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Life Cycle Assessment of Sodium-Nickel-Chloride Batteries

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Agenda

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   Environmental impact and recycling of different battery technologies
   Use-Case: Don Bosco mini grid in Tema, Ghana

3. **Methodology**
   Life Cycle Assessment of a $NaNiCl_2$ battery

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   Comparison with lead-acid and li-ion battery
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1. Problem Statement & Research Question

Problem Statement

- Battery storage systems are needed for a full transition to decarbonization of energy systems based on renewable energy sources to balance the fluctuations of energy generation, e.g in solar powered mini grids.[3]

- Batteries are often criticized
  - Toxicity and rare materials [22]-[25], [28], [29]
  - Short life cycle at high temperatures [22], [26]

- Sodium-Nickel-Chloride ($NaNiCl_2$) batteries
  - Abundant and low-cost materials [8]
  - Discharge and charge are nearly independent of outside temperature [11]

Research Question

Do $NaNiCl_2$ batteries offer advantages for decarbonization of energy systems compared to alternative battery types such as lithium-ion and lead acid batteries, regarding Global Warming Potential over 100 years (GWP_{100})?

Sources: [3], [8], [11], [22]-[26], [28], [29]

2. State of the Art | $NaNiCl_2$ battery

- Usable capacity (incl. efficiency losses): 41 kWh
- Modular design, expandable with additional storage capacity
  - Battery Container: Frame, insulation layer and ventilator
  - Module: Frame, insulation layer, heater and battery management systems (BMS)
  - Battery Cells: 140 tubular designed battery cells
- Insulation layers and heater for operation temperature of 250°C-320°C

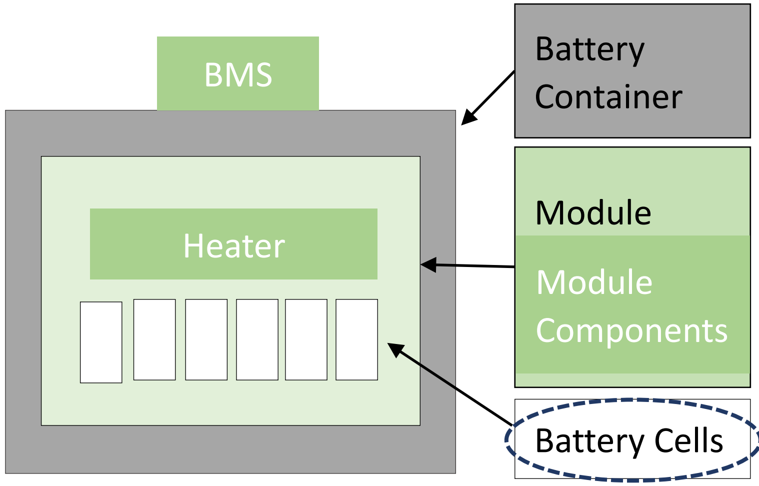

Figure 1: Structure of the analysed $NaNiCl_2$ battery (Illustration based on manufacturer information and Hesse et al. [7]).

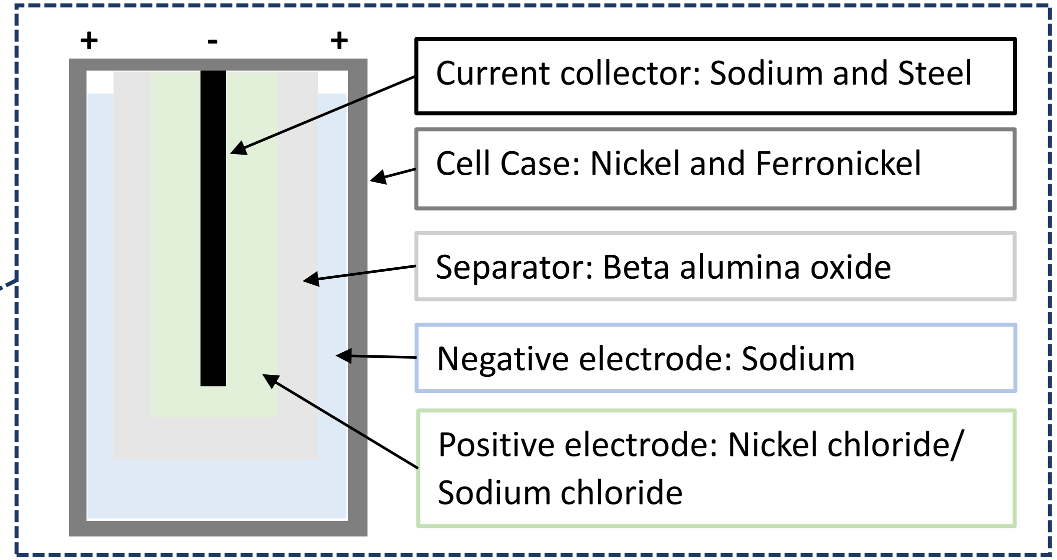

Figure 2: Tubular designed $NaNiCl_2$ battery cell (Illustration based on manufacturer information, EASE [11], Sakaebe [18] and Dustmann [19])

Sources: [7], [11], [18], [19]

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	Pro*	Contra*
Lithium-ion batteries:	• Possibilities for second-life applications [21]	• Production requires toxic and rare earth materials [22] • Toxic gas emissions hazardous to human health [23]-[25] • High temperatures shortens lifetime [22], [26] • Low recycling collection rates [21]
Lead-acid batteries:	• Dominant battery in Ghana • Recycling processes well-know, reaching a 100% in developed countries [30]	• Risk for human health, when processed in informal sectors as i.e. in Ghana [28], [29]
$NaNiCl_2$ batteries:	• Non-hazardous raw materials [32] • Recycling processes are mainly metallurgic and can be performed at local steel plants • Expected lifetime of more than 15 years/4,500 charging cycles [11]	• Stable temperature between 250°C-320°C needed for charging [11] • Not suitable for all applications / unsuitable for fast charging, because the charging current is limited by the endothermic charging reaction. • At present: Higher cost than lithium-ion and lead-acid batteries. By upscaling, economic advantage can be realized.

TABLE 1: Comparison of Lithium-ion, lead-acid and $NaNiCl_2$ batteries.
* This table does not claim to be exhaustive. It is intended to show the relevance of the study of salt batteries and in particular the EOL.

Sources: [22]-[26],[28]-[30], [32]

2. State of the Art | Use-case mini grid in Tema

- 2020: 14.1% of the population in Ghana had no access to electricity [34]
- 62% of the national grid mix is based oil and natural gas [36]
- Diesel generators are widely used [35]
- Off-grid/ mini grid solutions supplied by renewable energy, can satisfy the increasing electricity demand while ensuring a low-emission and reliable supply [37] [38].

Don Bosco Campus, Tema (GH). Picture by: Michele Velenderic.

Don Bosco mini grid in Tema, Ghana

- Provides energy for the campus of the Don Bosco Renewable Energy Center
- Five individual solar power systems with different types of batteries
- Li-ion batteries must be cooled → energy demand of air conditioner: 13.05 kWh per day.

Installation	Battery type	Nominal battery capacity @C100 [kWh]	Life cycle usable battery capacity [kWh]
Power room	Lead-acid	174.72	65.76
Chapel	Lead-acid	58.08	21.96
Provincial house	Li-ion	30.80	27.72
Provincial house	$NaNiCl_2$	38.60	34.74
Hostel	Li-ion	30.80	27.72
Canteen	Li-ion	61.60	55.44
Total		**394.00**	**233.34**

TABLE 2: Mini grid locations, battery types and capacities

Sources: [34], [35], [37], [38]

3. Methodology | Goal and Scope

Life Cycle Assessment (LCA) based on ISO 14040 and 14044.

Scope

- *Gradle-to-grave*
- *Impact category*: GWP_{100} in carbon dioxide equivalents (CO_2eq)
- *Functional unit*:
  - One kWh of battery capacity (nominal and life cycle usable)
    Whereby the life cycle usable capacity considers capacity losses over the lifetime, efficiency losses due to cooling/heating, ..
  - One kWh consumed
    Indicating one kWh of electricity output, which is discharged from the battery and consumed

Goal

- Analyse the environmental impact of $NaNiCl_2$ batteries
- Compare them with lead-acid and lithium-ion batteries
- Evaluate their use in the mini grid at the Don Bosco campus

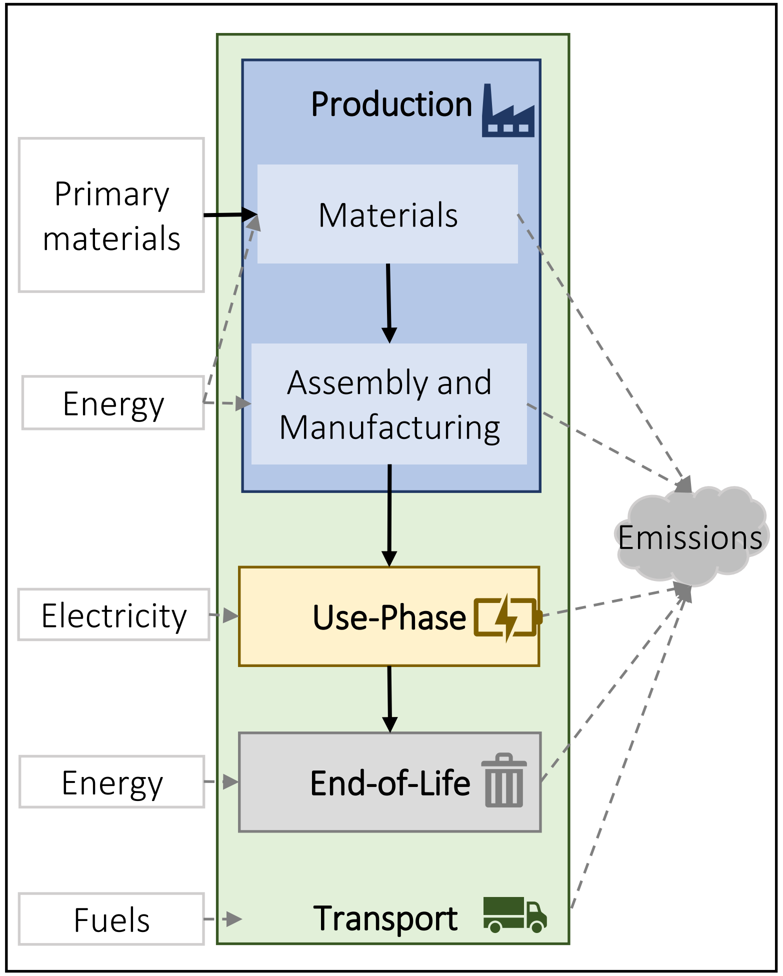

FIGURE 3: System boundaries of the conducted LCA.

3. Methodology | Life cycle inventory

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Production:

- Country specific data for processes and materials
    - 46% DE, 24% CH, 24% GB, 1% CN and 5% unknown
- Manufacturing in CH
- BoM & process information provided by manufacturer
- Modelling in GaBi

Transport:

- Means of transport:
  Truck & Containership
- Components to production site
- Battery to GH
- Battery to shredding/recycling facility

Use-Phase | Scenarios 1 and 2

	Scenario 1	Scenario 2
Nominal capacity	44.32 kWh	
Usable capacity	41.00 kWh	
Life cycle usable capacity	36.90 kWh	
Overall efficiency	85%	
Capacity loss factor	90%	
Charging cycles	4,500	3,500
Lifetime	15 years	10 years
kWh used over lifetime	166,050 kWh	129,150 kWh

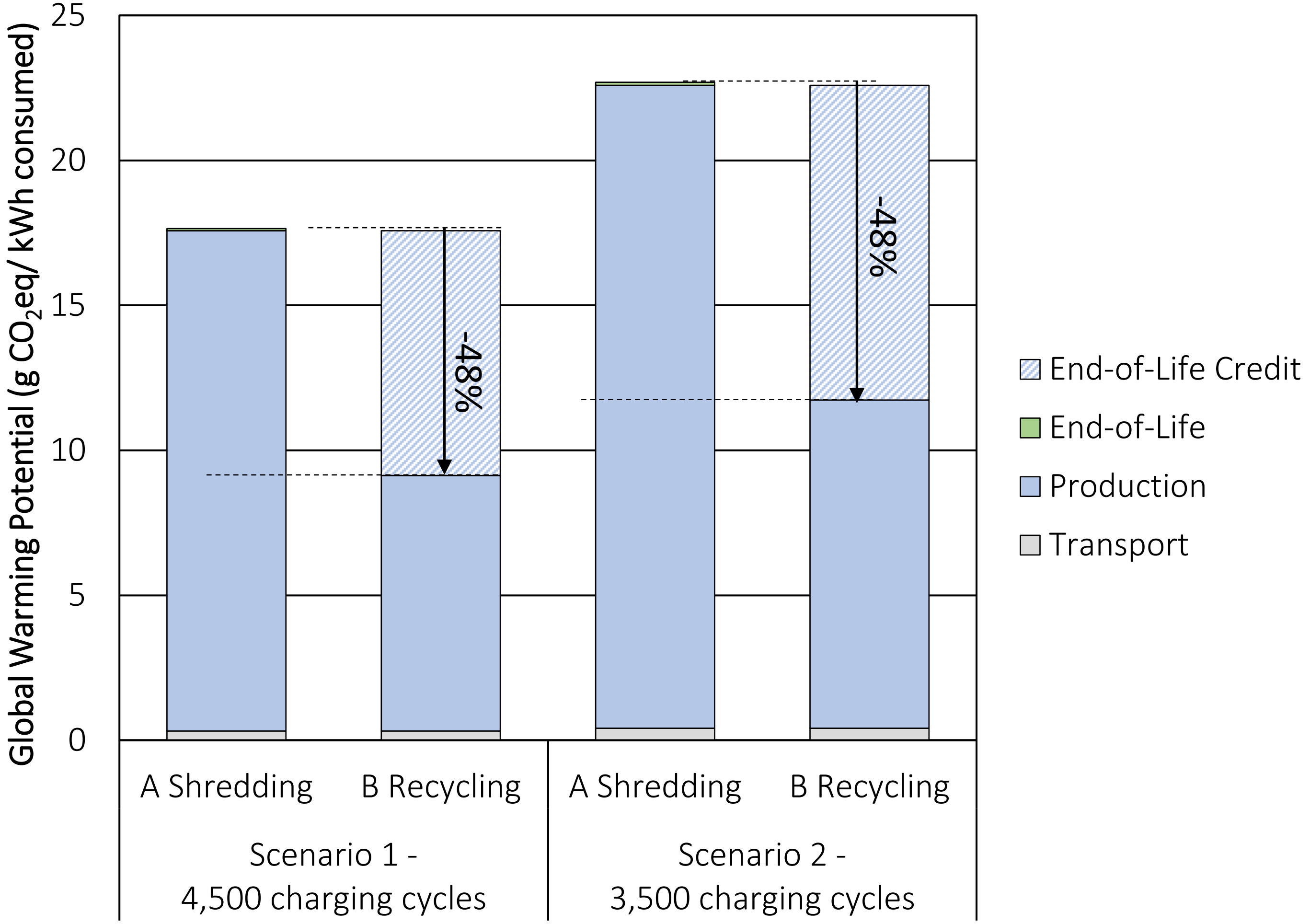
TABLE 3: Lifetime assumptions of the battery.

End-of-Life (EoL) | Scenarios A and B

- A: Shredding at waste collection center in Accra (GH)
- B: Recycling in steel industry in Kumasi (GH)
    - Nickel, Stainless Steel and SiO_2 brought back to the markets

4. Results

GWP$_{100}$ of $NaNiCl_2$ battery per kWh consumed for different scenarios



Overall GWP$_{100}$ caused by production, transport and EoL amounts to:

- 2,931 kg CO_2eq (Shredding)
- 1,516 kg CO_2eq (Recycling)

Recycling credits reduce the GWP$_{100}$ by 48%.

Less charging cycles in scenario 2, increase the GWP$_{100}$ by 29%.

FIGURE 4: Global Warming Potential of the analysed $NaNiCl_2$ batteries per kWh consumed for different scenarios regarding lifetime and EoL.

4. Results

Share of battery components in GWP_{100}

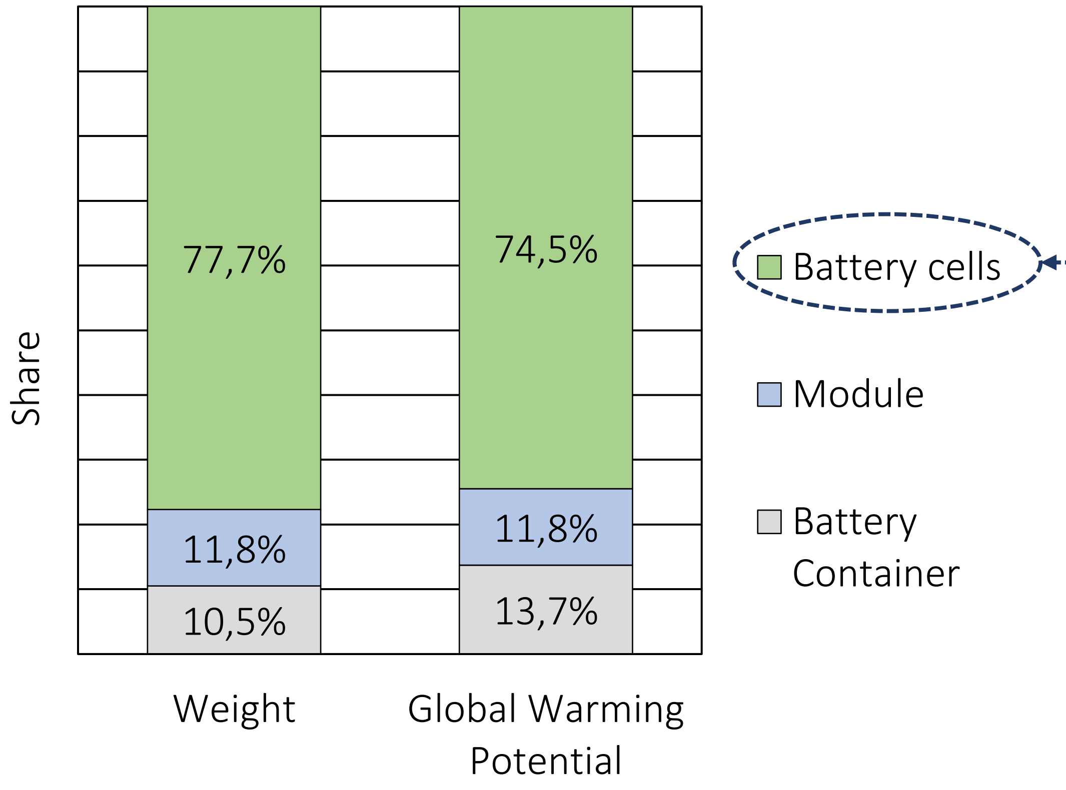


FIGURE 5: Share of battery components in Global Warming Potential and weight.

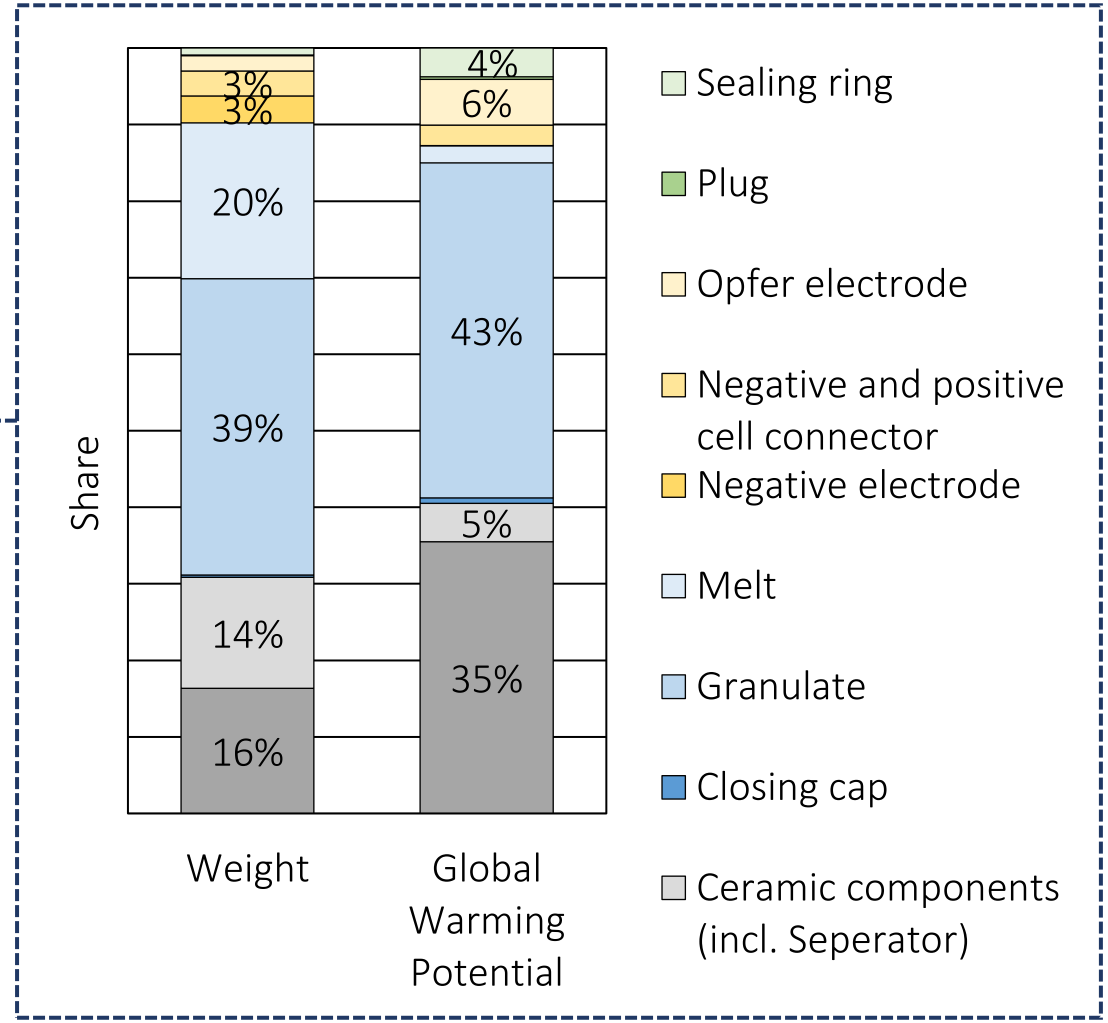
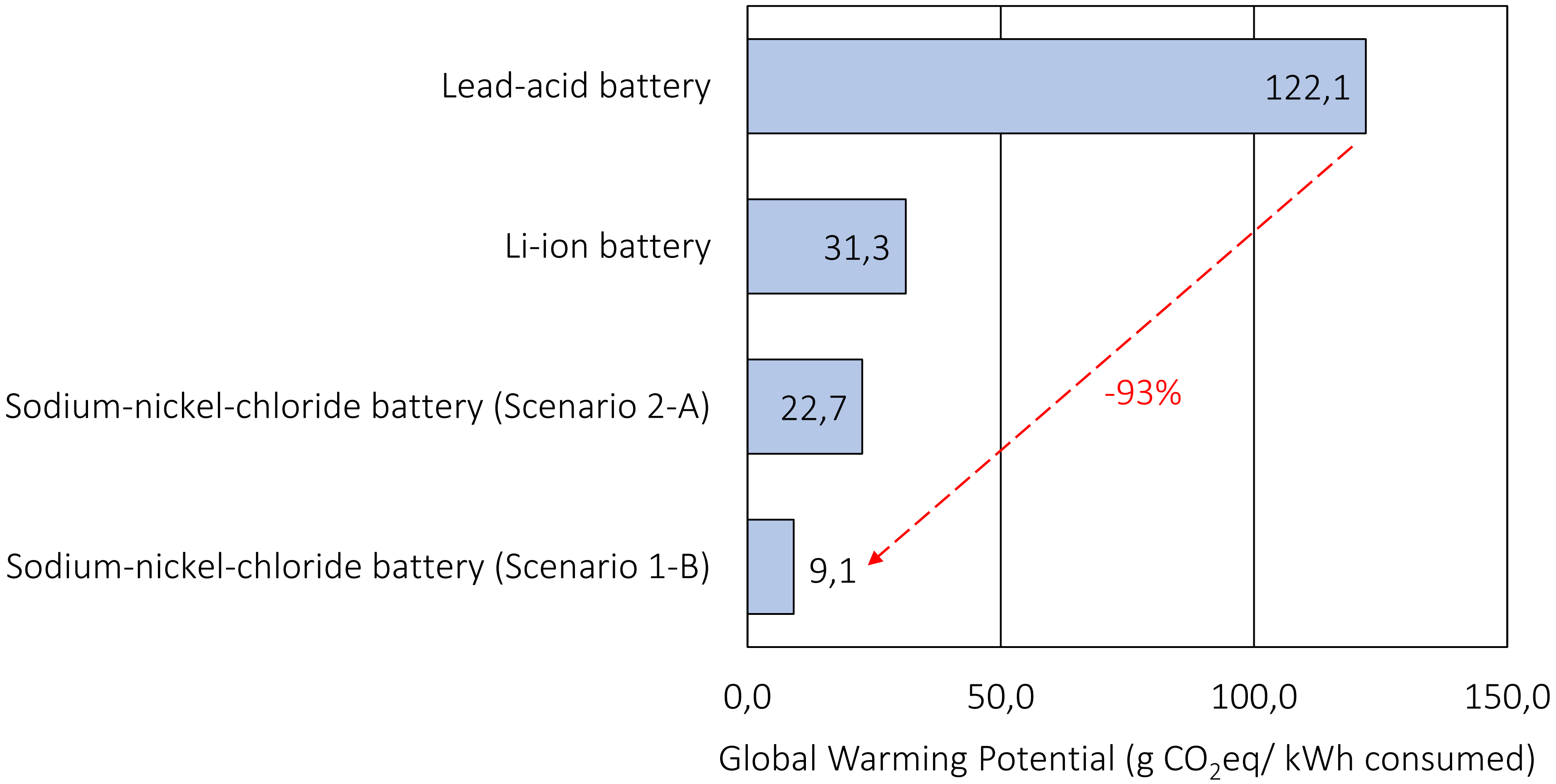


FIGURE 6: Share of cell components in Global Warming Potential and weight.

4. Results

Comparison of GWP_{100} of different batteries per kWh consumed



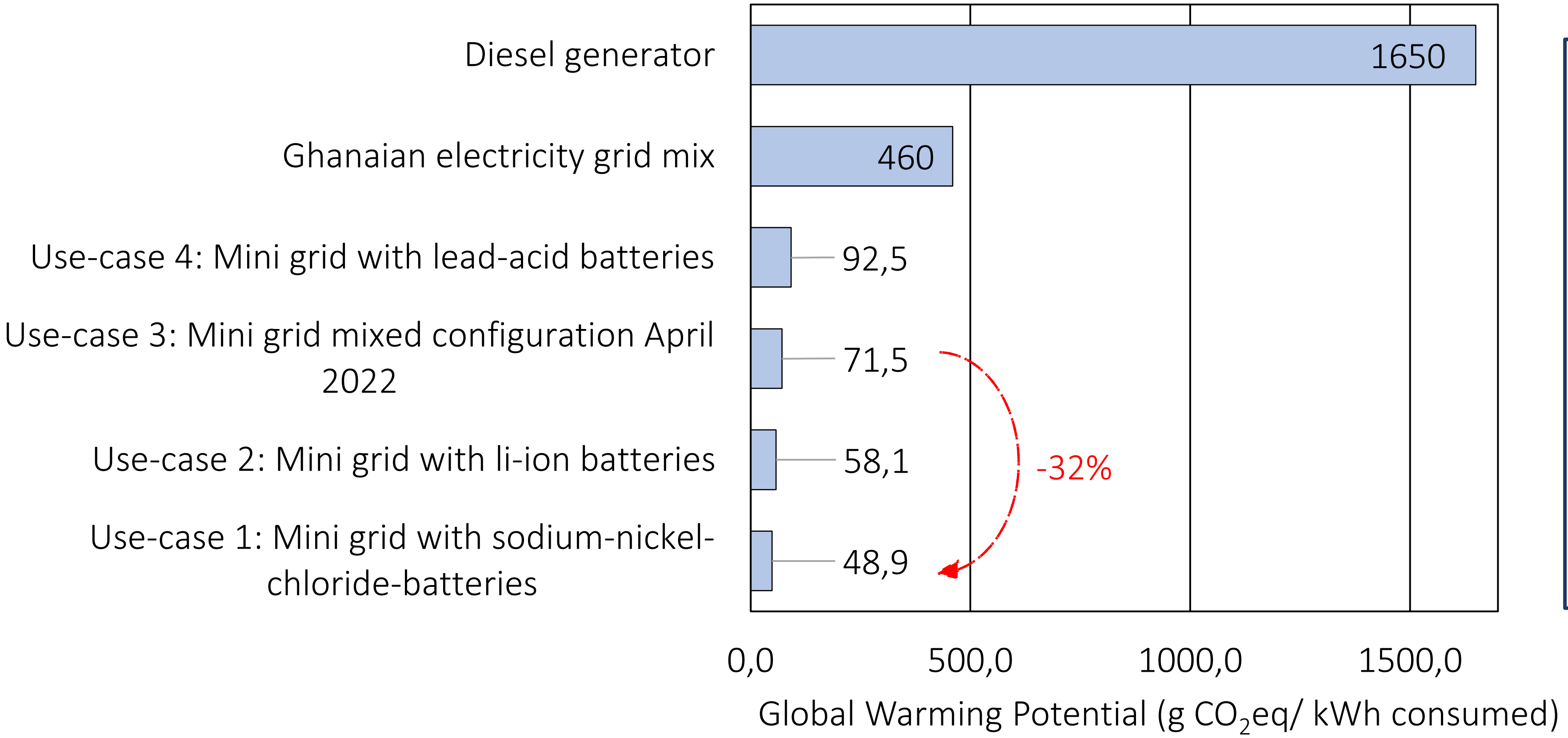
- $NaNiCl_2$ batteries can have a 93% lower GWP_{100} than lead-acid batteries, and 71% than li-ion batteries
- In the worst case (2-A), $NaNiCl_2$ still causes a 81% lower GWP_{100} than the lead-acid battery
- Comparatively high GWP_{100} of lead-acid battery because of low usable capacity and short lifetime

FIGURE 8: Comparison of Global Warming Potential of different battery technologies per kWh consumed. The GWP of lead-acid and li-ion batteries is obtained from Stinder et al. [17].

Sources: [17]

4. Results

Comparison of GWP_{100} of electricity supply in GH per kWh consumed



- All mini grid configurations achieve a significant reduction compared to the grid mix (GH)
- Compared to the use-case 2 (actual mini-grid configuration, the use-case 1 (only $NaNiCl_2$ batteries) reduces the GWP_{100} by 32%

Figure 9: Comparison of Global Warming Potential of electricity supply options in Ghana per kWh consumed. In use-case 3 37.6% of usable battery capacity is provided by lead-acid, 47.5% by li-ion and 14.9% by $NaNiCl_2$ batteries. The GWP of lead-acid and li-ion batteries is obtained from Stinder et al. [17]. The emission factor for the Ghanaian electricity mix was calculated according to the IGES List of Grid Emission Factors [56] for Diesel generator based on German Environment Agency [57].

Sources: [17], [56], [57]

5. Discussion and conclusion

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1. GWP_{100} of $NaNiCl_2$ batteries
   - 9.1 g CO_2eq are emitted per kWh consumed in the best case (lifetime of 4,500 charging cycles and nickel, stainless steel and silicon dioxide are recycled at the EoL)
   - 22.7 g CO_2eq are emitted per kWh consumed in the worst case (22% shorter lifetime and no recycling)

2. Hot-Spots in the production: Nickel materials, therefore recycling of nickel offers great potentials in terms of environmental impact and should be enforced.

3. $NaNiCl_2$ batteries could decrease the GWP_{100} per kWh consumed by up to 93% compared to lead-acid and up to 71% compared to li-ion batteries.

4. Lower consumption of toxic and rare materials, improves recyclability and simplifies the production.

5. However, the $NaNiCl_2$ batteries still have higher costs, economic advantage can only be realized by upscaling and $NaNiCl_2$ batteries are unsuitable for fast charging.

5. Discussion and conclusion

Further research topics

Evaluate additional impact categories like depletion of resources, human and eco toxicity.

Research the recycling of $NaNiCl_2$ batteries based on financial allocation.

Uncertain parameters like battery lifetime should be validated.

Useability of secondary material as an input.

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