Karlsruher Institut für Technologie

EnInnov2022
17. Symposium Energieinnovation | 16.02.–18.02.2022

Parameterstudie zu Lithium- und Natrium-Ionen Batterien: Umweltauswirkungen der Nutzungsphase

Manuel Baumann, Jens Peters, Joachim R. Binder, Marcel Weil

Institut für Technikfolgenabschätzung und Systemanalyse (ITAS)





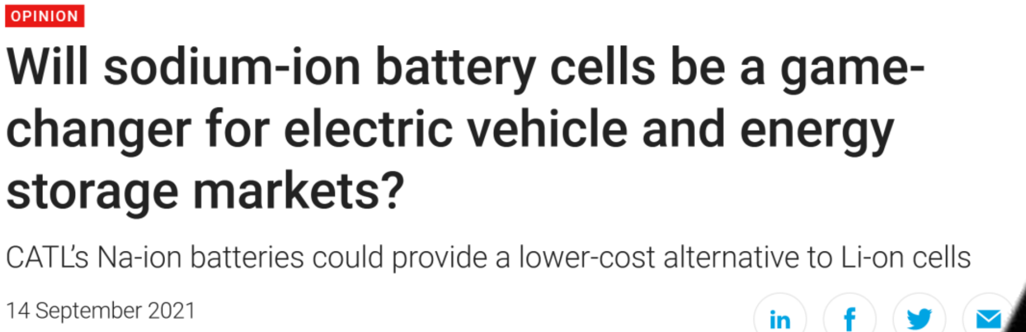
Introduction

- Demand for stationary battery storage of up to 47,858 GWh until 2050 (Ram et al.)

- Sodium-Ion batteries (SiBs) are considered as an alternative to overcome some sustainability challenges related to Lithium-Ion batteries (LiB) in stationary applications

- There are several companies (CATL, TIAMAT, Faradion) aiming to introduce SiB into markets

- **Only few studies about sustainability Available**

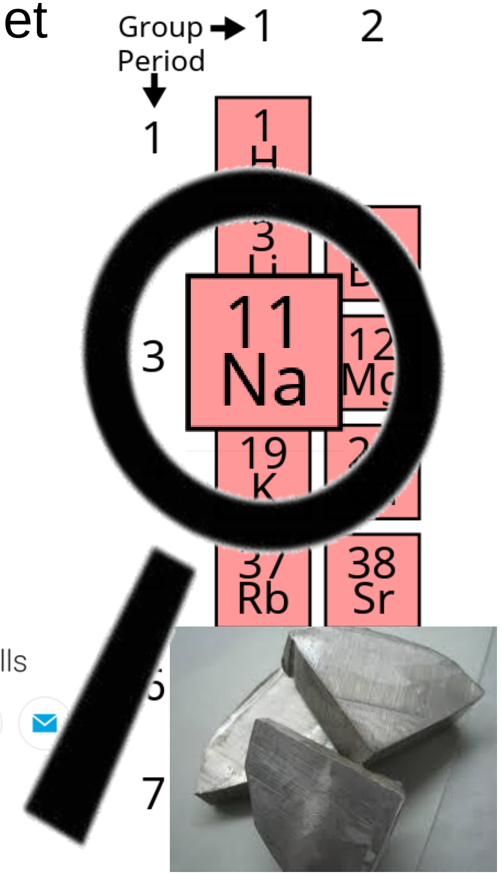

OPINION

Will sodium-ion battery cells be a game-changer for electric vehicle and energy storage markets?

CATL's Na-ion batteries could provide a lower-cost alternative to Li-on cells

14 September 2021

https://www.woodmac.com/news/opinion/will-sodium-ion-battery-cells-be-a-game-changer-for-electric-vehicle-and-energy-storage-markets/



https://en.wikipedia.org/wiki/Sodium

M. Ram, D. Bogdanov, A. S. Oyewo, and et al., “Global Energy System based on 100% Renewable Energy - Power Sector.,” Lappeenranta University of Technology, World Energy Watch Group, Lappeenranta, Berlin, Nov. 2017.

Jens Peters, Manuel Baumann, Marcel Weil, Stefano Passerini, On the environmental competitiveness of Sodium-Ion Batteries – Current state of the art in Life Cycle Assessment, 2021, Sodium-Ion Batteries: Materials, Characterization, and Technology. Ed. Philipp Adelhelm, Magdalena Titirici, Yong Sheng Hu, Wiley September 2021 (Forthcoming)

Introduction

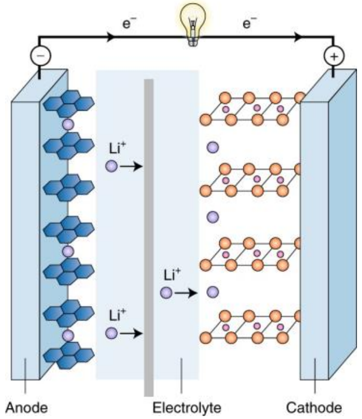
- SIB are based on essentially the same principle like LIB
- **Sodium** instead of **lithium** in the cathode active material and electrolyte salt
- **Aluminium** instead of **copper** for the current collector
- Use of several cathode materials

http://www.renewablesdaily.com/sodium-ion-batteries-are-improving

„Same, same but different „

Li-Ion Batteries

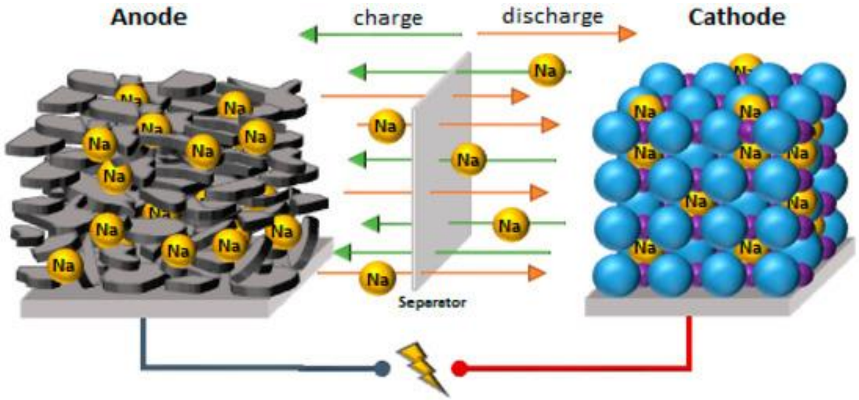
Anode Materials:
Graphite
Metallic Li



Li-Cathode Materials:
Ni
Co
Mn
FePO4
Al
…

Na-Ion Batteries

Anode Materials:
Hard Cabon
Metallic Na



Na-Cath. Materials:
Ni
Mn
FePO4
Ti
Al
…

Goodenough, J.B. How we made the Li-ion rechargeable battery. Nat Electron 1, 204 (2018). https://doi.org/10.1038/s41928-018-0048-6

J. F. Peters, A. Peña Cruz, und M. Weil, „Exploring the Economic Potential of Sodium-Ion Batteries“, *Batteries*, Bd. 5, Nr. 1, S. 10, März 2019, doi: 10.3390/batteries5010010.

Goal and scope

- Aim of the work:
- Life cycle assessment (LCA) of SIB under consideration of the whole life cycle – here focus on the **use phase**
- Compare Na-Ion alternatives to state of the Art Lithium-Ion Batteries (NMC 622, LiFP) & analyze required performance to be competitive with the same

Sustainable Energy & Fuels

ROYAL SOCIETY OF CHEMISTRY

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Cite this: *Sustainable Energy Fuels*, 2021, 5, 6414

On the environmental competitiveness of sodium-ion batteries under a full life cycle perspective – a cell-chemistry specific modelling approach†

Jens F. Peters, *[ab] Manuel Baumann, [c] Joachim R. Binder[d] and Marcel Weil[ce]

Assessed battery types

Adopted BatPac dimensioning tool by Argonne National Laboratories

Na-based cells

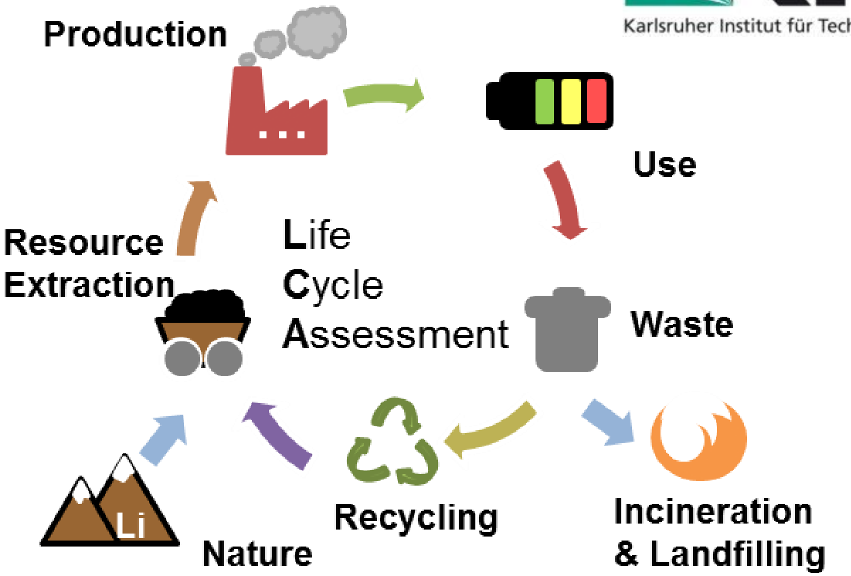
- NaNMMT SIB cell $Na_{1.1}(Ni_{0.3}Mn_{0.5}Mg_{0.05}Ti_{0.05})O_2$
- NaMMO $Na_{2/3}(Mn_{0.95}Mg_{0.05})O_2$
- NaNMC $Na_{1.05}(Ni_{0.33}Mn_{0.33}\text{-}Co_{0.33})_{0.95}O_2$
- NaPBA; $Na_2Fe\,[Fe(CN)_6]$)
- NaMVP $Na_4\text{-}MnV(PO_4)$

Li-based reference cells (benchmark)

- LiNMC622
- LiFP

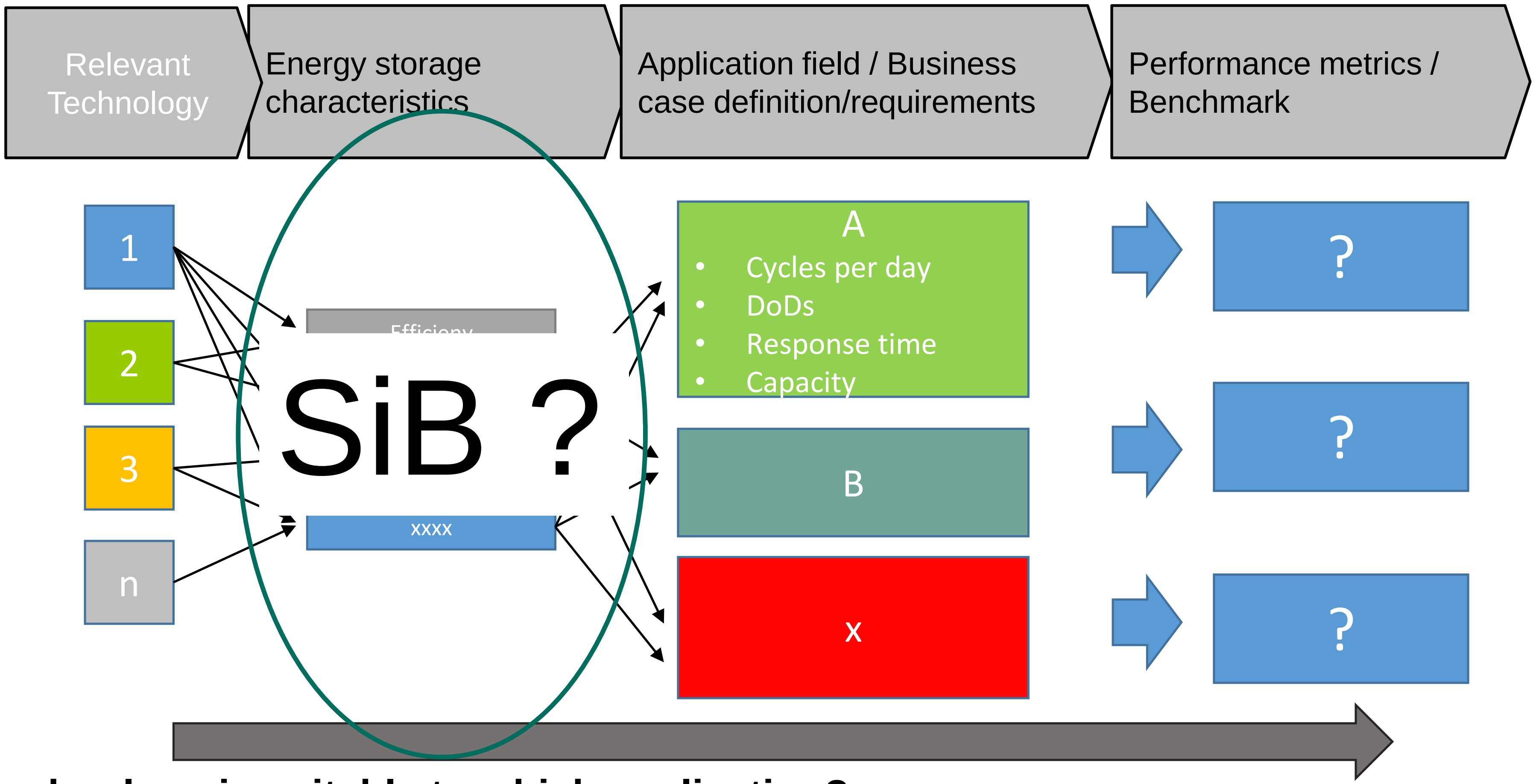
http://www.renewablesdaily.com/sodium-ion-batteries-are-improving

Assessment Framework



- Life cycle Assessment (LCA)
- cradle-to-grave approach
  - Manufacturing
  - **Use phase**
  - End of Life Phase
- openLCA 1.10.2 & ecoinvent 3.7.1
- Functional unit: 1 kWh of electricity provided by the battery cell over the lifetime of the assumed application.
- Impact Categories (ILCD)
  - (i) **global warming potential** (GWP) i.e., GHG emissions (kg CO2 eq. / kWh)
  - (ii) **abiotic resource depletion potential** (ADP) (kg Sb eq. / kWh)

Consideration of use phase



Which technology is suitable to which application?
Which one performs best?

Battery performance assumptions

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- In contrast to LiB, SiB are not established, only lab-scale data about performance available
- Parametric study, performance in orientation towards LiB technology
- Parametrized factors (only one at the time in the detailed analyses):
  - Efficiency (no differing c-rates, temperatures etc. considered)
  - Cycle Lifetime (fixed SoC, not changing c-rates etc.)
  - Energy density

Implies, that detailed analyses are required when better data is available

- Analyze which performance is required to be competitive with LiBs

	NaNMC, NaMMO, NaNMMT			NaPBA, NaMVP			LiFP			LiNMC		
	Min	Base	Max	Min	Base	Max	Min	Base	Max	Min	Base	Max
Efficiency	90	92	95	90	93	97	90	93	97	90	92	95
Min SOC%	10	20	25	5	20	20	5	20	20	10	20	25
Max SOC%	95	95	100	95	95	100	95	95	100	95	95	100
Cycle life	1000	4000	9000	1000	7000	10 000	2500	7000	10 500	1000	4000	9000
Calendric life time	10	15	20	10	15	20	10	15	20	10	15	20

Peters, J. F.; Baumann, M.; Binder, J. R.; Weil, M. On the environmental competitiveness of sodium-ion batteries under a full life cycle perspective – a cell-chemistry specific modelling approach. 2021. Sustainable energy & fuels. doi:10.1039/d1se01292d

Simplified application case

- Generic consideration of the use phase difficult
- Simplified case (e.g. “load shifting”)
- Two scenarios:
  - (i) electricity from grid
  - (ii) electricity from PV systems
- Cells exchanged in case of insufficient cycle or calendric lifetime

- The periphery has been neglected here (out of scope)

Parameter	Value	Unit
Capacity	2	MWh
Power	1	MW
Cycles per day	2	—
Project life time	20	years
Cycles over project lifetime	14 600	Cycles
Total energy stored	14,600 000	kWh
Total cycles per year	730	—
Operation rate per year	17%	1450 h

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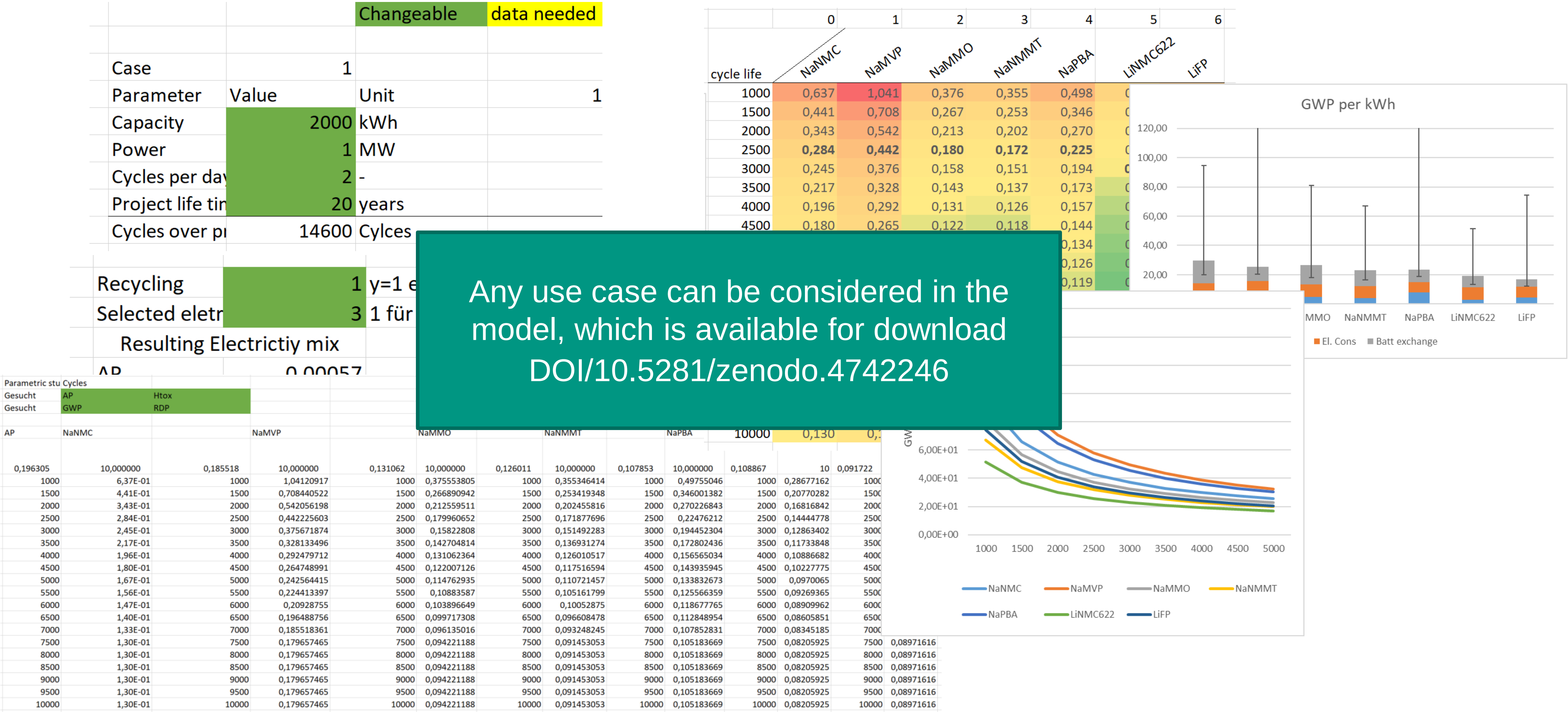
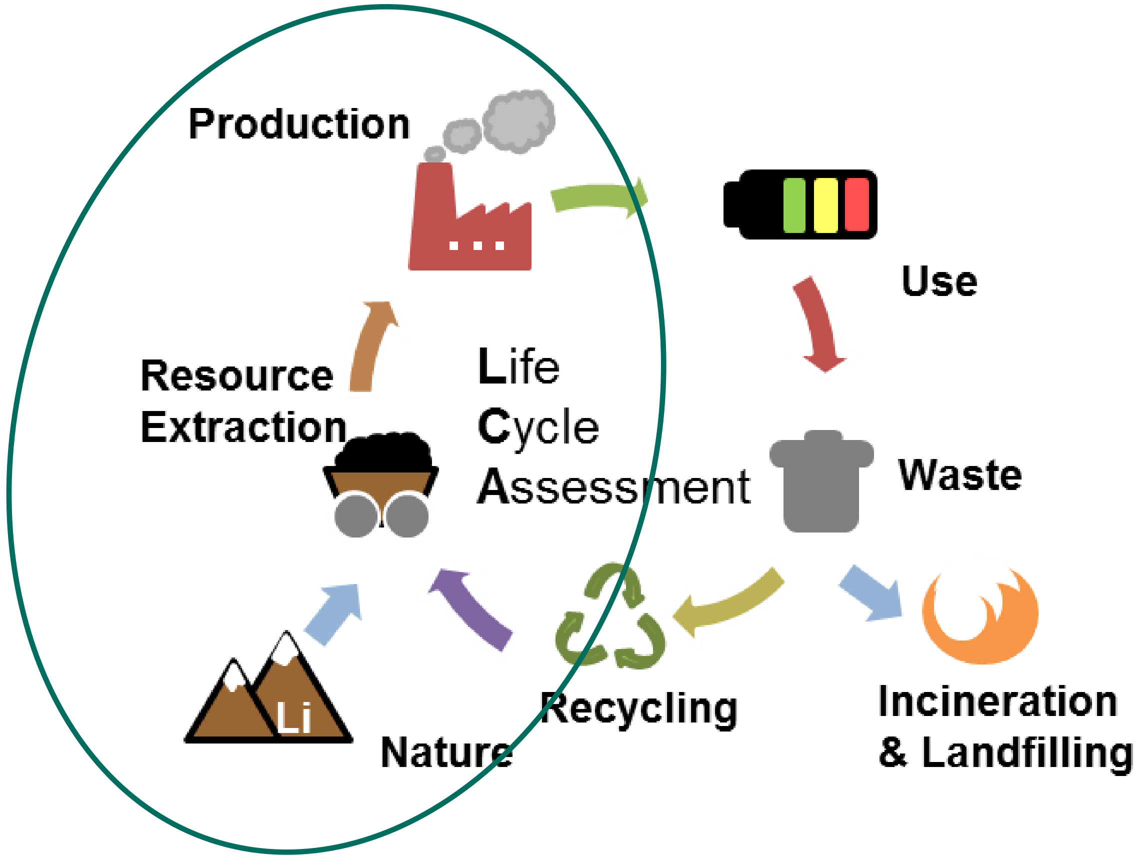
Simplified application case



Any use case can be considered in the model, which is available for download DOI/10.5281/zenodo.4742246

Results

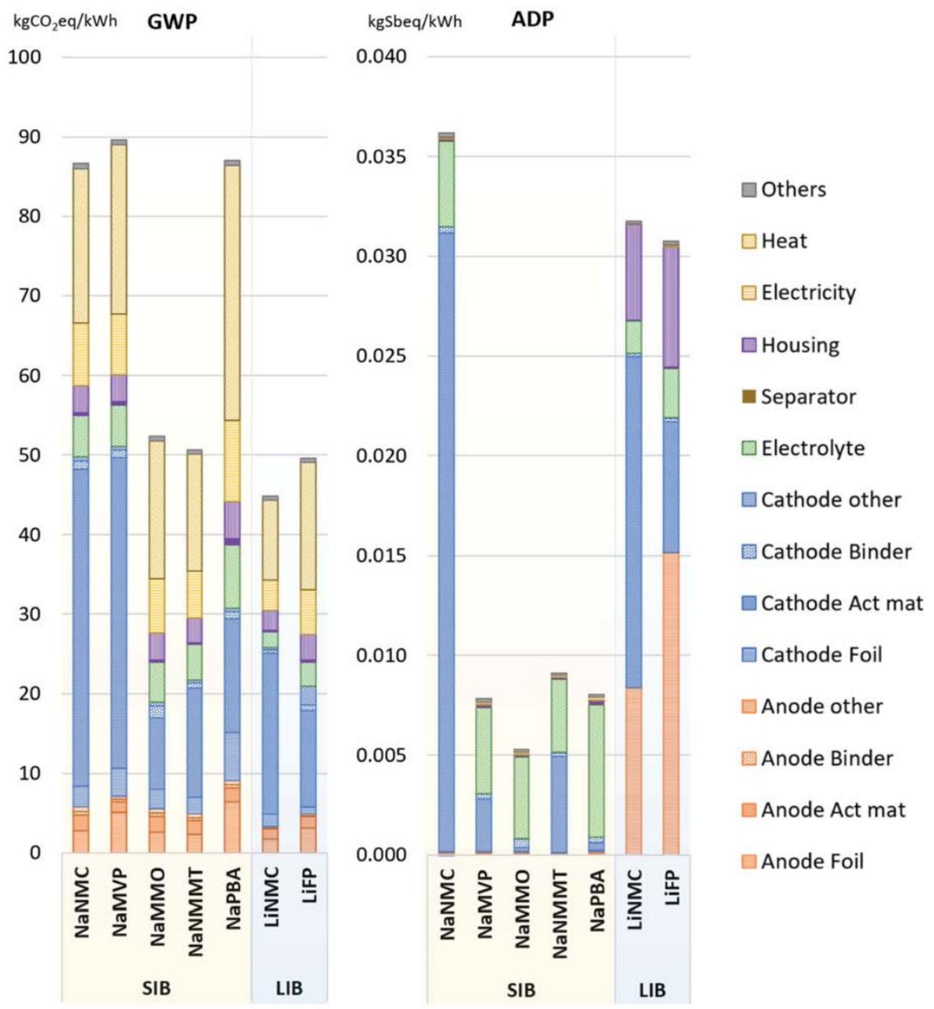
Manufacturing phase (cradle-to-gate)



Manufacturing phase (cradle-to-gate)

- No use-phase and end-of-life
- Impacts very different depending on impact category

- **GWP:** High for SiB, due to lower energy density (more active material required for the same capacity)
- **ADP:** Higher for Li-based and NaNMC impacts due to copper, cobalt and nickel contained in theells. SiB perform better



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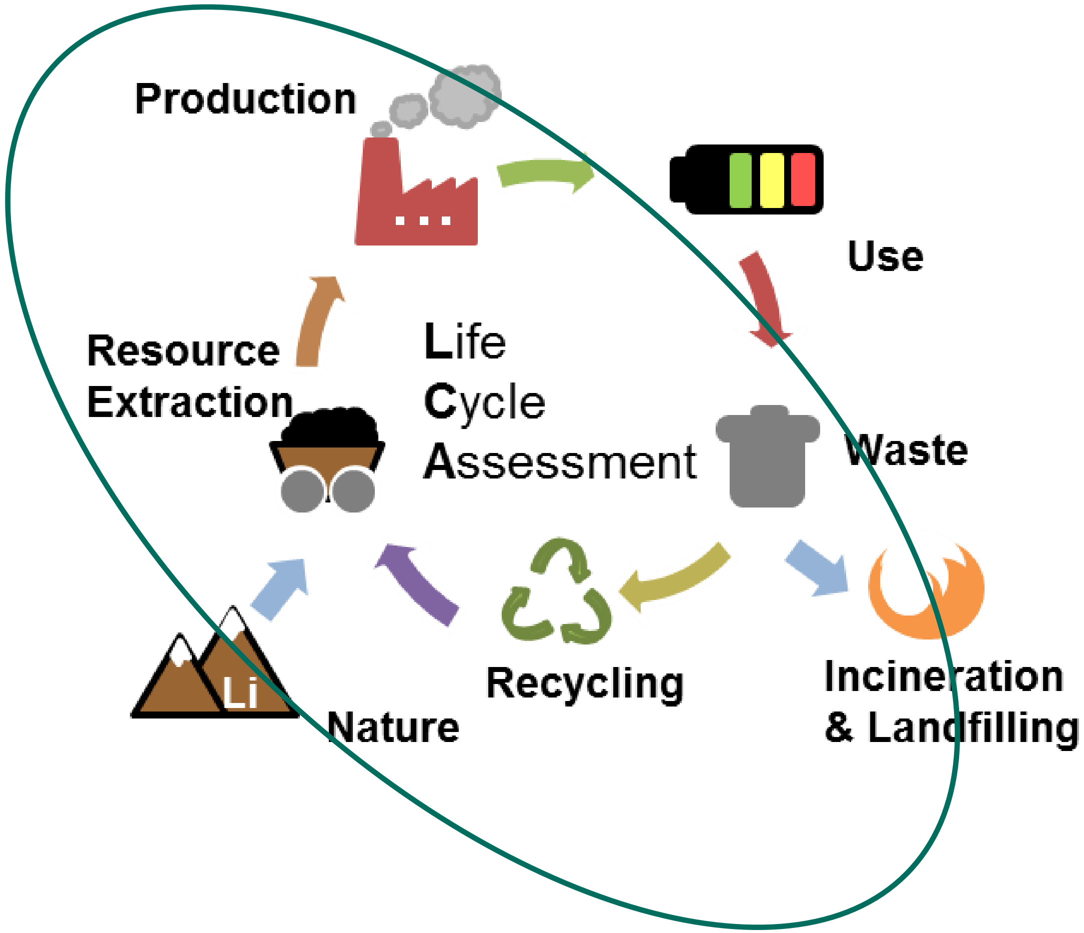
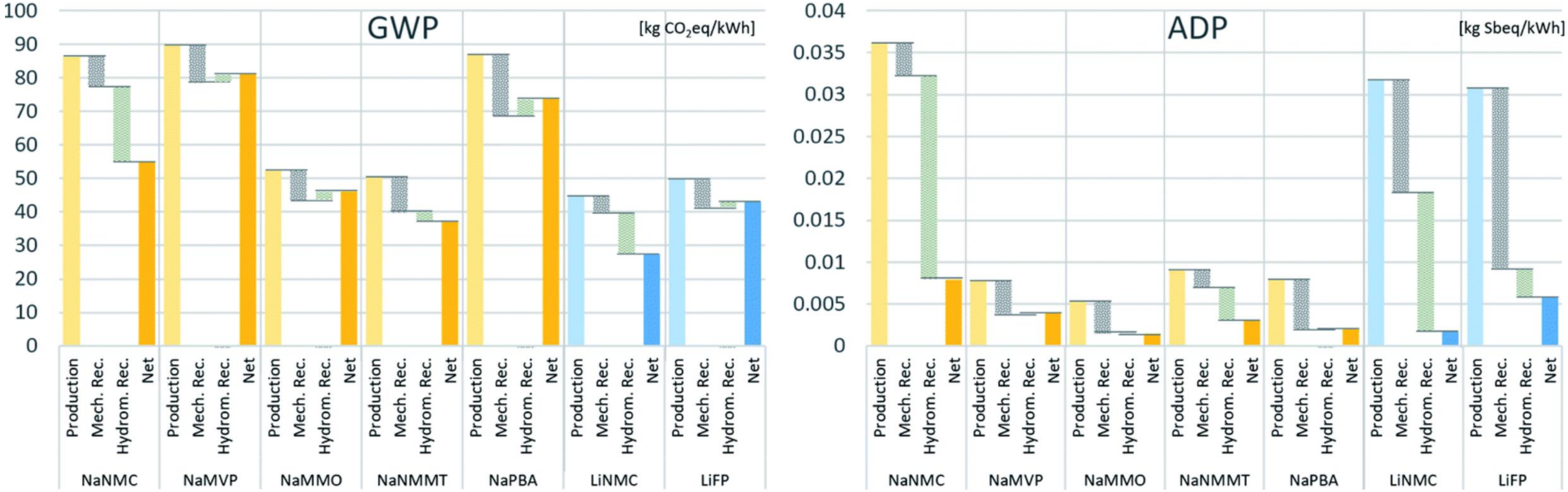
Results

End of Life



EOL-Phase

- Advanced Hydrometallurgical recycling, assuming closed loop recycling, significant reductions of impacts



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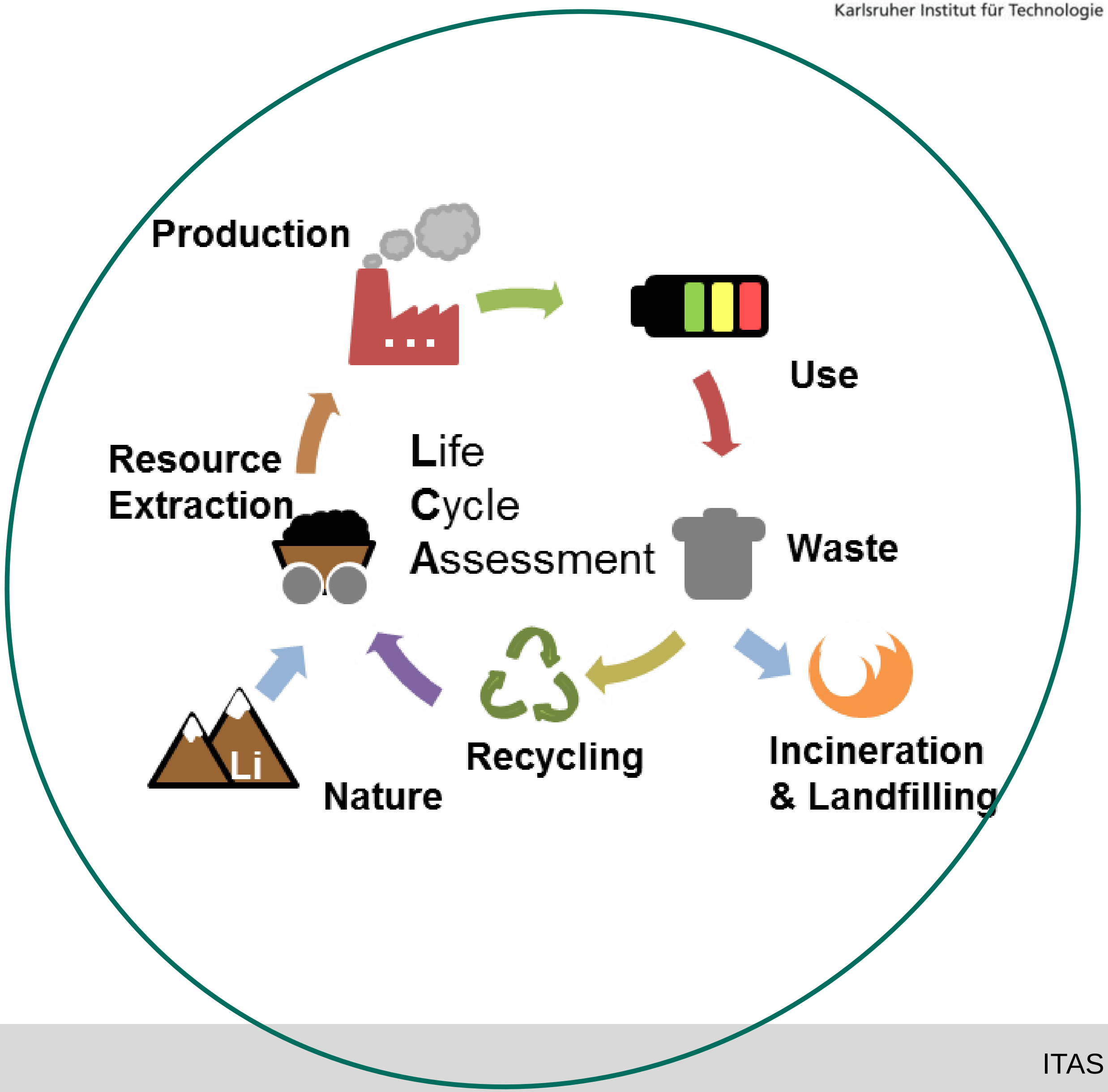
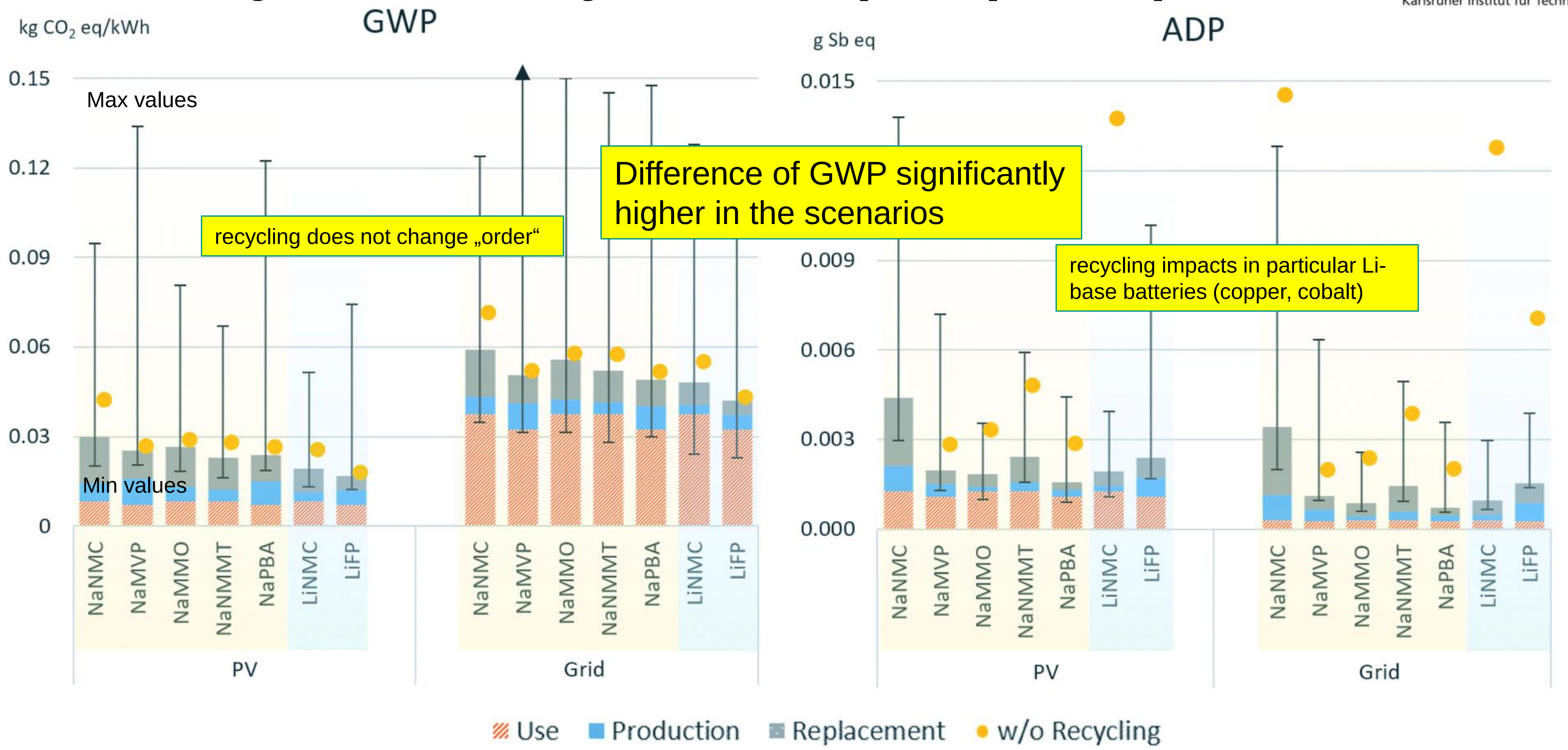
Results

Entire Life cycle



Efficiency and battery lifetime (use phase)



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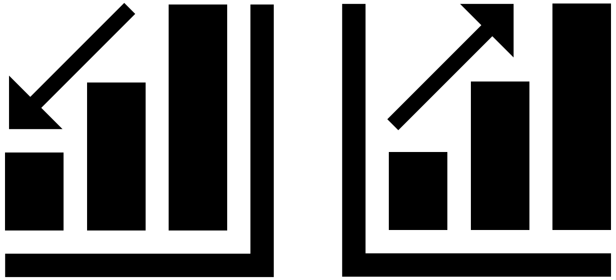
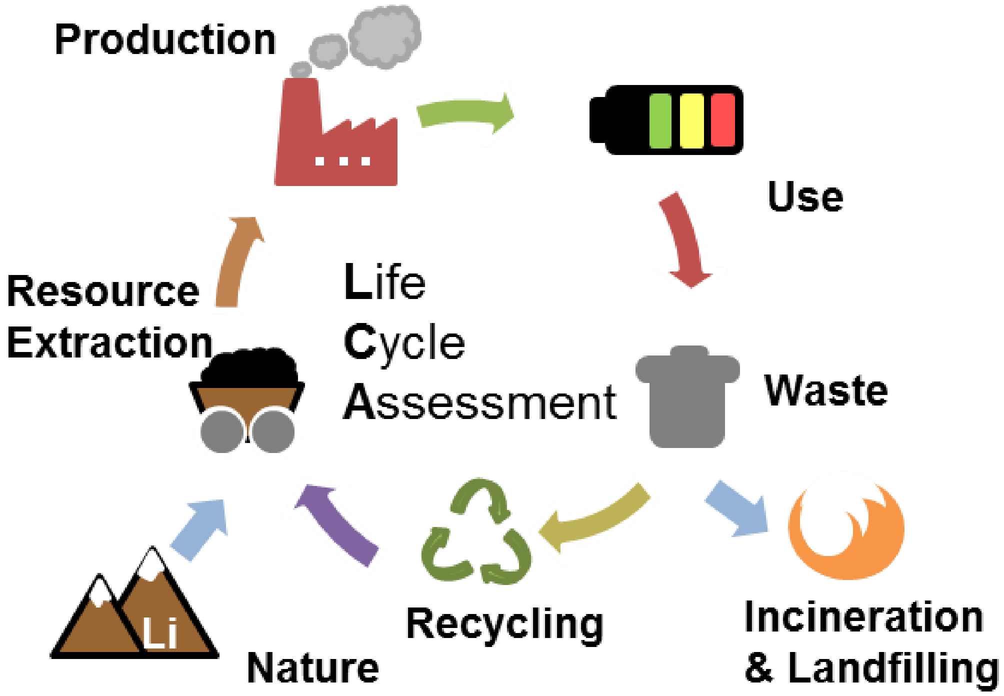
Sensitivity (Use Phase)

Entire Life cycle

Sensitivity Analysis





Role of energy density (use phase)

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Performance

- Worse
- Equal
- Better

Default values

Reference

En. Dens. Wh/kg	NaNMC	NaNVP	NaNMMO	NaNMMT	NaPBA	LiNMC	LiFP
	GWP kgCO2 eq /kWh						
100	74.6	124.0	72.3	64.1	91.8	74.6	85.0
110	67.8	112.7	65.7	[illegible]	83.4	67.8	77.3
120	[illegible]	[illegible]	[illegible]	[illegible]	76.5	62.2	70.8
130	57.4	95.4	55.6	[illegible]	70.6	57.4	65.4
140	53.3	88.6	51.6	45.8	65.5	53.3	60.7
150	49.8	82.7	48.2	42.7	61.2	49.7	56.7
160	46.6	77.5	45.2	40.0	57.3	46.6	53.1
170	43.9	72.9	42.5	37.7	54.0	43.9	50.0
180	41.5	68.9	40.1	35.6	51.0	41.5	47.2
190	39.3	65.3	38.0	33.7	48.3	39.3	44.7
200	37.3	62.0	36.1	32.0	45.9	37.3	42.5
210	35.5	59.0	34.4	[illegible]	[illegible]	35.5	40.5
220	33.9	56.4	32.8	[illegible]	[illegible]	33.9	38.6
230	32.4	53.9	31.4	[illegible]	[illegible]	32.4	36.9
240	31.1	[illegible]	30.1	[illegible]	[illegible]	31.1	35.4
250	29.9	[illegible]	28.9	25.6	36.7	29.8	34.0
260	28.7	47.7	[illegible]	24.6	35.3	28.7	32.7
270	[illegible]	[illegible]	[illegible]	23.7	34.0	27.6	31.5
280	[illegible]	[illegible]	25.8	22.9	32.8	26.6	30.4

Target

Target

Achieved

Reference

En. Dens. Wh/kg	NaNMC	NaNVP	NaNMMO	NaNMMT	NaPBA	LiNMC	LiFP
	ADP gSb eq./kWh						
100	10.85	5.96	2.28	5.10	2.65	4.64	11.50
110	9.86	5.42	[illegible]	[illegible]	2.41	4.21	10.45
120	9.04	4.97	[illegible]	[illegible]	2.21	3.86	9.58
130	8.34	4.59	[illegible]	[illegible]	2.04	3.57	8.84
140	7.75	4.26	[illegible]	[illegible]	1.89	3.31	8.21
150	7.23	3.98	1.52	3.40	[illegible]	[illegible]	7.66
160	6.78	3.73	1.43	3.19	[illegible]	[illegible]	7.18
170	6.38	3.51	1.34	3.00	1.56	2.73	6.76
180	6.03	3.31	1.27	2.83	[illegible]	[illegible]	6.39
190	5.71	3.14	1.20	2.68	1.39	2.44	6.05
200	5.42	2.98	1.14	2.55	1.32	2.32	5.75
210	5.17	2.84	1.09	2.43	1.26	2.21	5.47
220	4.93	2.71	1.04	2.32	1.20	2.11	5.23
230	4.72	2.59	0.99	2.22	1.15	2.02	5.00
240	4.52	2.49	0.95	2.12	1.10	1.93	4.79
250	4.34	2.39	0.91	2.04	1.06	1.85	4.60
260	4.17	2.29	0.88	1.96	1.02	1.78	4.42
270	4.02	2.21	0.85	1.89	0.98	1.72	4.26
280	3.87	2.13	0.82	1.82	0.95	1.66	4.11

Target

Peters, J. F.; Baumann, M.; Binder, J. R.; Weil, M. On the environmental competitiveness of sodium-ion batteries under a full life cycle perspective – a cell-chemistry specific modelling approach. 2021. Sustainable energy & fuels. doi:10.1039/d1se01292d

Cycle Life Time

Reference | Reference

Cycle life / Cycles	NaNMC	NaMVP	NaMMO	NaNMMT	NaPBA	LiNMC	LiFP
	GWP gCO2 eq /kWh						
1000	94.60	133.99	80.80	67.03	122.46	51.52	74.30
1500	65.83	91.72	56.63	47.45	84.04	37.11	51.93
2000	51.45	70.59	44.55	37.66	64.83	29.91	40.74
2500	42.82	57.91	37.30	31.79	53.30	25.59	34.03
3000	37.07	49.45	32.47	27.88	45.61	22.71	29.56
3500	32.96	43.42	29.01	25.08	40.12	20.65	26.36
4000	29.88	38.89	26.43	22.98	36.01	19.11	23.96
4500	27.48	35.36	24.41	21.35	32.80	17.91	22.10
5000	25.56	32.55	[illegible]	20.05	30.24	16.94	[illegible]
5500	23.99	30.24	21.48	18.98	28.15	16.16	[illegible]
6000	22.68	28.32	20.38	18.09	26.40	15.50	18.37
6500	21.58	26.69	19.45	17.34	24.92	14.95	17.51
7000	20.63	25.30	18.66	16.69	23.65	14.48	16.77
7500	20.12	24.56	18.23	16.35	22.98	14.22	16.38
8000	20.12	24.56	18.23	16.35	22.98	14.22	16.38
8500	20.12	24.56	18.23	16.35	22.98	14.22	16.38
9000	20.12	24.56	18.23	16.35	22.98	14.22	16.38
9500	20.12	24.56	18.23	16.35	22.98	14.22	16.38
10000	20.12	24.56	18.23	16.35	22.98	14.22	16.38

Cycles	NaNMC	NaMVP	NaMMO	NaNMMT	NaPBA	LiNMC	LiFP
	ADP mgSb eq./kWh						
1000	0.0138	0.0072	0.0035	0.0059	0.0044	0.0039	0.0102
1500	0.0096	0.0052	0.0028	0.0044	0.0033	0.0030	0.0071
2000	0.0075	0.0041	[illegible]	[illegible]	0.0028	0.0026	0.0056
2500	0.0063	0.0035	0.0022	0.0031	0.0024	0.0023	0.0047
3000	0.0054	0.0031	0.0020	0.0028	0.0022	0.0022	0.0041
3500	0.0048	0.0028	[illegible]	0.0026	0.0020	0.0020	0.0037
4000	[illegible]	[illegible]	0.0018	0.0024	0.0019	0.0019	0.0034
4500	[illegible]	0.0024	0.0018	0.0023	0.0018	0.0019	0.0031
5000	0.0038	0.0023	0.0017	0.0022	0.0018	0.0018	0.0029
5500	0.0035	0.0022	0.0017	0.0021	0.0017	0.0017	0.0027
6000	0.0033	0.0021	0.0016	0.0020	0.0016	0.0017	0.0026
6500	0.0032	0.0020	0.0016	[illegible]	0.0016	0.0017	0.0025
7000	0.0031	0.0020	0.0016	0.0019	0.0016	0.0016	0.0024
7500	0.0030	0.0019	0.0016	0.0019	0.0015	0.0016	0.0023
8000	0.0030	0.0019	[illegible]	[illegible]	0.0015	0.0016	0.0023
8500	0.0030	0.0019	0.0016	0.0019	0.0015	0.0016	0.0023
9000	0.0030	0.0019	0.0016	0.0019	0.0015	0.0016	0.0023
9500	0.0030	0.0019	0.0016	0.0019	0.0015	0.0016	0.0023
10000	0.0030	0.0019	0.0016	0.0019	0.0015	0.0016	0.0023

Default values

Target

Achieved

Target

Performance

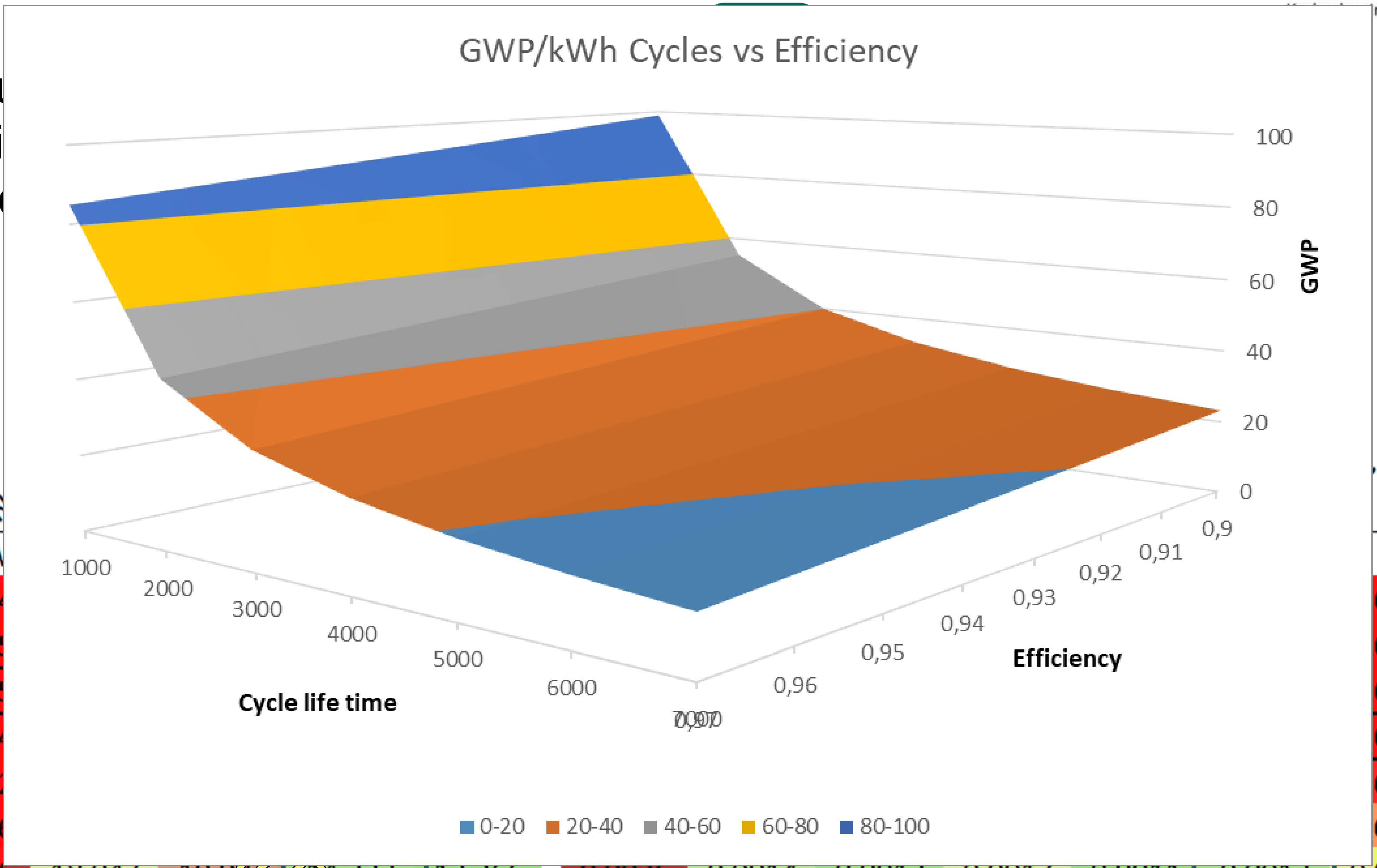
- Worse
- Equal
- Better

Peters, J. F.; Baumann, M.; Binder, J. R.; Weil, M. On the environmental competitiveness of sodium-ion batteries under a full life cycle perspective – a cell-chemistry specific modelling approach. 2021. Sustainable energy & fuels. doi:10.1039/d1se01292d

Efficiency

Performance

- high efficiencies wou… order to equal the Li… environmental impa…



Effi-cienc…	NaNMC	N…	N…											LiFP
Eff.			GW…											
90%			29.134											0029
91%	31.253	27.955	27.765											0028
92%	.876	26.614	26.425											0026
93%	8.528	25.301	25.114											0024
94%	27.209	24.016	23.832											0022
9…	25.917	22.758	22.57…											00…
	24.653	21.527	21.346	18.047	19.9…	…4.332	13.266	0.0036	0.0014	0.0012	0.0017	0.0011	0.0012	0.0019
97%	23.415	20.321	20.142	16.877	18.74…	13.200	12.145	0.0034	0.0013	0.0010	0.0016	0.0009	0.0011	0.0017

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Conclusion

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- Study gives first tendencies for SiB cells in early development stages
- SiB close to or even better than that of their LIB counterparts (NaMMO and NaNMMT)
- SIB, if unable to achieve higher energy densities, a high cycle life is the key for unlocking their potential
- Use case plays a significant role for overall impacts (here simplified)
- In any case, detailed analyses are required if better performance data is available

For future works:

- Publication, dimensioning tool and results openly available

Conclusions

Underlying data available openly on Zenodo:

- Excel-based cell dimensioning tool, allows for incorporating also other cell chemistries
- Numeric results and graphics
- Life cycle inventory data for import and direct re-use in openLCA (requires ecoinvent 3.7.1)
- DOI/10.5281/zenodo.4742246

https://zenodo.org/badge/DOI/10.5281/zenodo.4742246.svg


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May 7, 2021 Software Open Access

On the environmental competitiveness of Sodium-Ion batteries under a full life cycle perspective – A cell-chemistry specific modelling approach

Peters, Jens F.; Baumann, Manuel; Binder, Joachim; Weil, Marcel

This upload provides the full supplementary information and the MS-Excel based cell dimenioning tool used in the underlying publication (Environmental impacts of Sodium-Ion Batteries – Advances in production, use and recyclability)

It is based on the BatPac-Tool created by Argonne National Laboratories, but with some substantial modifications:

- Reduction to dimensioning on battery cell leve, with no need to define a whole vehicle battery pack
- Inclusion of a detailed and cell-chemistry specific recycling model
- Automatic generation of inventory tables for life cycle assessmen

The tool is free to use and to update as long as the underlying original publication is cited properly

In addition, the inventory data used for calculating the results are also provided as JSON-LD files for direct import into openLCA and in ILCD format for import into other LCA software. The LCI is based on ecoinvent 3.7; use with other ecoinvent versions might require re-linking of flows.

This work was funded by the European Union's Horizon 2020 Research and Innovation Programme under the Marie Skłodowska-Curie Grant Agreement No. 754382 and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany´s Excellence Strategy – EXC 2154 – Project number 390874152. However, its content does not reflect the official opinion of the funding entities. Responsibility for the information and views expressed herein lies entirely with the authors.

Preview

SIB-LCA-Update_2021_ILCD-Export_ei371_2021-08-15.zip

- ILCD
  - contacts
    - 41f6c41a-42b0-4ecd-808d-0600bcfadb14.xml 1.6 kB
    - c4597934-ecac-422c-b431-382e85fdcb83.xml 1.6 kB
  - flowproperties
    - 01846770-4cfe-4a25-8ad9-919d8d378345.xml 2.2 kB
    - 838aaa20-0117-11db-92e3-0800200c9a66.xml 2.2 kB
    - 93a60a56-a3c8-11da-a746-0800200b9a66.xml 2.2 kB
    - 93a60a56-a3c8-19da-a746-0800200c9a66.xml 2.2 kB
    - 93a60a56-a3c8-21da-a746-0800200c9a66.xml 2.2 kB
    - 93a60a56-a3c8-22da-a746-0800200c9a66.xml 2.2 kB
    - f6811440-ee37-11de-8a39-0800200c9a66.xml 2.2 kB
  - flows
    - 03de3d31-34fb-4ed9-872d-4acd5ebd7a92.xml 3.3 kB
    - 04b06043-ab0b-4125-9982-dec1687edda5.xml 3.0 kB
    - 0639ab9a-43bd-48b8-b8d9-99c50aa022fd.xml 3.4 kB
    - 06440ac0-a1f5-4ba5-a0f7-727570bfbfff.xml 3.3 kB
    - 081e318e-b5f5-4f93-8c48-ab0bf5c43f2a.xml 3.4 kB

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Publication date: May 7, 2021

DOI: 10.5281/zenodo.4742246

Keyword(s): battery assessment; cell layout; recycling model; inventory data; dimensioning tool, lithium-ion; sodium-ion

Grants: European Commission:

- GOT ENERGY - GOT ENERGY TALENT. Attracting Talented Researchers within the Spanish Campus of International Excellence 'Smart Energy' and the region of Madrid. (754382)

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Thank you for your attention!

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Acknowledgement: This work contributes to the research performed within the Helmholtz Association project "Energy System 2050 "and at CELEST (Center for Electrochemical Energy Storage Ulm-Karlsruhe) which is funded by the German Research Foundation (DFG) under Project ID 390874152 (POLiS Cluster of Excellence).