Sustainable Circularity

Digital Product Passports as Instrument for Sustainable Product Management

ERSCP Webinar, Sept. 17, 2026

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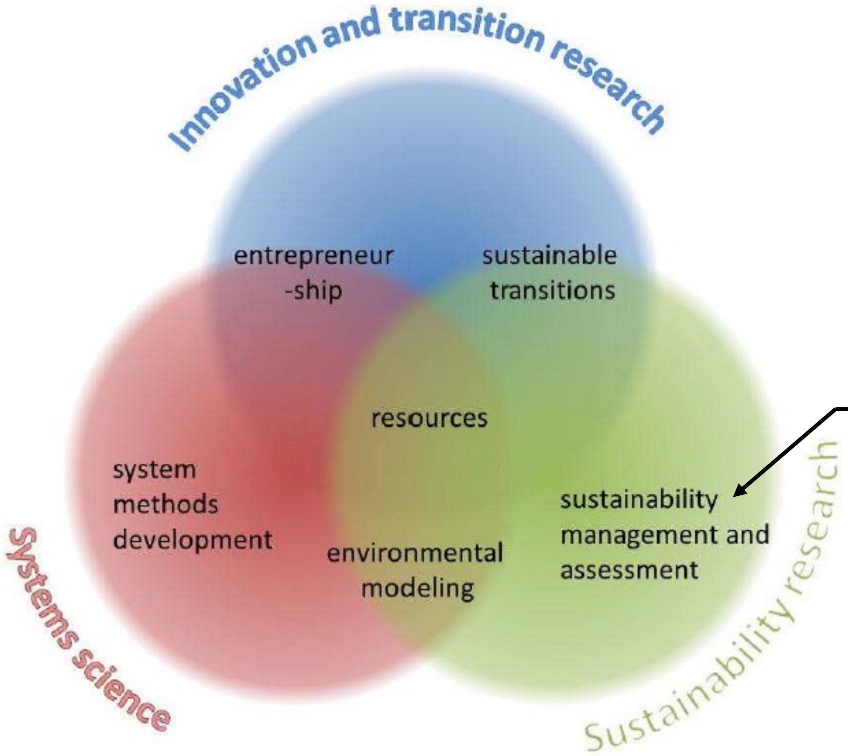
Research group "Corporate and Product Sustainability"



- Sustainability on organizational level (strategies, business models, innovation, assessment)
- Sustainability on product level (product development, supply chain management, circular economy, assessment)

Agenda

1. **Strategic conceptualization: what is a DPP?**
2. **Implementation: data requirements and availability**
3. **From data to decisions: DPP and sustainability assessments**

Strategic conceptualization

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Relevance of DPPs

- Regulations:
  - Ecodesign for Sustainable Products Regulation (ESPR, in force 2024): DPP as a horizontal EU instrument, rolled out product group by product group
  - EU Battery Regulation: a battery passport becomes mandatory from February 2027
  - EU-documents defined mandate, but (in the beginning) not much content
  - Sustainability and circularity only partially addressed
- Research gap:
  - In 2021/22 (when we started this work) no peer-reviewed concept translated sustainability and circularity objectives into a concrete framework for a digital battery passport (DBP)

Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases

- Research question:

  What kind of information does a digital battery passport for an electric vehicle battery need to provide in order to help DBP users enhance the sustainability and circularity performance of EVBs and their value chains?

- Sub research questions:
  - SRQ1: Who are the potential users of an EVB digital battery passport?
  - SRQ2: Which potential use cases may be supported by a DBP?

Berger, K.; Schöggl, J-P.; Baumgartner, R.J. (2022). Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases. *Journal of Cleaner Production, 353, 131492*, https://doi.org/10.1016/j.jclepro.2022.131492

Methode: literature review and stakeholder mapping as basis for concept development

1

Stakeholder mapping

SCOPIS approach (Fritz et al., 2018)

- Literature review of the EVB value chain
- Value chain diagram (VCD) developed
- Validated: research group (n=7), then 3 industry experts

OUTCOME

VCD + identification of DBP users (→ SRQ1)

→

2

Systematic literature review

PRISMA protocol (Moher et al., 2009)

- 1,190 records identified (1,140 database + 50 grey lit.)
- Screened for duplicates, title/abstract, full text
- 129 references included in the end

OUTCOME

Potential use cases + information needs (→ SRQ2)

→

3

Concept development

Bottom-up, iterative

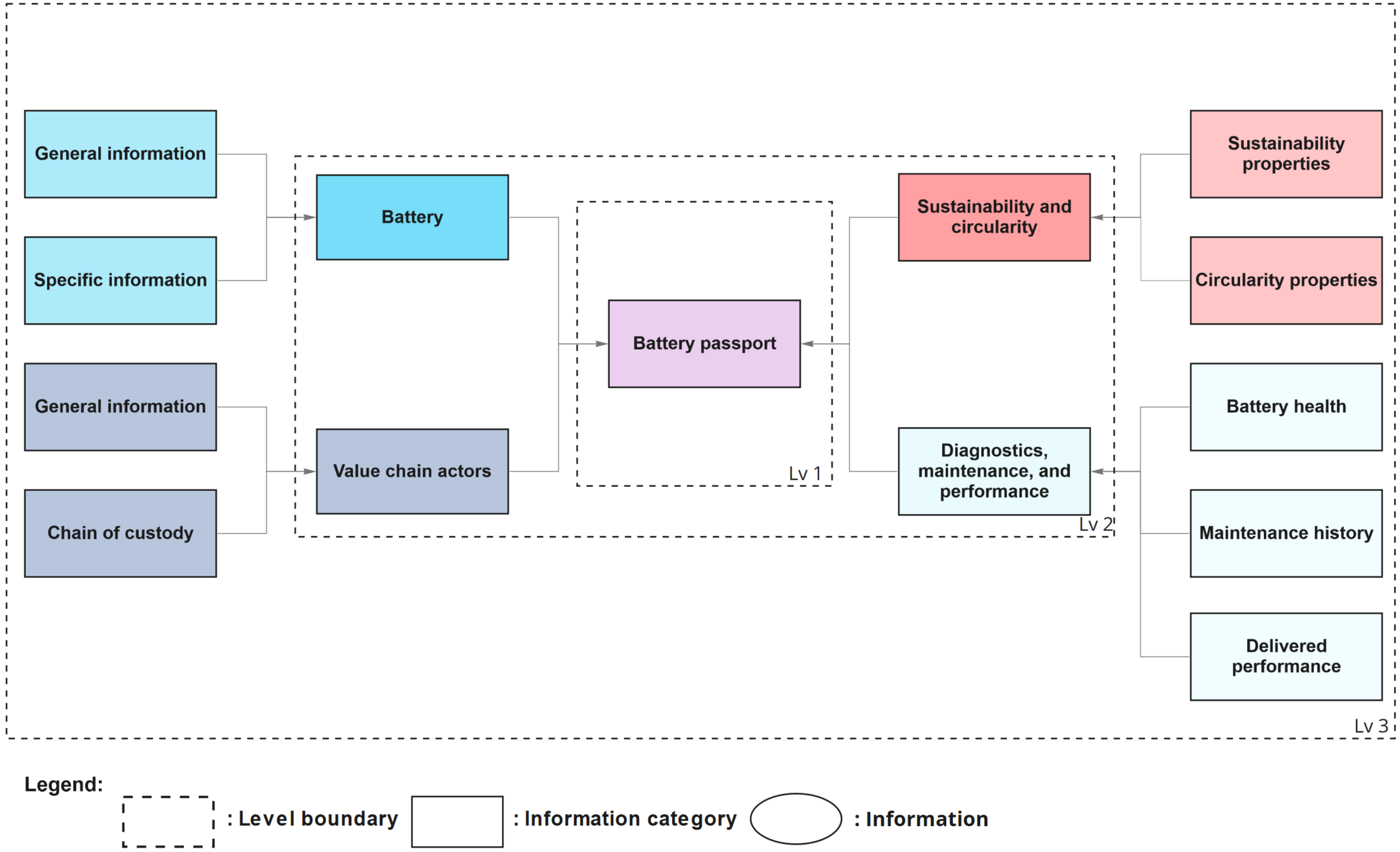
- Categorisation of data points from stages 1–2
- Iterative development within the research group
- Validated by 3 industry experts

OUTCOME

The DBP concept itself

Berger, K.; Schöggl, J-P.; Baumgartner, R.J. (2022). Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases. *Journal of Cleaner Production, 353, 131492*, https://doi.org/10.1016/j.jclepro.2022.131492

Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases



Identification of the EVB value chains' constitution

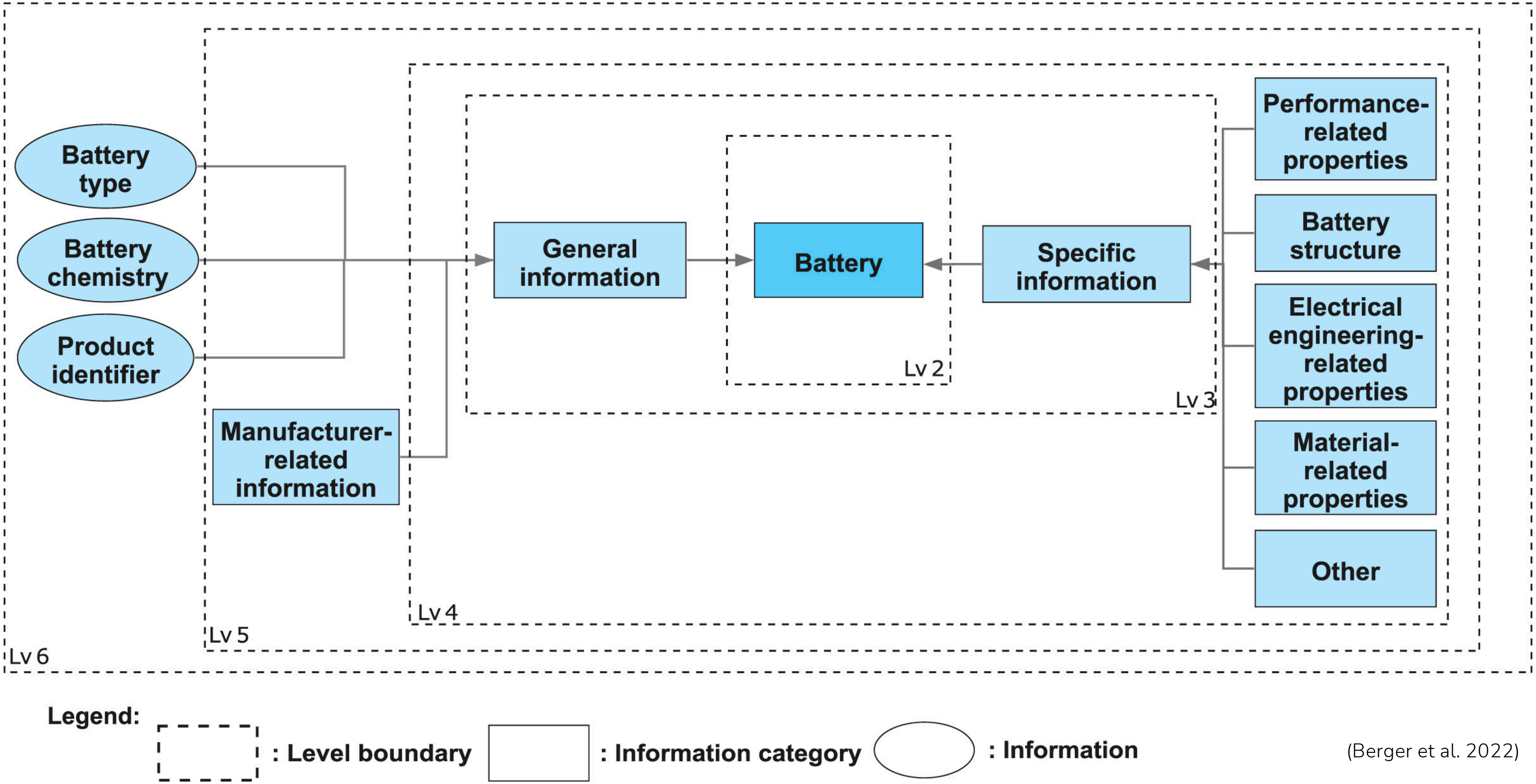
Digital battery passport concept

- 4 main information categories
- 7 information layers
- 54 data points

Four practical use cases (OEM, recycler, EV user, regulatory body)

(Berger et al. 2022)

Example: Battery information



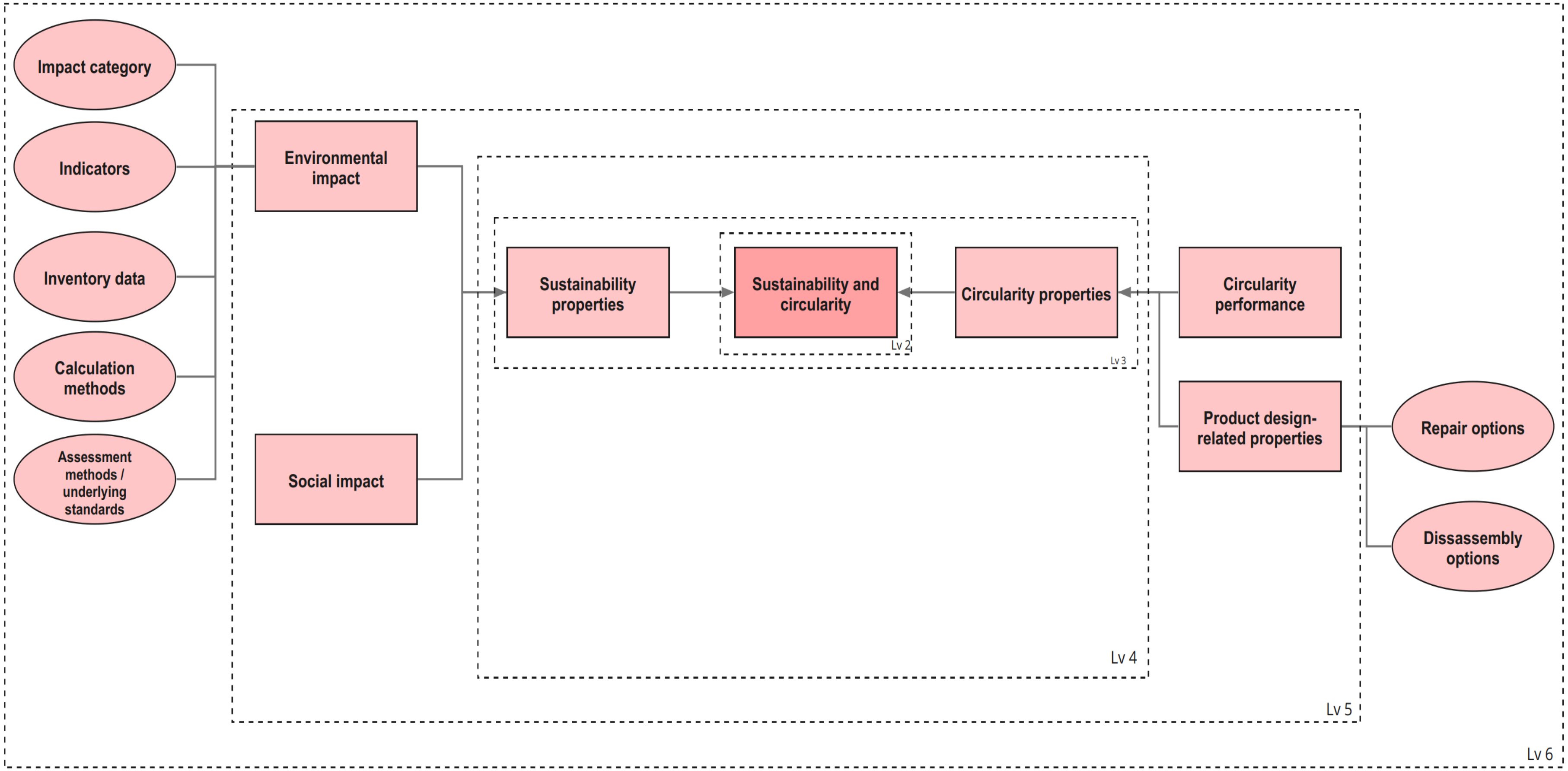
(Berger et al. 2022)

Example: Sustainability and circularity information

e.g., GWP, Eutrophication, Ocean acidification, ...

e.g., part and material specifications

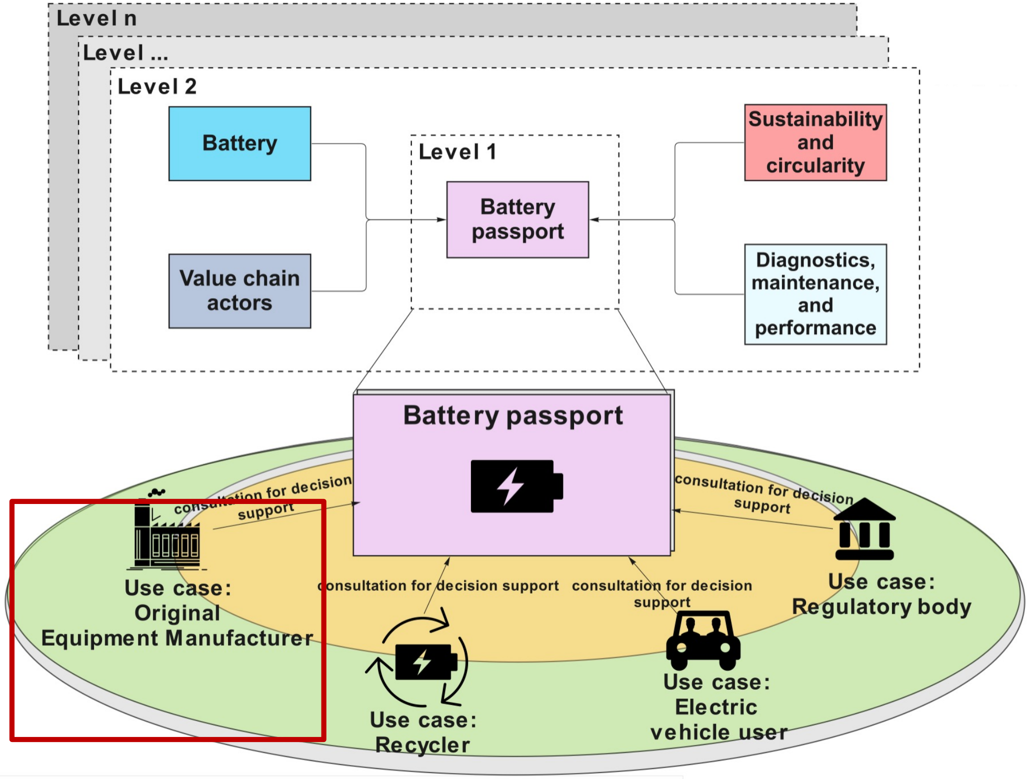
e.g., ReCiPe, CML, ...



(Berger et al. 2022)

DBP use case: OEM

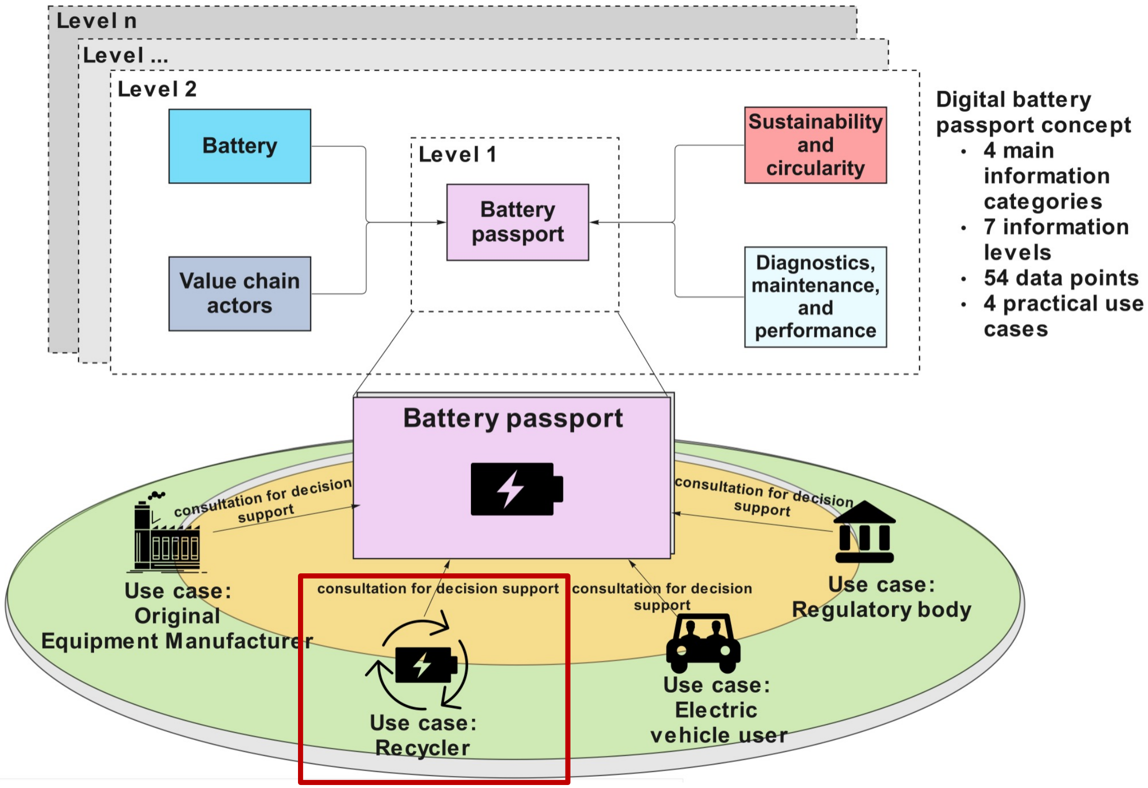
- OEM seeks to improve the EVB’s life cycle sustainability and circularity
  - Minimizing negative environmental and social impacts
  - Maximizing EVB circularity
  - Prioritization of performance, technical and safety requirements
- Step one: clear product identification
- Category “Battery” Step two: information about the status quo of the EVB’s sustainability and circularity performance
  - Category “Sustainability and circularity”
  - Category “Value chain actors”



Use cases for a digital battery passport (Berger et al. 2022)

DBP use case: Recycler

- Lack of relevant information: e.g. EVB battery chemistry, application, disassembly instructions (Bai et al., 2020)
- Increase in waste battery volume and possible recycling pathways (Harper et al., 2019)
- Need for product-related information, especially battery chemistry and hazardous substances for safe EVB handling
- Product-specific information (e.g., SOH, safety measures) as enablers for the determination of the suitability of second use of the battery

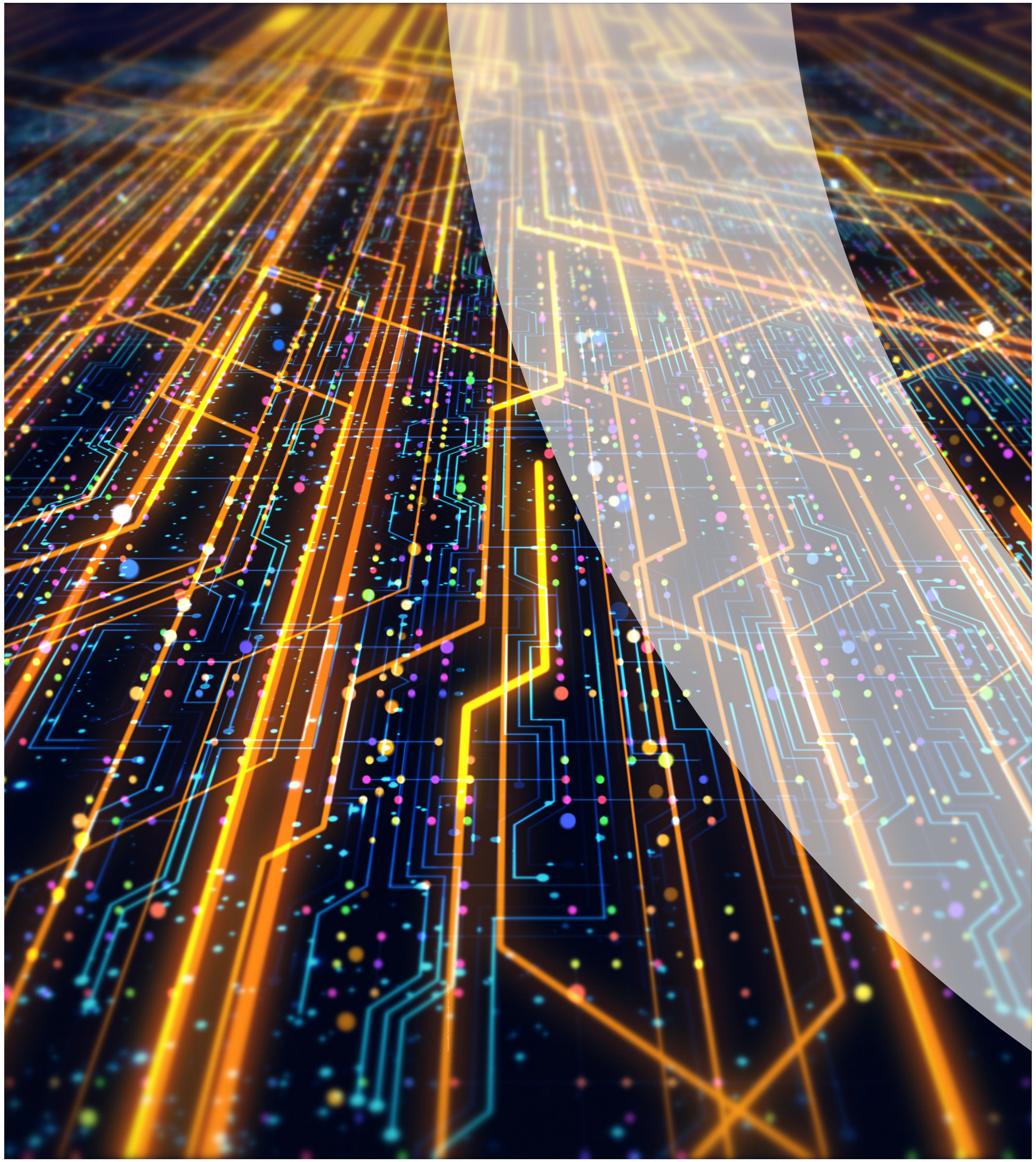


Use cases for a digital battery passport (Berger et al. 2022)

Contributions and open questions

- Contributions:
  - To our knowledge, the first peer-reviewed paper which defines DPP in terms of sustainability and circularity
  - Provides scientific basis for the adoption of DPPs, also beyond EV-batteries
  - Framework goes beyond regulations to employ a comprehensive sustainability perspective
- Open questions:
  - Which data a required and are available in detail?
  - How does user roles look like in detail?
  - Which drivers and barriers are relevant for DPP implementation?
  - Which role play DPPs in sustainability assessment?

(Berger et al. 2022)



Implementation

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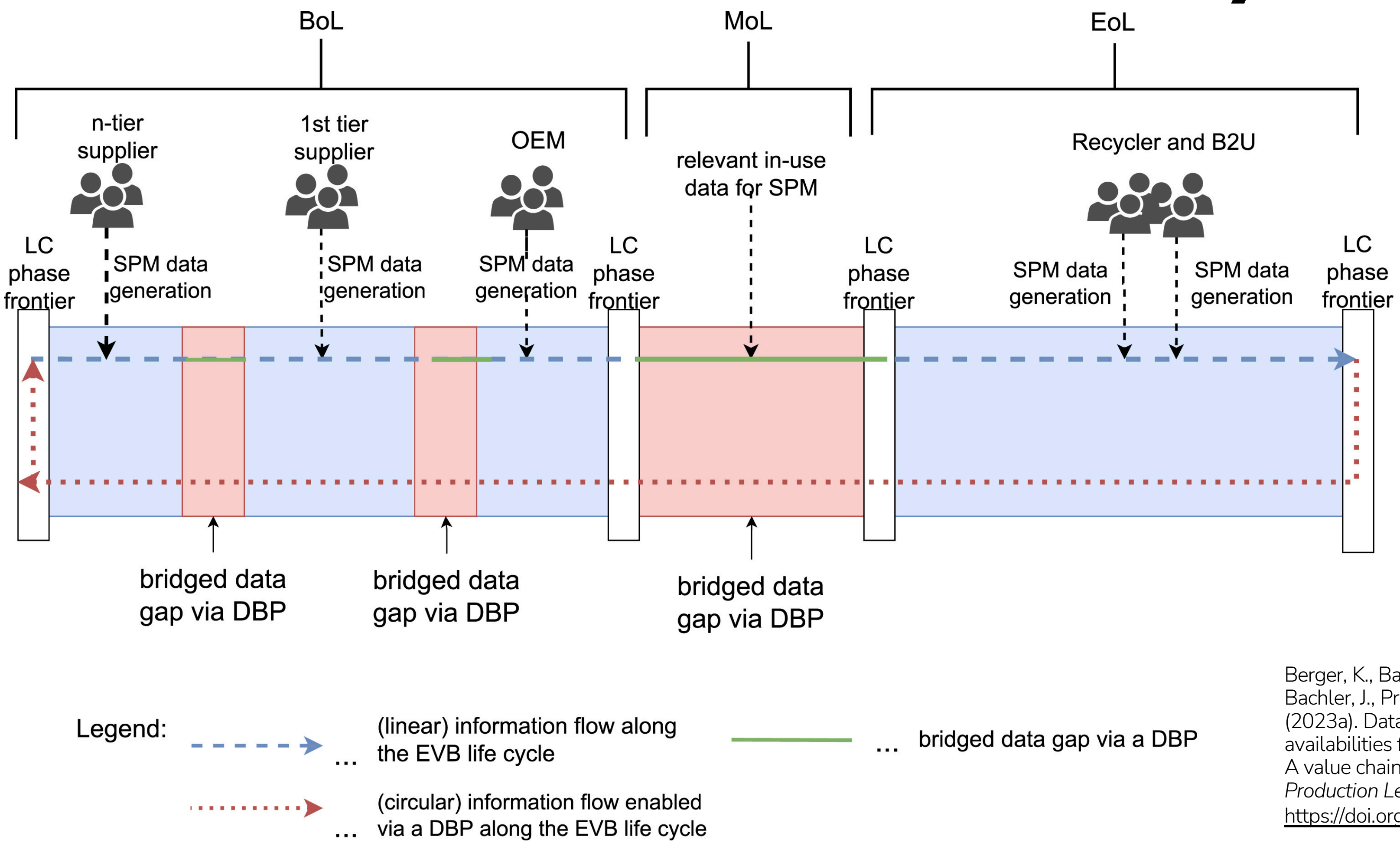
Data requirements and availabilities for a digital battery passport – A value chain actor perspective

- **Aim:** Identification of data requirements and availabilities for DPPs from a value chain actor perspective
- RQ1: What kind of data does a digital battery passport have to offer to support direct electric vehicle battery value chain actors in their sustainability-oriented electric vehicle battery management?
- RQ2: Which of the required data do value chain actors perceive to be available along the electric vehicle battery value chain?
- **Methods:** Stakeholder focus group workshops (online), semi-structured expert interviews, follow-up stakeholder focus group workshops; qualitative content analysis and subsequent result synthesis, N = 18

Berger, K., Baumgartner, R.J., Weinzerl, M., Bachler, J., Preston, K., Schöggl, J-P (2023a). Data requirements and availabilities for a digital battery passport – A value chain actor perspective. *Cleaner Production Letters*, 4, 100032, https://doi.org/10.1016/j.clpl.2023.100032

Stakeholders involved in the study



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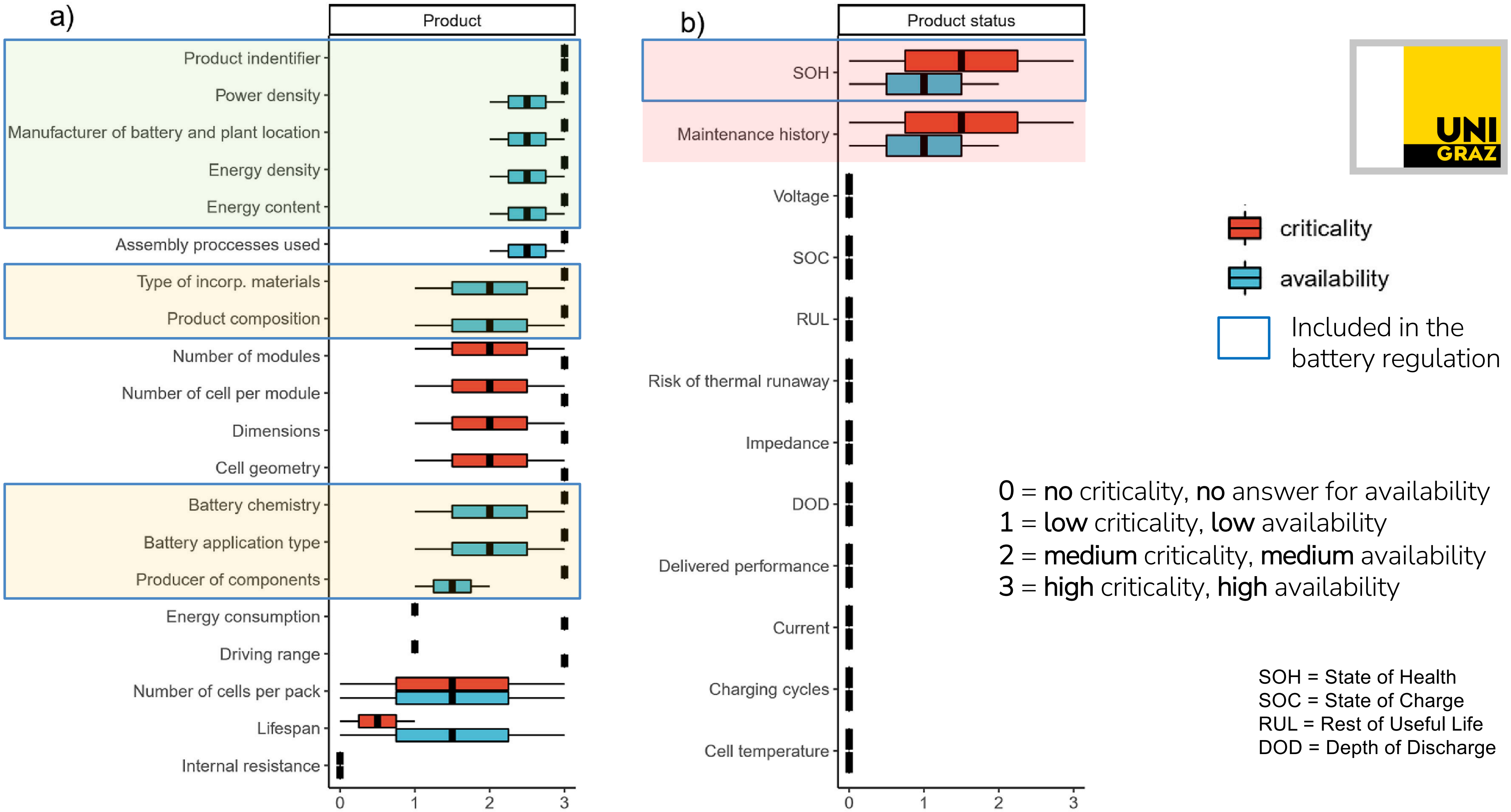
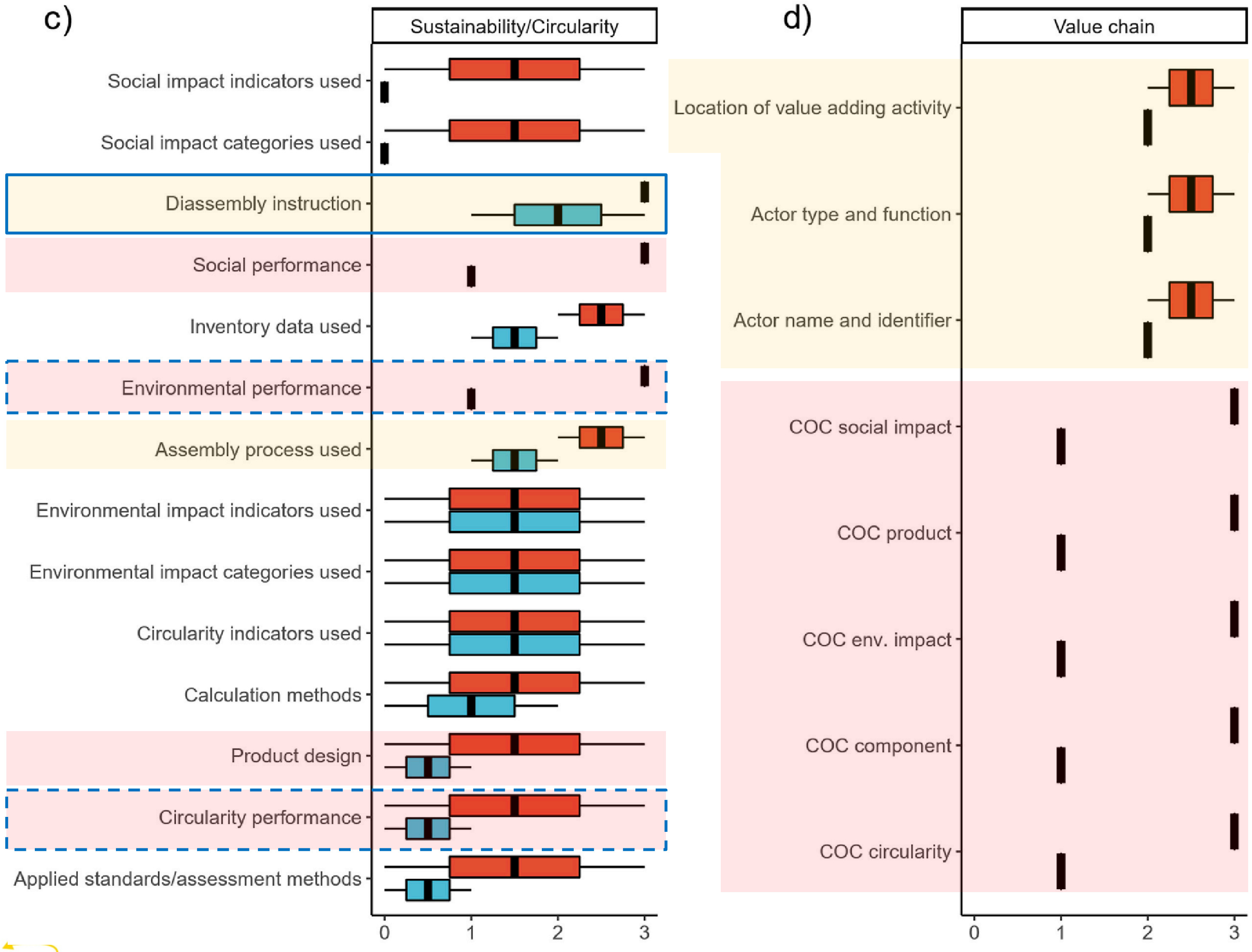


0 = **no** criticality, **no** answer for availability
1 = **low** criticality, **low** availability
2 = **medium** criticality, **medium** availability
3 = **high** criticality, **high** availability

SOH = State of Health
SOC = State of Charge
RUL = Rest of Useful Life
DOD = Depth of Discharge

(Berger et al. 2023a)



criticality

availability

Included in the battery regulation

Partly included in the battery regulation

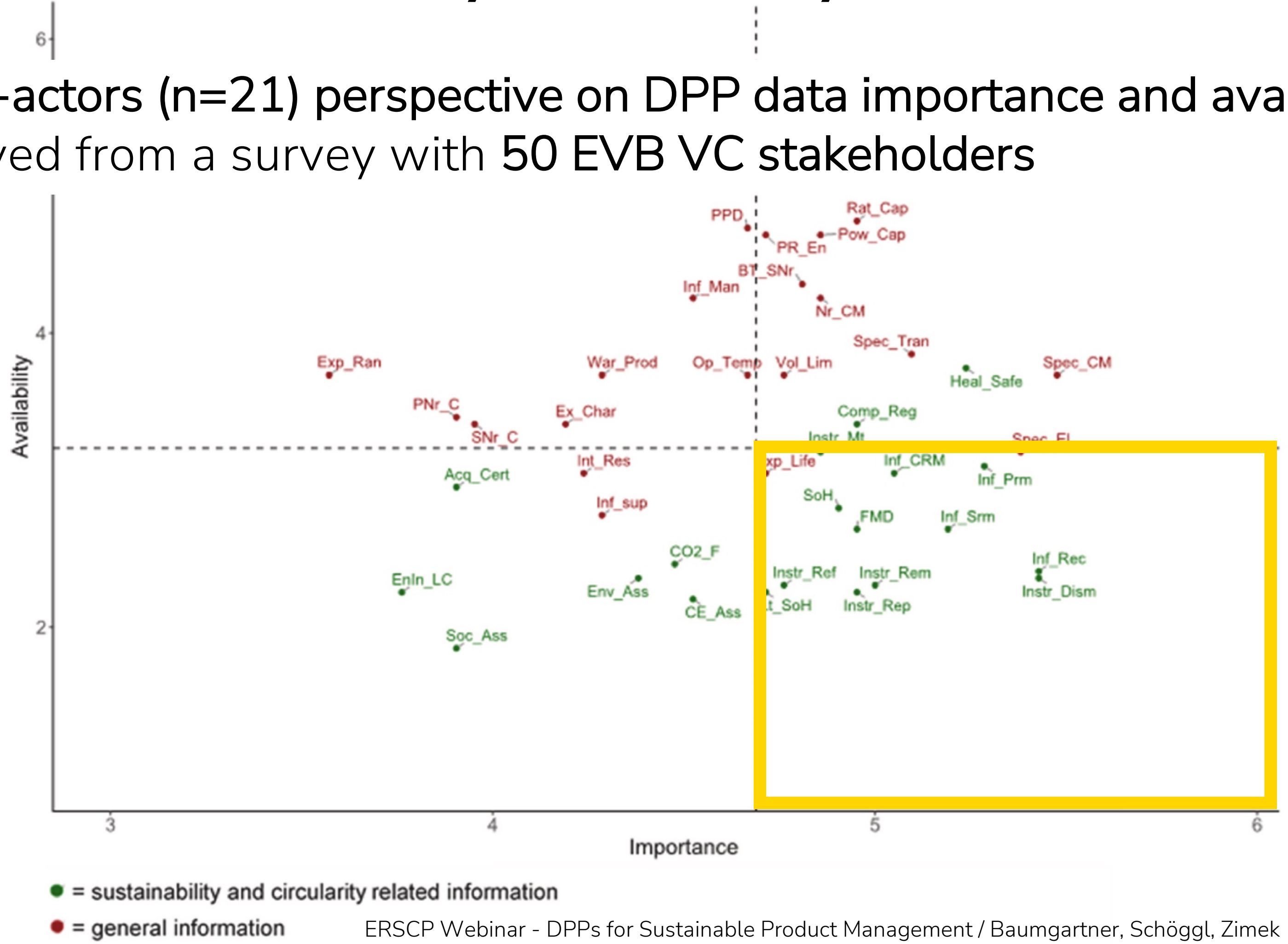
0 = no
1 = low
2 = medium
3 = high

COC = Chain of Custody

(Berger et al. 2023a)

Digital product passports for electric vehicle batteries: Stakeholder requirements for sustainability and circularity

EOL-actors (n=21) perspective on DPP data importance and availability derived from a survey with **50 EVB VC stakeholders**

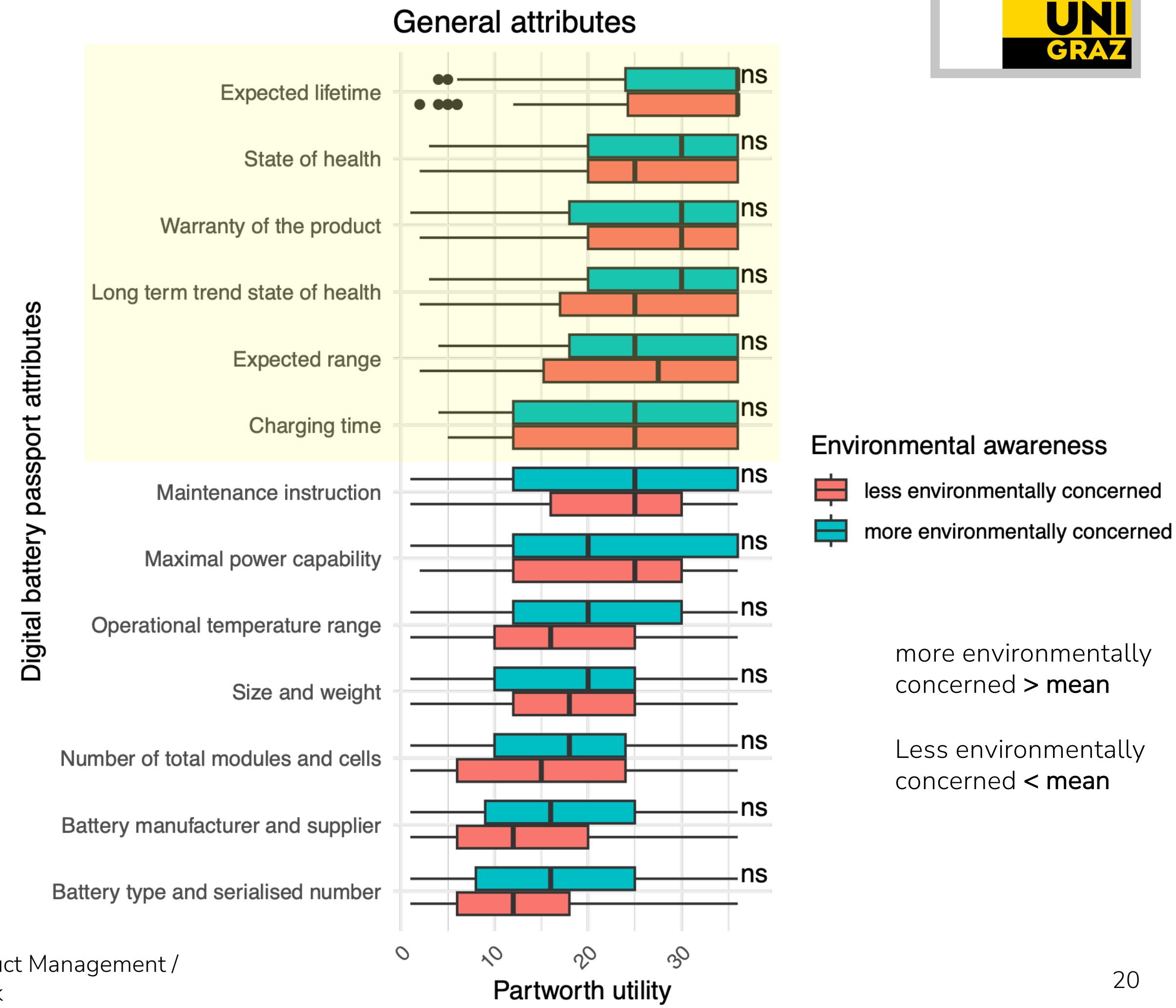


Sustainability and circularity information considered important but having low available

Pohlmann, A., Popowicz, M., Schöggl, J.-P., Baumgartner, R.J., 2025. Digital product passports for electric vehicle batteries: Stakeholder requirements for sustainability and circularity. Cleaner Production Letters 8, 100090. https://doi.org/10.1016/j.clpl.2024.100090

DPP data requirements of consumers: General information

- **Online survey** with (prospective) EV user via electric mobility forums
- **211** participants
- Rating of **22 information attributes'** importance using a self-explicated conjoint analysis
- Environmental awareness (Diekmann & Preisendörfer 2003) and technology affinity used as control variables

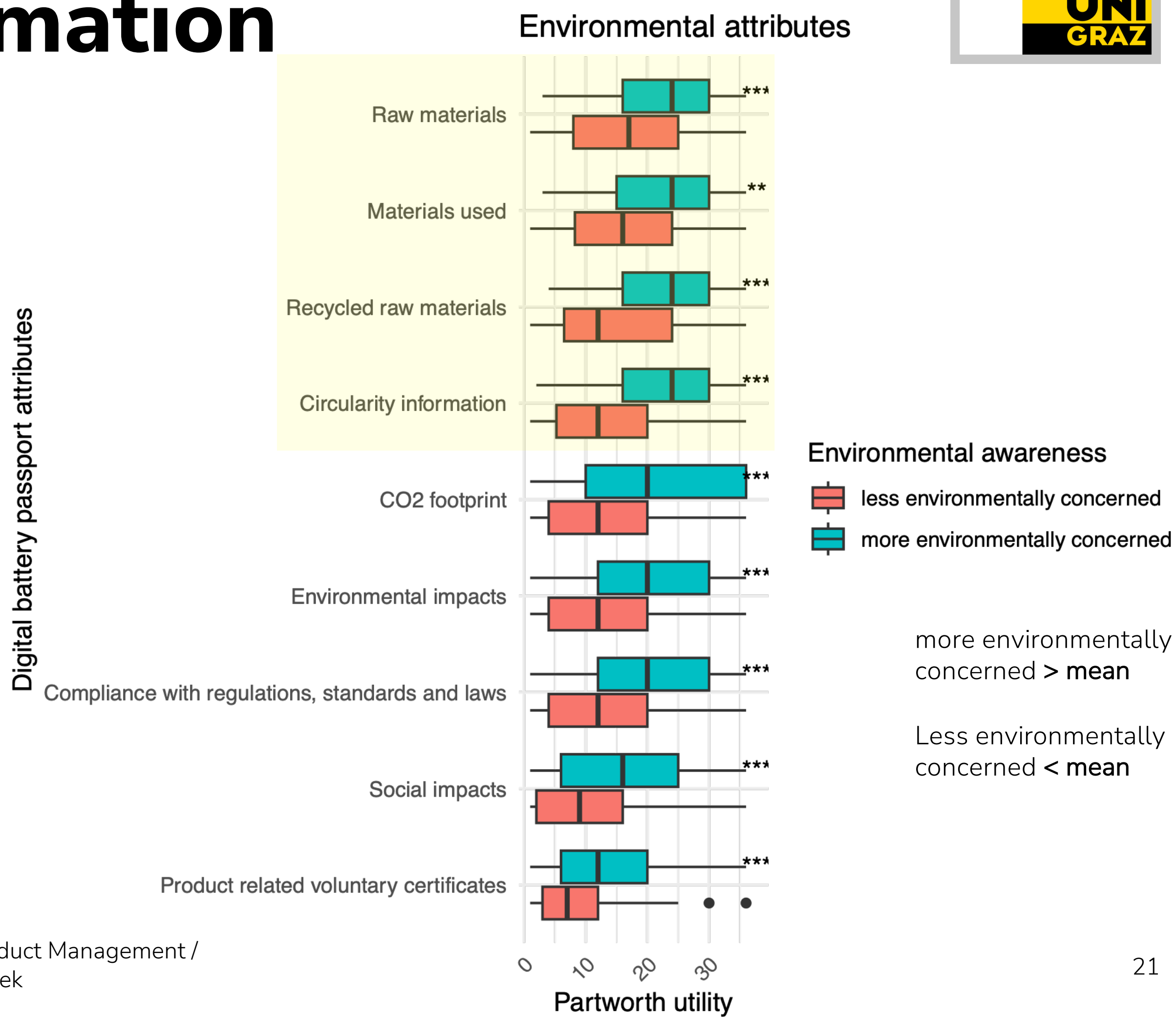


more environmentally concerned > **mean**

Less environmentally concerned < **mean**

DPP data requirements of consumers: Environmental information

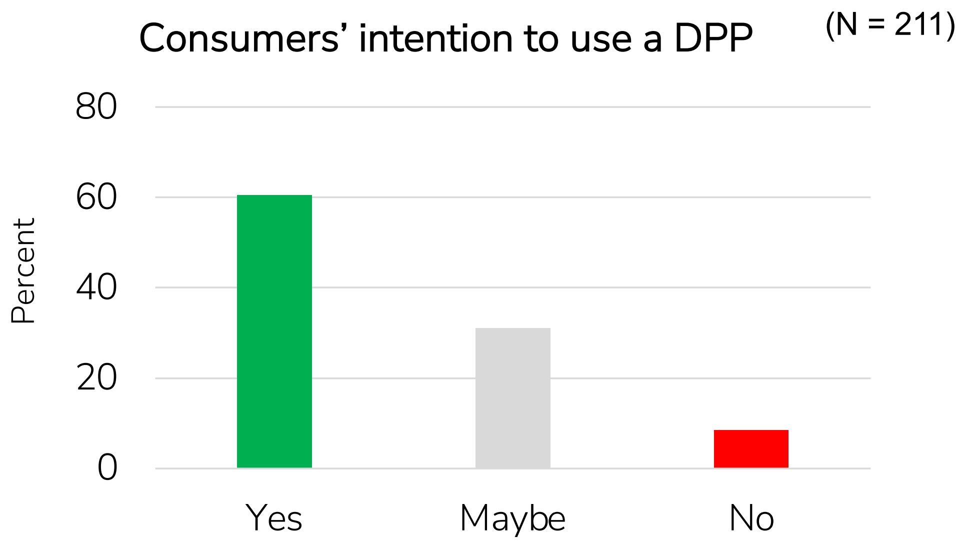
- **Online survey** with (prospective) EV users via electric mobility forums
- **211** participants
- Rating of **22 information attributes'** importance using a self-explicated conjoint analysis
- Environmental awareness (Diekmann & Preisendörfer 2003) and technology affinity used as control variables

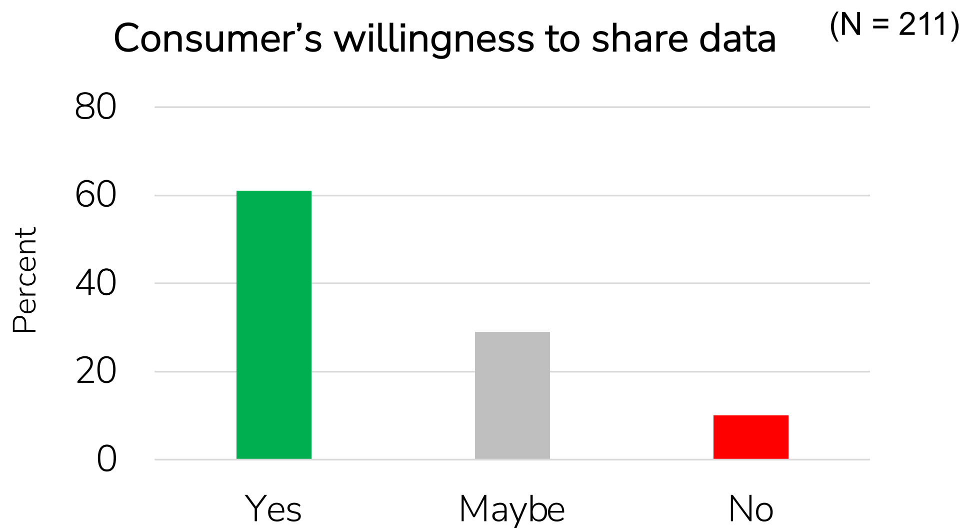


more environmentally concerned > **mean**

Less environmentally concerned < **mean**

EV consumers' intention and willingness to use a digital battery passport





Barriers and enablers for DBP stakeholders

Barriers

Main theme	Description
Uncertainty of stakeholders (frequency: 59) **Uncertainty**	Reflects uncertainty of stakeholders regarding the DPP concepts. Respective sub-themes comprise: uncertainty regarding data needs, data security concerns, unclear means of DPP implementation, unclear DPP definition, unclear user roles
Technological barriers (frequency: 45) **Technological barriers**	Concerns the perceived barriers related to implementation using available technologies. Respective sub-themes comprise: high complexity, data quality issues, data security issues, data storing and processing challenges, large data volumes, lacking IT infrastructure
Insufficient willingness to share information (frequency: 42) **Willingness to share data**	Refers to stakeholders' lack of willingness to share required information. Respective sub-themes comprise: IPR concerns, knowledge transfer, lack of data sharing incentives, loss of business integrity and reputation, competitive disadvantages, unclear data ownership
Lack of clear legal requirements and standards (frequency: 24)	Refers to the perceived lack of clear legal requirements and standards regarding DPP information content and implementation.
Other (frequency: 3)	Refers to other themes identified. This entails sub-themes complexity of the value chain, lack of data documentation

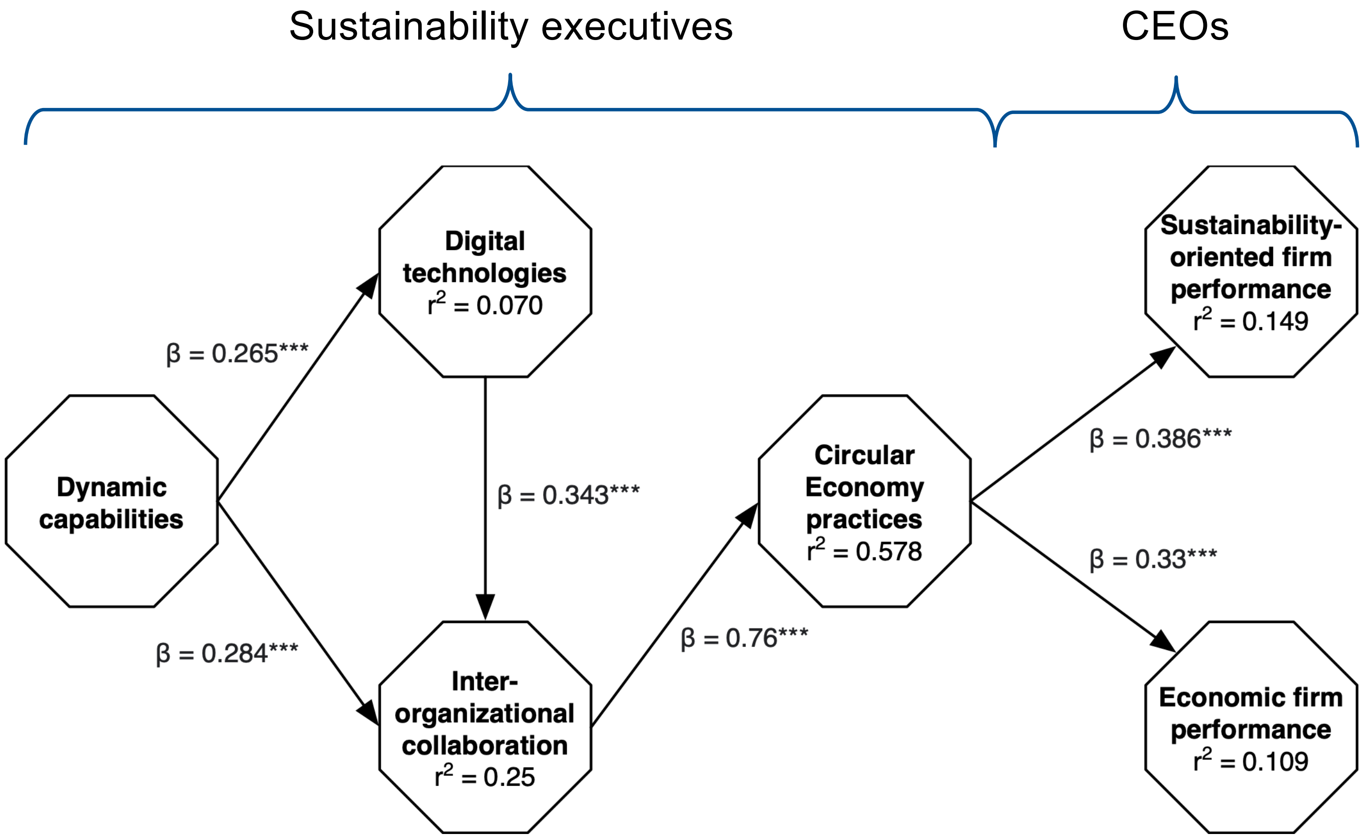
Enablers

Main theme	Description
Willingness to share information (frequency: 57) **Willingness to share data**	Refers to stakeholders' willingness to share required information. Respective sub-themes comprise: access to new markets, increase in business integrity and reputation, competitive advantage, intrinsic motivation to do good, knowledge transfer, marketing reasons, monetary incentives (cash for data), regulatory pressure, risk avoidance
Digital technologies (frequency: 23) **Digital technologies**	Refers to digital technologies being able to enable DPP implementation. Respective sub-themes comprise: enabling value chain transparency and traceability, enabling trust between stakeholders
requirements and standards (frequency: 8)	Refers to clear legal requirements and standards regarding DPP information content and implementation being needed to enable DPPs
Other (frequency: 3)	Refers to other themes identified. This covers the sub-categories creating demand in information, willingness to procure data

Berger, K., Baumgartner, R. J., Weinzerl, M., Bachler, J., & Schöggl, J.-P. (2023d). Factors of digital product passport adoption to enable circular information flows along the battery value chain. *Procedia CIRP, 116*, 528–533. https://doi.org/10.1016/j.procir.2023.02.089

The role of interorganizational collaboration and digital technologies in the implementation of circular economy practices

- **Random sampling** of 112 Austrian manufacturing companies
- **Multiple-respondent design**
- **Model evaluation and comparison** according to Hair et al. (2021)
- **Sample size exceeded minimum requirements** based on conservative estimation using the inverse square root method (Kock and Hadaya, 2018)



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From data to decisions

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From data to decisions: what are DPPs actually for?

- Segments A & B: *What* a DPP is and *how* it is being implemented?
- Segment C: **How we turn DPP data into better sustainability decisions?**
- Focus:
  1. **Assessment frameworks** for sustainability and circularity
  2. **Systemic vs. Narrow** sustainability performance
  3. **The social dimension** in DPPs

From indicators to decisions: how sustainability assessments work

- Sustainability assessments typically combine:
  - **Data** (inventory: materials, energy, locations, processes, social conditions)
  - **Methods** (LCA, SLCA, circularity metrics, risk assessment)
  - **Indicators** (e.g., carbon footprint, toxicity, circularity, social risk scores)
  - **Decision contexts** (design choices, sourcing, policy, end-of-life)
- Key modelling choices:
  - **System boundaries**: which processes, actors and impacts are in or out?
  - **Functional unit**: what service or function are we assessing?
  - **Time horizon**: short- vs long-term impacts and effects
- Result:
  - Assessments translate complex reality into **simplified metrics**, which are necessary for decision-making, but always a **reduction** of the real system.

Why a systemic perspective is essential (NSP vs SSP)

- Zimek & Baumgartner (2024)* distinguish:
  - Narrow sustainability performance (NSP)
    - Performance within the assessed system (e.g., one product, one factory, one company)
    - Often focused on **efficiency** (less impact per unit)
  - Systemic sustainability performance (SSP)
    - Performance at higher systems levels (sector, society, ecosystems)
    - Focused on **effectiveness** for sustainable development
- Risks if we stay „narrow“:
  - Burden shifting
  - Rebound effects
  - Ignoring social systems
- Systemic assessments asks:

  *How do interventions affect **larger systems over time**, not only the assessed unit?*

What DPPs can provide to sustainability assessments

- DPPs can **enrich the data layer** of assessments:
  - Granular product-level data across life cycles
  - Information from multiple **value chain actors**
  - Machine-readable, updatable formats
- Examples of DPP contributions:
  - **Inventory data** for environmental LCA or SLCA
  - Material composition, origin, recycled content, process data
- **Structure and process data** for circularity assessment:
  - Repairability, modularity, dismantling instructions, EoL options
- **Context and origin data** for social assessment:
  - Sourcing regions, due diligence outcomes, certifications
- Potential impact:
  - Better alignment between **assessed systems** and **real systems**
  - More realistic view of **interdependencies** across value chain

From DPP data fields to decision-relevant indicators

Raw data in a DPP is not yet a decision tool!

	DPP data	Indicators
Design & development	material composition, recycled content, hazardous substances, design for repair/disassembly	climate footprint, resource depletion, toxicity, circularity scores, social risk indicators

… we have to map concrete DPP data to indicators that decision-makers "understand"

Social issues in DPPs: current gaps

- The Social Sustainability Delta (2SD) concept (Zimek et al. 2026):
  - DPPs risk a **social sustainability delta ->** critical social impacts stay outside the DPP scope; Gap between:
    - A **holistic social sustainability reference** (UNEP guidelines) and
    - what regulators, industry (and other stakeholders) actually prioritise and request
- Observed patterns:
  - Policymakers: focus on compliance-critical topics (child labour, forced labour, discrimination)
  - Industry: focus on implementable topics (health and safety, supplier audits)
  - Researchers: wider, systemic view including vulnerable groups and communities
- Implication for DPPs:
  - If DPPs reflect only one perspective, many relevant social impacts stay invisible
  - Reducing 2SD is key if DPPs are to support systemic sustainability performance

What DPP-enabled systemic decision support could look like

- For **design & engineering**:
  - Scenario comparisons: material choices and design options with NSP and SSP impacts
- For **procurement & sourcing**:
  - Supplier selection based on combined information on environmental and social impacts (indicators) drawn from DPPs
- For **policy & regulation**:
  - Monitoring whether sector-wide DPP data show progress in SSP, not just compliance rates
- For **end-of-life actors**:
  - Prioritising recovery and treatment based on material value and social risk profiles

The key is the connection …

- DPPs provide **data**,
- assessment methods provide **structure**, and
- decision processes provide **direction**.

If we manage to connect these three elements, DPPs can evolve from a compliance mechanism into a genuine instrument for sustainable product management.

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Discussion

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