Battery recycling from electric vehicles in Europe: What can be expected?

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Scope of the paper

2020 EU Commission proposal tackling the regulation of the battery sector:

- **2030 and 2035 goals for the use of recycled material (cobalt, lead, lithium, nickel)**
- Recovery objectives
- Carbon footprint constraints

$\Longrightarrow$ Given the time lapse before the end-of-life of batteries and technical changes in the sector, are the proposed rates realistic ?

Li-ion batteries: a fast developing sector

A growing sector driven by the development of the EV market...

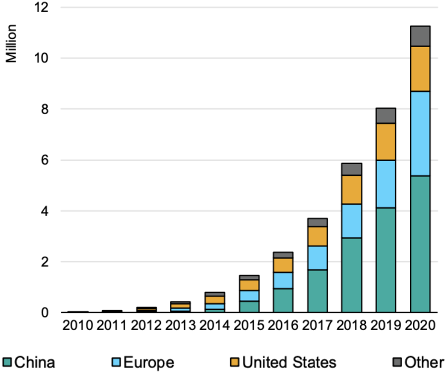


Figure: Stock of EVs (IEA 2021)

...and technical progress **pushing costs downwards**: from USD 1 100 per kilowatt-hour (kWh) in 2010 to USD 156/kWh in 2020 (IEA, 2020)

Growing concerns regarding the sustainability of batteries

- **Environmental impacts** of the battery lifecycle: minerals extraction and end-of-life management ;
- **Social impact** of mineral extraction ;
- Localized resources for minerals and risks of **supply chain stress** ;
- An industry yet **to be developed** in the EU

Some answers at EU level:
$\Longrightarrow$ European Battery Alliance
$\Longrightarrow$ EC proposal for a regulation concerning batteries and waste batteries

EU Commission proposal

- Incentives to invest in batteries
- Develop recycling
- Contain environmental and social challenges

$\Longrightarrow$ Recycling is central

3-steps requirement for the use of recycling contents:

Use of recycled content (Article 8)	01/2027: Mandatory declaration about the amount of recovered cobalt, lead, lithium and nickel contained in the batteries' active materials	01/2030: Minimum shares of recovered materials as condition for placement on EU market (12% cobalt, 85% lead, 4% lithium, 4% nickel)	01/2035 Higher minimum shares of recovered materials (20% cobalt, 85% lead, 10% lithium, 12% nickel)

Figure: source: IFRI 2021

Li-ion recycling (1)

Recycling is put forward in the EU:

- A global development of recycling facilities (e.g.: Northvolt Ett 2022, 25kt batteries /year)
- 2017 European Battery Alliance
- Should answer environmental and supply concerns

With threats and limitations:

- Various technologies exist on the market, especially on the cathode
- Questions on the economic profitability of the process
- Various recycling process, with different results

Material footprint of technologies

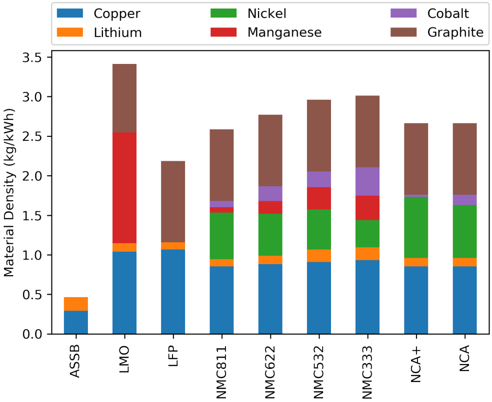


Figure: Battery cell mineral compositions (source: IAE and Xu et a.l. 2020) - other materials not considered

Important variety of technologies hence mineral used in battery manufacturing.
There is also a possibility of technological switch (with solid state).

Objective of the paper

We compute available mineral resource for recycling in the EU battery sector, taking into account:

- Durability of batteries in the economy
- Projected growth of the EV sector
- Technical changes for the Li-ion batteries impacting market shares and demand of minerals in the industry

We use data from the IAE, with extrapolation curves for the expected sales of EVs and market shares of battery technologies.

Are the proposed EC rates for recycled mineral incorporation realistic ?

Literature

We relate to the following trends of literature:

- Prospective analysis on the demand of material: Ballinger et a.l. (2019), Sato and Nakata (2019), Xu et a.l. (2020)
- Techno-economic analysis of Li-ion recycling: Lv et a.l. (2018), IEA (2020 & 2021)
- Resource economics: Rosendahl and Rubiano (2019), Lafforgue and Rougé (2019), Lafforgue and Lorang (2020)

Key findings

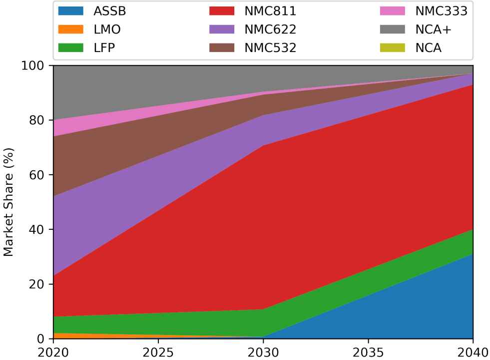
- European Commission proposes **optimistic targets** for incorporating recycled inputs in Li-ion batteries in 2030.
- Missed objectives are especially true for cobalt recycling.
- The environmentally more ambitious SDS scenario lead to lower recycling ratios as demand for batteries grows faster.
- Longer battery lifetimes implies harder recycling objectives to reach

Methodology: overview

Our goal is to compute the ratio of a recycling potential over demand.
Our methodology can be summarized as follows:

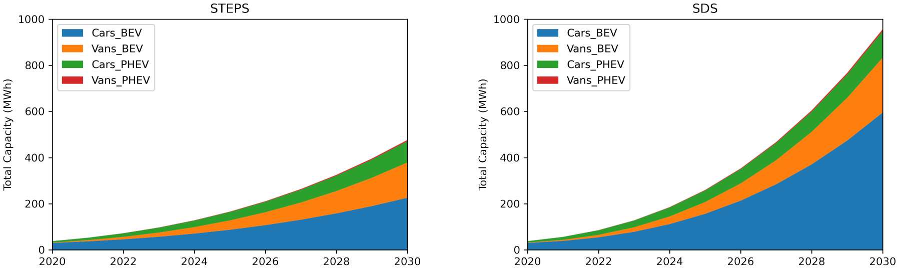
- dynamic material flow model on material demand and waste
- data from projections (that we interpolate) of IEA reports (Global EV, critical material) that details
  - evolution of EV sales
  - evolution of battery market shares
  - material composition of battery cells
- we make additional assumptions on
  - battery sizes
  - parameters of survival functions

IEA Projections: technical change



Data from IEA.
There is a shift from Cobalt/Manganese toward Nickel based batteries, with the eventual rise of solid-state batteries.

IEA Projections: EV batteries growth



EV batteries capacity extrapolated growth (2020-2030) - IAE data.
Stated Policies scenario (STEPS)
Sustainable development scenario (SDS) - more ambitious

Annual material flow

Aggregate flow of material k at year t for the Li-ion sector:

$$Q_{k,t} = \sum_i \sum_j V_{i,t} b_{i,t} m_{j,t} w_{j,k} \tag{1}$$

$V_{i,t}$: Flow of EVs for usage i, at year t
$b_{i,t}$: Size (kWh) of battery for usage i at year t
$m_{j,t}$: Market share of battery technology j at year t
$w_{j,k}$: Weight (kg/kWh) of input k for technology j

Projected recycling potential

The lifetime of batteries is modeled with cumulated probabilities to go to waste at year t $P_{i,j,\tau,t-\tau}$ for a usage i, battery technology j, when produced at year τ. The cumulated pool of material k waste from generation τ at year t is:

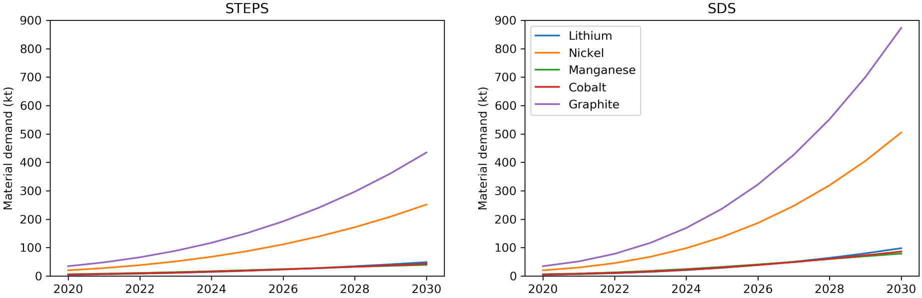
$$B_{k,\tau,t} = \left(\sum_i \sum_j V_{i,\tau} b_{i,\tau} m_{j,t} w_{j,k} \right) P_{i,j,\tau,t-\tau} \tag{2}$$

We use a probability $P_{i,j,\tau,t-\tau}$ based on a Weibull distribution calibrated with minimum, maximum and most likely lifespans of Li-ion batteries.

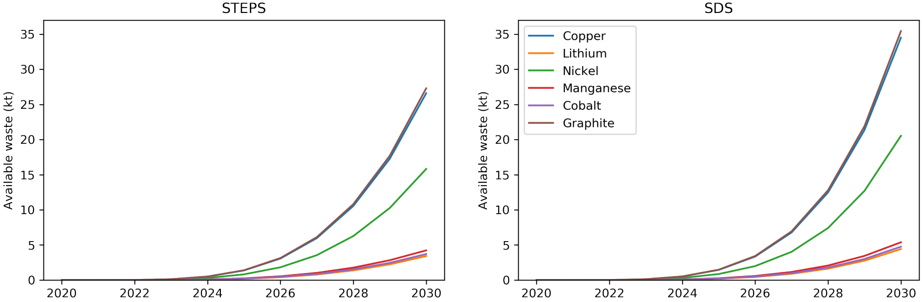
Waste flow at year t of material k:

$$W_{k,t} = \sum_{\tau=0}^{t-1} (B_{k,\tau,t} - B_{k,\tau,t-1}) \tag{3}$$

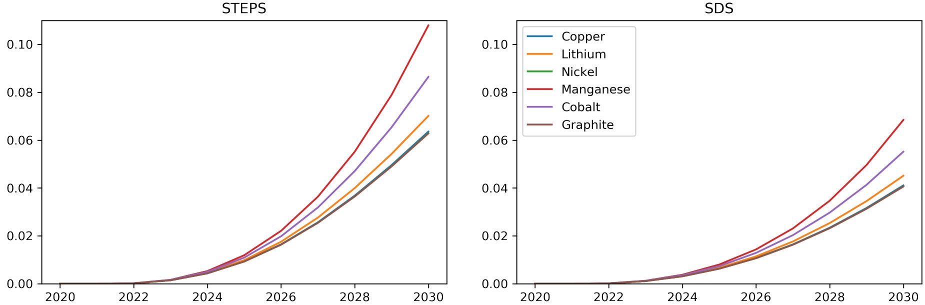
Material demand



Available waste flow

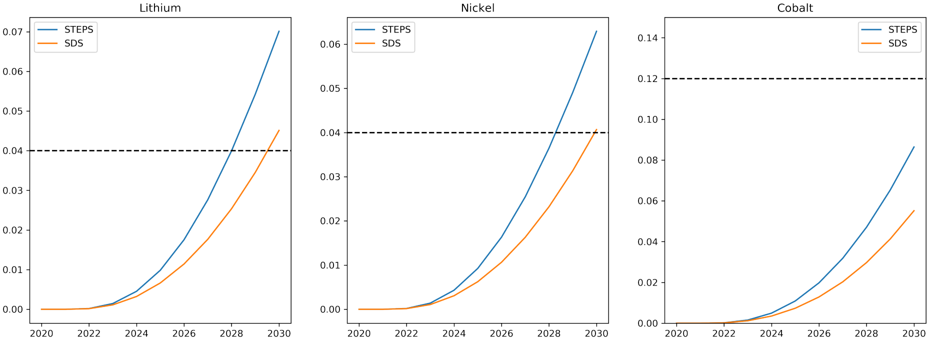


Waste on demand ratios



Waste on demand ratios are lower under the SDS scenario, as the battery flow growing fast after 2025.

2030 policy objectives



Waste objectives are not met for Cobalt, as there is an early shift from Co/Mn to Ni batteries and an ambitious objective.
With this reasoning in mind, Nickel recycling can barely reach its objective in SDS scenario.

Additional remarks on the recycling strategy

Our results should also be mitigated by the efficiency of the recycling process in place:

- Recycling can be uneconomical in some cases;
- Battery recovery can suffer from losses and leakages;
- Some recycling methods have mineral losses.

We also examine the case of the strategic choice of conserving a waste pool up to 2030:

Copper	Lithium	Nickel	Manganese	Cobalt	Graphite
0,16	**0,17**	**0,15**	0,27	**0,22**	0,15

Sensitivity analysis

We examine the influence of the lifetime of batteries. Our main results use 10 years as the most probable duration, and we test here 8 and 12 years.
We observe lower rates for longer lifetimes.

Lifetime	Copper	Lithium	Nickel	Manganese	Cobalt	Graphite
8 years	0,12	0,14	0,12	0,20	0,17	0,12
10 years	0,06	0,07	0,06	0,11	0,09	0,06
15 years	0,01	0,01	0,01	0,01	0,01	0,01

Figure: Recycling ratios in 2030 (STEPS)

Lifetime	Copper	Lithium	Nickel	Manganese	Cobalt	Graphite
8 years	0,09	0,09	0,08	0,14	0,11	0,08
10 years	0,04	0,05	0,04	0,07	0,06	0,04
15 years	0,00	0,01	0,00	0,01	0,01	0,00

Figure: Recycling ratios in 2030 (SDS)

Conclusion

- European Commission proposes **optimistic targets** for incorporating recycled inputs in Li-ion batteries in 2030
- Missed objectives are especially true for **cobalt** recycling, however its use should be in decline
- The environmentally more ambitious SDS scenario lead to **lower recycling ratios** as demand for batteries grows faster
- Longer battery lifetimes implies harder recycling objectives to reach
- The European Commission proposal is more focused on the strategical aspects of the policy, than social and environmental

Further work :

- Extrapolate up to 2035 for Step-3 objectives
- Technological switch (e.g. ASSB)

Thank you !

Appendix

Technology	Li	Ni	Co	Mn	Al	Cu	Graphite	Si
Pyro	90%	98%	98%	90%	0%	90%	0%	0%
Hydro	90%	98%	98%	98%	90%	90%	90%	90%
Direct*	90%	90%	90%	90%	90%	90%	90%	90%
Mechanical*	90%				90%	90%		

	Not present
	Lost
	Potentially economical
	Eonomical

Figure: Recycling rates of technologies (source: Xu et a.l. 2020)

Loss of material and uncertainty on the profitability
Potentially polluting pyro-process (Lv et a.l. 2018)