Technische Universität Braunschweig

Institut für Werkzeugmaschinen und Fertigungstechnik

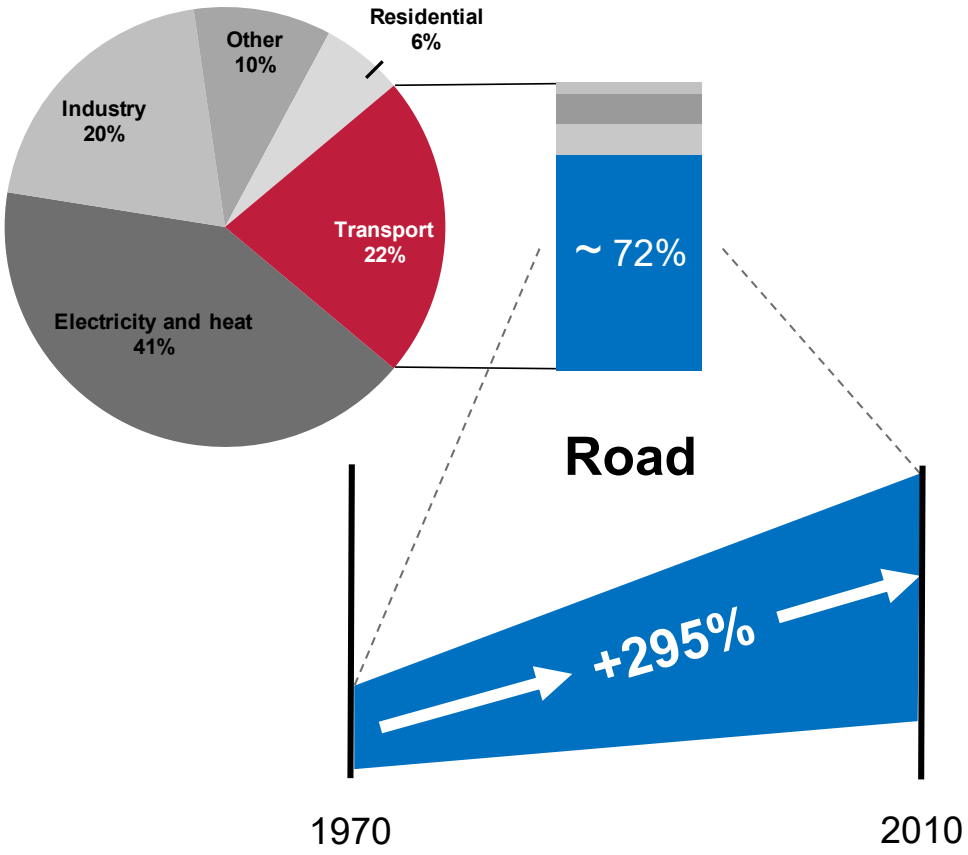
Environmental Life Cycle Evaluation of Electric Vehicles and the Significance of Traction Batteries

10th International AVL Exhaust Gas and Particulate Emissions Forum
20th February, 2018 | Ludwigsburg, Germany

Felipe Cerdas, MSc., Prof. Dr.-Ing. Christoph Herrmann
Institut für Werkzeugmaschinen und Fertigungstechnik

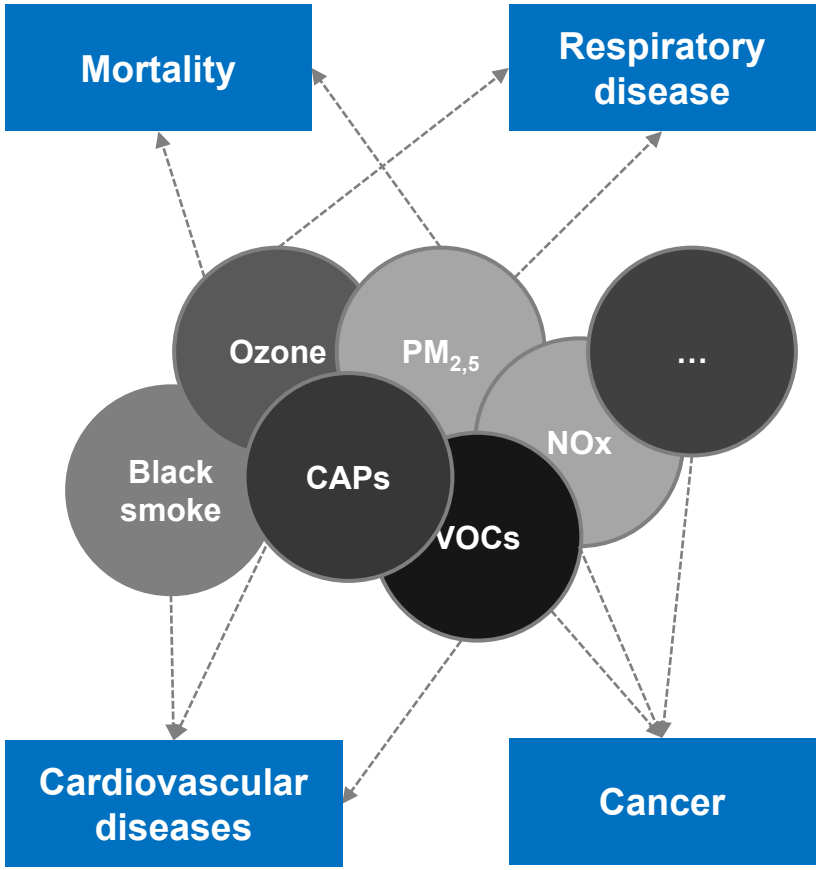
Motivation
Challenges related to the use of motorized vehicles

Antrophogenic GHGs per sector in 2011



Data source: IEA (2012)

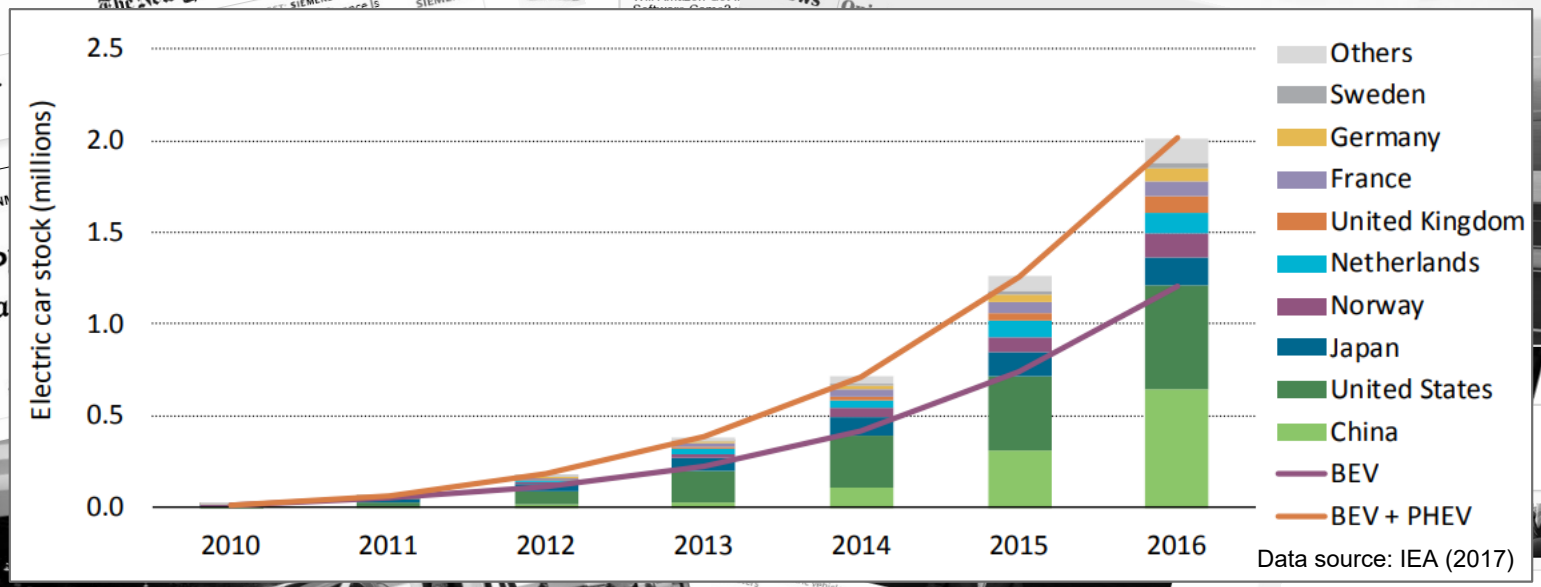
Health outcomes associated with transport related air pollutants



Based on WHO 2011

Motivation

The rise of Electromobility



Data source: IEA (2017)

Motivation

none, less or different environmental impact?

“Zero emissions”

“Zero g CO2/km”

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Guardian sustainable business Transport

Nickel mining: the hidden environmental cost of electric cars

The extraction of nickel, mainly mined in Australia, Canada, Indonesia, Russia and the Philippines, comes with environmental and health costs

▲ The mining and processing of nickel-rich ores can generate high loadings of dust concentrations of potentially toxic metals, including nickel itself, copper, cobalt an… Ahmad/Reuters

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Guardian sustainable business Rethinking business

The rise of electric cars could leave us with a big battery waste problem

Carmakers, recyclers and tech startups are working to solve the question of how to deal with lithium-ion batteries when they

China's Hubei province. The …nages

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Magazine

How environmentally friendly are electric cars?

By Andrew Bomford
BBC Radio 4's PM programme

11 April 2013 Share

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Elektroautos

Sauber? Kommt drauf an …

Elektroautos sind keinesfalls automatisch umweltfreundlicher als Benziner oder Diesel.

Von **Dirk Asendorpf**

3. Dezember 2015, 3:16 Uhr / Editiert am 4. Dezember 2015, 19:01 Uhr / 90 Kommentare

INHALT

Seite 1 — Sauber? Kommt drauf an …

Seite 2 — "Elektroautos sind eine sehr teure Art der

Das großspurige Werbeversprechen der kalifornischen Elektroautoschmiede Tesla lautet: "Keine Emissionen. Kompromisse." In drei Sekunden beschleunigen die ru… 100.000 Dollar teuren und über zwei Tonnen schwere Elektroflitzer von null auf hundert. Und das ohne Emi…

Agenda

1	LCA and its application to electromobility
2	Significance of the battery system
3	Relevance of recycling

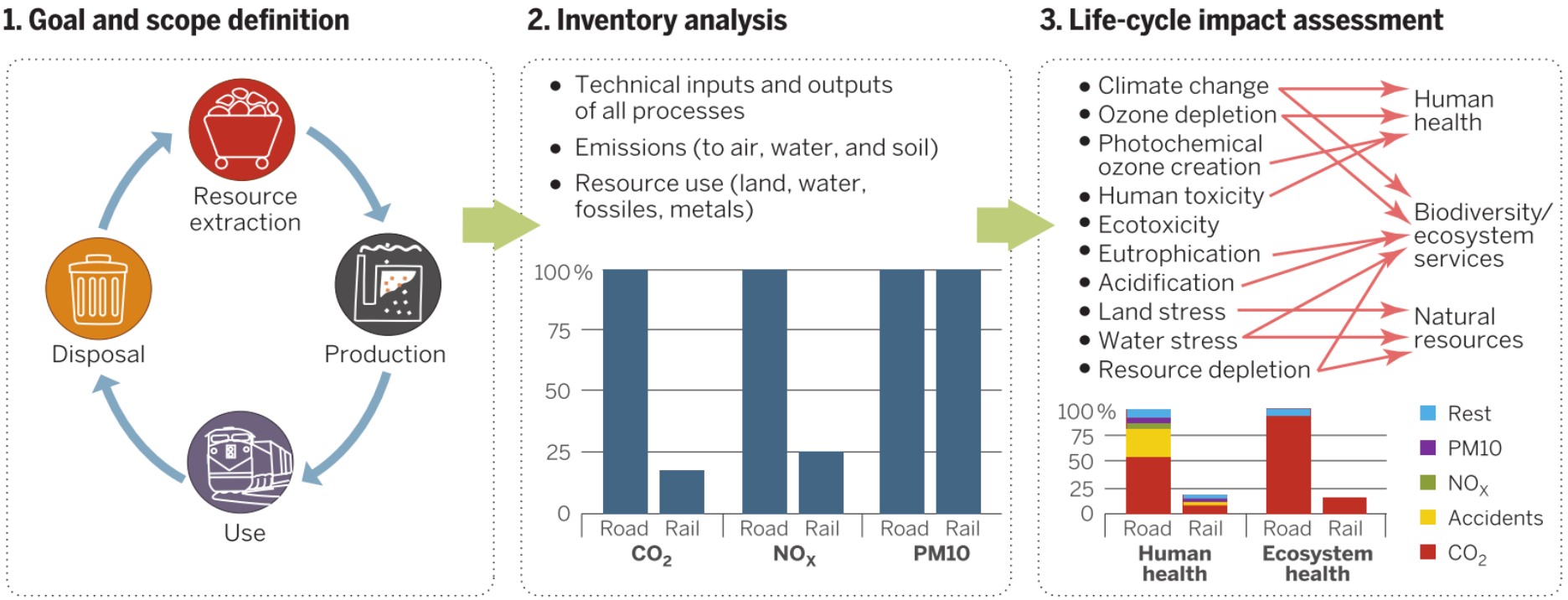
Agenda

1 LCA and its application to electromobility

2 Significance of the battery system

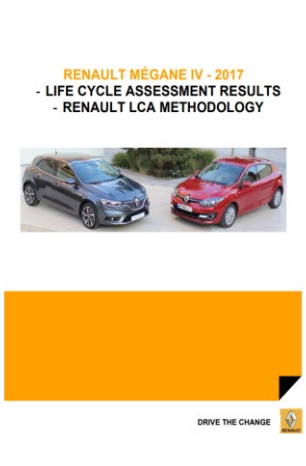
3 Relevance of recycling

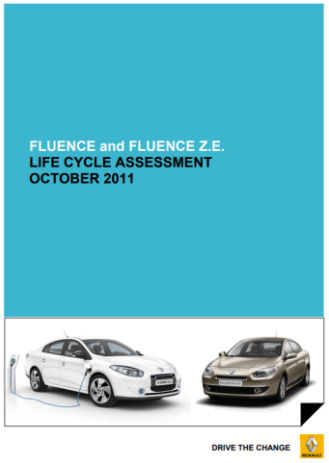
Life Cycle Assessment (LCA)
The four steps

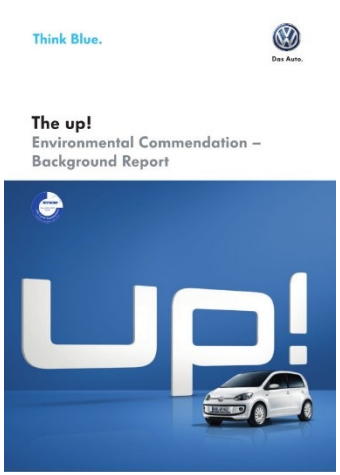


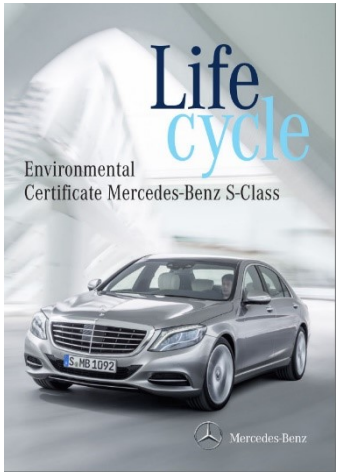
[Hellweg and Milá i Canals 2014]

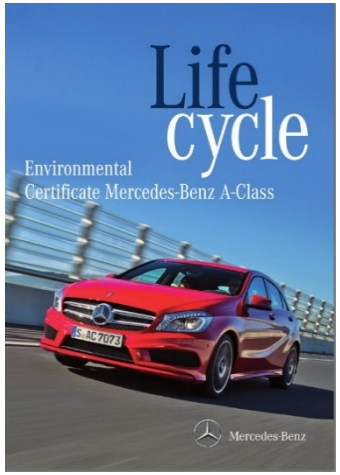
LCA
application in the automotive industry





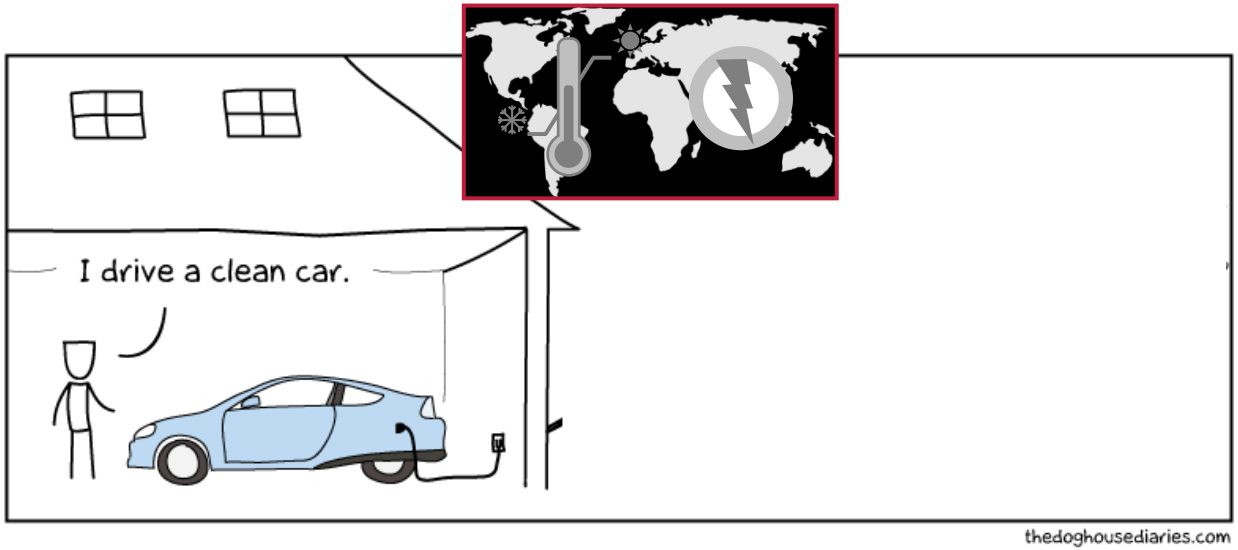




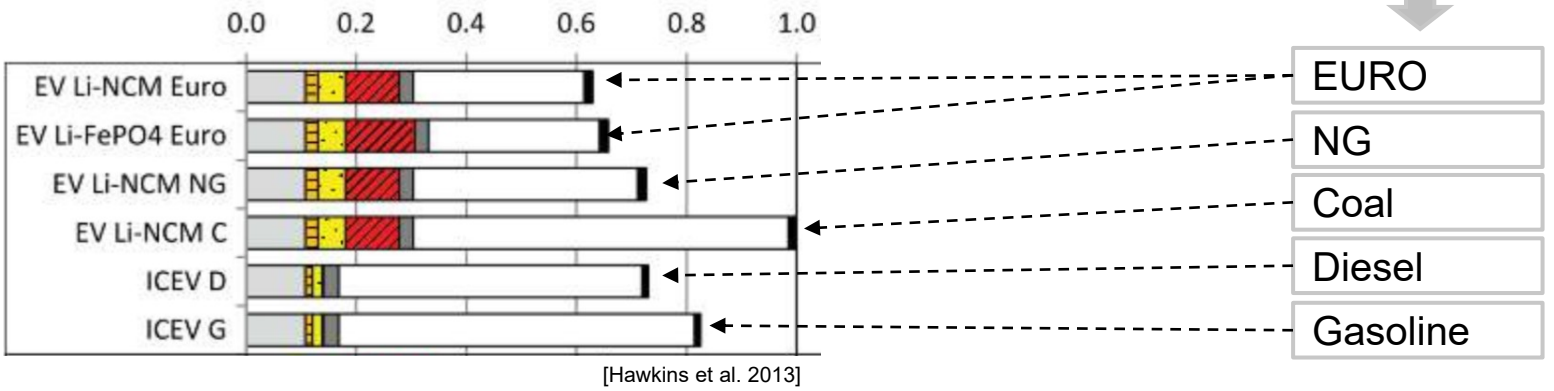


[figures courtesy of Volkswagen, Renault, Daimler, Audi]

EV compared to ICEs
LCA results and influencing factors

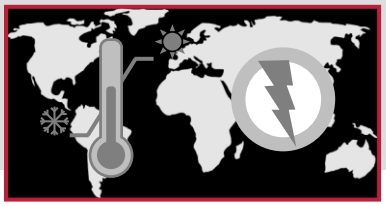


GWP



[Hawkins et al. 2013]

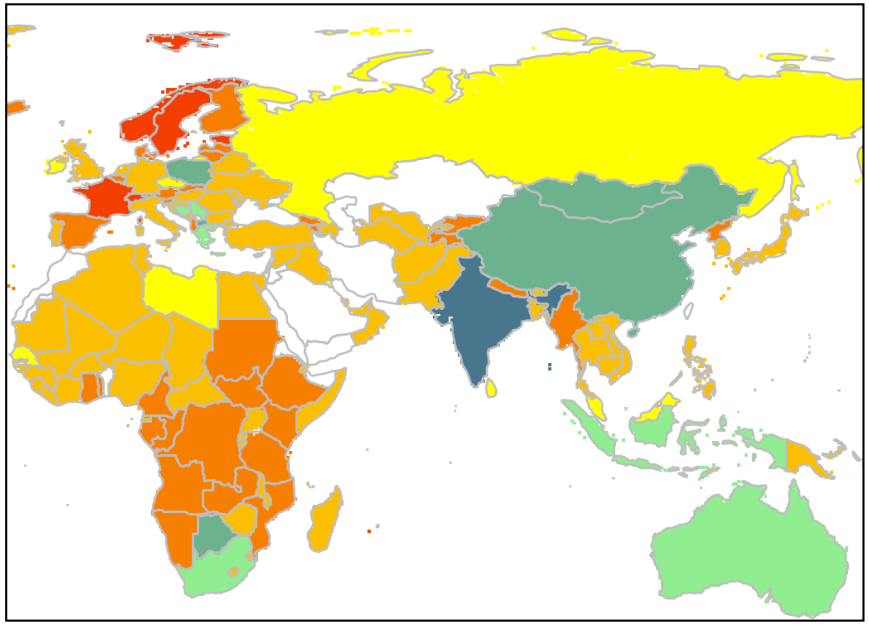
EV compared to ICEs
LCA results and influencing factors



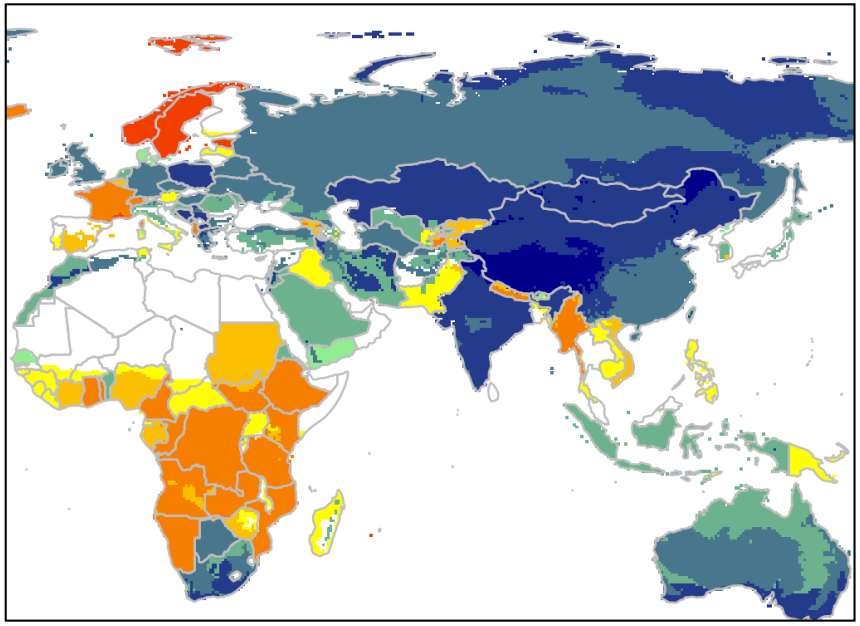
Scenario description

ICE vehicle:	Gasoline	**EV battery:**	Li-FePO4	**Impact Category:**	Climate change	**Daily use:**	Commuter	**Seasonal use:**	Even

Regional electricity mix



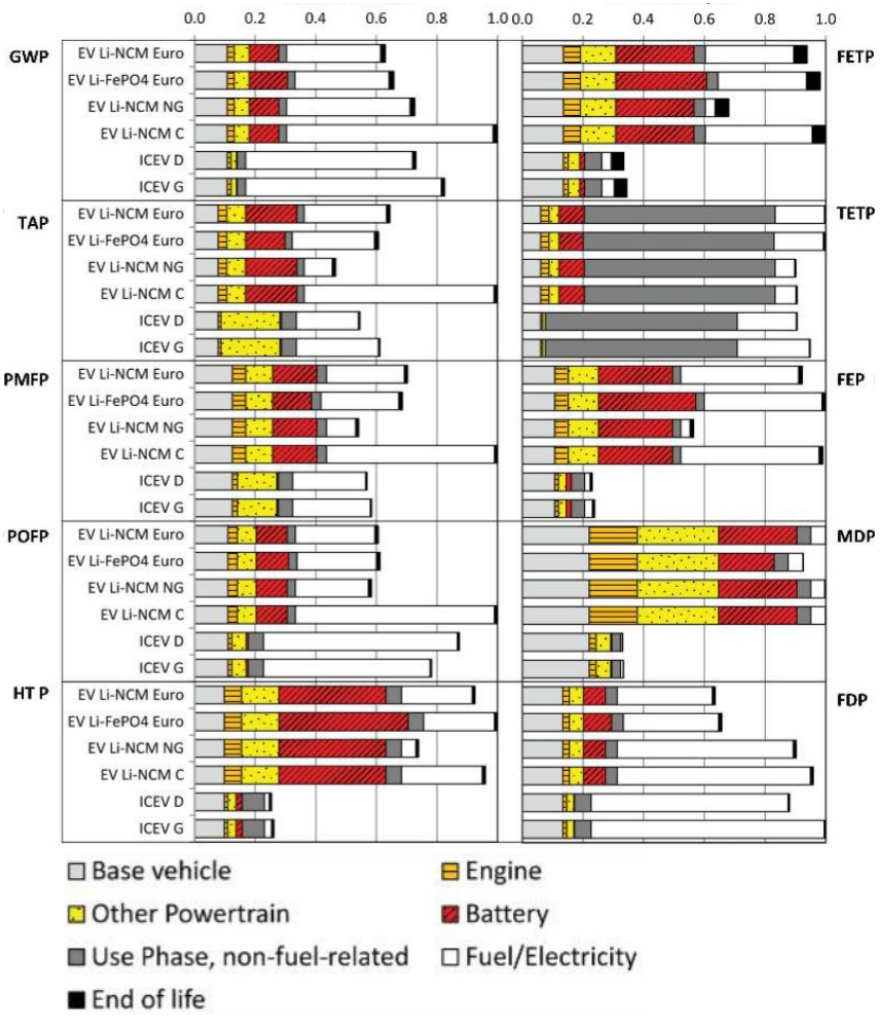
Regional electricity mix and ambient temperature

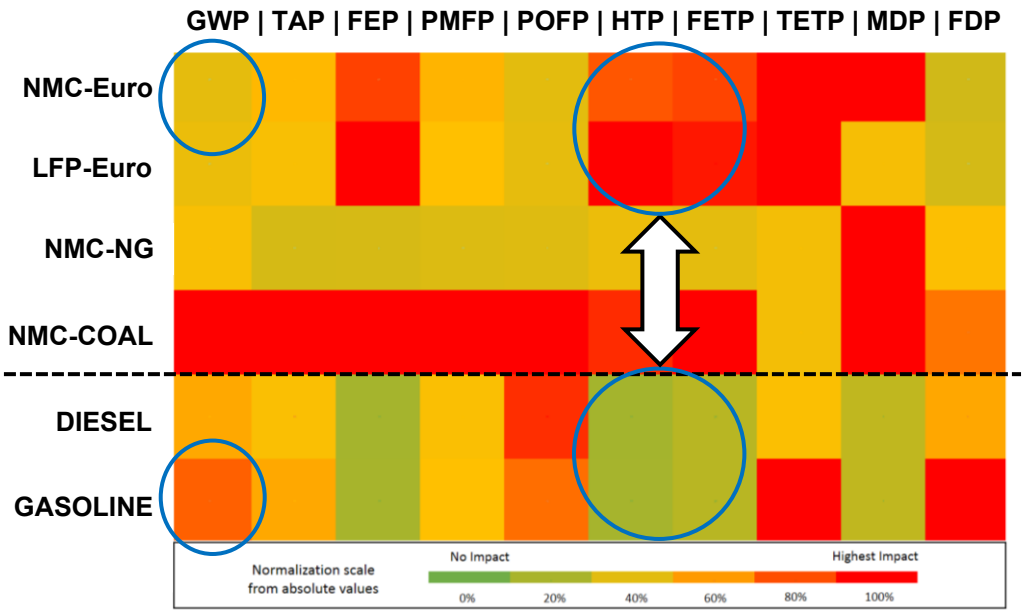


ICEV= Internal combustion engine vehicle
LEV= (Lightweight) Electric vehicle

[Egede 2016]

EV compared to ICEs
Problem shifting

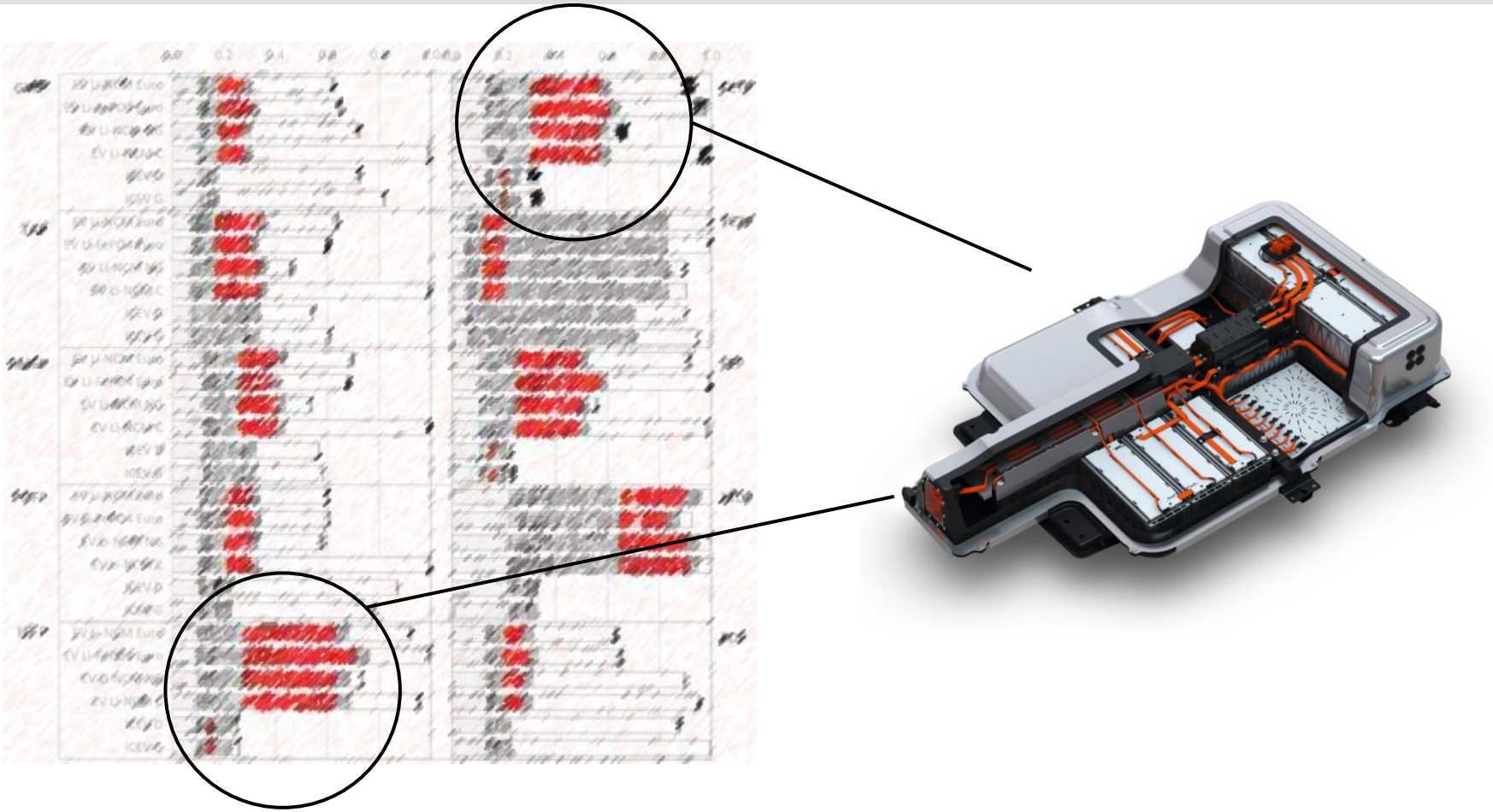




global warming (**GWP**), terrestrial acidification ($\mathbf{TAP_{100}}$), particulate matter formation (**PMFP**), photochemical oxidation formation (**POFP**), human toxicity ($\mathbf{HTP_{inf}}$), freshwater eco-toxicity ($\mathbf{FETP_{inf}}$), terrestrial eco-toxicity ($\mathbf{TETP_{inf}}$), freshwater eutrophication (**FEP**), mineral resource depletion (**MDP**) fossil resource depletion (**FDP**)

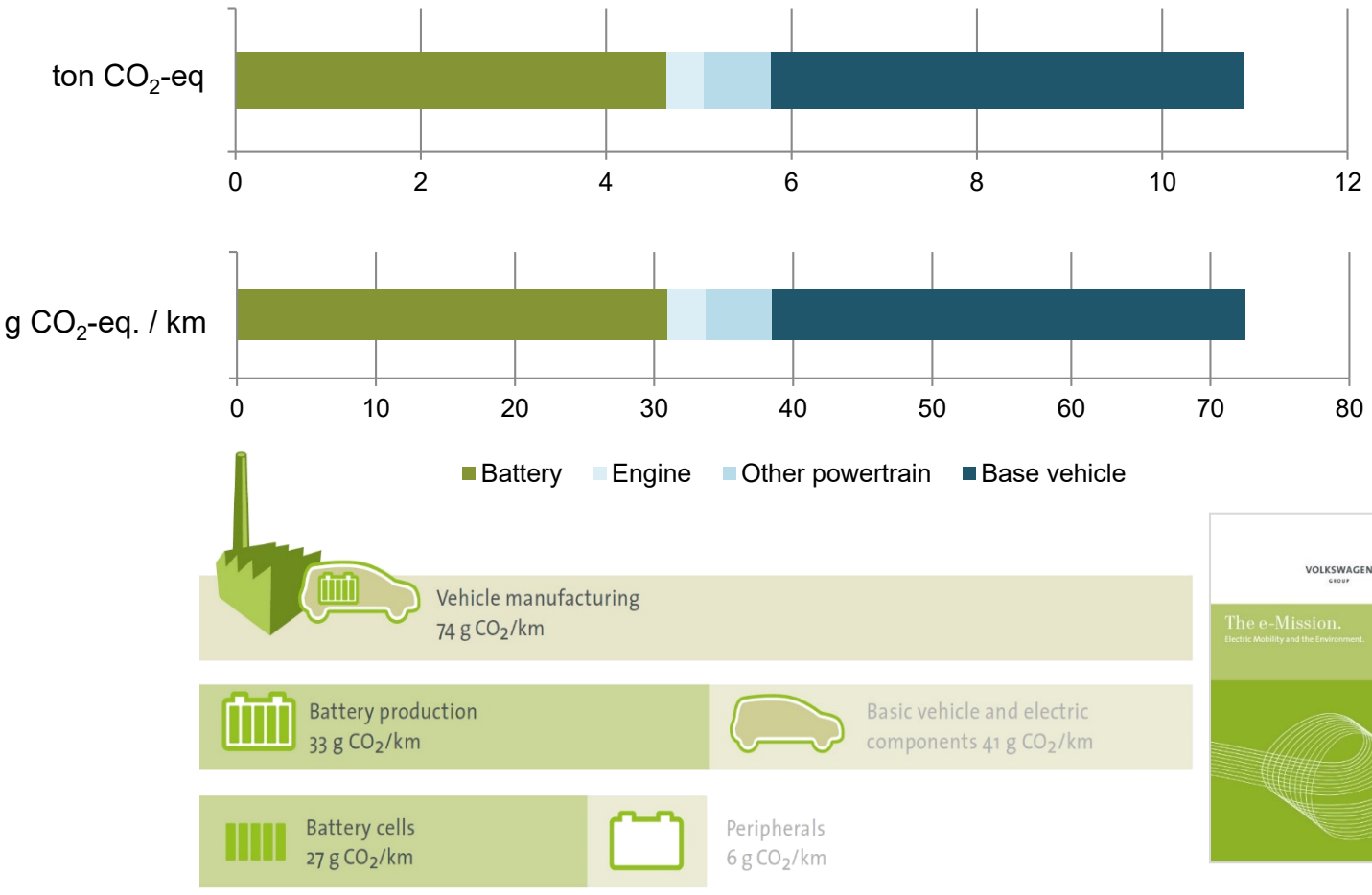
[Hawkins et al. 2013, Cerdas et al. 2018]

EV compared to ICEs
The significance of the battery system



[Hawkins et al. 2013, Volkswagen]

Significance of the Battery System
Cradle to Gate GWP of EVs



[Hawkins et al. 2013, Volkswage AG]

Agenda

1 LCA and its application to electromobility

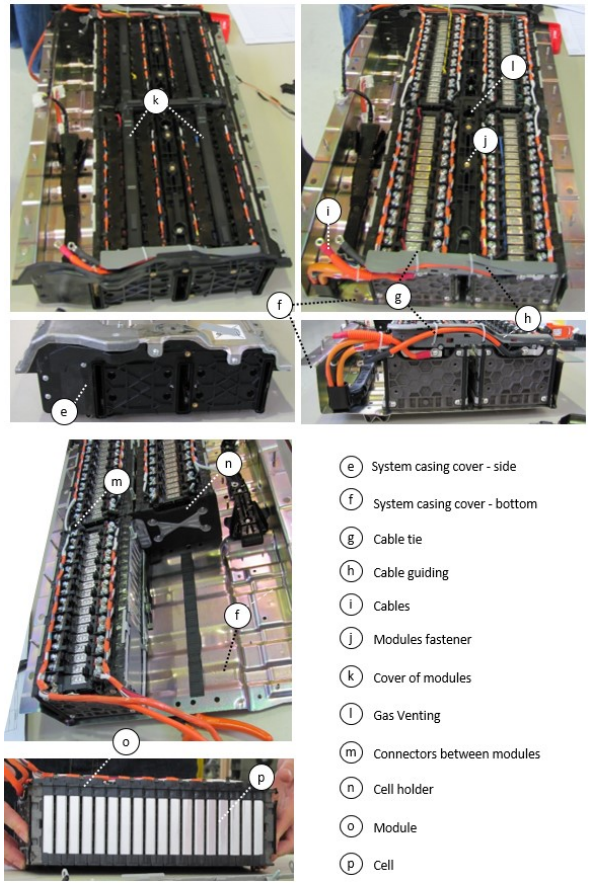
2 Significance of the battery system

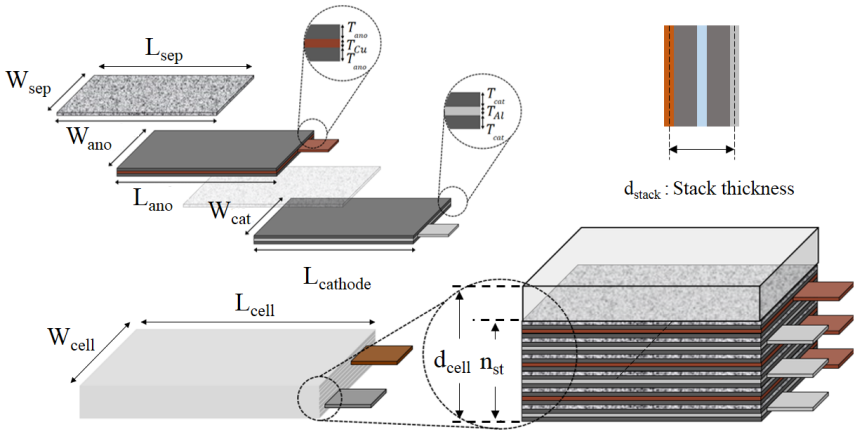
3 Relevance of recycling

Significance of the Battery System

Estimation of mass and energy content of a battery system

Disassembly experiments
(Projects LithoRec I and II)



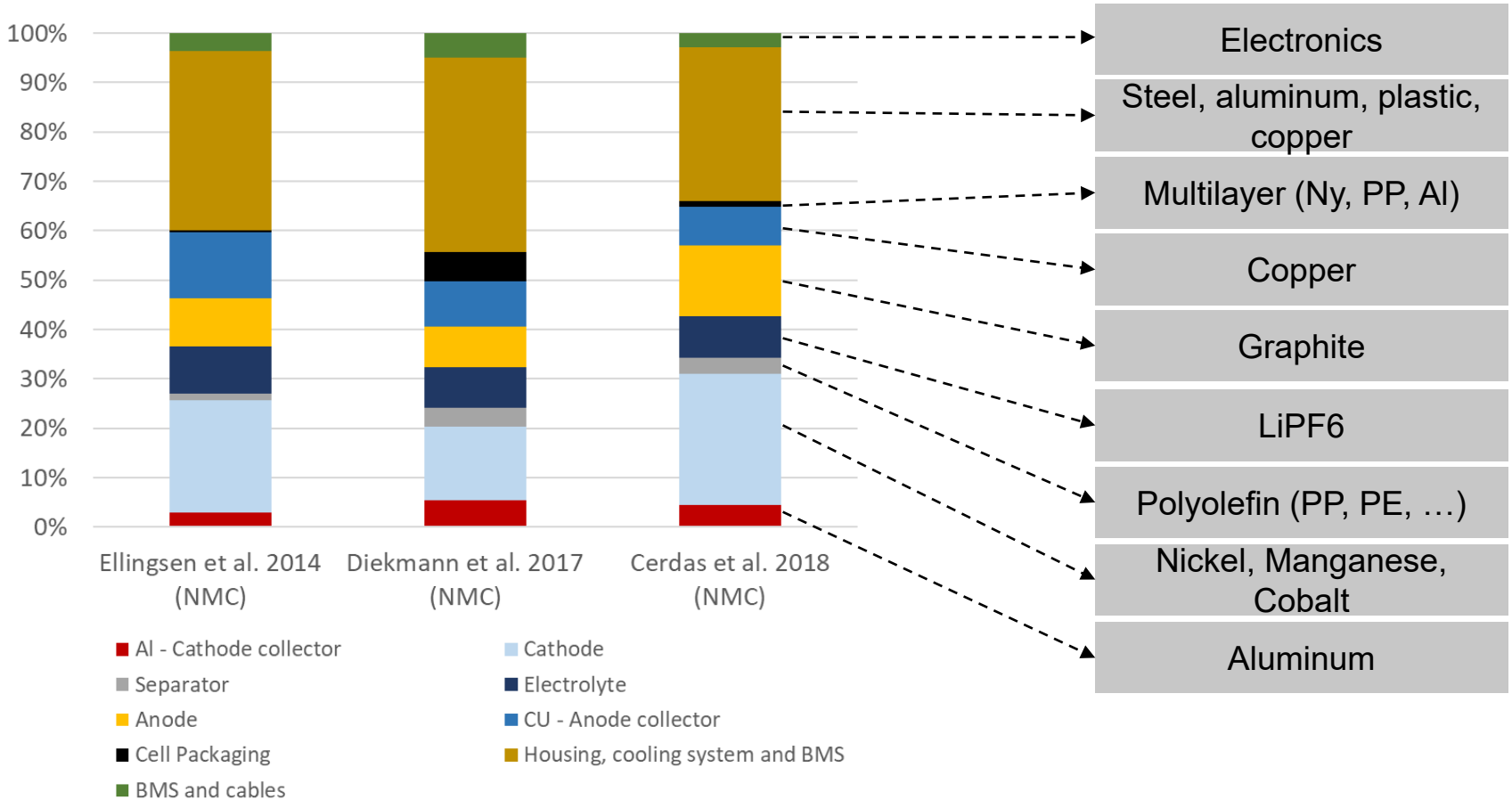


Cell Mass/Energy model
(Project Benchbatt)

[Cerdas et al. 2018, LithoRec Project, Cerdas et al. 2018]

Significance of the Battery System

Estimation of mass and energy content of a battery system



[Ellingsen et al. 2013, Diekmann et al. 2017, Cerdas et al. 2018]

Significance of the Battery System
Material and energy consumption of manufacturing

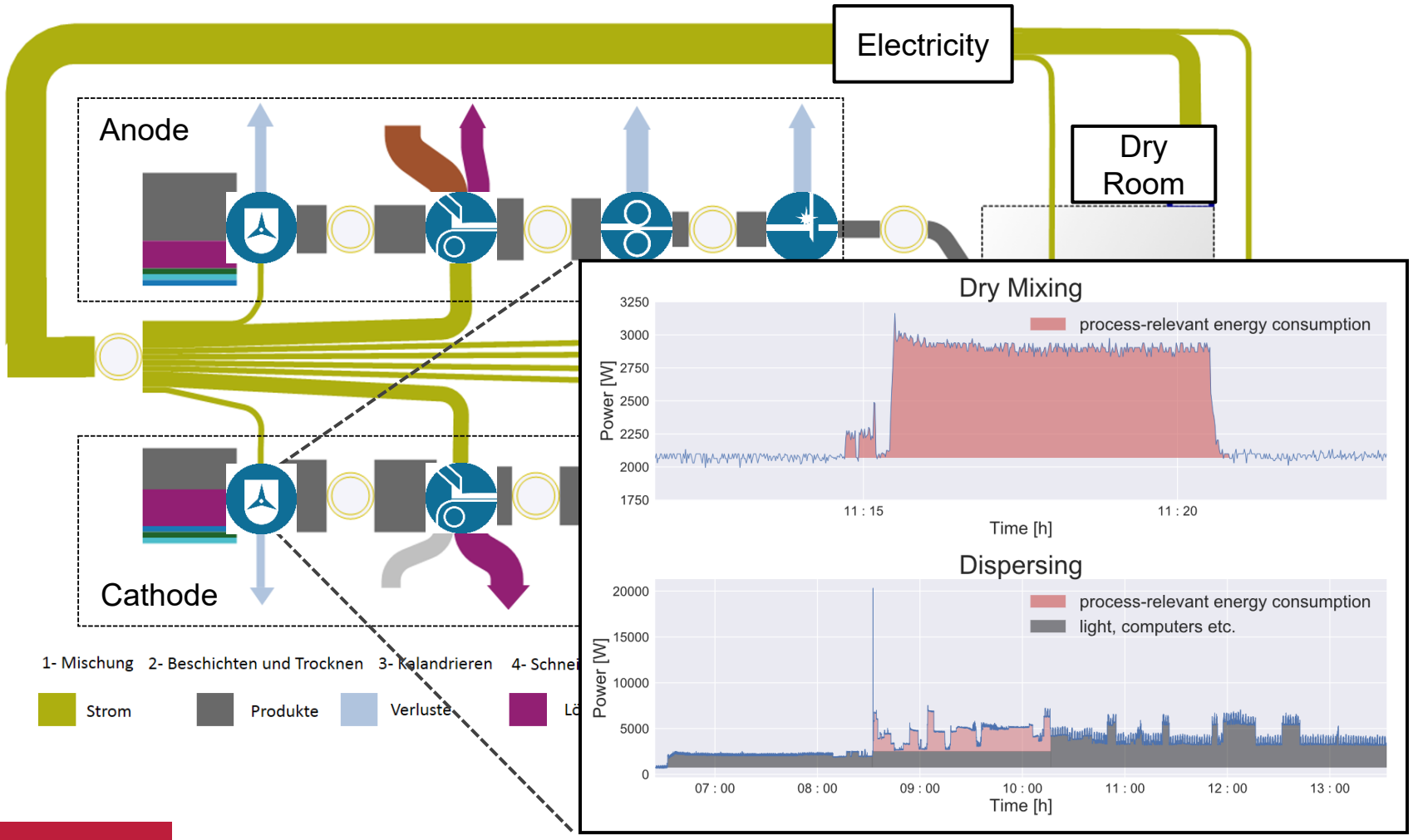
Variation of the reported energy required for the manufacturing of battery cells

Author	kWh/kWh_{batt}	
Ellingsen et al. 2014	162,7	Top-down
Notter et al. 2010	0,861	Bottom-up
Zackrisson et al. 2010	125,3	Top-down
Majeau-Bettez et al. 2011	131,4	Top-down
Dunn et al. 2012	2,97	Top-down
Yuan et al. 2012	461,98	Bottom-Up

Significance of the Battery System
Battery LabFactory Braunschweig (BLB)

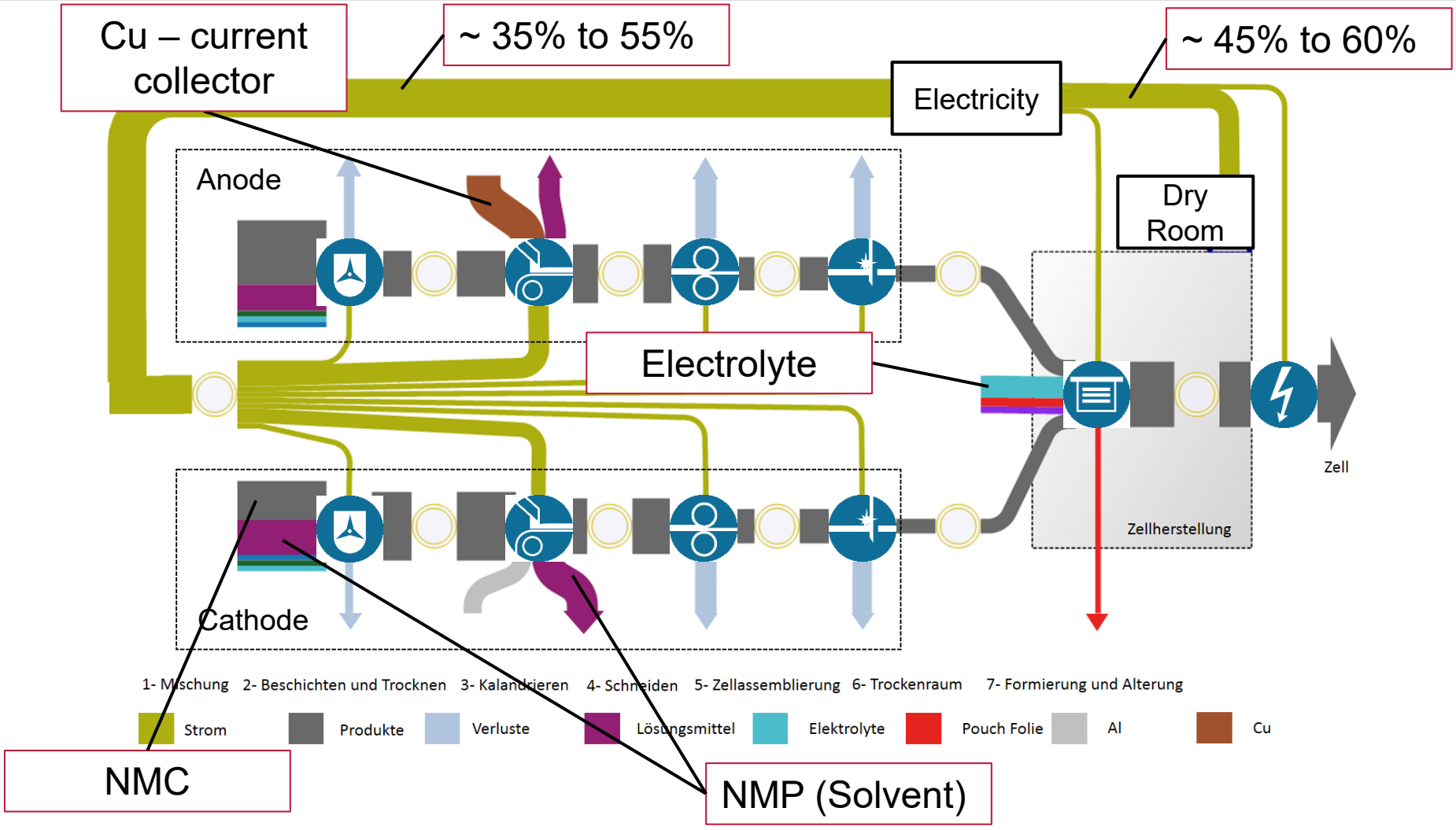
Significance of the Battery System

Material and energy consumption of manufacturing



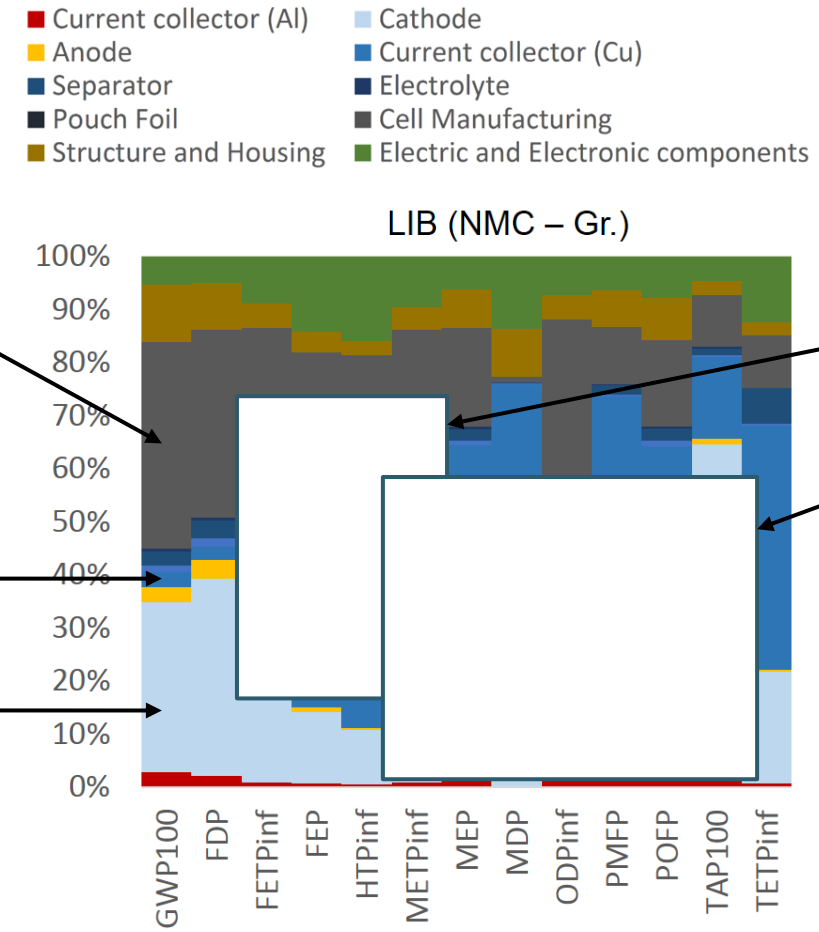
Significance of the Battery System

Material and energy consumption of manufacturing



Significance of the Battery System

Cradle to Gate LCA results and contributions



Cell Manufacturing Energy (~40% of the impact)

Copper (very little)

Cathode Material (~ 35% of the impact)

Copper

Cobalt
Nickel
Manganese!

~ 4,6 tons CO_2-eq

[Cerdas et al. 2018]

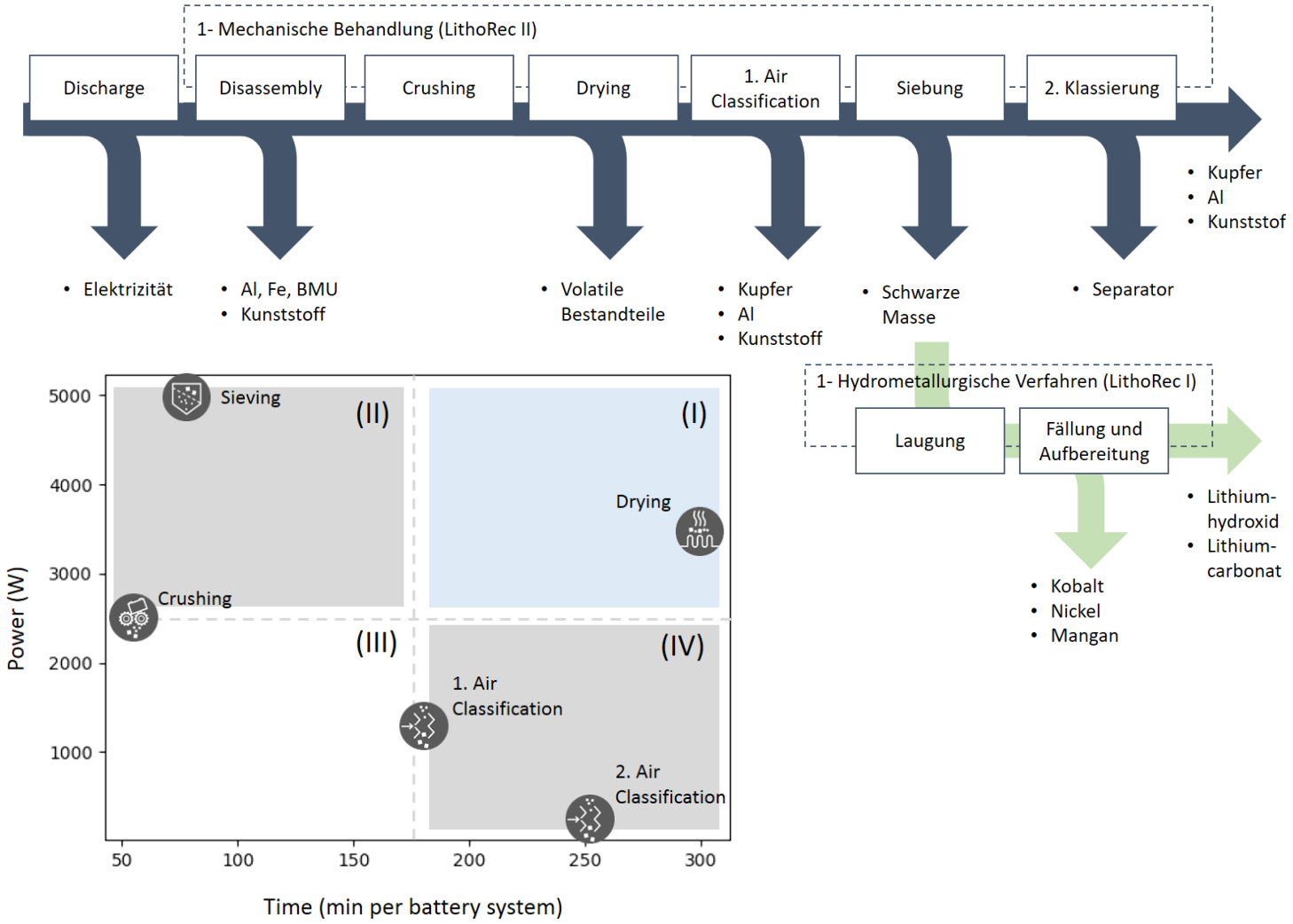
Agenda

1 LCA and its application to electromobility

2 Significance of the battery system

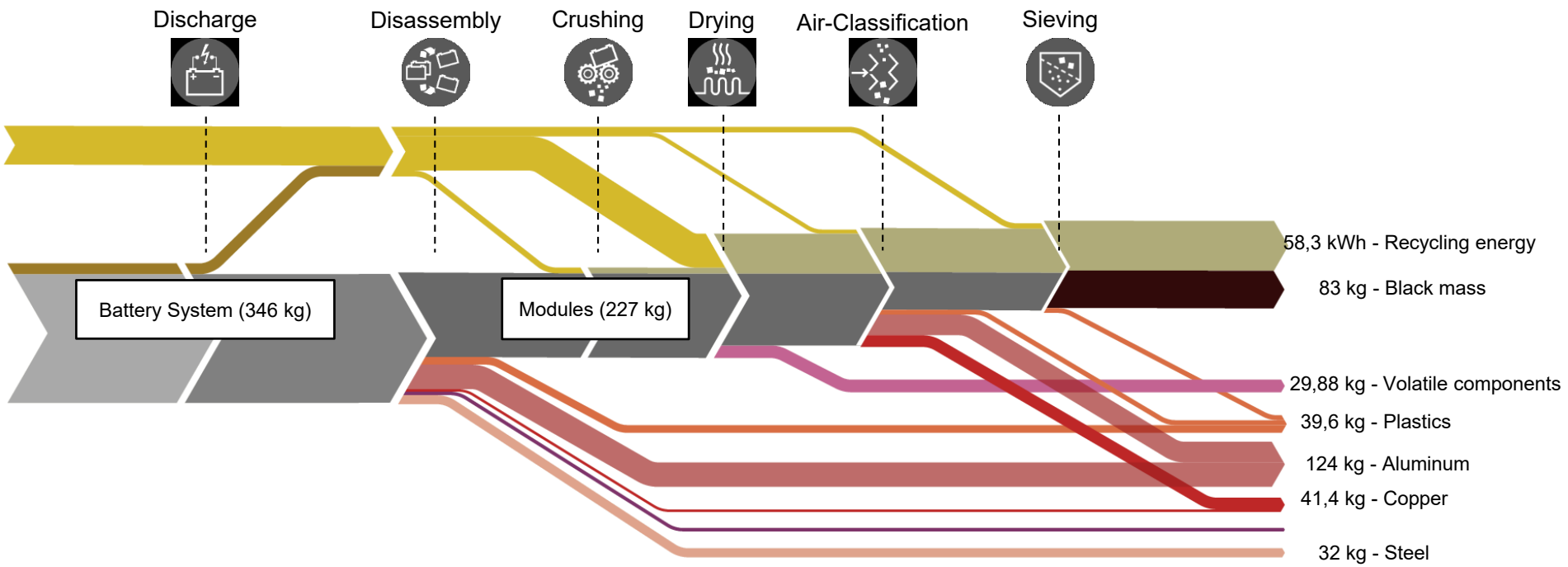
3 Relevance of recycling

Recycling
Process chain and energy portfolio in LithoRec



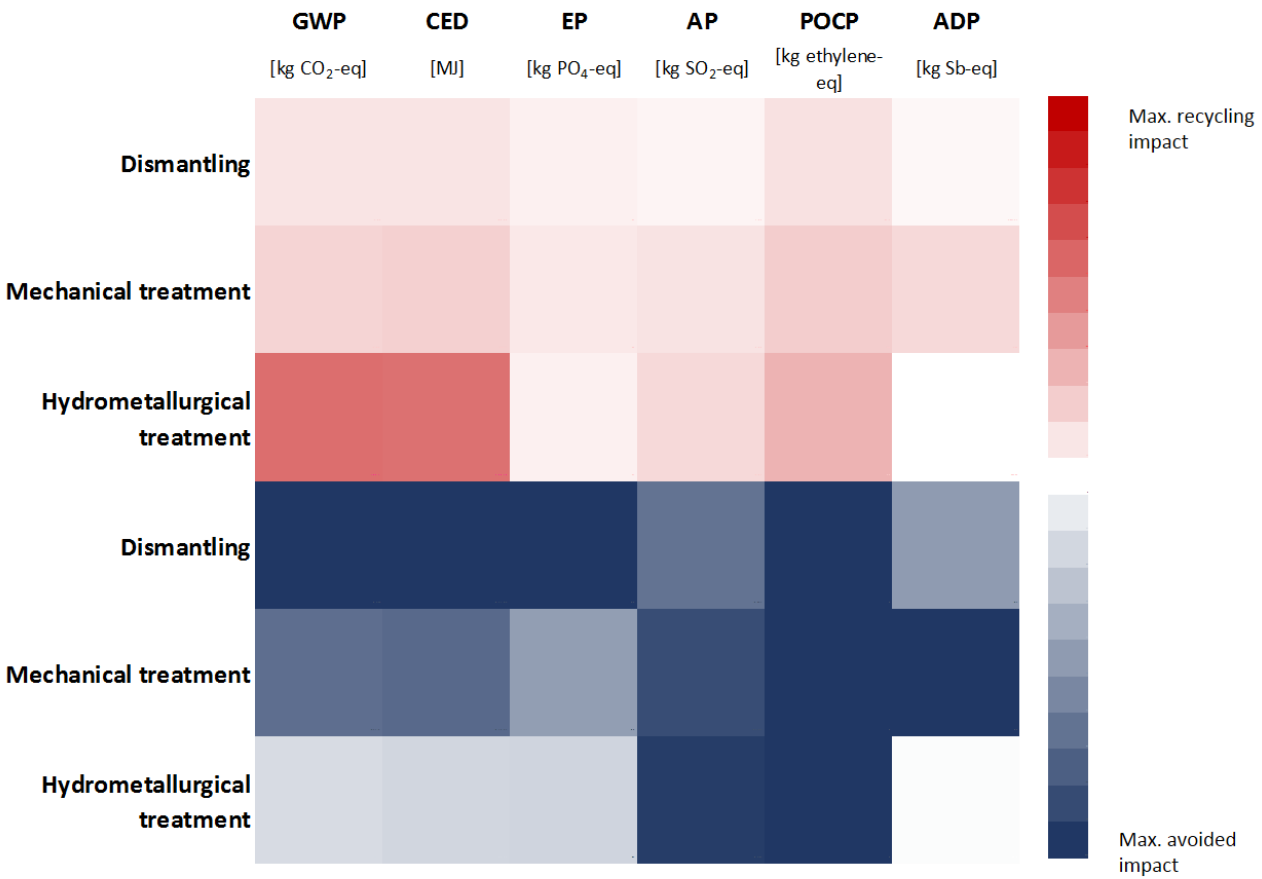
[LithoRec, Cerdas et al. 2018]

Recycling
Material and energy flows in LithoRec



[LithoRec, Cerdas et al. 2018]

Recycling
Environmental Impact of Recycling

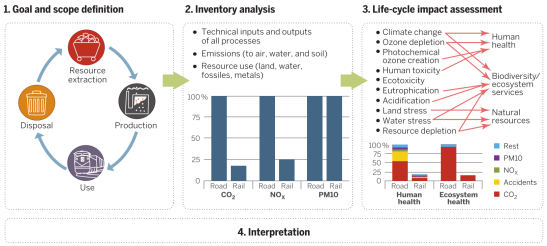


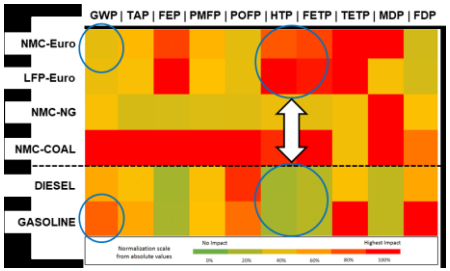
	GWP	CED	EP	AP	POCP	ADP
recycling impact	2209,00	36569,00	0,70	9,28	0,62	0,04
avoided impact	4934,00	83260,00	5,60	76,65	3,00	0,30

[LithoRec, Cerdas et al. 2018]

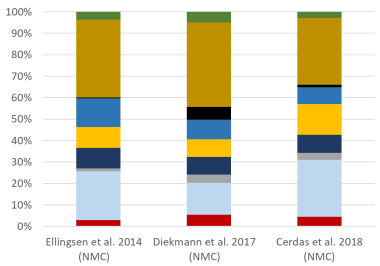
Summary

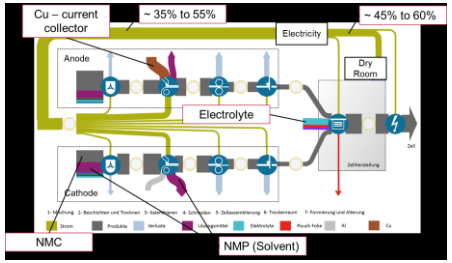
1

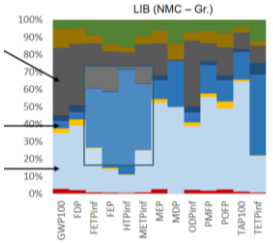

1. Goal and scope definition
Resource extraction
Production
Use
Disposal
2. Inventory analysis
Technical inputs and outputs of all processes
Emissions (to air, water, and soil)
Resource use (land, water, fossiles, metals)
Road Rail
CO2
NOx
PM10
3. Life-cycle impact assessment
Climate change
Ozone depletion
Photochemical ozone creation
Human toxicity
Ecotoxicity
Eutrophication
Acidification
Land stress
Water stress
Resource depletion
Human health
Biodiversity/ ecosystem services
Natural resources
Rest
PM10
NOx
Accidents
CO2
Human health
Ecosystem health
4. Interpretation


GWP | TAP | FEP | PMFP | POFP | HTP | FETP | TETP | MDP | FDP
NMC-Euro
LFP-Euro
NMC-NG
NMC-COAL
DIESEL
GASOLINE
Normalization scale from absolute values
No impact
Highest impact

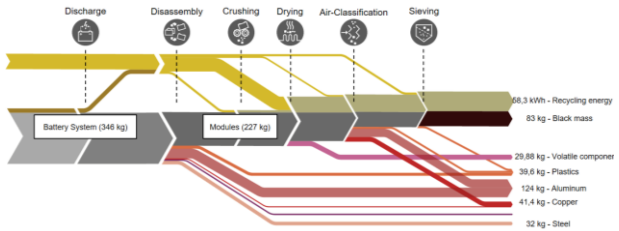
2

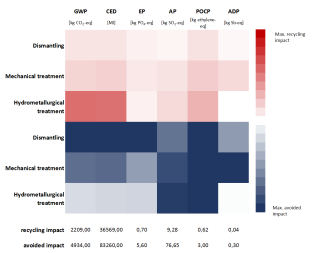

Ellingsen et al. 2014 (NMC)
Diekmann et al. 2017 (NMC)
Cerdas et al. 2018 (NMC)


Cu – current collector
~ 35% to 55%
~ 45% to 60%
Electricity
Anode
Dry Room
Electrolyte
Cathode
NMC
NMP (Solvent)


LIB (NMC – Gr.)
GWP100
FDP
FETPinf
FEP
HTPinf
METPinf
MEP
MDP
ODPinf
PMFP
POFP
TAP100
TETPinf

3


Discharge
Disassembly
Crushing
Drying
Air-Classification
Sieving
Battery System (346 kg)
Modules (227 kg)
68,3 kWh - Recycling energy
83 kg - Black mass
29,88 kg - Volatile componer
39,6 kg - Plastics
124 kg - Aluminum
41,4 kg - Copper
32 kg - Steel


GWP
CED
EP
AP
POCP
ADP
Dismantling
Mechanical treatment
Hydrometallurgical treatment
recycling impact
avoided impact

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