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Source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fblog.turkishairlines.com%2Ftr%2Fistanbul-bogazi%2F&psig=AOvVaw0TlU7XnBHOy8HoaSA9vq_8&ust=1712909268891000&source=images&cd=vfe&opi=89978449&ved=0CBIQjRxqFwoTCLDLBb_cuYUDFQAAAAAdAAAABAE

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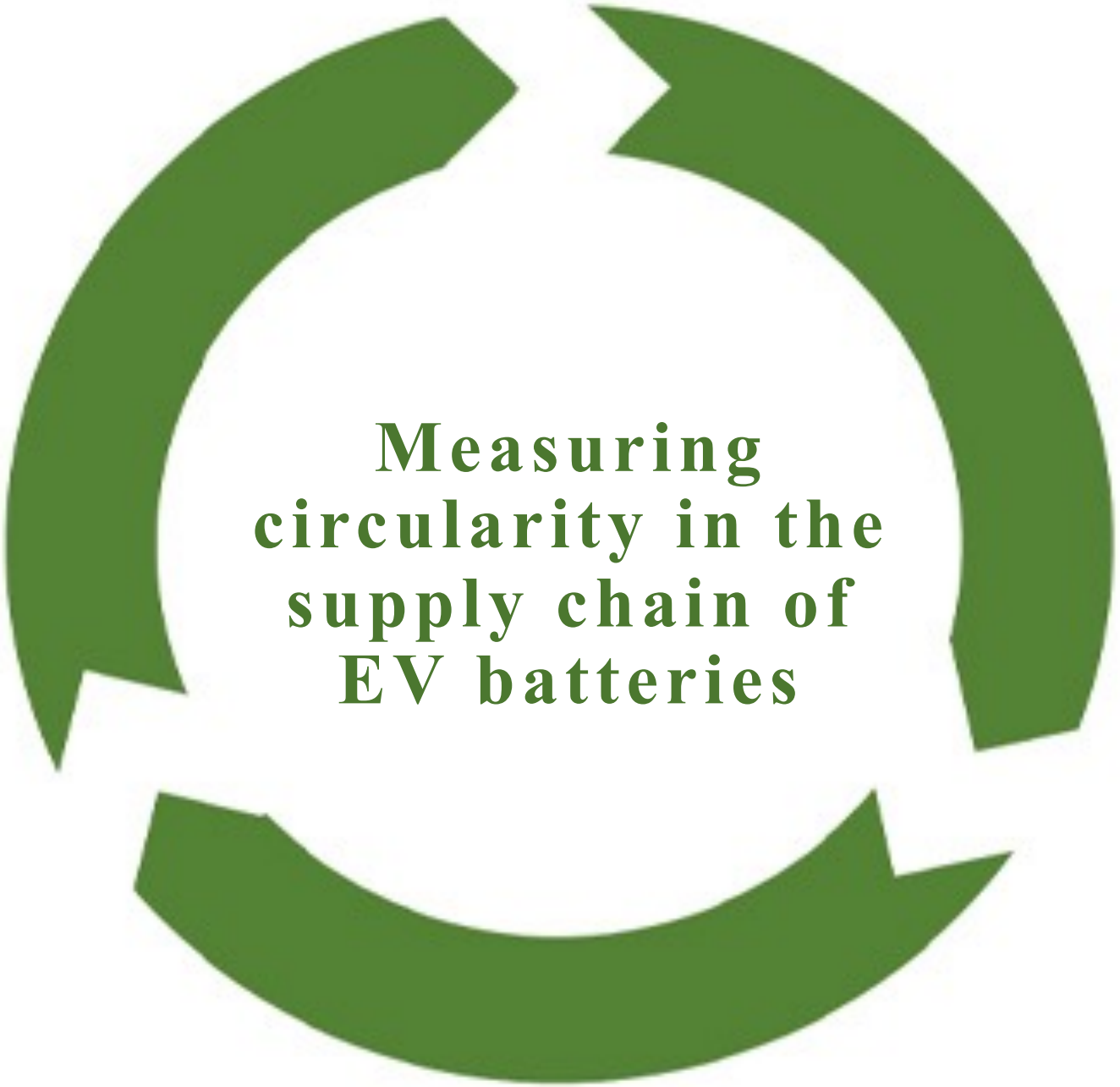


Measuring circularity in the supply chain of EV batteries

Supervisors:

Fabien MANGIONE (G-SCOP)

Van-Dat CUNG (G-SCOP)

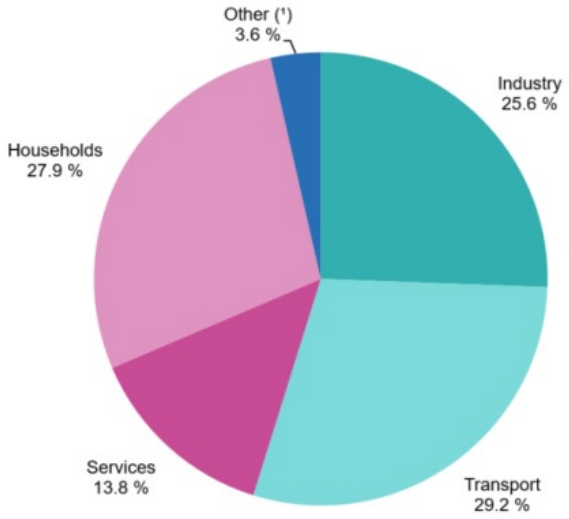
Mario CORTES-CORNAX (LIG)

Industrial collaboration:

VERKOR

Why Electric Vehicles?

Final energy consumption by sector, EU, 2021
(% of total, based on terajoules)



(¹) International aviation and maritime bunkers are excluded from category Transport.
Source: Eurostat (online data code: nrg_bal_c)

eurostat

transformative shift towards ***sustainability***
driven by the growing recognition of ***environmental concerns***
increasing ***charging infrastructure*** and ***technological innovations***

“ The global EV fleet is expected to increase from

14 million in 2023 to 965 million in 2050,

significantly boosting material demand for battery manufacturing. ”

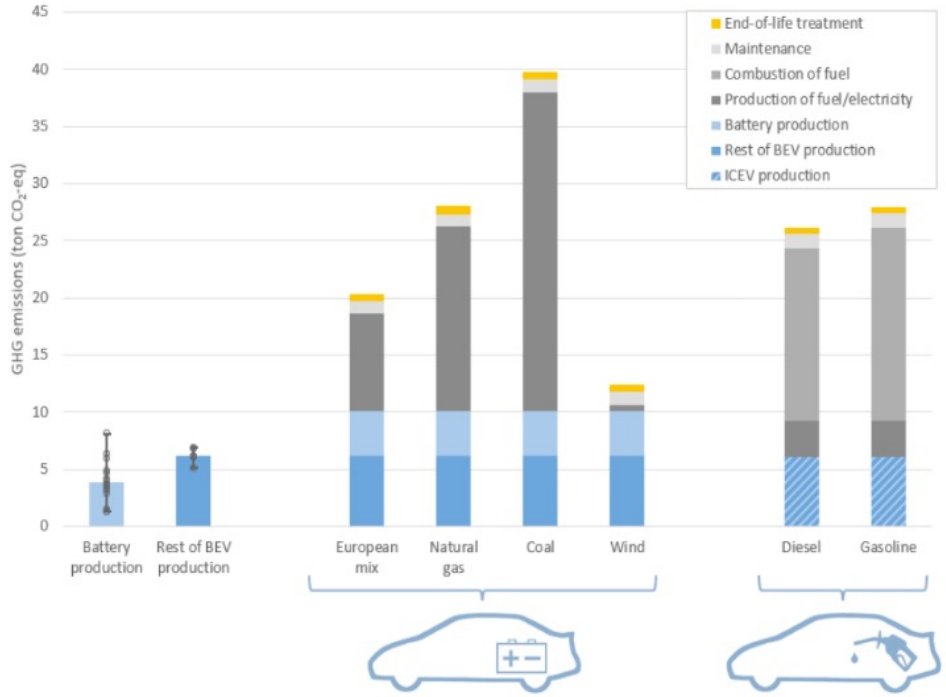
(PNAS Nexus, 2023)

Why Electric Vehicles?

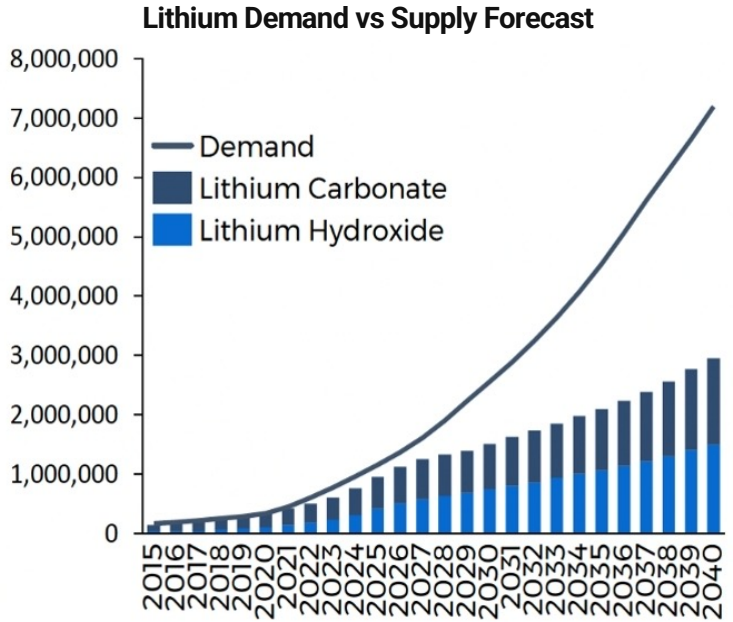
- Very high sensitivity to electrical mix
- Dependency on the conditions of use
  - Temperature, type of charge/discharge, lifespan
- **Supply chain disruptions**

> “The crucial question is not related to resource depletion but rather the capacity of production to adapt quickly enough for an explosion of the request.”

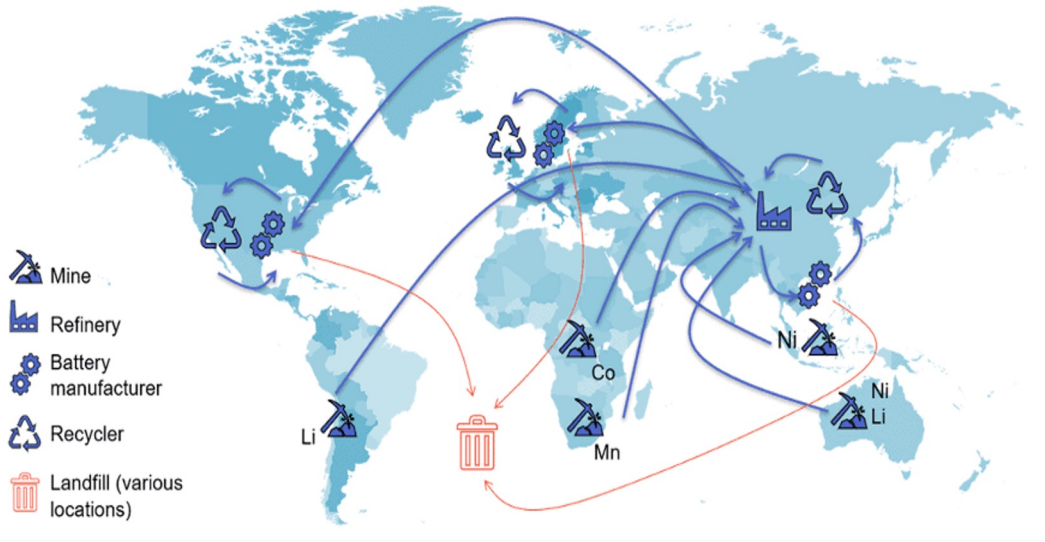
Lifecycle GHG emissions of mid-sized 24 kWh battery electric (left) and internal combustion engine (right) vehicles



Source: Ellingsen and Hung, 2018



Source: Mangrove Lithium, 2021



Source: Mangrove Lithium, 2021

Research Question:

What could be the Circular Supply Chain (CSC) indicators for EV manufacturing during the supply chain design phase?

Research Gap:

Measuring circularity of EV batteries on material level

Classification of indicators that consider several dimensions

Levels	Indicators	Reference	The power of circling longer				The power of inner cycle				Tools
			Length of use	Consecutive loops	Length of loops	Number of loops	Savings on material	Savings on energy	Savings on labor	Savings on pollution	
Product level	Product Circularity Indicator (PCI)	Bracquené et al. (2020)	X				X				Excel
Product level	Product-Level Circularity Metric (PCM)	Linder et al. (2017)					X		X		Excel
Product/ material	Life Cycle Assesment (LCA)		X				X	X		X	Software
Material level	Material Circularity Indicator (MCI)	EMF (2015)	X				X				Excel
Material level	Reuse Potential Indicator (RPI)	Park et al. (2014)		X			X			X	Formulas
Material level	Circularity Calculator (CC)	Pauw et al. (2021)					X		X		Excel
Material level	Circular Economy Index (CEI)	Di Maio et al. (2015)					X				Excel
Material level	Circularity Material Indicator Circ(T)	Pauliuk et al. (2017)					X		X		Excel
Territorial material	Regional material flow tools to promote circular economy	Virtanen et al. (2019)					X			X	Formulas
Energy flow	Circularity Index (CI)	Cullen (2017)	X					X			Formulas
Design alternatives	Concept Circularity Evaluation Tool (CCET)	Albaek et al. (2020)				X	X				Excel
Company level	Circulytics	EMF (2020)	X				X	X			Web-based
Company level	Circular Transition Indicators (CTI)	World Business Council (2023)			X	X		X		X	Web-based

Indicators	Reference	The power of circling longer				The power of inner cycle				Tools
		Length of use	Consecutive loops	Length of loops	Number of loops	Savings on material	Savings on energy	Savings on labor	Savings on pollution	
Global Circularity Indicator (GCI)	***Kurt et al. (2022)***	***X***	***X***	***X***	***X***	***X***	***X***	***X***	***X***	***Formulas***
Circularity Package	GreenDelta GmbH (2023)	X		X	X	X	X		X	Add-on
MCI & RPI & Climate Change	Niero et al. (2019)	X	X			X	X		X	MCDA
CTI and MCI	Schulz et al. (2023)			X	X	X	X		X	Sensitivity Analysis

Global Circularity Indicator - Kurt et al. (2022)

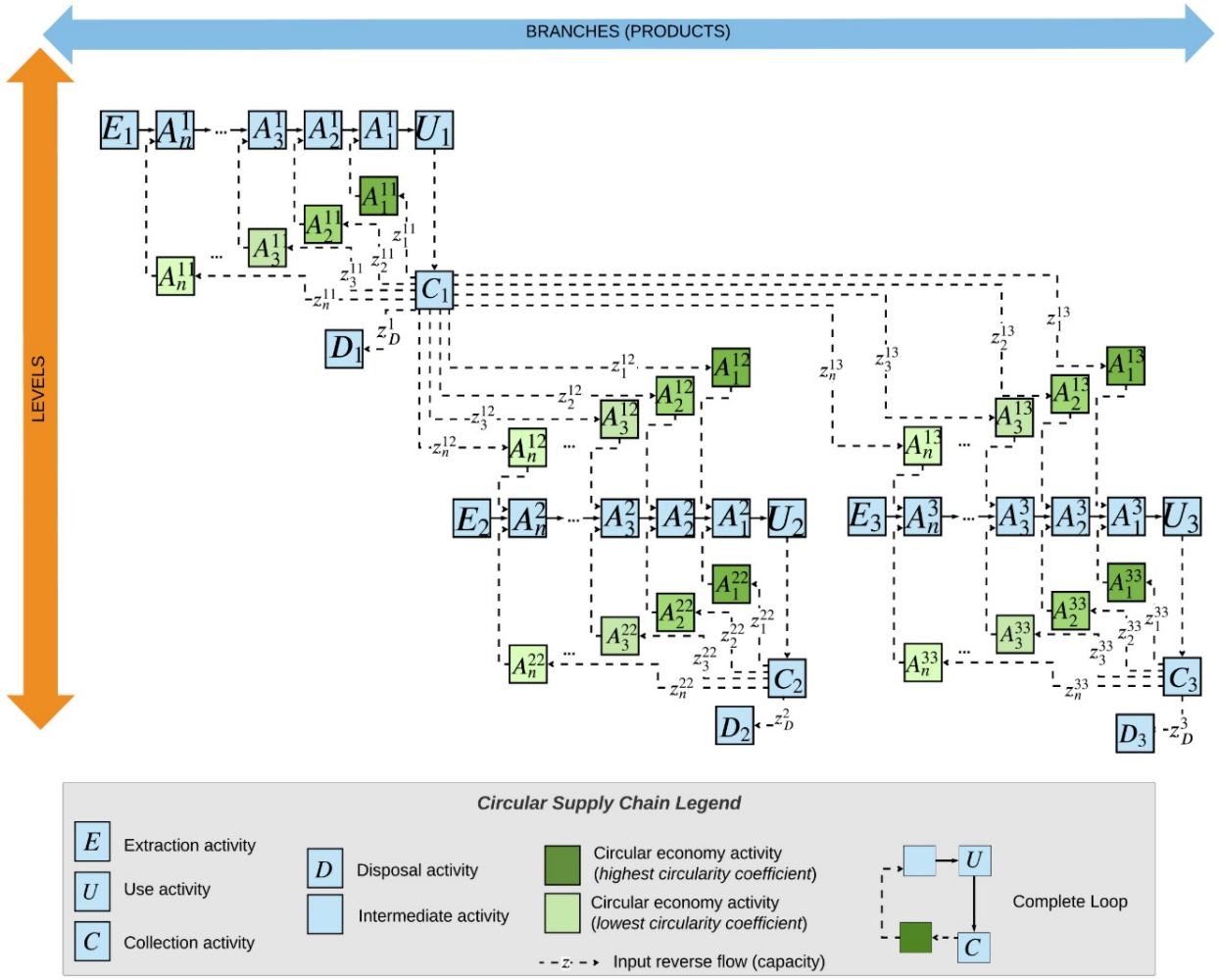


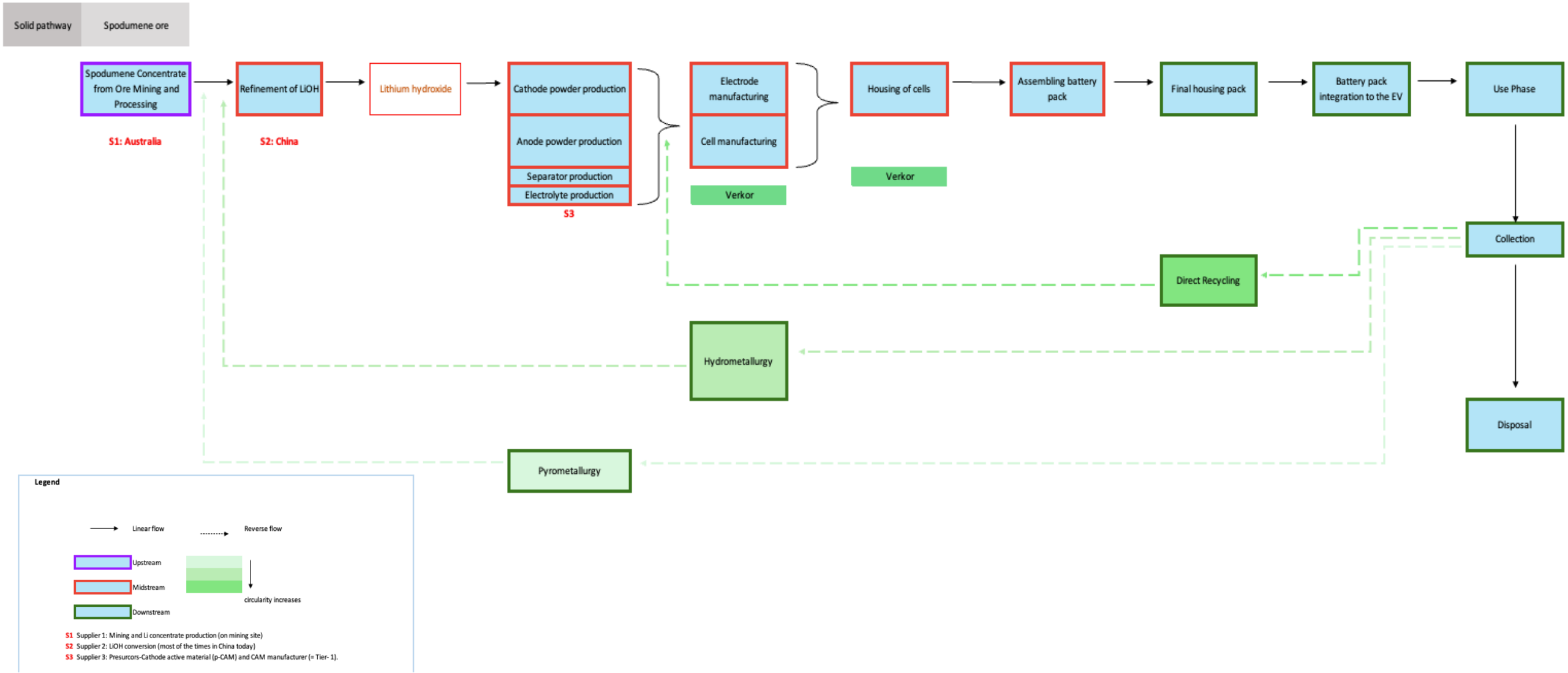
Figure 5.2: An example of mathematical representation of CSC

Source: Kurt et al. (2022)

Circularity Coefficient :

Savings made by producing a product through a CE activity instead of producing a product from zero

Lithium Process Chain

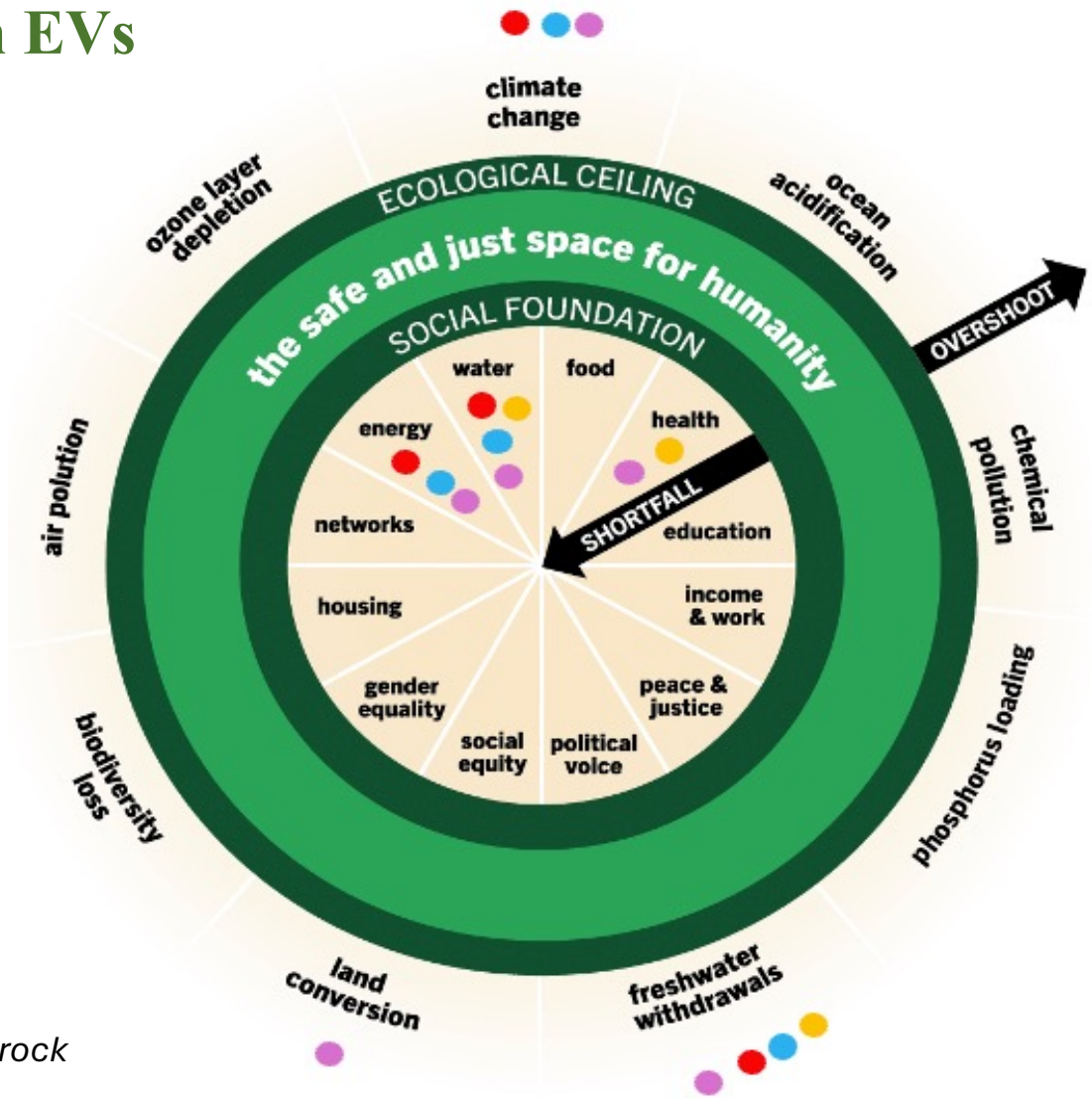


Different Approaches to Measure Circularity in EVs

Kelly et al. (2021)	Calzolari et al. (2022)	Schenker et al. (2022)
GHG emissions (kgC02eq)	CO2 emissions (kgC02eq)	Climate Change Impacts (kgC02eq)
Energy consumption (kWh)	Energy use (kWh)	Particulate matter (µDALY)
Freshwater consumption (m3)	Water use (m3)	Water scarcity (m3)

My Proposition	
Material	**Life Cycle**
Resource use efficiency	GHG emissions (kgC02eq)
Length of use	Energy consumption (kWh)
Length of loops	Freshwater consumption (m3)
	Land conversion (m2)
	Particulate matter (µDALY)

AS-IS / AS-IF
Li extraction
Brine vs. Spodumene rock

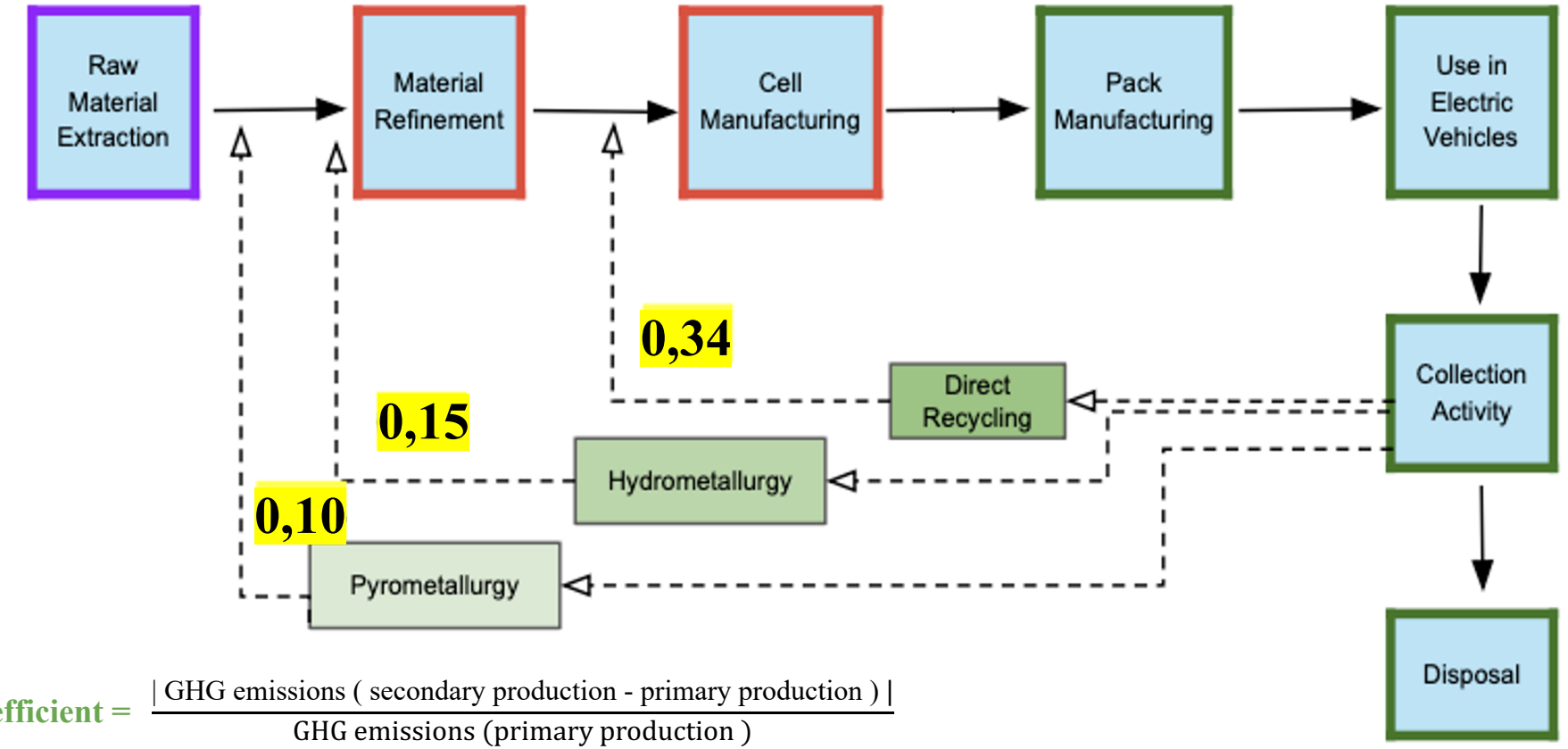


Source: K. Raworth, 2017

Circularity Coefficient Based on GHG Emissions for different recycling techniques

European Battery Framework Scenario

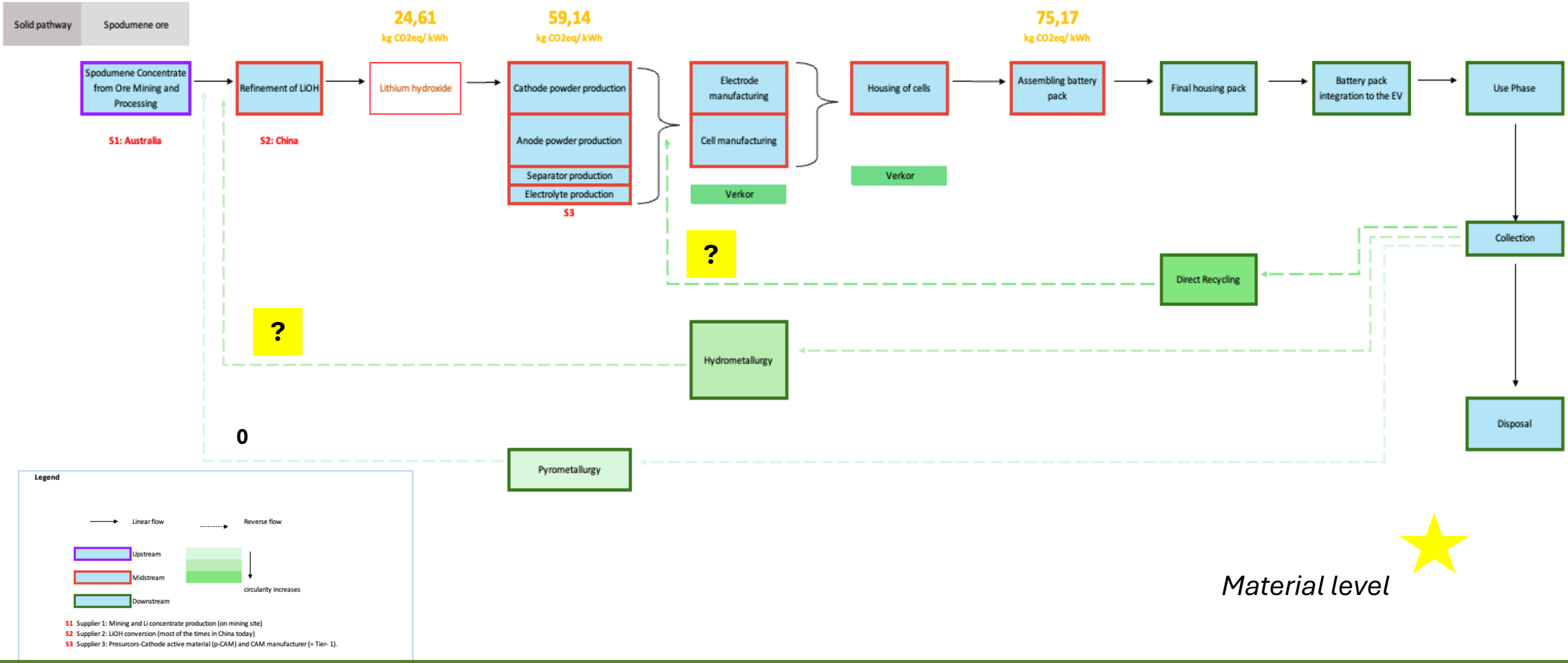
Mandatory minimum levels of recycled content declared by the new EU regulatory framework for batteries ***12% cobalt, 4% lithium, and 4% nickel for 2030; increasing to 20% cobalt, 10% lithium, and 12% nickel in 2035***. Manganese, graphite, copper, and aluminum are assumed to be incorporated at 10%. *(PNAS Nexus, 2023)*



Product level

$$\text{Circularity Coefficient} = \frac{|\ \text{GHG emissions (secondary production - primary production)}\ |}{\text{GHG emissions (primary production)}}$$

Circularity Coefficient Based on GHG Emissions on material level



Material level

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- Kurt et al., 2022 Link: https://theses.hal.science/tel-03615489

THANK YOU

FOR YOUR ATTENTION

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