SUPPLY DISRUPTION PROBABILITIES OF RENEWABLE ENERGY SOURCES AND STORAGE TECHNOLOGIES:

ASSESSMENT FROM AN ENERGY SYSTEM PERSPECTIVE

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1 Energy System Analysis and Raw Material Criticality

- Uncertainties regarding future climate neutral energy system
- Typically scenario development based on cost minimization
- Further factors of interest:
  - Environmental impacts
  - Macro economic impacts
  - Social impacts
  - **Raw material needs**

    Sensitive dependence of clean technologies on metallic elements

    Change of geopolitical dependencies possible

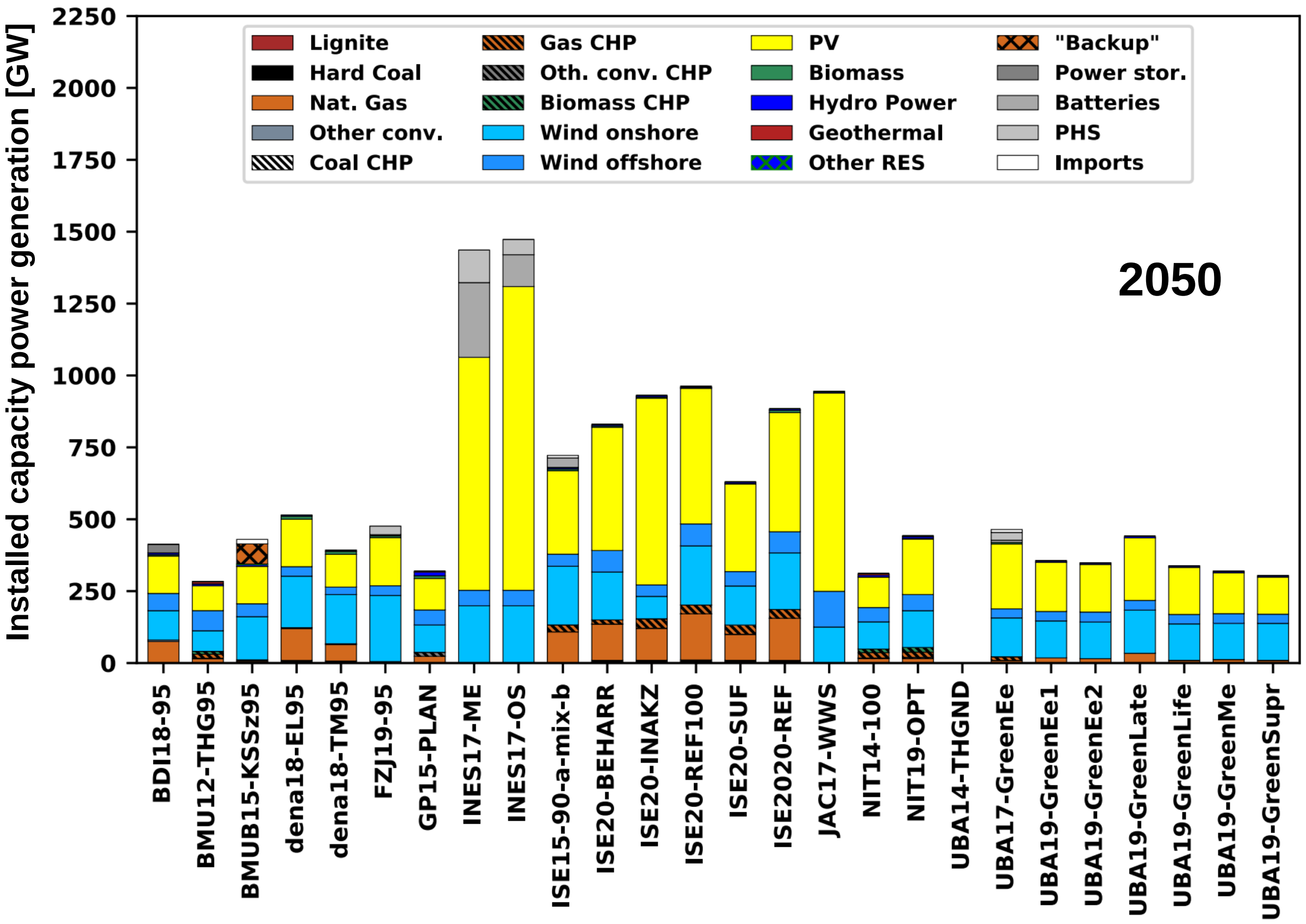


Fig.1: Energy transformation scenarios for Germany in comparison (Naegler et al., 2021).

1 Energy System Analysis and Raw Material Criticality

Aim of present study: Transfer of technology-level SDP indicator to the field of energy system analysis

- Geopolitical focus
- Create a basis for deriving a scenario-level supply risk indicator
- Consistency with optimizing Energy System Modeling

2 Technology-Level Criticality Concepts

Material-level criticality

Definition: “A measure of the (economic) risk […] for a specific consumer over a certain period” (Frenzel et al. 2017)

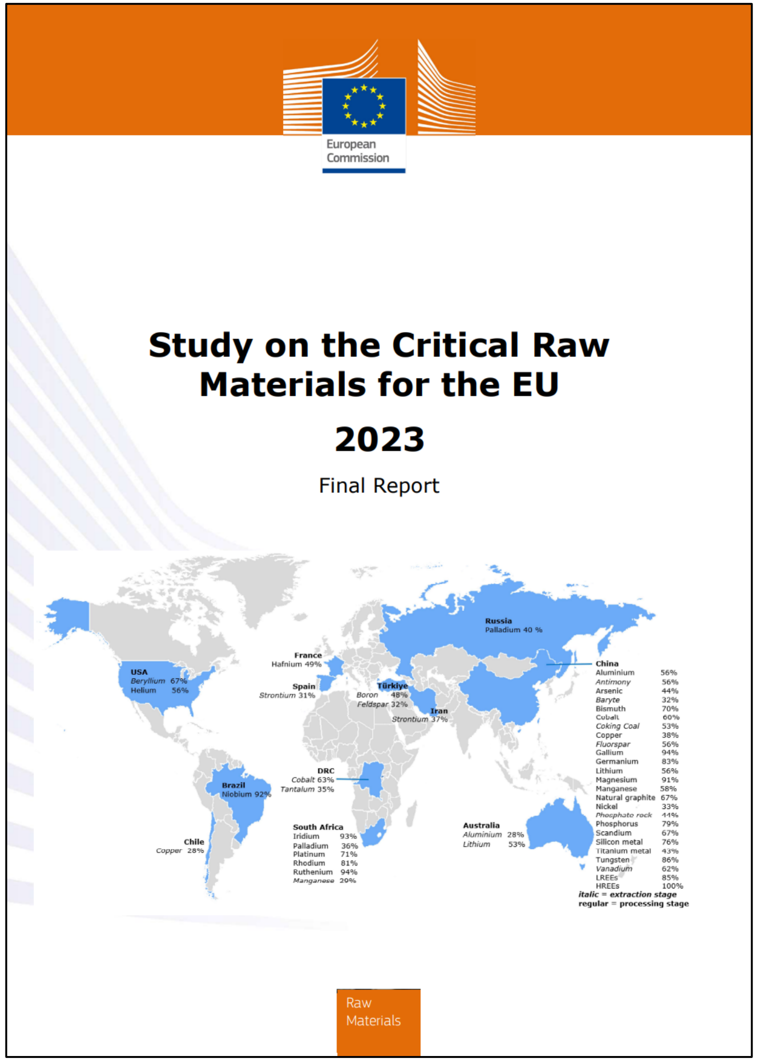
Risk is a function of:

(1) **Supply Disruption Probability (SDP)**

Operationalized by the EU SDP indicator

(2) Associated Economic Importance / Vulnerability (EI)

Supply Disruption Probability (SDP) Indicator by the EU used



2 Technology-Level Criticality Concepts

Properties of technologies

- Material composition and efficiency
- Technological learning

Data from „INTERESSE“
Gervais et al. 2022

Photovoltaics

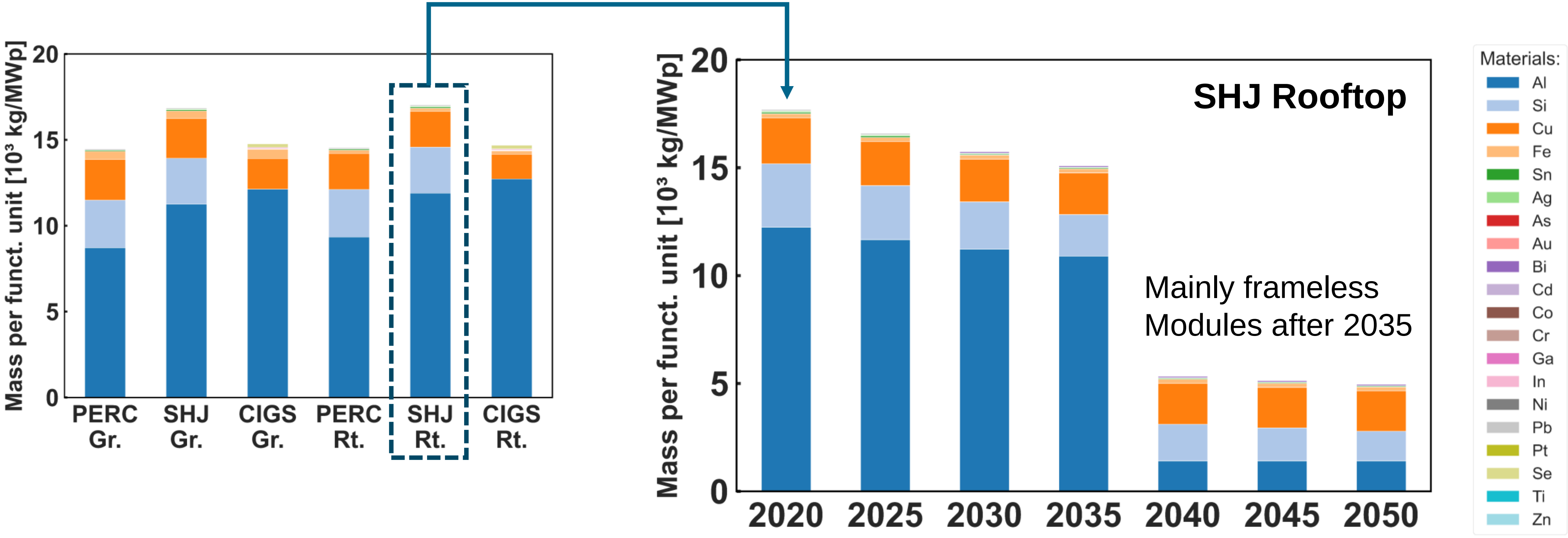


Fig. 2: Mass development of PV technologies.

2 Technology-Level Criticality Concepts

Properties of technologies

- Material composition and efficiency
- Technological learning

Data from „INTERESSE"
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Wind Power

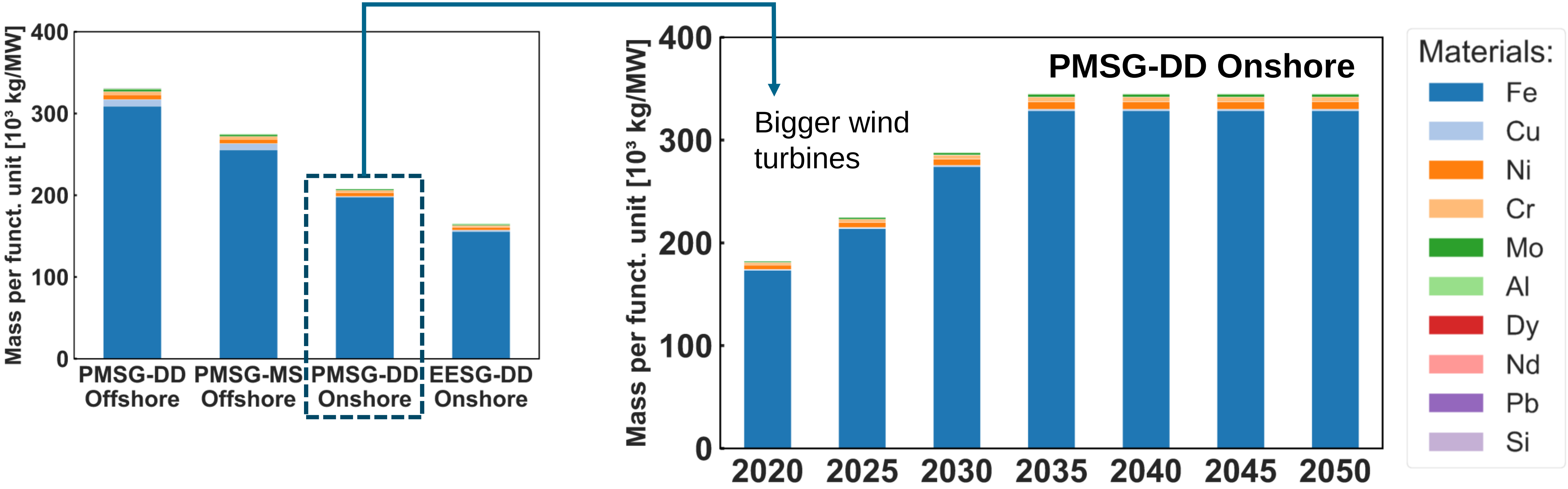

Fig. 3: Mass development of wind energy technologies.

2 Technology-Level Criticality Concepts

Properties of technologies

- Material composition and efficiency
- Technological learning

Data from „INTERESSE“
Gervais et al. 2022

Batteries

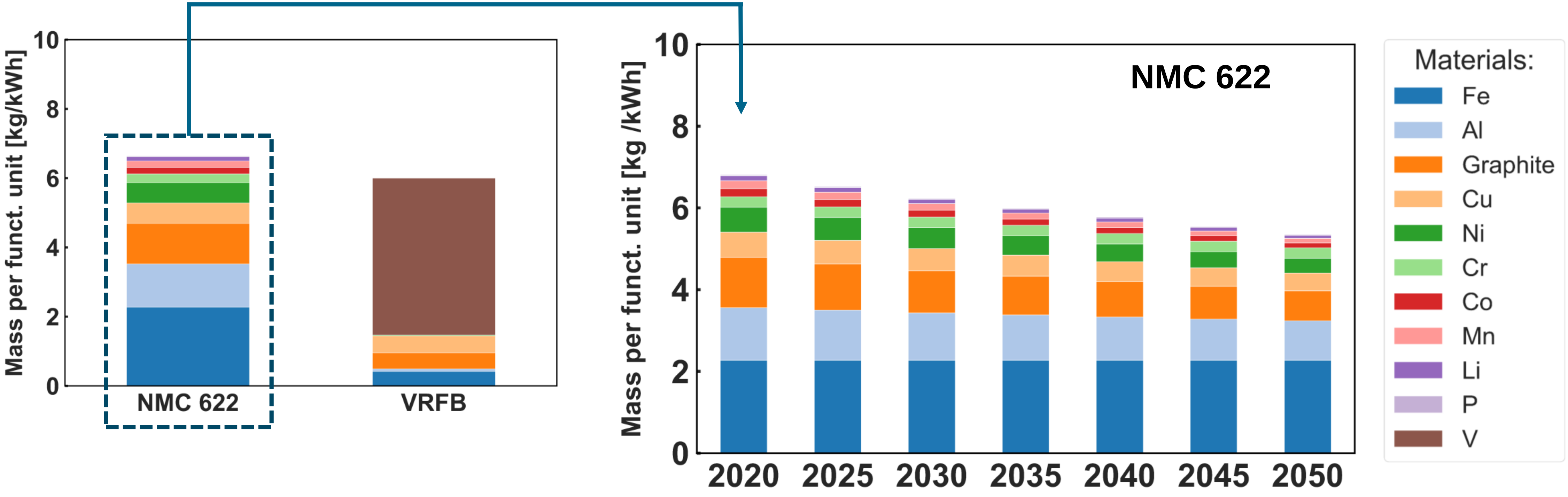

Fig. 4: Mass development of battery technologies.

2 Technology-Level Criticality Concepts

Aggregation method

State-of-the-art technology-level criticality assessments:

Approximation of technology level criticality as weighted sum of constituent material criticalities

$$SDP_T = \sum_i sdp_i * w_i$$

i :	Materials used in a technology T
SDP_T :	Supply Disruption Probability (SDP) of a technology T
sdp_i :	Supply Disruption Probability (SDP) of material i
w_i :	Weights

Different choices of weights correspond to different aggregation methods

3 RES and Storage Technologies Case Study

Requirements for Technology-Level Criticality Indicator

1. Comparability of different (sub) technologies

2. Temporal development of SDP due to technological learning visible

3. Suitability for further aggregation to scenario level

4. Consistency with approach of optimizing energy system models

3.1 RES and Storage Technologies Case Study

Criticality aggregation from material to product level

Weighting by material mass shares

$$w_i = \frac{m_i}{\sum_j m_j} = \frac{m_i}{M}$$

Weighting by material cost shares

$$w_i = \frac{c_i}{\sum_j c_j} = \frac{c_i}{C} = \frac{m_i \cdot c_i^*}{\sum_j \left(m_j \cdot c_j^*\right)}$$

Equal weighting

$$w_i = \frac{1}{n}$$

Maximum weighting

$$w_i = \begin{cases} 1; & \gamma_i = \max(\gamma_1, \ldots, \gamma_n) \\ 0; & else \end{cases}$$

With:

- w_i: Weighting factor for material i
- m_i: Mass of material i
- M: Sum of all material masses
- c_i: Costs of material i
- c_i^*: Specific costs of material i (per mass unit)
- C: Sum of all material costs

Method by **Helbig et al. 2016**

- Origin: technology assessment
- Test for energy system analysis application

3.1 RES and Storage Technologies Case Study

Comparability of subtechnologies

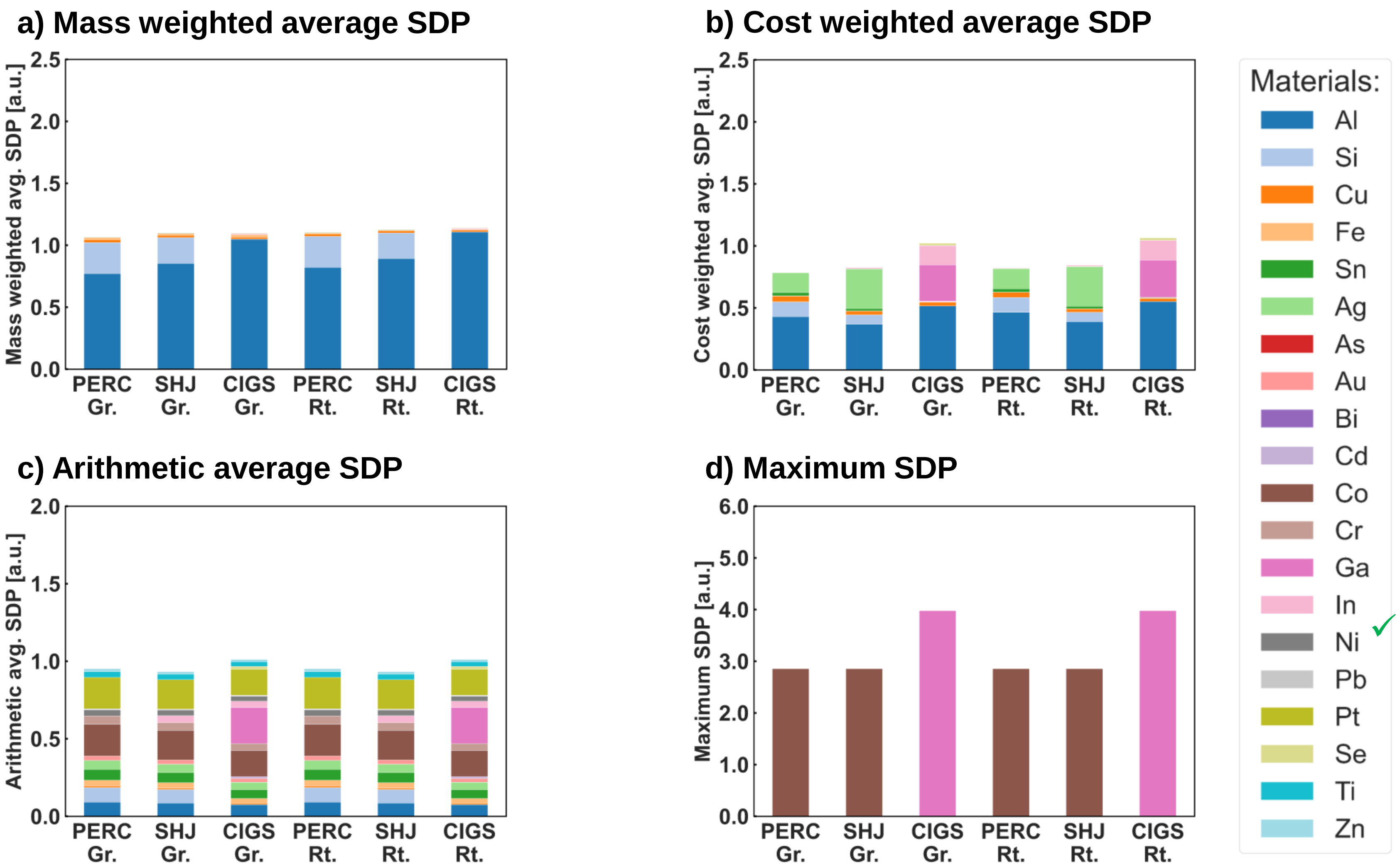

Fig. 5: Relative SDP aggregation for PV technologies.

Observations for <u>all</u> technologies:

- Aggregation determines ranking
- Aggregation determines impact of materials
- Stakeholder specific perspectives

✓ **Meaningful comparison of different (sub)technologies**

3.1 RES and Storage Technologies Case Study

Comparability of subtechnologies

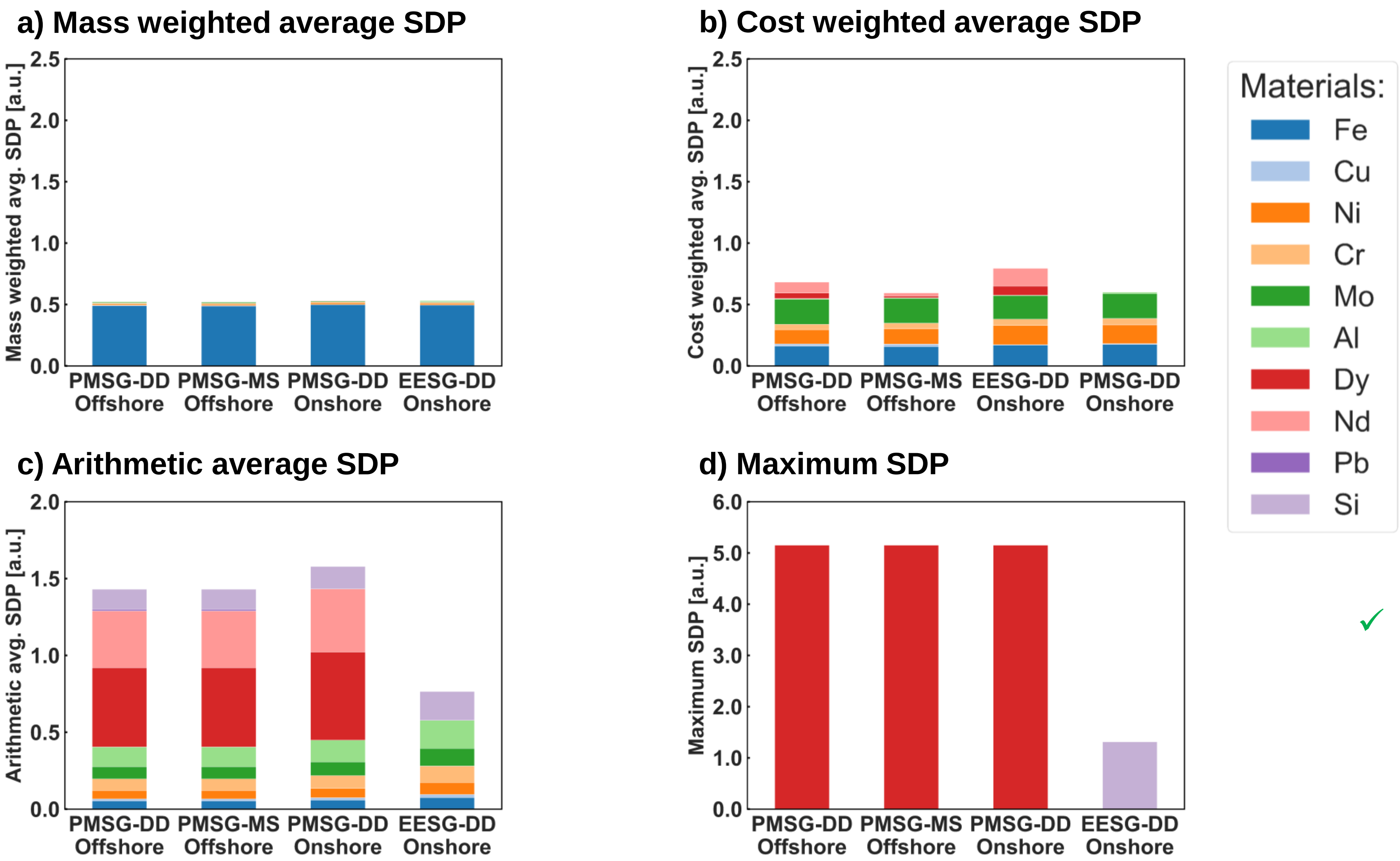

Fig. 6: Relative SDP aggregation for wind energy technologies.

Observations for all technologies:

- Aggregation determines ranking
- Aggregation determines impact of materials
- Stakeholder specific perspectives

✓ **Meaningful comparison of different (sub)technologies**

3.1 RES and Storage Technologies Case Study

Comparability of subtechnologies

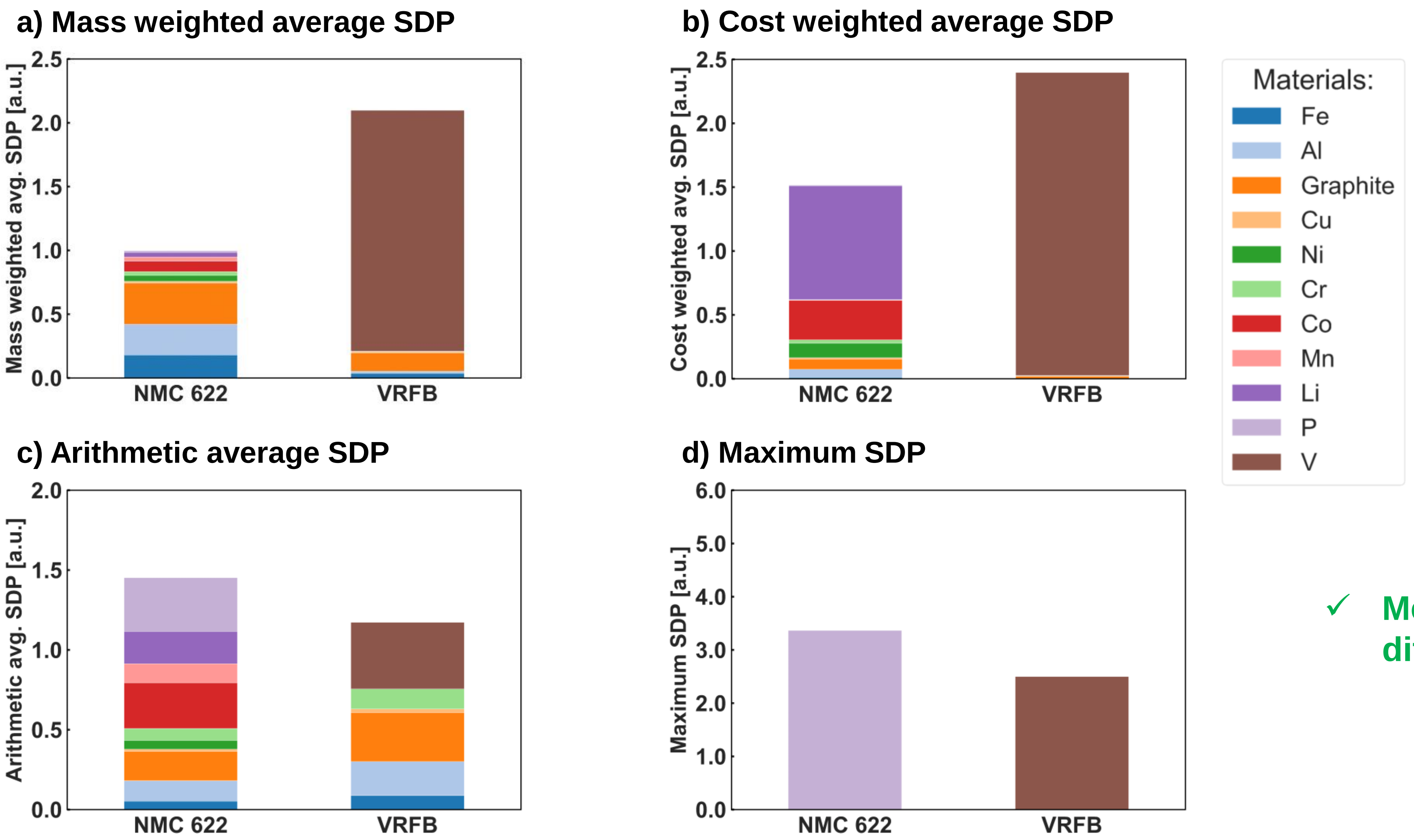

Fig. 7: Relative SDP aggregation for battery technologies.

Observations for all technologies:

- Aggregation determines ranking
- Aggregation determines impact of materials
- Stakeholder specific perspectives

✓ **Meaningful comparison of different (sub)technologies**

3.1 RES and Storage Technologies Case Study

Temporal Development of SDP: Photovoltaics (SHJ Rooftop)

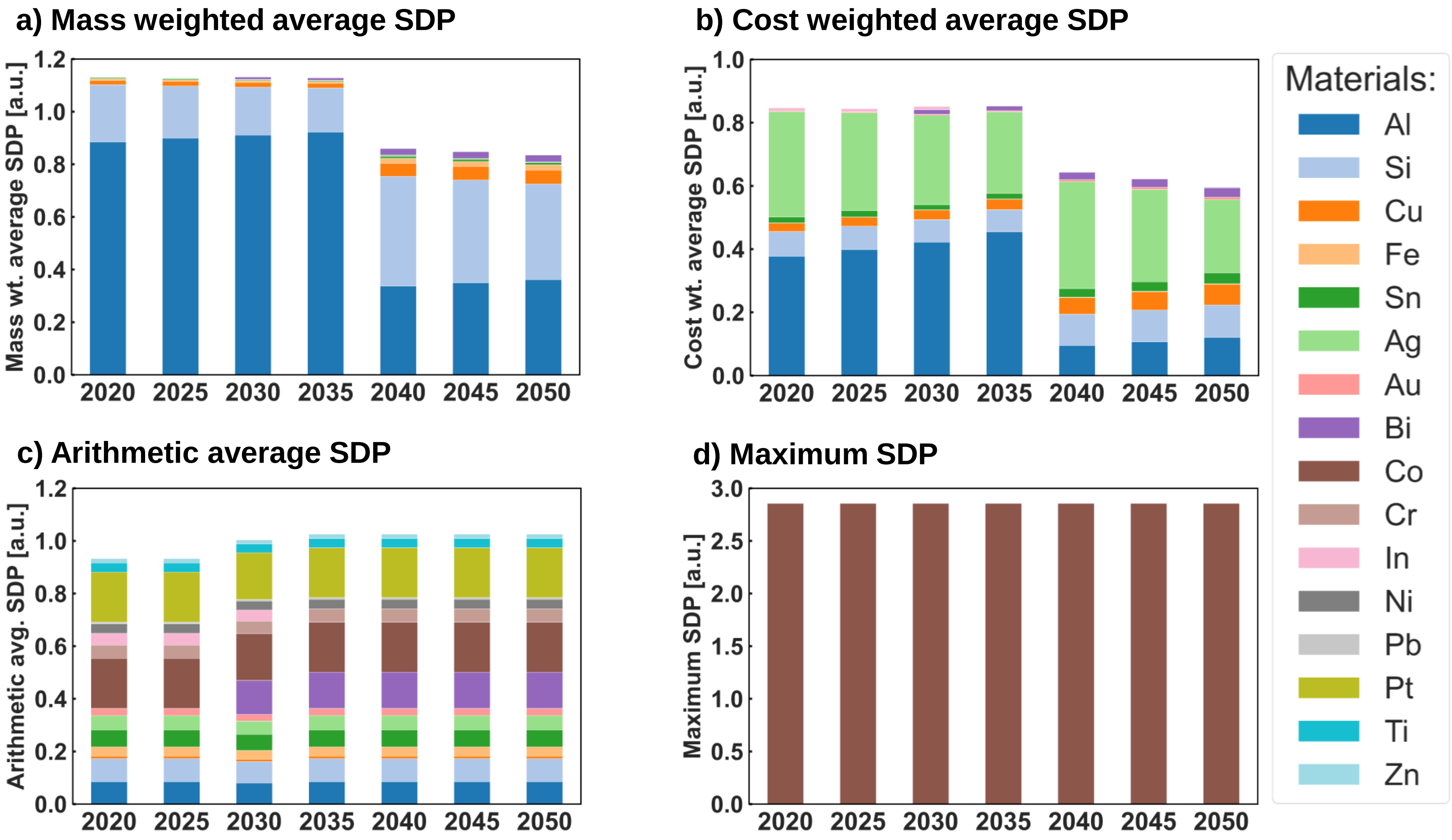

Fig. 8: Temporal development of SDP aggregation for Silicon Heterojunction Solar Cells.

Observations:

Good representation of temporal development:

- Mass weighted average SDP
- Cost weighted average SDP

Little temporal development:

- Arithmetic avg. SDP
- Maximum SDP

❖ **Temporal development partially meaningful**

3.1 RES and Storage Technologies Case Study

Suitability for further aggregation to the scenario level

- Consider two functional units with same performance
- One has twice the mass of the other.
  - Calculation yields same numeric value
  - Material efficiency not included

❖ **Aggregation to scenario level not appropriate**

Consistency with the approach of optimizing energy system models

❖ **Any number of functional units yields the same numeric value**

Approach with “robust relation to the functional unit” required

3.2 RES and Storage Technologies Case Study

Criticality aggregation from material to product level

Weighting by absolute material mass

$$w_i = m_i$$

Weighting by absolute material costs

$$w_i = c_i = m_i \cdot c_i^*$$

With:

- w_i: Weighting factor for material i
- m_i: Mass of material i
- M: Sum of all material masses
- c_i: Costs of material i
- c_i^*: Specific costs of material i (per mass unit)
- C: Sum of all material costs

Adapted from **Terlouw et al. 2019**

3.2 RES and Storage Technologies Case Study

Mass weighted and cost weighted SDP: Comparison of PV subtechnologies

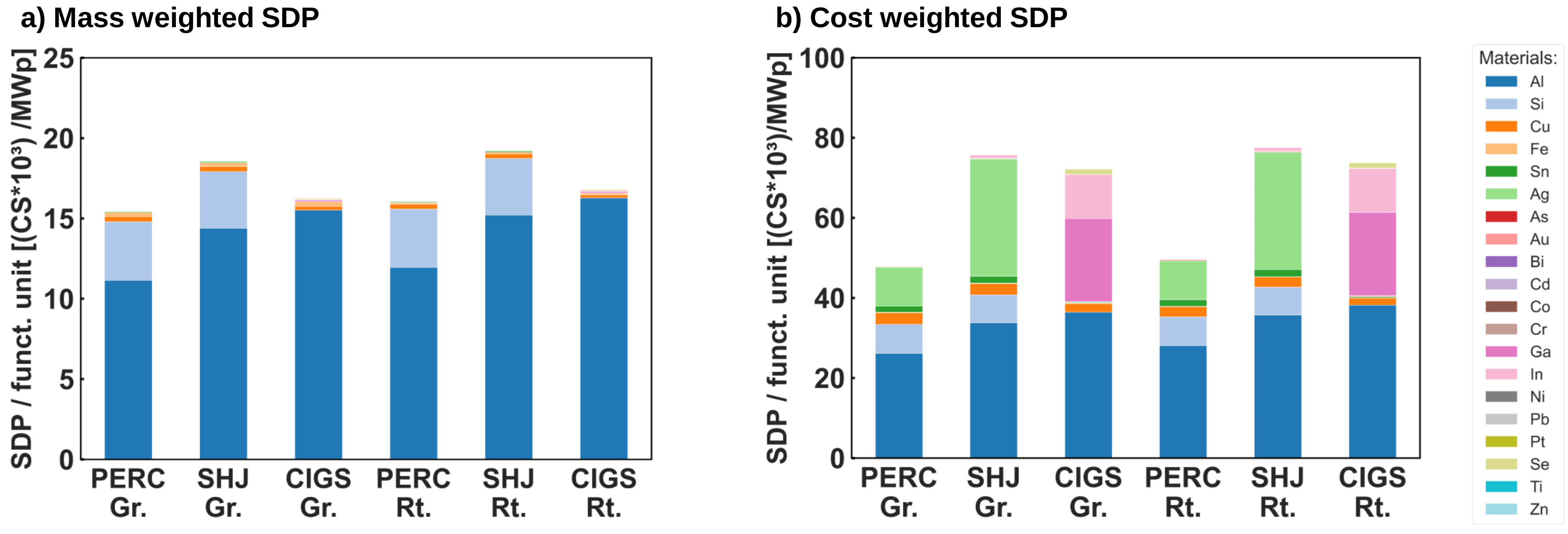

Fig. 9: Mass weighted and cost weighted SDP aggregation for PV technologies.

✓ **Meaningful comparison of different (sub)technologies**

- Option to highlight minor materials via cost weighting
- Option to normalize over world production (Talens Peiro 2022)?

3.2 RES and Storage Technologies Case Study

Absolute approaches: Temporal Development of SHJ Rooftop solar cells

a) Mass weighted SDP **b) Cost weighted SDP**

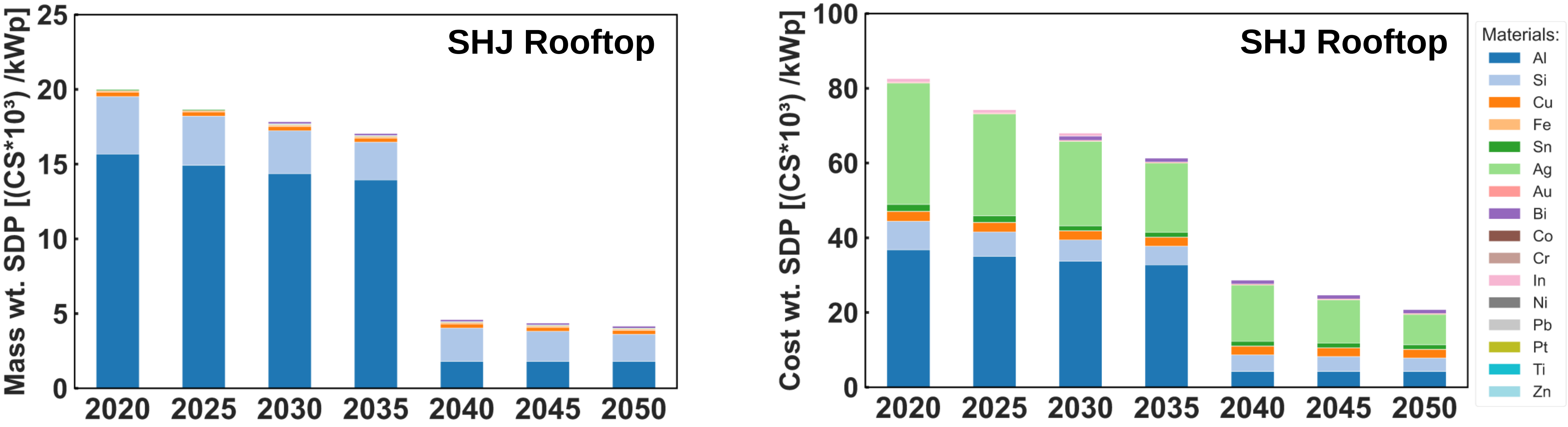

Fig. 10: Temporal development of mass weighted and cost weighted SDP aggregation for PV technologies.

✓ **Temporal development of SDP meaningful**

3.2 RES and Storage Technologies Case Study

Suitability for further aggregation to the scenario level

- Strategies with less material consumption considered “less critical”

✓ **Fulfilled due to consideration of total mass**

- Suitability for comparison of different transformation strategies

✓ **Visibility of differences expected**

Consistency with the approach of optimizing energy system models

✓ **Higher number of functional units yields a higher numeric value**

4 Conclusions

- ✓ Evaluated impact of aggregation technique on technology-level SDP
- ✓ Tested technology-level SDP indicators with respect to scenario criticality considerations
- ✓ Derived insights for integrating criticality considerations into ex-post energy system analysis
- ✓ Derived insights for integrating criticality considerations as an input into energy system modeling

References

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Thanks for your attention!