle sales over the next 10 years, relative to current expectations. But there is a solution. What if, instead of chasing ever-increasing battery pack capacities, automotive manufacturers were to focus on smaller packs?

What is the “right” vehicle range?

BEV range

Exawatt believes the widespread assumption of a consumer need for increasing battery range, and therefore increased lithium consumption per vehicle, is built upon a flawed premise: that drivers make frequent long journeys. However, the overwhelming majority of car/van vehicle journeys are very short. According to annual surveys conducted from 2002 to 2020 by the UK Department for Transport (**Figure 2**), 99% of UK car journeys were under 100 miles, and the average trip was under 10 miles [6]. Therefore, a BEV battery that enables hundreds of miles of driving range is massively under-utilised for relative to the average usage profile, unnecessarily increasing the upfront cost of the vehicle **and** its carbon footprint.

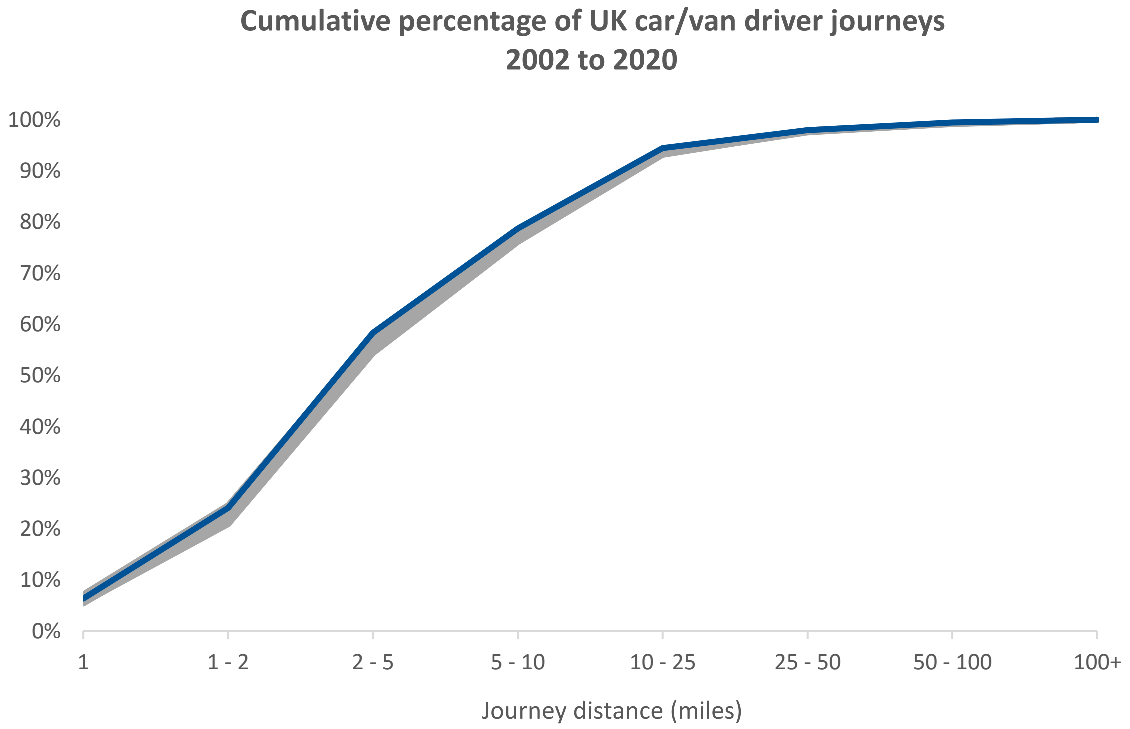

Figure 2: UK car/van journeys from 2002-2020, grey lines denote 2002 – 2019 and the blue line denotes the result of the 2020 survey. Source: National Transport Survey from the UK Department for Transport [6]

In this whitepaper, we outline the cost savings that could be achieved by decreasing pack size; we compare manufacturing emissions for small and large packs; and we propose solutions to alleviate range anxiety during those rare long car journeys.

For illustrative purposes, we will compare the economic and environmental costs of battery packs at two “nodes”: 30 kWh and 60 kWh. We emphasise that we are not suggesting that auto makers must, or can, halve the average size of their packs; we are arguing that pack sizes need to decrease.

The economic cost of large battery packs

Cell and pack economics

The price of LCE in China has risen dramatically over the past nine months. Cathode active material manufacturers reported that their LCE purchase cost grew by a factor of five between September 2021 and March 2022, from $15/kg to $75/kg. This effect was also illustrated further downstream, when two of the world's largest cell manufacturers, CATL and BYD, increased their cell prices by 10% and 20% in November 2021, respectively, citing raw materials supply chain issues.

Using the Exawatt Battery Cost Model (BCM), and average spot prices for raw materials, we estimate that the cost to manufacture an NMC 811 pouch cell in China has risen from $80/kWh in 2020 to $137/kWh in the first half of 2022 (**Figure 3**). Furthermore, the cost of the cathode alone in 2022 accounts for more than 66% of the total cost, compared to about 40% in previous years. When applying additional costs at the pack assembly step, plus a margin for the manufacturers, the pack price rises above $200/kWh in 2022.

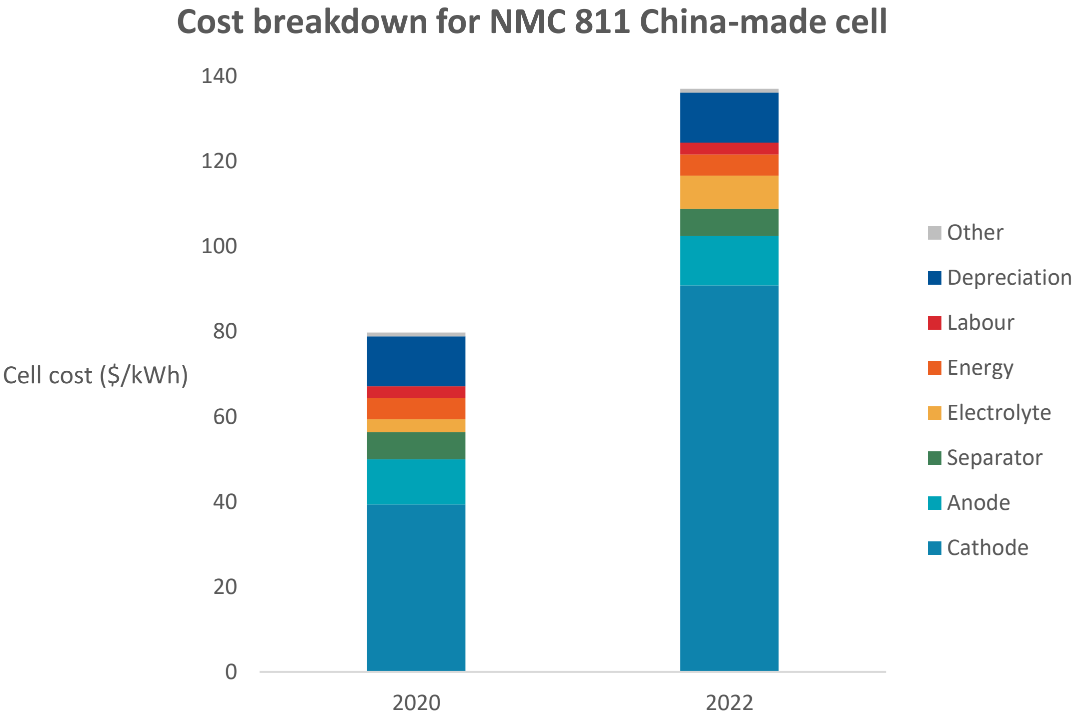

Figure 3: The impact of spot price on the cost of NMC 811 pouch cells made in China. Source: Exawatt BCM

In a BEV, a pack price of $200/kWh translates to a total cost to the OEM of more than $6,000 for a 30 kWh pack, and more than $12,000 for a 60 kWh pack (note: these pack sizes are used for illustrative purposes only). The pack size reduction yields a saving of $6,000, which could translate to a $9,000 reduction in BEV price after margin stacking. Furthermore, the energy efficiency of the vehicle increases as the pack gets smaller, due to the significant weight reduction of the vehicle.

Therefore, a smaller pack can save on the initial upfront cost of a vehicle and, through an increase in efficiency and thus a reduction in overall electricity use, provide a small decrease in operating costs.

The environmental cost of large battery packs

Embedded CO_2 equivalent

Given that one of the key arguments for reducing battery pack size is rooted in sustainability – using fewer technology materials and saving part of the environmental burden of mining, processing and refining them – Minviro developed environmental impact insights to match against Exawatt's cost analysis. It is increasingly clear that raw materials supply choices are the key driver of battery environmental impacts [7], but how does this translate to the different cost scenarios explored so far?

Life cycle assessment (LCA) was used to quantify the environmental impact of both battery scenarios, with a focus on the global warming potential impact category as an indicator of climate change impact. The same bills of materials used for the cost modelling presented above were used as inputs for the life cycle inventory, and the information was connected to Minviro's raw material impact database to calculate the kilograms of direct and indirect CO2 equivalent emitted to make each pack. The methodology uses the framework from Environmental Footprint 3.0 [8], using major raw material impact data generated by Minviro for the NMC 811 bill of materials, and background impact data from Ecoinvent 3.8 for all other inputs. Manufacturing electricity calculations are based on a combination of Minviro internal calculations for electrode production and a flexible cell manufacturing academic model for assembly [9].

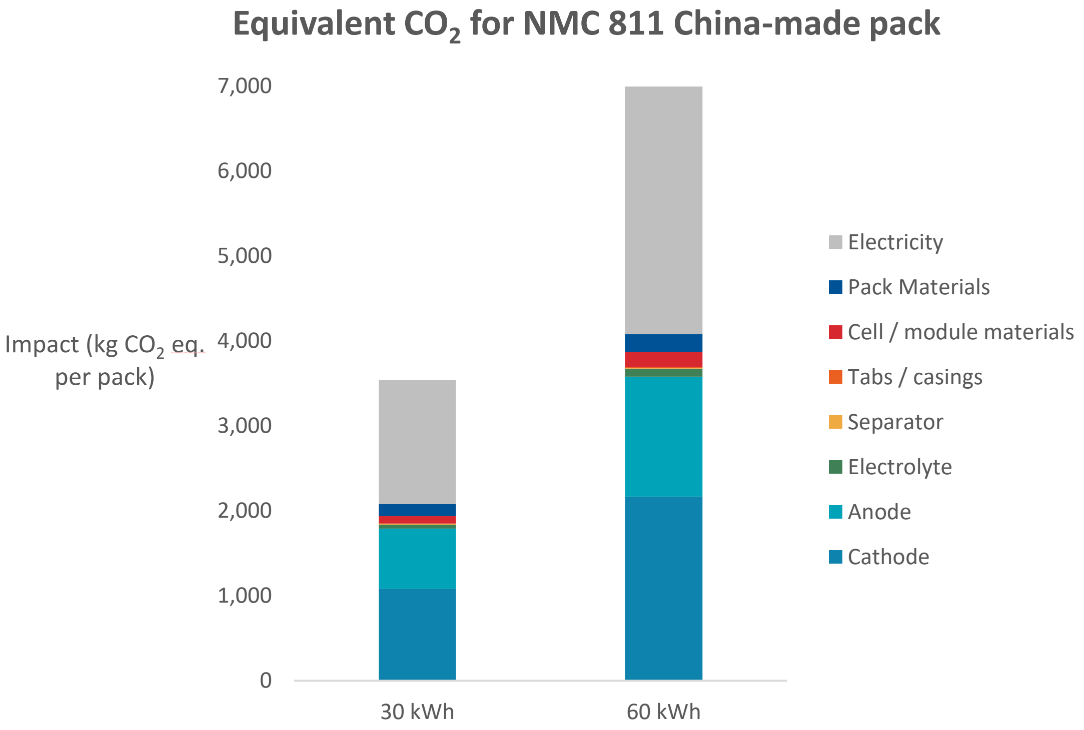

Figure 4: Carbon emitted when producing a 30 kWh and 60 kWh battery pack. Source: Minviro's LCA impact database

As expected, halving the battery pack size roughly halves the total climate change impact, as all material and energy inputs are reduced by ~50%, excluding some casing components.

When considered on a per-kilowatt-hour basis (the normal manner to present battery LCA conclusions), this results in global warming impacts of 118 and 117 kg CO_2 eq. per kWh for the half and full-size batteries, respectively, based on Exawatt's bill of materials. As such, smaller batteries, with a proportionately smaller capacity, will result in negligible difference in kWh-normalised impact.

For the cumulative impact of the packs, the half-size battery has a global warming potential impact of 3,535 kg CO_2 eq. per 30 kWh pack, whilst the full-size battery's impact is 6,994 kg CO_2 eq. per 60 kWh pack. Provided a battery still performs as needed within an electric vehicle, the half-size battery provides an obvious, tangible environmental boon.

Comparing the environmental impact of the packs (**Figure 4**) to Exawatt's price breakdown (**Figure 3**), some key differences between main contributors are clear. Firstly, electricity impacts, which are contained within the relevant components in the cost model but are separated in the environmental analysis for clarity, are large given the placement of this hypothetical battery production near a fossil-fuel-dominant grid mix in a common battery-producing region of China. By manufacturing identical battery packs with a source of renewable energy, this particular impact can be reduced significantly.

Raw material impacts are, by contrast, more difficult to address and must involve upstream production considerations. Anode environmental impacts, in particular those from graphite sources, are often significantly underestimated [10], due to historic use of country averages on non-asset-specific LCA data inputs or inaccurate process data [11]. In this study, the relative anode environmental impact, calculated using high-quality, regionally accurate data, outweighs its relative cost contribution, indicating the discrepancy between sustainable and low-cost materials. Often cheap materials are produced using more impactful energy sources, and this presents a huge issue, and an opportunity, for battery supply chains to leverage sustainable resource streams. The same is true for all major battery components in this study (in particular, high-mass inputs like lithium and base metal sulfates), and discerning lower-impact cathode, anode and cell/pack components must be integral to strategic and low-impact battery project planning.

In general, the relationship between the environmental impact and cost benefit of halving battery size is simple but has many internal complexities when considering supply chains. The boundary between the most cost-effective and most sustainable battery configuration is difficult to pinpoint, but by using the combined approach of cost analysis and LCA for a single bill of materials, we gain insights into the best way to approach this problem. Furthermore, during the use phase the cumulative electricity requirements (and the related impacts) will be lower for a smaller pack size, owing to reduction in mass of the final vehicle.

Exawatt and Minviro recommendations

There are several routes to enabling smaller pack sizes, and we discuss a few of them below.

Fast charging

The first route is fast charging. By increasing the rate at which a vehicle can be charged, charging times can be reduced to levels that would be acceptable for mainstream drivers on long journeys. For example, a 150-mile journey at an average speed of 50 mph would take 3 hours, or 180 minutes. If we set a 10% limit on stopping time (18 minutes), this would require C-rates exceeding 3C across the UK fleet, rather than among a relatively small set of vehicles (**Figure 5**).

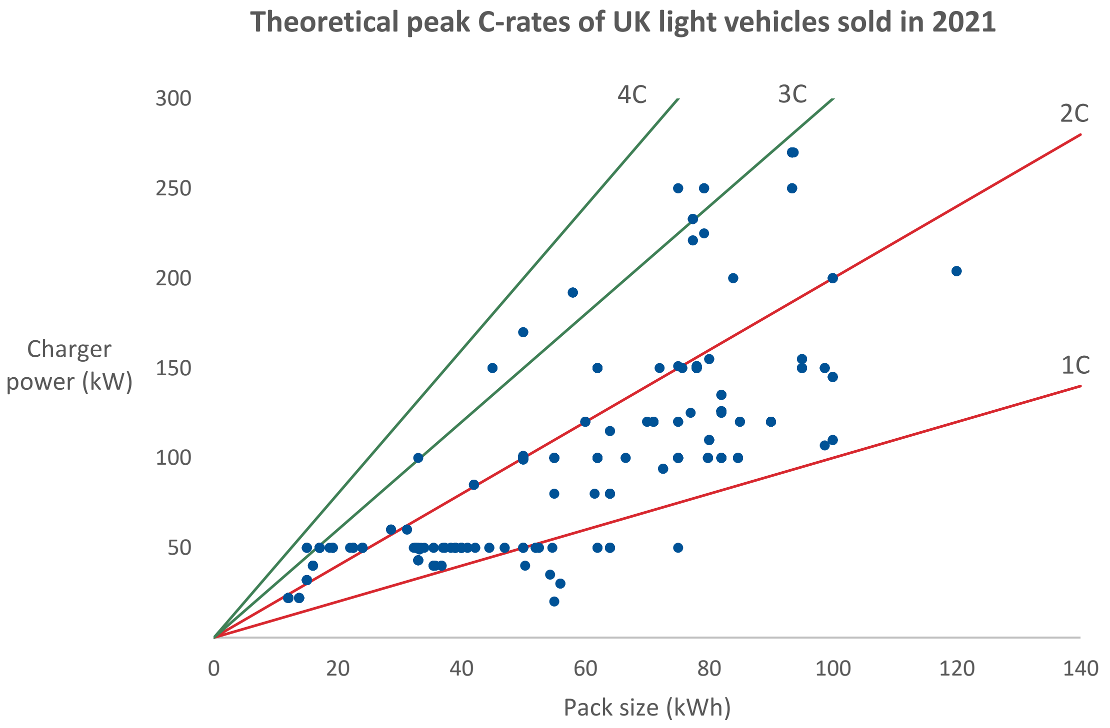

Figure 5: Theoretical peak C-rates of UK light vehicles sold in 2021. Source: Exawatt, UK Department for Transport [12]

Improved materials

With a smaller battery pack, the average depth of discharge is likely to exceed that of a large pack in general use. This would require cathode materials to be mechanically strong and resistant to degradation. One potential solution is the use of lithium iron phosphate (LFP). Traditionally ignored for automotive applications, LFP has experienced a stellar rise in the past year, due to its low cost and innovations in cell design that have enabled it to rival NMC 622 in pack-level energy density. LFP's long cycle life also makes it a prime candidate for cells that undergo regular deep cycling. A second solution is to engineer the cathode particles to be resistant to degradation, either through a single-crystal morphology, or by engineering transition metal concentration gradients into particles.

Range extenders

Range extenders, as deployed by BMW in some early versions of its i3 model, use a secondary energy source to charge a battery pack while driving, reducing the need for stops during those rare long journeys and alleviating range anxiety. This can be achieved by splitting a battery pack into two, with the discharged battery being charged while the traction motors run from the charged pack. In the short term, the range extender can be based on existing small and efficient internal combustion engines (ICEs), while hydrogen fuel cells may emerge as a competitive technology in the long term.

Conclusions

Conclusions

Ultimately, the desire to switch from ICE vehicles to EVs is environmentally driven. It is therefore imperative that we design vehicles that aid in this goal, while meeting the needs of drivers.

For the electric vehicle industry to adopt small packs as the norm, one or more of the following developments must occur:

- Educate OEMs and vehicle buyers that “small is beautiful” from a cost, performance and environmental perspective
- Improve cell C-rate capabilities while minimising cell degradation, to enable ultra-rapid charging of small packs at widespread motorway service areas
- Focus on cell chemistries that can support high depths-of-discharge with minimal degradation, to maximise the use of the lithium in the battery
- Incorporate range-extending technology to enable longer journeys without the need to carry pack weight that is, for most purposes, “idle”
- Develop novel business models, including battery swapping and leasing arrangements that allow drivers to switch between short- and long-range models as their needs change

Building EVs with appropriately sized battery packs not only ensures that the materials supply chains are of sufficient size to enable today’s aggressive EV sales targets to be met, but also reduces the cost and environmental impact of the vehicles (**Figure 6**). Both factors will be critical to enable widespread EV adoption while maintaining global decarbonisation goals.

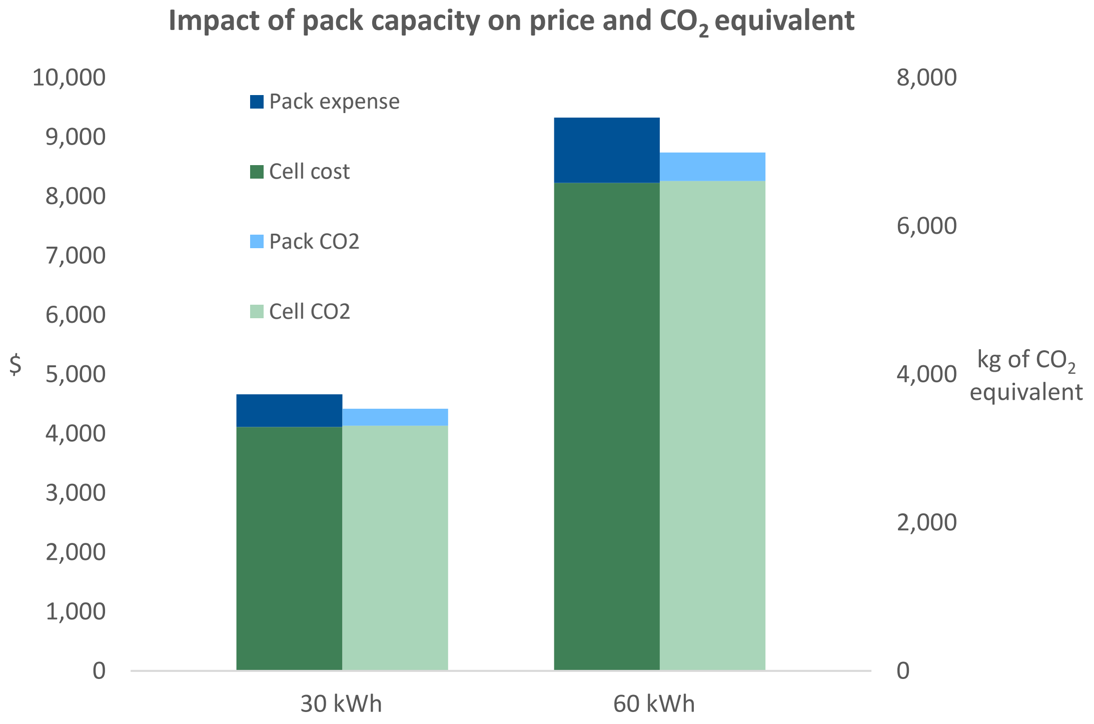

Figure 6: The impact of battery capacity on pack price and CO$_2$ equivalent. Source: Exawatt and Minviro

Future work

Future work

The global supply of lithium for all applications is likely to fall far short of demand until at least 2030, so finding ways to reduce lithium intensity in the EV sector at large is beyond critical: there's no other option. Reducing the size of the average EV battery pack makes sense from an economic and environmental perspective, but as we have argued in this whitepaper, mapping the journey to smaller batteries requires careful consideration of multiple factors, from cell chemistry and design to infrastructure improvements and even changes in the architecture of the EV powertrain itself.

This whitepaper opens the door to future analysis into the cost and environmental impact of current and future battery technologies. Of particular interest is the trade-off between cost and emissions when comparing different battery chemistries, raw materials supply chains and cell/pack designs.

A topic not explored here, but of increasing focus, is the rise of sodium-ion batteries and the disruptive effect they could pose to the demand for lithium-ion batteries given their potential cost and environmental benefits and the possibility that sodium-ion materials supply chains may face fewer upstream challenges. Finally, increasing the energy efficiency of vehicles, through the use of silicon carbide (SiC) inverters or improved tyres, for example, enables a reduction in grid electricity generation requirement, yielding cost and environmental savings across the supply chain.

Swift and effective decarbonisation of the automotive sector requires careful strategic decision-making with respect to vehicle electrification. OEMs, cell/battery manufacturers, materials suppliers, policy makers and investors must understand the cost **and** climate impacts that arise from their decisions. For more information on how Exawatt and Minviro can help, feel free to connect and contact us, see the back of this document.

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Ed Rackley PhD

A materials scientist by first degree, Ed completed his PhD in electrochemical systems at the University of Sheffield. Ed has experience in cell cathode manufacturing.

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As part of her Materials Science MEng at the University of Sheffield, Catie joined Exawatt in May 2022. She plans to continue her studies in battery science at PhD level.

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