EERA
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Environmental Impacts of Lithium-Ion Batteries

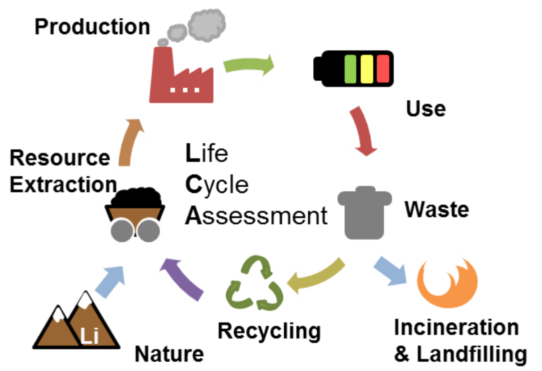


Figure 1. Principle of LCA: Environmental impacts are quantified along the whole life cycle of a product or service

Background

Lithium Ion batteries (LIB) are experiencing a stunning growth. Due to their superior characteristics in terms of power, energy density, lifetime and efficiency, but also due to drastic decreases in cell prices they are the technology of choice for mobile applications (handheld devices and electric mobility), but also for stationary installations that provide flexibility and stability to the grid. However, concerns are increasingly raised regarding the environmental impacts and the resource demand associated with their production. These issues are targeted within the SP6 of the EERA Joint Program on Energy Storage, dealing with the environmental and economic impacts of energy storage technologies. Life cycle assessment (LCA) is the prevailing methodology applied for quantifying the impacts of goods, products or services over their whole life cycle under consideration of numerous different impact categories [1]. For LIB, several studies have been released in the last years dealing with the environmental impacts of their use and manufacturing [2,3].

Battery production

- Highly energy intensive (dry room operation)

- Requires partially scarce or energy intensive metals like Ni, Co, Cu, Li, Al

- Fluorinated and toxic compounds in electrolyte and Binder

+ High energy density reduces amount of battery required per unit (e.g. kWh) of storage capacity

Battery operation

+ Charge-discharge efficiency (low electricity loss)

+ Lifetime (amortization of manufacturing impacts)

+ Energy density / weight (for mobile operation)

Quantifying environmental impacts

Different environmental impacts need to be considered when assessing LIB, among these greenhouse gas emissions (GHG), resource depletion, toxic impacts on humans and environment, air pollution, acidification, and many more. Since these are often difficult to quantify and difficult to communicate to the public, assessments are often limited to GHG emissions and resource impacts [2]. However, impacts in other categories might be more severe and contribute more to the environmental burden of LIB than their GHG emissions, what needs to be considered when assessing LIB.

The cumulative energy demand (CED i.e., total energy demand including all upstream processes like mining, transport, electricity generation and so on) is often considered a good first proxy for environmental impacts of industrial processes. For LIB, the average CED for producing 1 kWh of storage capacity is 328 kWh (average value across all studies from a meta-review [2]), giving an idea of the importance of the manufacturing process. This energy investment needs to be amortized during use: For a battery with a lifetime of 1000 cycles, each kWh provided over its life would carry a "backpack" of 0.33 kW. In terms of GHG emissions, an average 166 kg CO_2^{eq} are emitted for producing 1 kWh of battery. Also this needs to be amortized, resulting in a backpack of GHG emissions of roughly 30-40,000 km for an average small-mid-sized car (distance

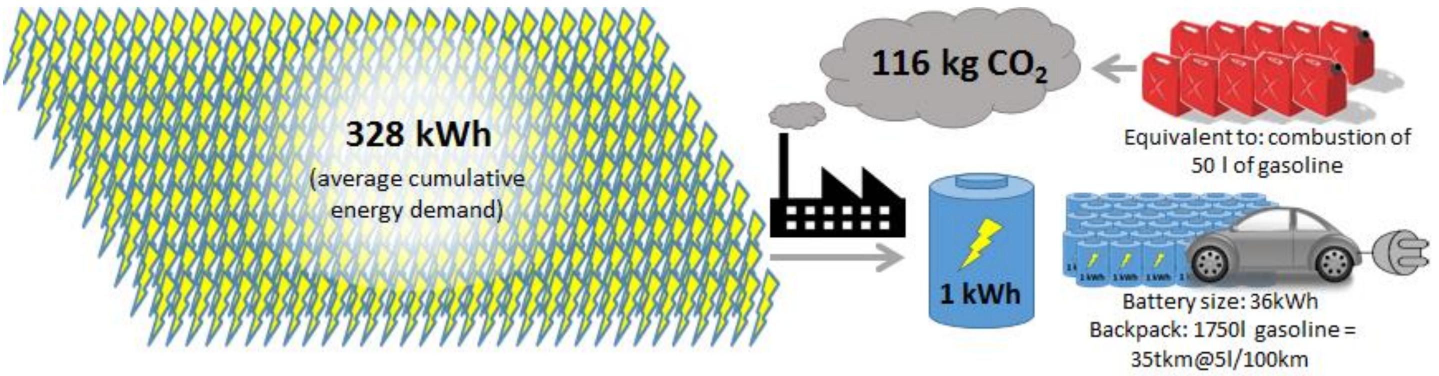
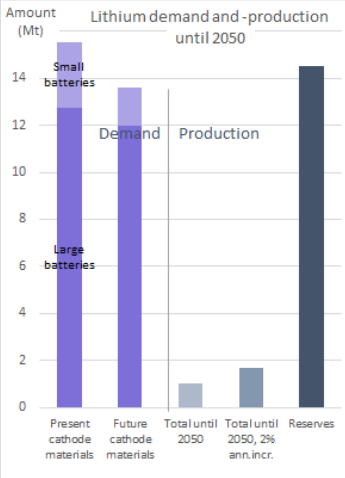
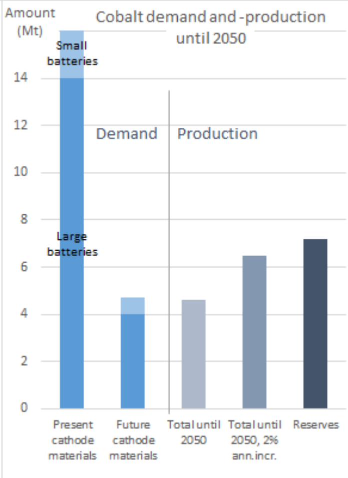


Figure 2. Average cumulative energy demand and CO2 emissions for manufacturing 1 kWh of lithium-ion battery. Own picture, data from [2]

a conventional car could travel just until emitting the GHG caused by the producing the equivalent electric vehicle's battery; without considering yet the emissions associated with electricity generation).

Several key drivers for the high energy demand of LIB production and the associated environmental impacts can be identified from existing studies [2,3]. These are the high energy demand of the battery manufacturing plants (caused to a significant share by large dry rooms required for the handling of the highly hygroscopic electrolyte) in combination with their locations (LIB manufacturing mainly in China and Japan with a comparably carbon intensive electricity mix). Also the mining activity associated with the metals required in the LIB is a major source of impacts. Especially the scarcer metals like cobalt and nickel, but also copper are associated with high impacts from mining activities, caused by leaching and emission of toxic and often acidic effluents and gases. Since these materials are also the most expensive ones, efforts are already being made in reducing their content, especially cobalt. However, they provide key properties to the cathode materials, like stability or capacity, why their substitutability is limited.





End-of-life / Recycling

- Few established processes, recycling costly

- No labelling for identification of cell chemistry

- Safety issues due to fluorinated electrolyte (toxic and flammable)

- Only part of materials can be recovered due to high integration of cells

Resource availability

Lithium-ion batteries rely on numerous functional materials, among them cobalt, nickel, lithium, copper or graphite. Some of them are classified as critical regarding supply reliability by the EU, while others are simply scarce. Here, tools like material flow analysis in combination with scenario development allow to provide a first (though uncertain) picture of possible resource shortages [4]. While the absolute values obtained by different studies vary, the probability seems high that for a full energy transition (i.e. a profound decarbonisation of the economy) on global scale lithium-ion batteries would be limited by significant resource constraints (regardless of the environmental impacts associated with the widespread mining activities) [5]. Other issues repeatedly raised in relation with the resource demand and mining activities of the battery industry are social impacts in the countries of origin. Child labour in the Democratic Republic of Congo associated with cobalt mining is the most prominent example in this regard [6]. Recycling allows to reduce the demand for virgin material and thus the impacts from mining and resource extraction significantly. However, it is still lacking technical maturity and an efficient legal framework that supports efficient and environmentally friendly processes.

Potential, barriers and challenges

LIB exhibit significant environmental impacts from their production. These are partially compensated during the use-phase by their high performance and long lifetime during operation, but the time for amortization (which depends on the application) is still significant. Recycling can reduce the environmental impacts to a certain amount, but there are challenges associated with the temporal delay between battery production and recovery / recycling, with insufficient return and collection incentives, insufficient design for recycling and a lack of information about the actual cell chemistry at hand (labelling) [7]. On the other hand, there is also high potential for further improving the environmental performance by sourcing renewable electricity for cell manufacturing, increasing the lifetime of batteries (also by second use) and by improving the recyclability. It must also be considered that for a continued exponential growth triggered by a worldwide energy transition, resource availability might be limiting factor, why a one-sided bet on one single technology seems to be a bad idea. For minimising the environmental impacts of a society increasingly based on (renewable) electricity, a mix of technologies is required, but also measures on the consumption side.

Advantages

High performance (use-phase)
Long cycle life and life-time
High efficiency

Drawbacks

Energy intensive manufacturing
Require partially scarce metals
Limited recyclability
Contain toxic substances

Challenges

Increase energy density
Design for recycling
Avoid critical materials

References

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