A methodology for end-to-end digitalization of battery cell production

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CONTENT

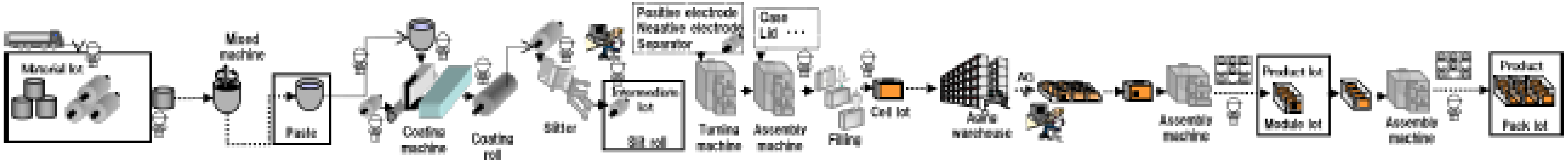
Introduction

BMW CELL MANUFACTURING COMPETENCE CENTER

15 000 m^2 facility commissioned in 2022 to demonstrate BMW's ability to industrially produce battery cells

Source: BMW Group Press, 2022

INTRODUCTION – BATTERY CELL PRODUCTION



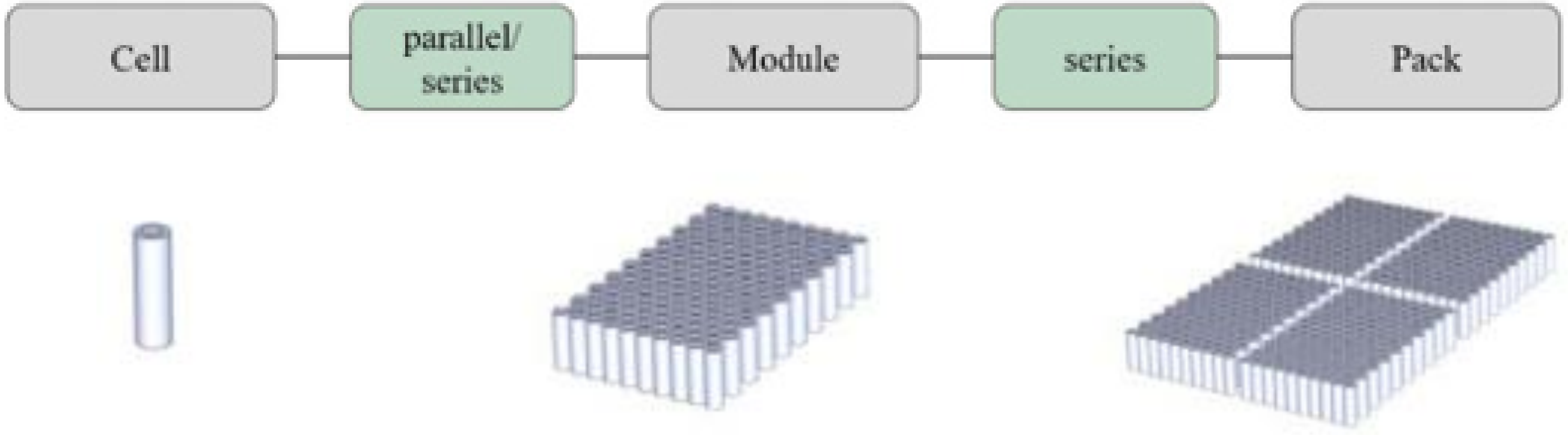
Acceptance → Mixing → Coating → Drying → Pressing / Slitting / Assembling → Filling → Charging / Discharging / Aging / Visual inspection

Source: Haghi, 2022

Electrode Manufacturing

Cylindrical Cell

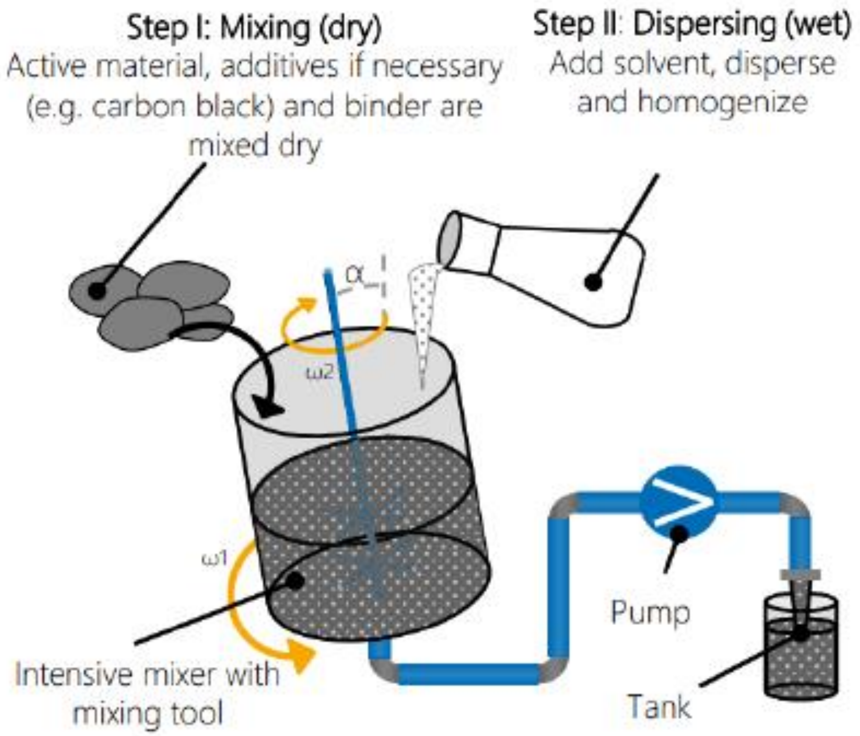
INTRODUCTION – BATTERY CELL PRODUCTION



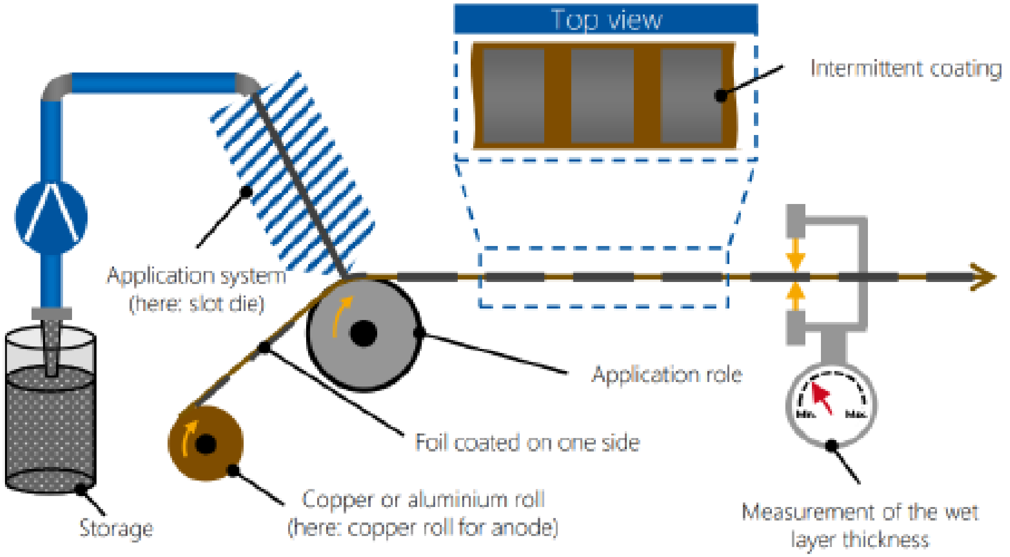
Source: Zwicker, 2020

INTRODUCTION – ELECTRODE MANUFACTURING

Mixing



Coating



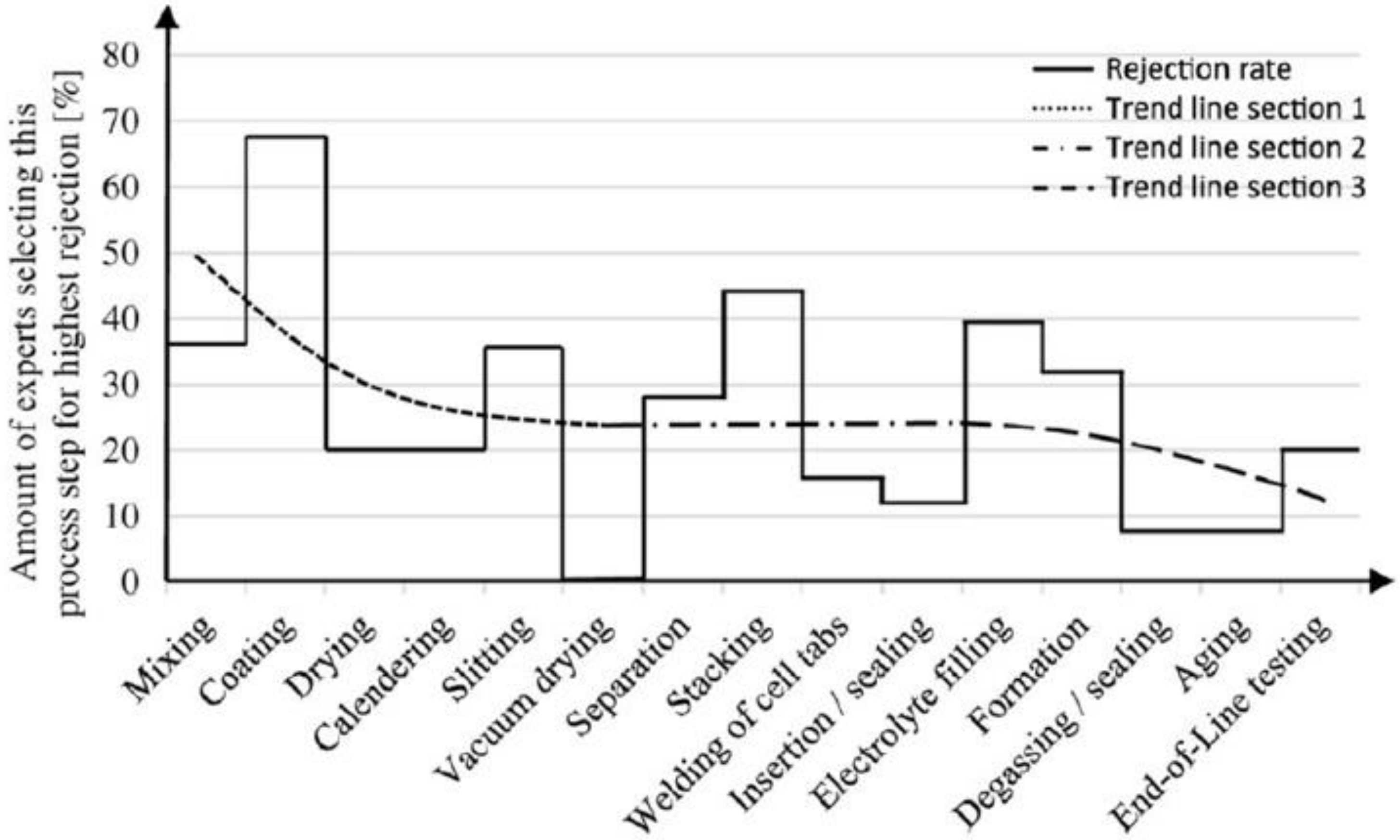
Source: RWTH, 2018

INTRODUCTION – ELECTRODE MANUFACTURING

Source: https://www.dailymotion.com/video/x7o5glx

INTRODUCTION - ELECTRODE MANUFACTURING

High scrap rate for mixing and coating

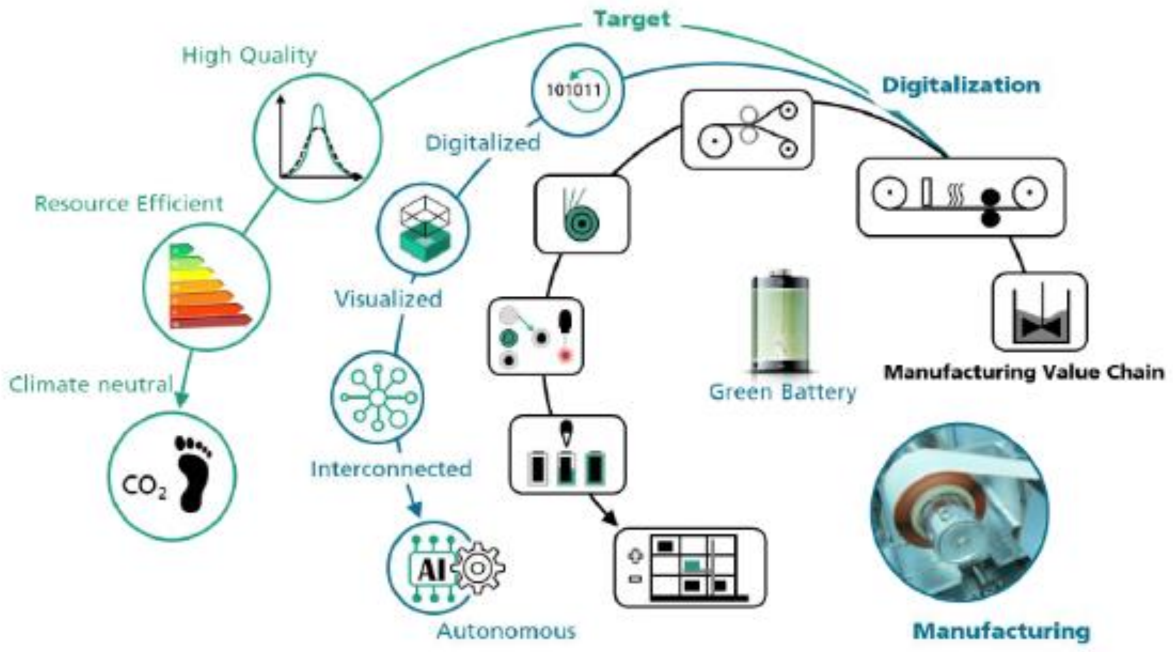


Source: Kehrer, 2021

Motivation

MOTIVATION

Benefits of the digital transformation



Source: Kaus, 2020

EU Battery Regulation (2026)

Challenges: lack of data acquisition, poor data quality, scarcity of usable data

Source: https://cicenergigune.com/en/blog/battery-passport-regulation-batteries-europe

Problem statement

KEY CONCEPTS

End-to-end digitalization: creation, acquisition, transport and storage of data from sensors to cloud databases

“Better data, not bigger data” Andrew Ng

Tackle lack of data acquisition, poor data quality, scarcity of usable data

EXISTING DIGITALIZATION STRATEGIES

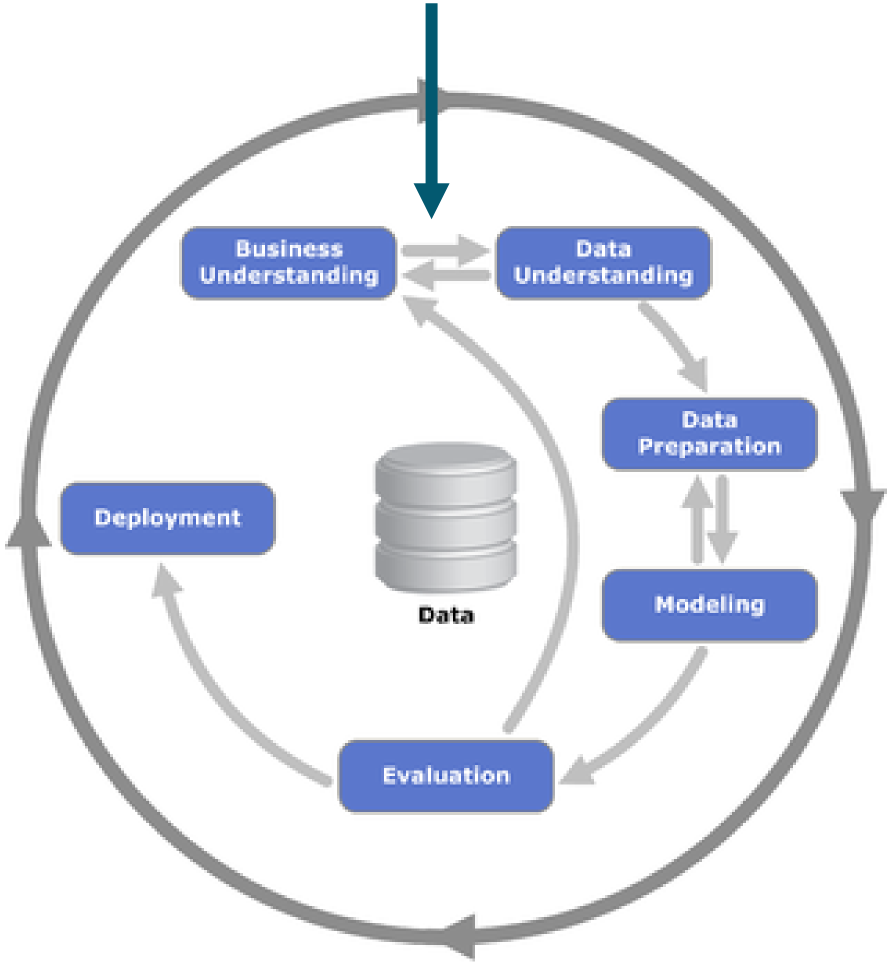
- CRoss Industry Standard Process for Data Mining (CRISP-DM)
- Most widely used analytics model
- Data understanding (describe, explore, verify data)

Cons

- Pre-dates big data era (conceived in 1996)
- Lacks an intermediate methodology between Business Understanding and Data Understanding

How BMW should connect its business objectives regarding battery production to data created during the processes ?

Contribution of this thesis



Source: Wikipedia CRISP-DM

EXISTING DIGITALIZATION STRATEGIES

	Huber et al 2019	Han et al 2020	Kintscher et al 2020	Kampker et al 2023	Haghi et al 2021	Wanner et al 2021
Conceptual Criteria						
End-to-end digitalization	◑	◔	◔	◑	◑	◑
Scalability	●	◑	◔	●	●	◑
Facilitate fast commissioning	◑	○	○	◑	◑	○
Enhance sustainable production	◕	○	●	●	◑	●
Accurate data modelling	◔	◑	◑	◔	○	○
Automation degree of the data acquisition	◑	●	●	◔	◔	●
Technical Criteria						
Interoperability	○	●	●	○	○	◑
Machine connectivity	○	●	●	○	○	◔
Cybersecurity	○	○	○	○	○	○
Big data	◑	○	◑	◑	◔	◔
Data storage	◔	○	○	○	○	◕
Data quality check	○	◕	○	◑	◑	○
User-friendly BI dashboards	○	◑	○	○	◑	○

Symbol	Interpretation
○	not fulfilled - criterion not mentioned
◔	low fulfillment - criterion only referred to
◑	medium fulfillment - criterion somewhat discussed
◕	high fulfillment - novel method proposed
●	complete fulfillment - main focus of the study

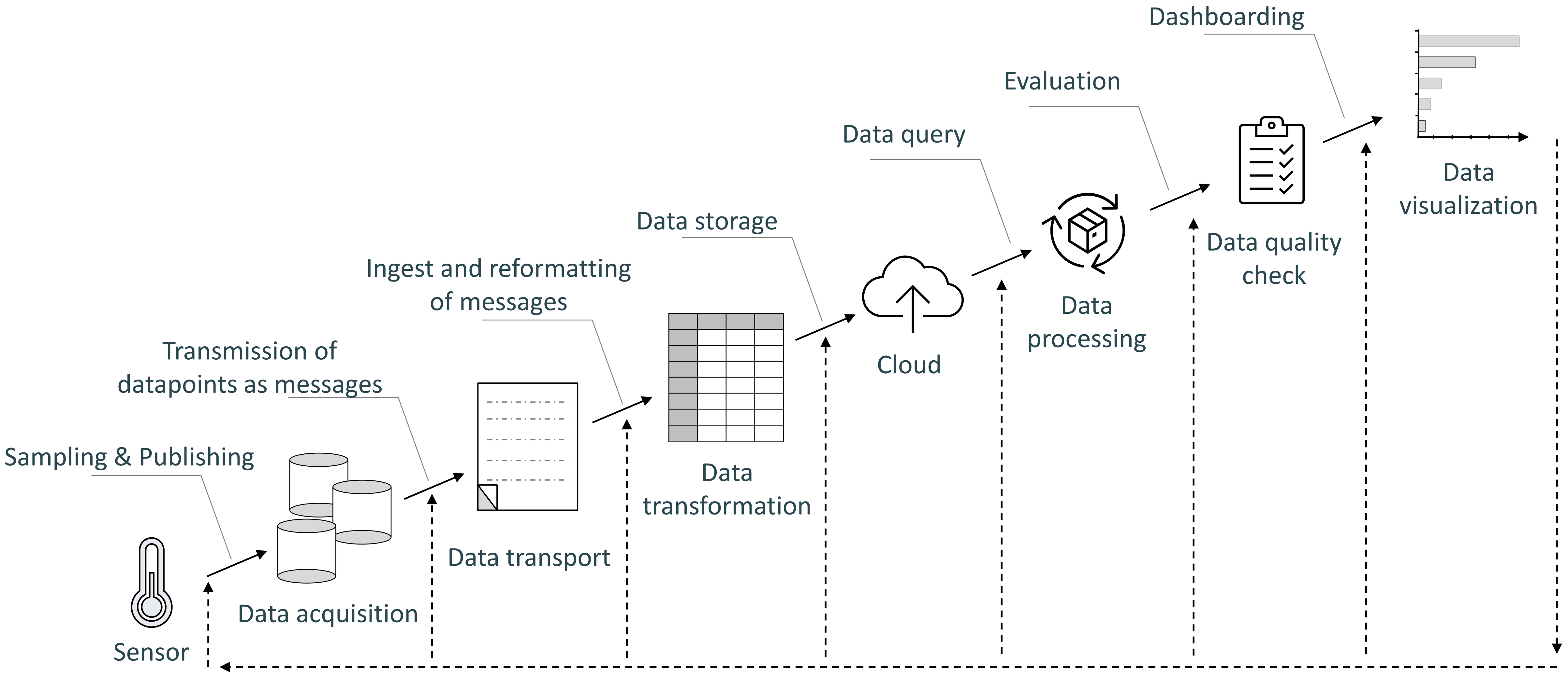
OBJECTIVE

Formulate a standard methodology to acquire and store data

Characteristics of battery production	Requirements for a digitalization methodology
Complex process with many interdependent steps	→ Accurate data modelling
Large number of parameters	→ Scalability
High scrap rate	→ Facilitation of fast commissioning and production ramp-up
Traceability	→ Connection of machines from different vendors – Automation of data acquisition
Industrial scale	→ Handling of big data → Cybersecurity → Data accuracy

OBJECTIVE

Formulate a standard methodology to account for all the steps from a sensor to the cloud



RESEARCH QUESTIONS

1. What is the right methodology for fast connection of large amount of parameters (critical parameters) originating from various machines in a complex manufacturing process?

2. What is a suitable data integration strategy to support the implementation of the proposed methodology?

SCOPE

1. Data created by or attached to the battery beyond the manufacturing plant such as sales, usage or recycling data is excluded

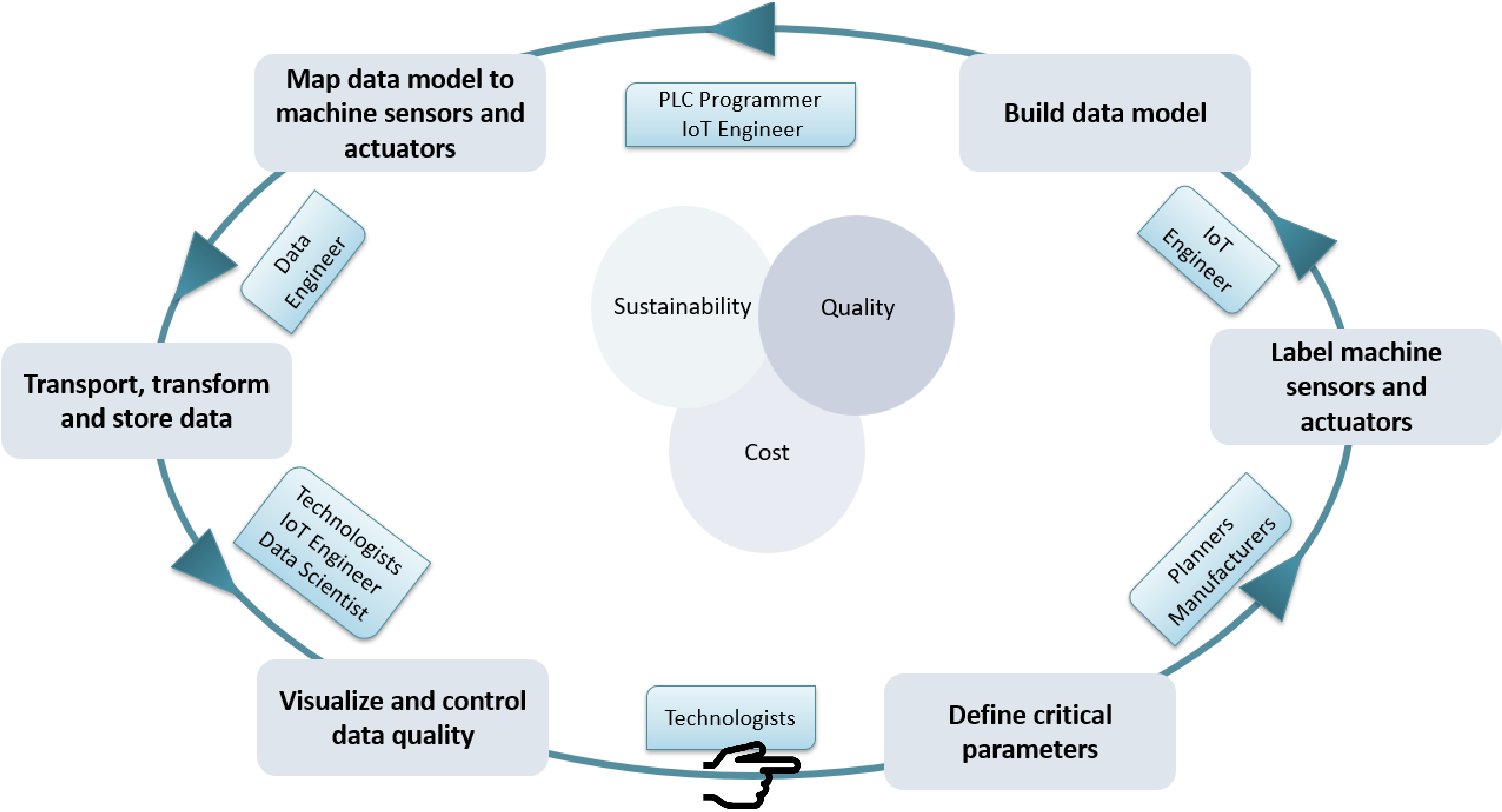
2. No data analytics approach

3. Results dependent on the status of implementation onsite

The proposed methodology for digitalization of battery production

METHODOLOGY FOR DIGITALIZATION OF BATTERY PRODUCTION

The proposed methodology involves 6 sequential steps and a multi-stakeholder collaboration



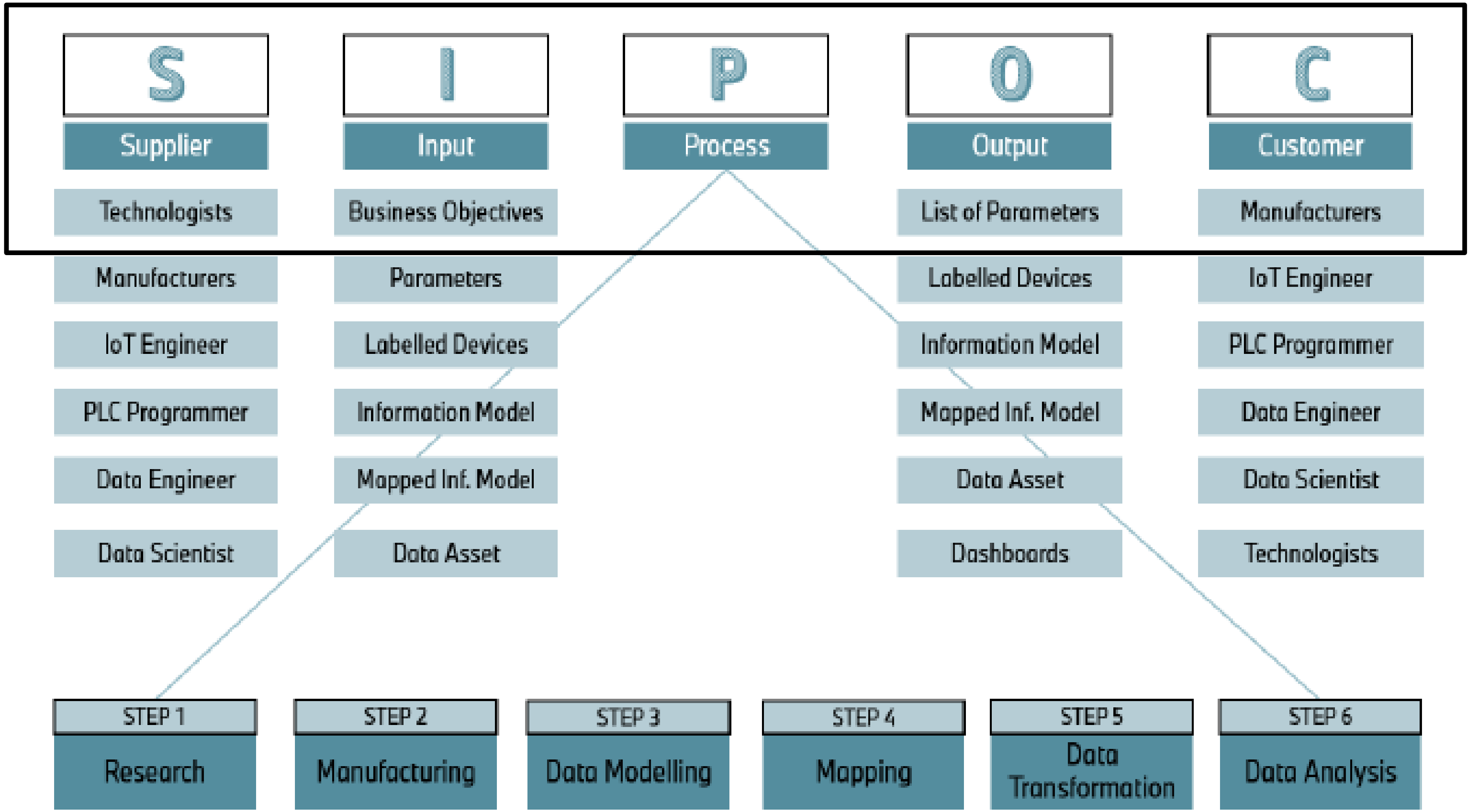
METHODOLOGY FOR DIGITALIZATION OF BATTERY PRODUCTION

STEP 1	STEP 2	STEP 3
List of critical parameters	**Labelling of machine sensors**	**Data modelling**
Enumerate the business objectives of the digital transformation and identify the critical parameters that should be monitored.	Specific symbols and IDs are assigned to each component to help in locating them accurately within the machine.	Standardized representation of each machine’s data and functionalities, facilitating interoperability.

METHODOLOGY FOR DIGITALIZATION OF BATTERY PRODUCTION

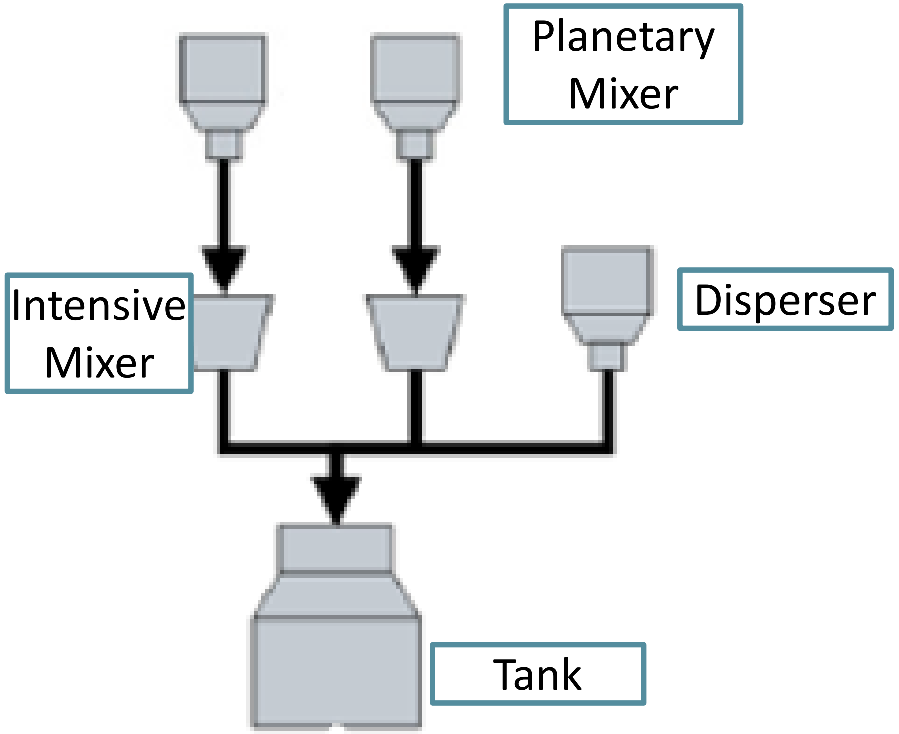
STEP 4	STEP 5	STEP 6
Mapping Establishment of a connection between the variables generated in a machine's PLC and the custom data model.	**Data transport and transformation** Collection of data from the machines and utilization of appropriate communication protocols and technologies to securely transmit the acquired data.	**Visualization and data quality control** Tackling data quality issues such as invalid data, inaccurate data, incomplete data, inconsistent data and redundant data.

THE STAKEHOLDERS

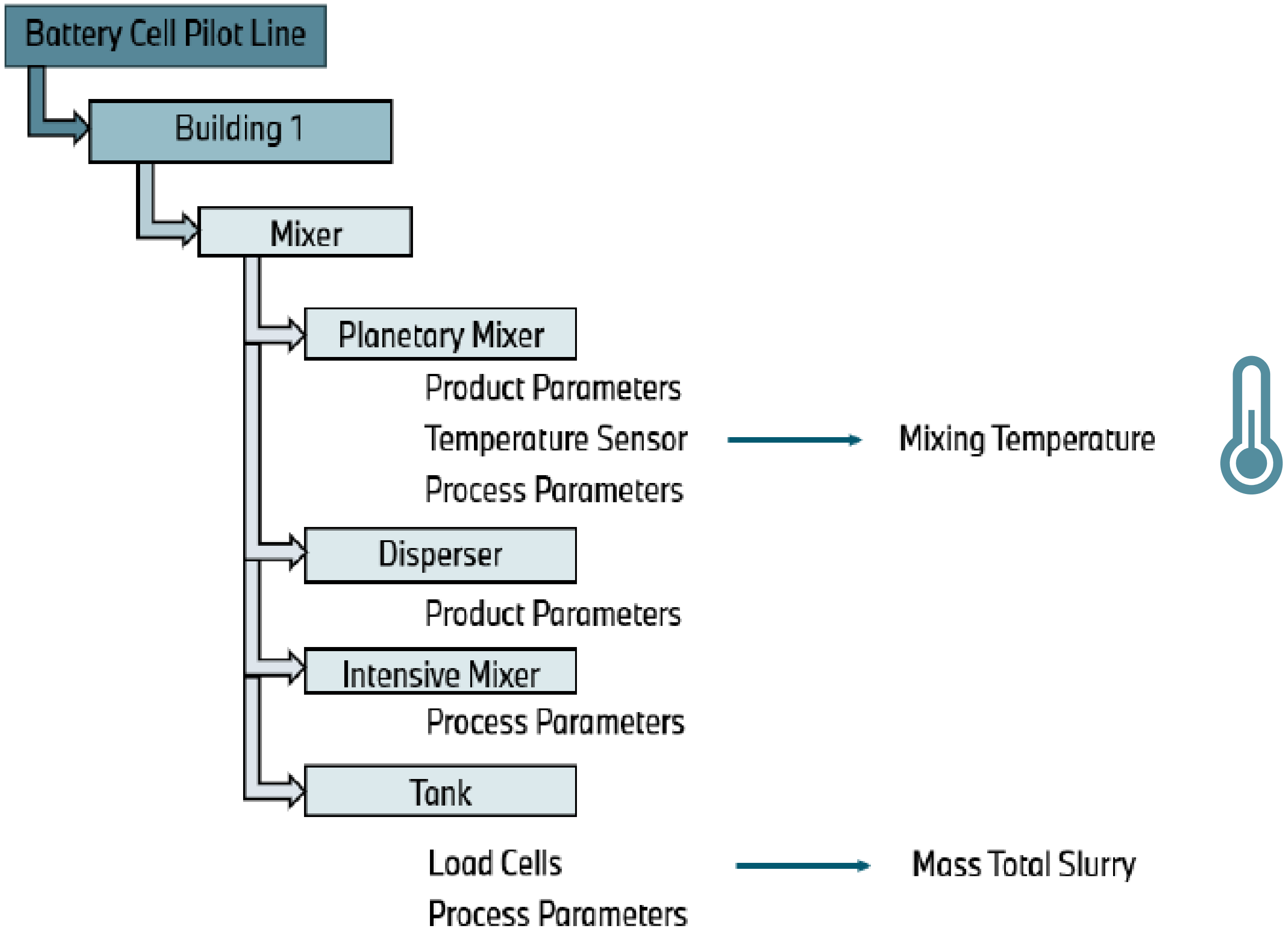


Case study

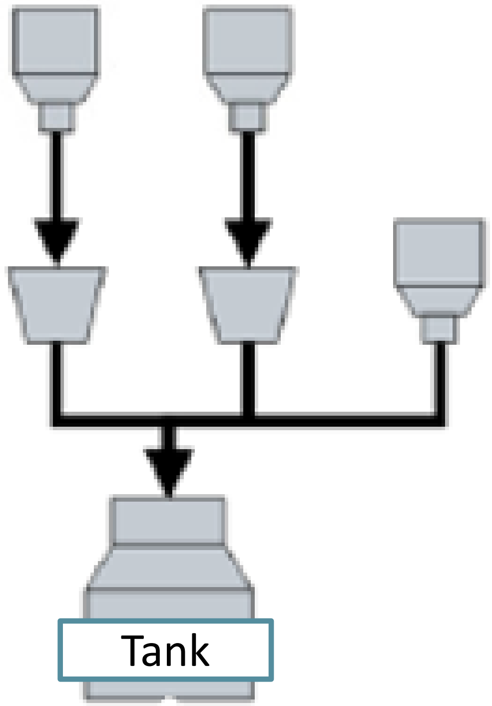
CASE STUDY – CONNECTION OF THE MIXING MACHINE



200+ parameters including measurement values, IDs, control limits and setpoints



CASE STUDY – CONNECTION OF THE MIXING MACHINE



200+ parameters including measurement values, IDs, control limits and setpoints

Source: BMW Group Press, 2022

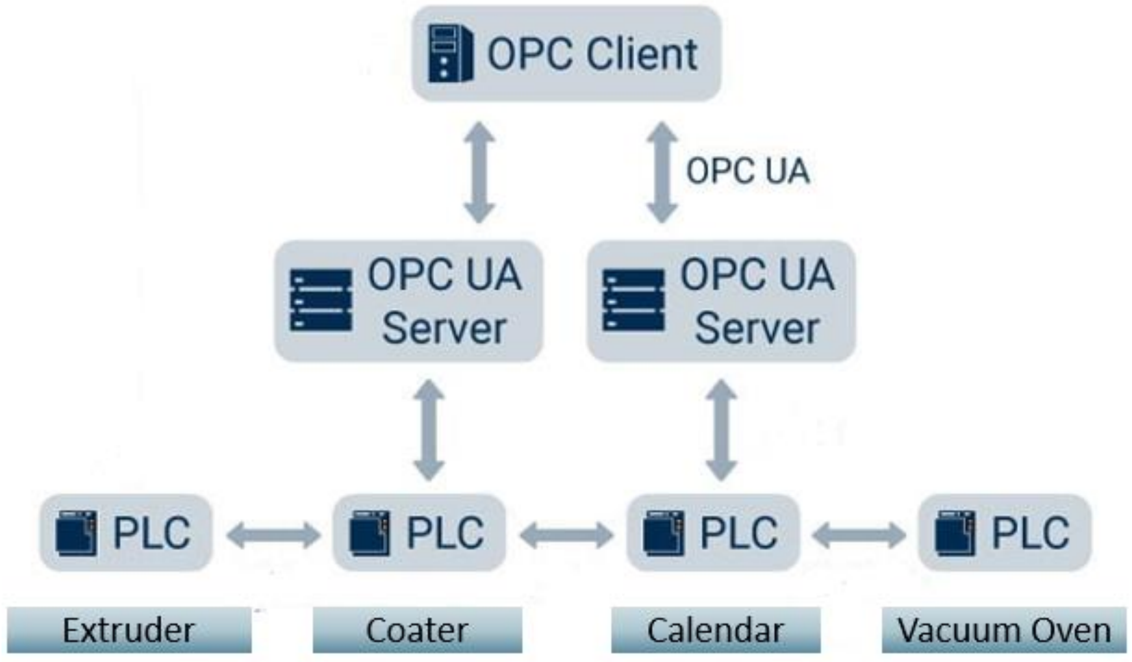
CASE STUDY – LIST OF PARAMETERS & LABELLING OF MACHINE SENSORS

- Specify the categories of parameters (measurements, recipe, machine states and materials/products/processes)
- Distinguish in-line continuous variables from data aggregated per batch, shift or process
- Propose a consistent nomenclature, suitable engineering units, and the need for control limits

Masterstring	Parameter Name	Unit	Category	Setpoint	Limits
Mixer_PlanetaryMixer_ TemperatureSensor	MixingTemperature	°C	Process - Continuous	☑	☑

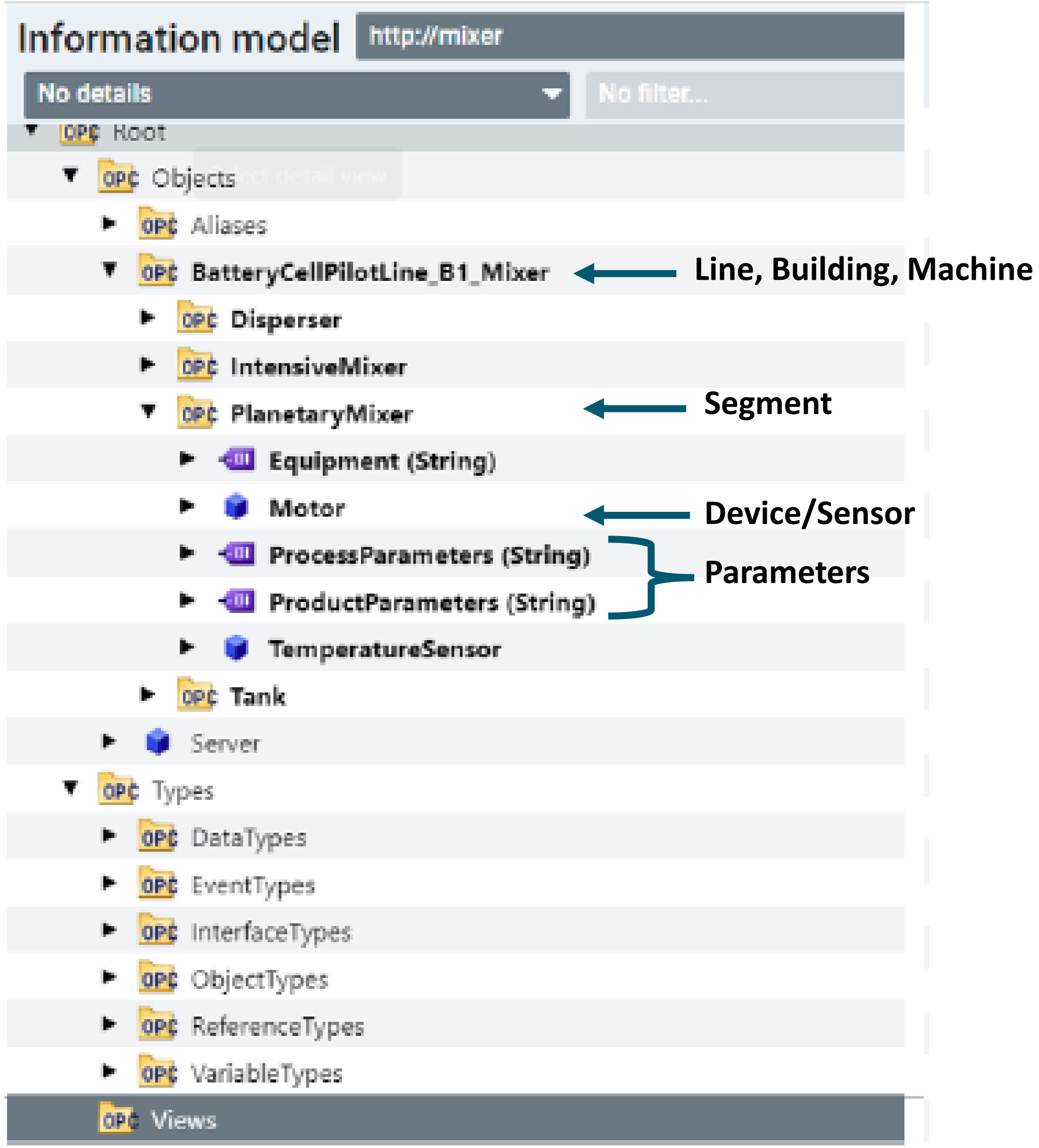
CASE STUDY – OPC UA DATA MODELLING

- OPC UA (Open Platform Communications Unified Architecture) is a communication protocol designed for industrial automation that provides a standardized framework for seamless interoperability between various devices, machines, and systems
- Platform-independent and supports multiple operating systems and programming languages
- Encryption, authentication, and access control mechanisms
- Data modelling approach
- Server – client interactions to collect data



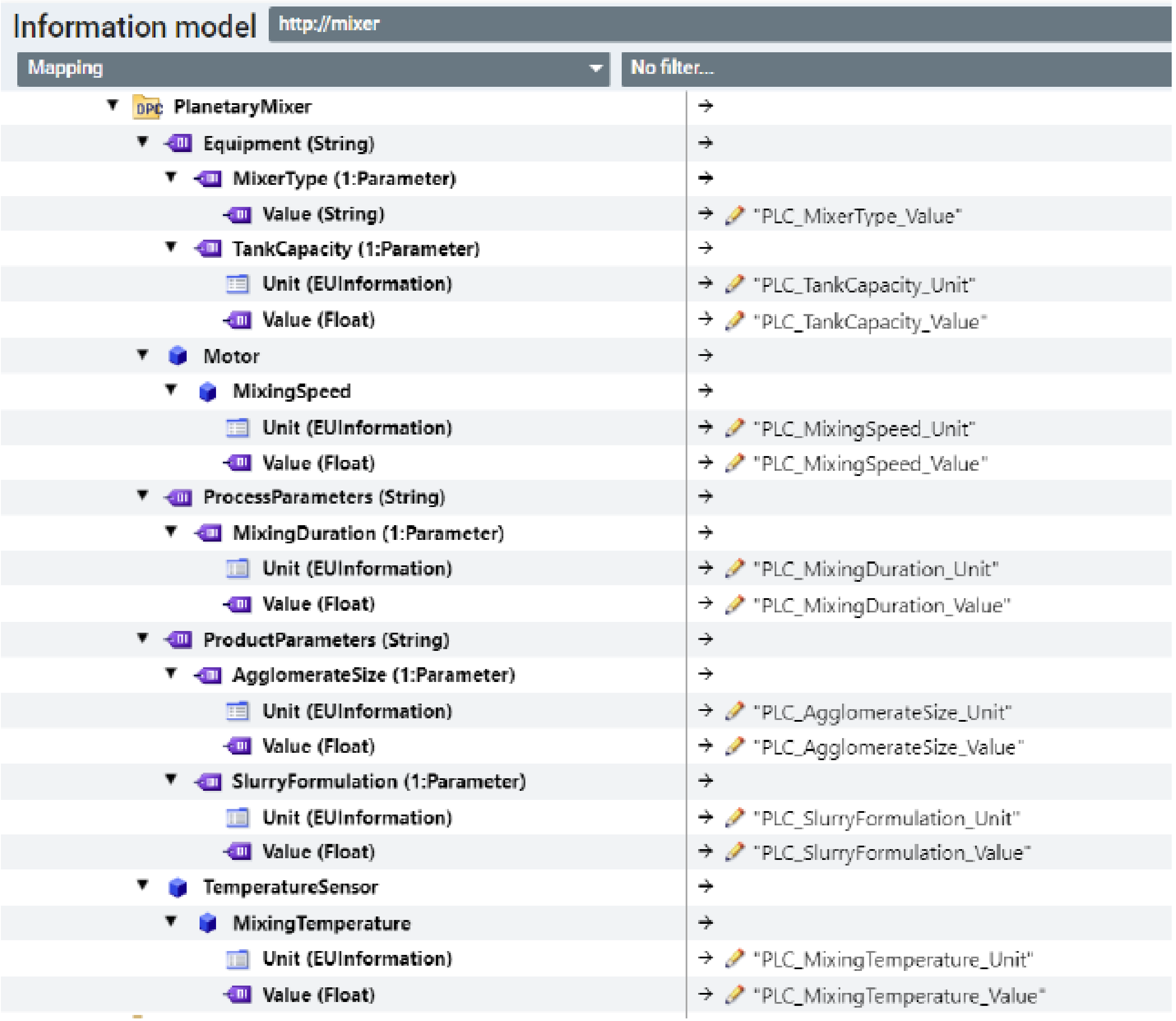
CASE STUDY – OPC UA DATA MODELLING

- The data model is a hierarchical structure of nodes that represent all data and functionalities of a machine on the OPC UA server.
- The modelling follows cross-BMW specifications to ensure applicability to all the production lines.
- The overall tree structure of the data model replicates the machine structure and guarantees that all the items are uniquely identified.

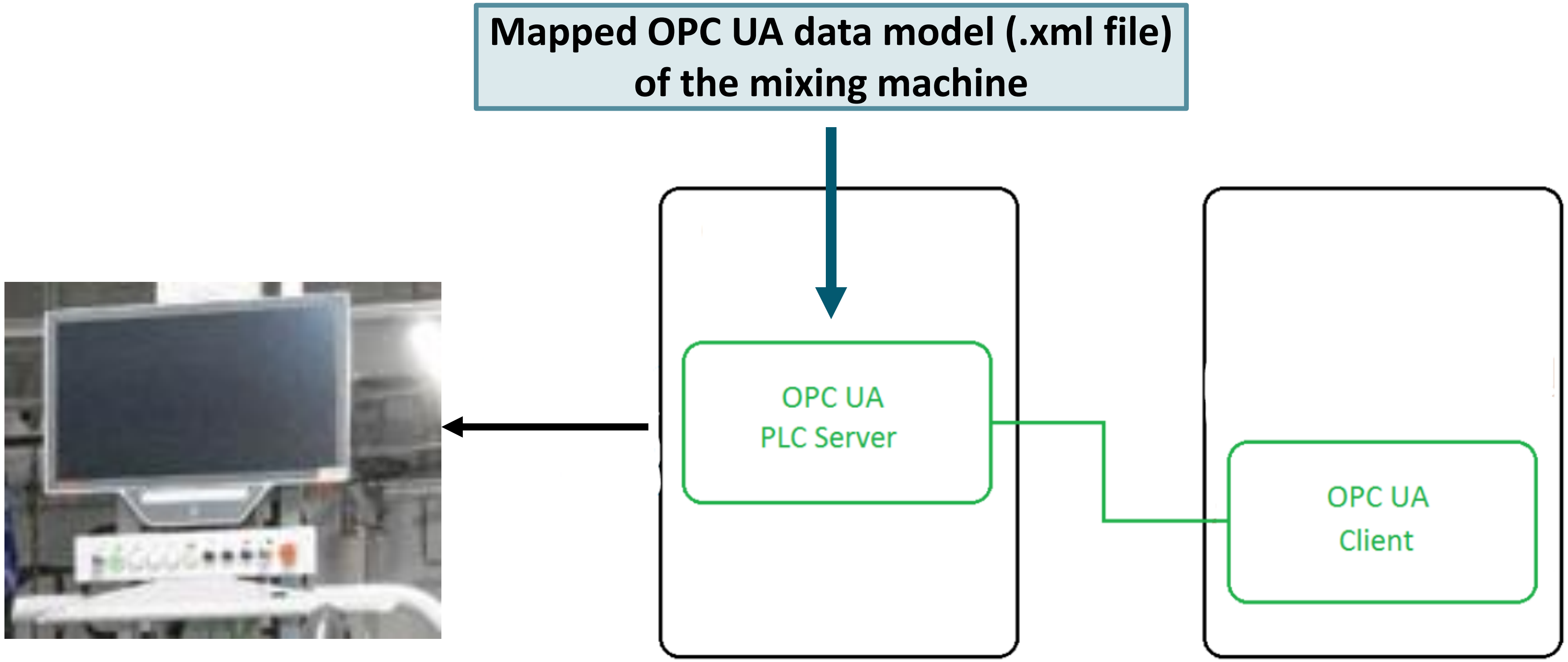


CASE STUDY - MAPPING

- The mapping establishes a connection between the PLC variables and the OPC UA server (through the data model).
- It results in the same representation of data between the PLC and the OPC UA server.



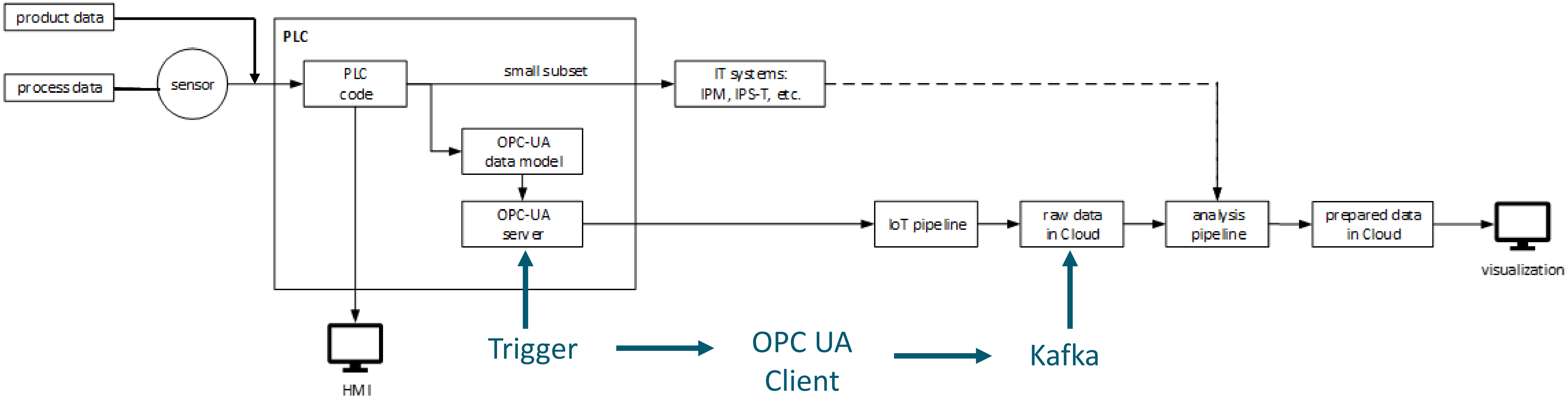
CASE STUDY - MAPPING



Source: readthedocs/PLC

CASE STUDY – DATA TRANSPORT, TRANSFORMATION AND STORAGE

- The OPC UA client operates by establishing a subscription with the OPC UA server and receiving data updates only when the trigger values are incremented.
- A JSON configuration file is used to define the parameters for data retrieval (by nodeID), the sampling interval (frequency at which OPC UA server samples data values from sensors), publishing interval (frequency at which OPC UA server sends data updates to the client), and triggered groups.
- Kafka is a real-time data streaming platform that receives all messages from the client and allows for cloud ingest.



CASE STUDY – DATA TRANSFORMATION

Structure of the JSON payload


```
{
    "nodeType": "Float",
    "nodeId": "ns=4;s=\"Root\".\"Objects\".\"Mixer\".\"TemperatureSensor\".\"Temperature\"",
    "serverTimestamp": "2023-06-22T13:36:26.6984871Z",
    "sourceTimestamp": "2023-06-22T13:36:26.6984871Z",
    "status": "Good",
    "value": {
      "Value": 19.5,
      "Unit": "°C"
    }
```

CASE STUDY – DATA TRANSFORMATION

#	ts_utc	message_id	data_key_val_string	measured_value
1	2023-06-15 10:36:33.777787 UTC	cc22074c-ee08-4fd1-986c-c43377b2...	ns=4;s="Root"."Objects"."Machine...	19.83507
2	2023-06-15 07:44:52.873863 UTC	cc22074c-ee08-4fd1-986c-c43377b2...	i=2260	{"ProductUri":"https://www.sieme...
3	2023-06-15 10:23:07.777782 UTC	e81f533c-caec-498b-88dd-b598f4d...	ns=4;s="Root"."Objects"."Machine...	19.89294
4	2023-06-15 07:44:52.873863 UTC	e81f533c-caec-498b-88dd-b598f4d...	i=2260	{"ProductUri":"https://www.sieme...
5	2023-06-15 10:27:10.777784 UTC	d257c65f-b538-46fe-8cf8-b5586c9d...	ns=4;s="Root"."Objects"."Machine...	19.89294
6	2023-06-15 07:44:52.873863 UTC	d257c65f-b538-46fe-8cf8-b5586c9d...	i=2260	{"ProductUri":"https://www.sieme...
7	2023-06-15 10:07:34.277786 UTC	57ba68e4-9601-4f0c-86a1-a9585c3...	ns=4;s="Root"."Objects"."Machine...	19.83507
8	2023-06-15 07:44:52.873863 UTC	fa2dd5ef-89ad-4452-9810-13fd0427...	i=2260	{"ProductUri":"https://www.sieme...
9	2023-06-15 10:23:36.777786 UTC	2fb68976-fac2-46da-ae12-e4d9388...	ns=4;s="Root"."Objects"."Machine...	19.878473
10	2023-06-15 07:44:52.873863 UTC	2fb68976-fac2-46da-ae12-e4d9388...	i=2260	{"ProductUri":"https://www.sieme...
11	2023-06-15 10:30:47.277785 UTC	824f3f5f-789e-49ed-a671-631b14fc...	ns=4;s="Root"."Objects"."Machine...	19.849537
12	2023-06-15 07:44:52.873863 UTC	824f3f5f-789e-49ed-a671-631b14fc...	i=2260	{"ProductUri":"https://www.sieme...
13	2023-06-15 07:44:52.873863 UTC	57ba68e4-9601-4f0c-86a1-a9585c3...	i=2260	{"ProductUri":"https://www.sieme...
14	2023-06-15 10:47:13.777788 UTC	f5a8dfcd-f2c6-4892-a2f2-79b6fc59c...	ns=4;s="Root"."Objects"."Machine...	19.849537

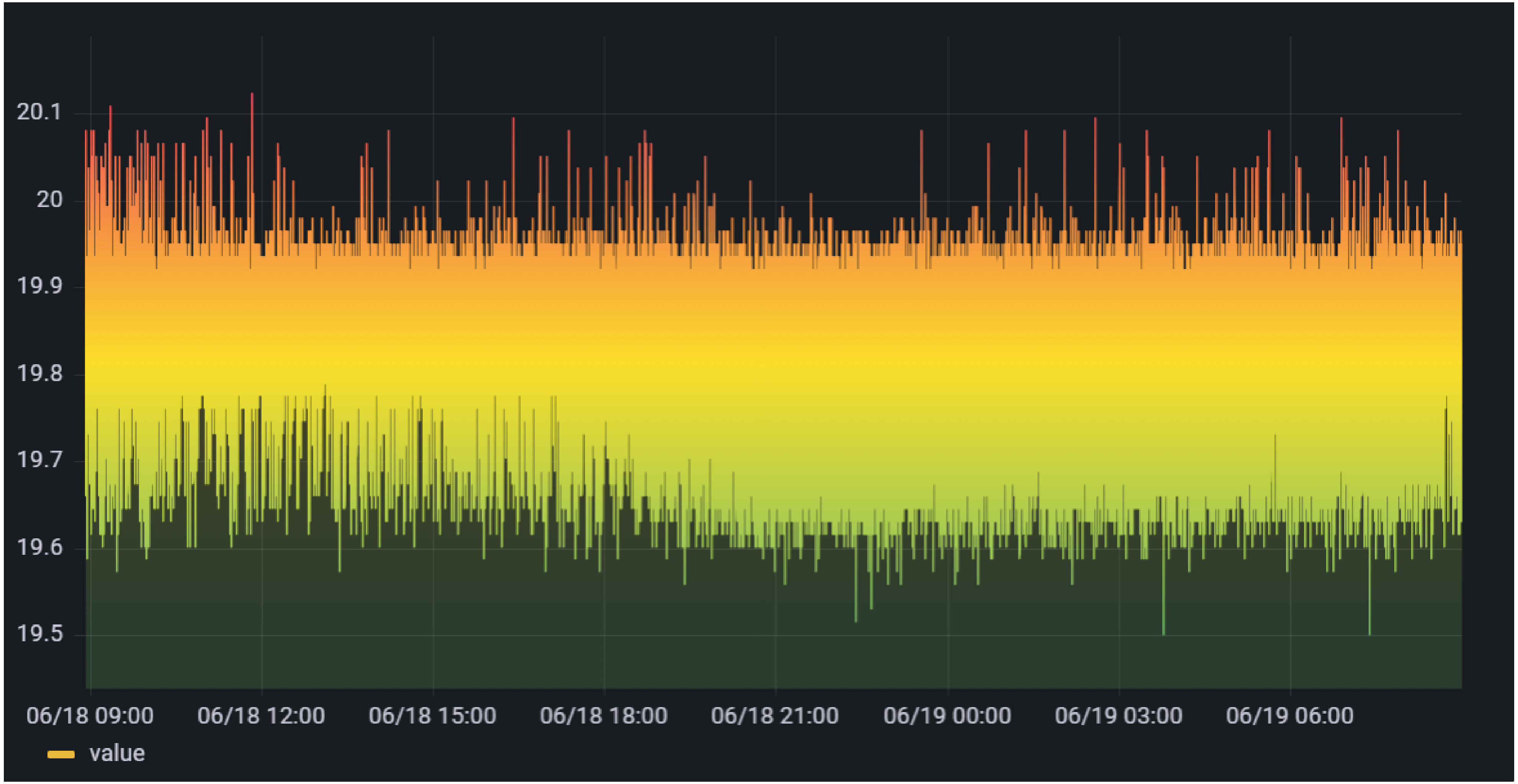
CASE STUDY - DATA QUALITY CONTROL

Raw data → Data Issues Identification →

Invalid data →	data outside of the measurement range of the specific sensors
Inconsistent data →	random sampling frequencies, inconsistent sampling frequencies
Incomplete data →	sensors sampled at different sampling frequencies, hardware failure → signal loss
Inaccurate data →	random noise generated by the equipment
Redundant data →	two sensors measuring the same parameters, a parameter that is both measured and calculated

CASE STUDY - VISUALIZATION

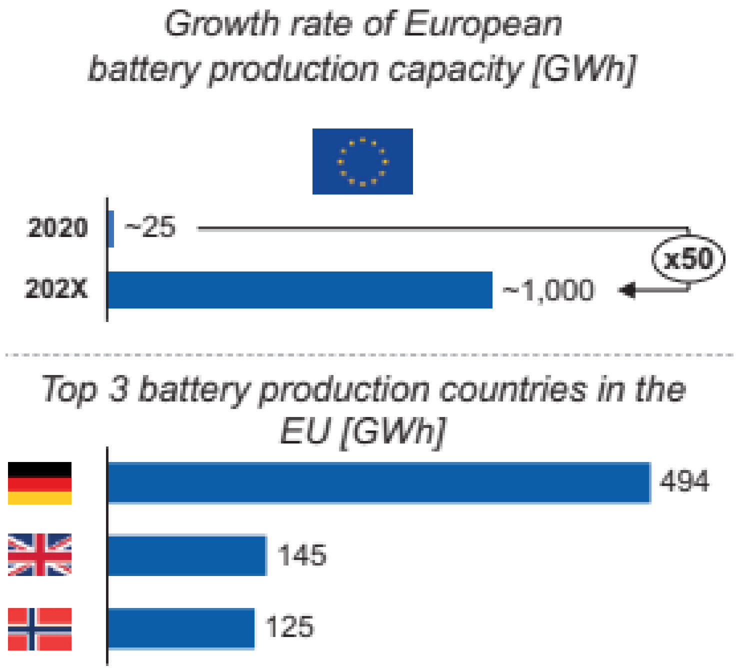
- Temperature data from (temperature sensor of the planetary mixer)
- From 18/6 to 19/6 at a sampling & publishing interval of ~100 ms

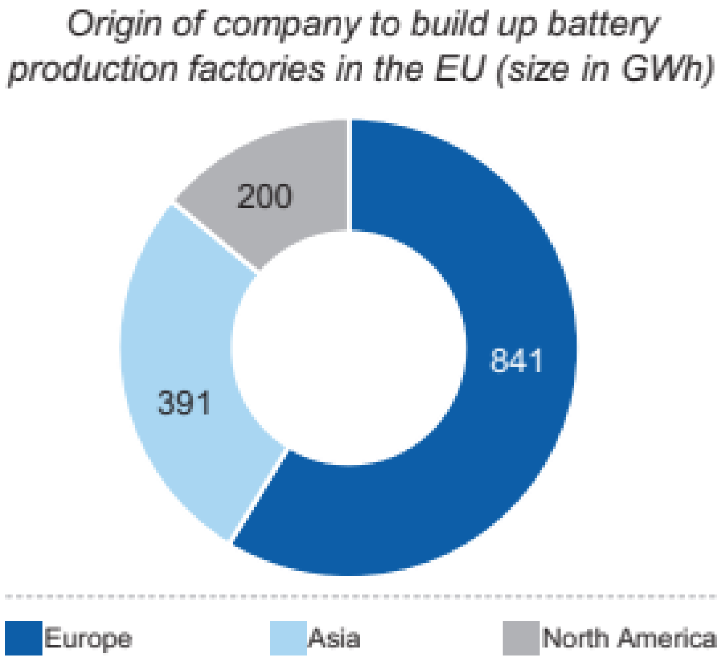


Socio-economic and environmental impacts

SOCIO-ECONOMIC IMPACTS

Affordability and accessibility of electric vehicles

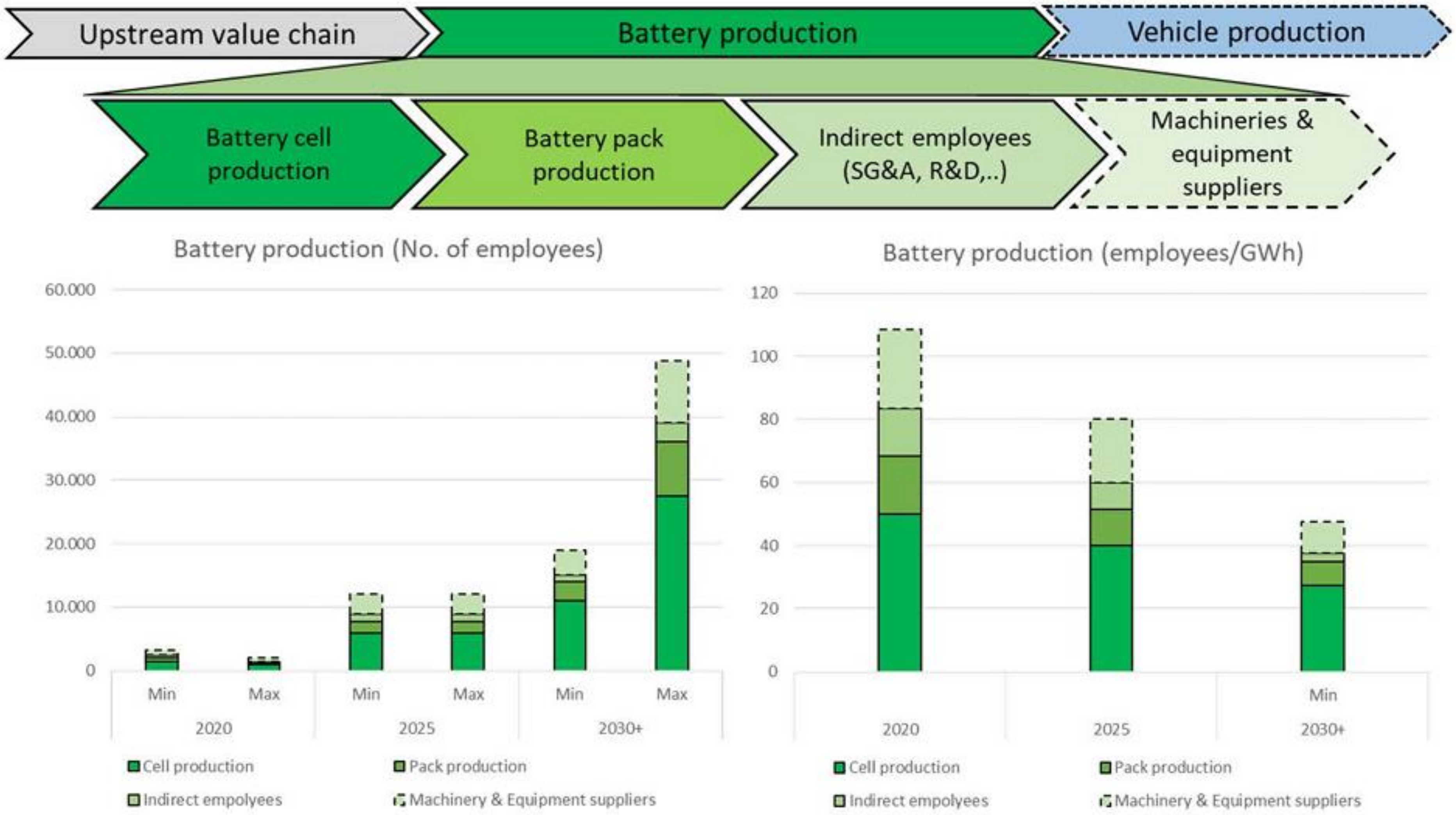




Source: Heimes, 2022

SOCIO-ECONOMIC IMPACTS

Skilled Employment



Source: Future Expert Needs in the Battery Sector, 2021

SOCIO-ECONOMIC IMPACTS

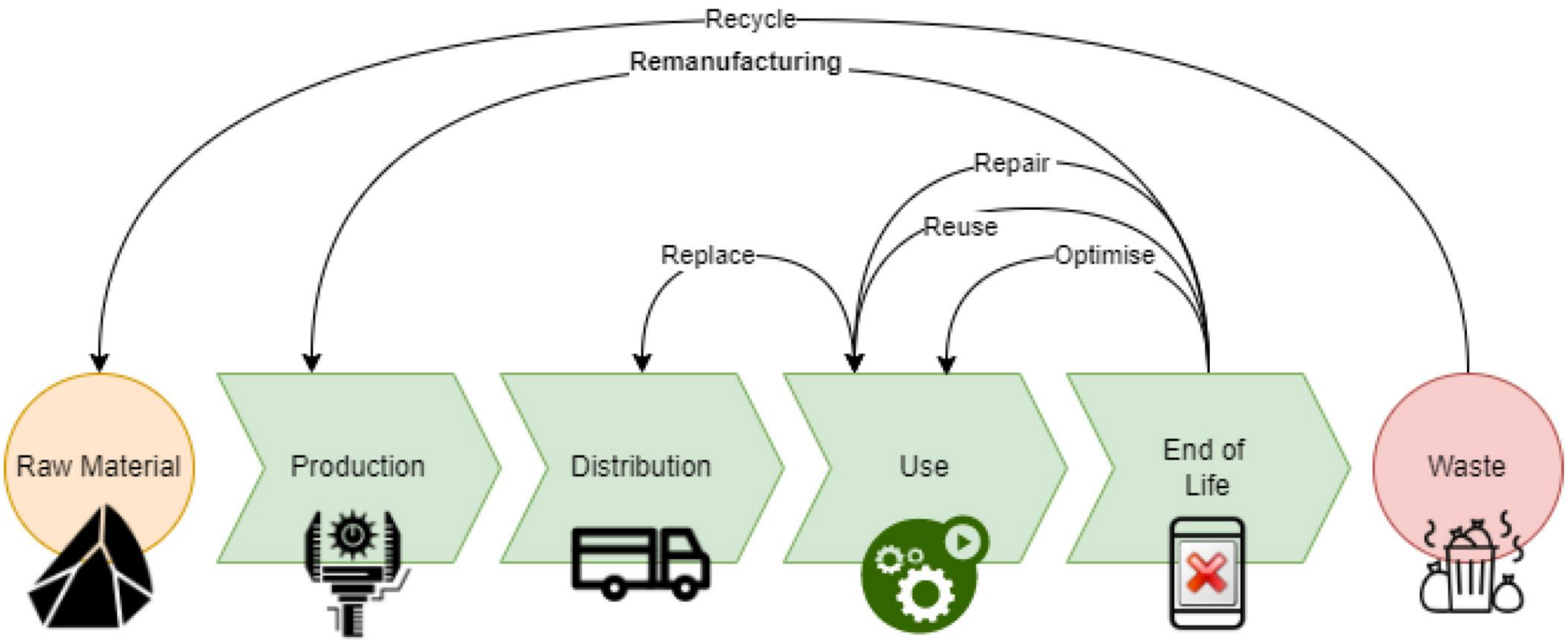
Future Need for Digital Skills

Cross-cutting skills	6 Establish a digital mindset (e.g. simulation data analytics, AI). Put into standard curriculum. 7 System view and understanding along the value chain. 8 Soft skills (also intercultural)	6 Establish a digital mindset and need to find software engineers. 7 System view and understanding along the value chain. 8 Soft skills (also intercultural)	6 Establish a digital mindset (e.g. simulation data analytics, AI). Put into standard curriculum. 7 Systems engineer seeing all aspects of parts of battery system. Awareness of different „languages" 8 Soft skills (also intercultural)	1 Identify the concrete	Measures 1 to 17

Source: Future Expert Needs in the Battery Sector, 2021

ENVIRONMENTAL IMPACTS

Facilitation of the circular economy through traceability



Source: Khan, 2022

- Material IDs
- Process IDs
- Cell IDs
- Meter Counters

SUMMARY

- Digitalization of the battery cell production entails the creation, acquisition, transport and storage of data from all the sensors on the production line.
- The first steps of the digitalization methodology formulate and structure a list of critical parameters that capture the business objectives set for the production. OPC UA facilitates the tracking of all the relevant parameters via a server-client subscription method.
- The latter steps illustrates a data integration strategy that processes large volume of data (approx. 100x GB/day at stable production stages) securely and integrates seamlessly into existing data streaming & storage technologies.
- Multi-stakeholder collaboration across the whole battery production chain (suppliers, process engineers, technologists, IoT engineers, data engineers and analysts).

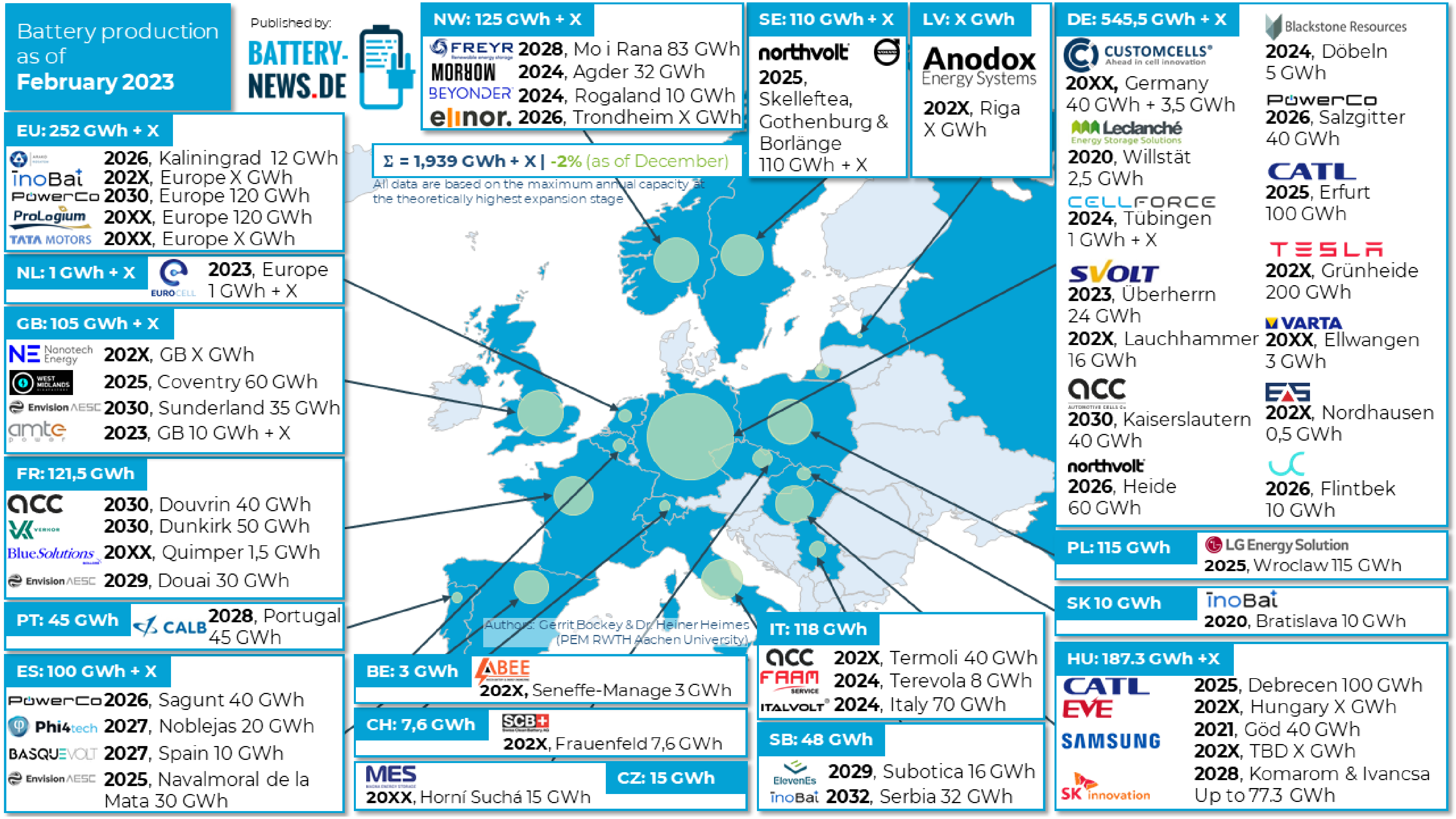
FUTURE WORK

1. A rigorous method for data quality check
2. Strategies to reduce costs from data streaming and storage
3. Identification of suitable data analytics techniques to derive insights from the stored data


JOY IS
ELECTRIC
JOY IS
ELECTRIC

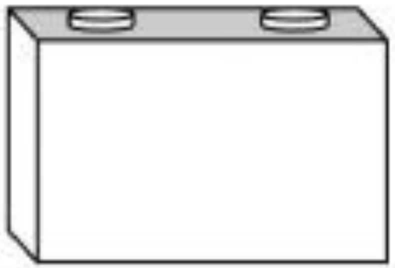
BACKUP SLIDE

Battery Cell Manufacturers in Europe (Feb 2023)



BACKUP SLIDE

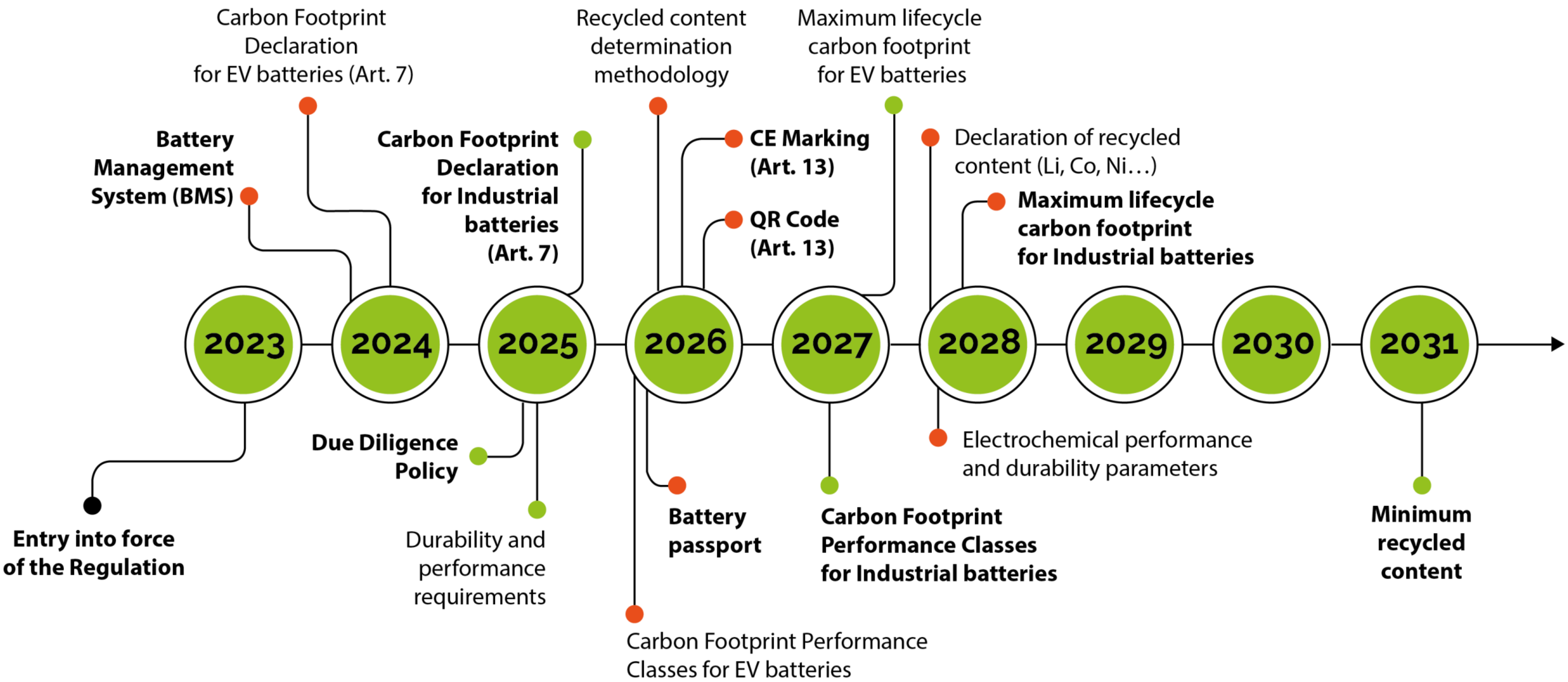
Different Types of Battery Cells

Cylindrical cell	Prismatic cell	Pouch cell
		
• Small size (e.g. 18650 type (ø 18 mm, height 650 mm)) • Hard casing • Low individual cell capacity • Build in safety features • Comparably cheap	• Hard casing • Large size • High individual cell capacity	• Soft casing • Large size • High individual cell capacity • Geometrical deformation during (dis-)charging

Source: Zwicker, 2020

BACKUP SLIDE

Timeline of New EU Battery Regulation

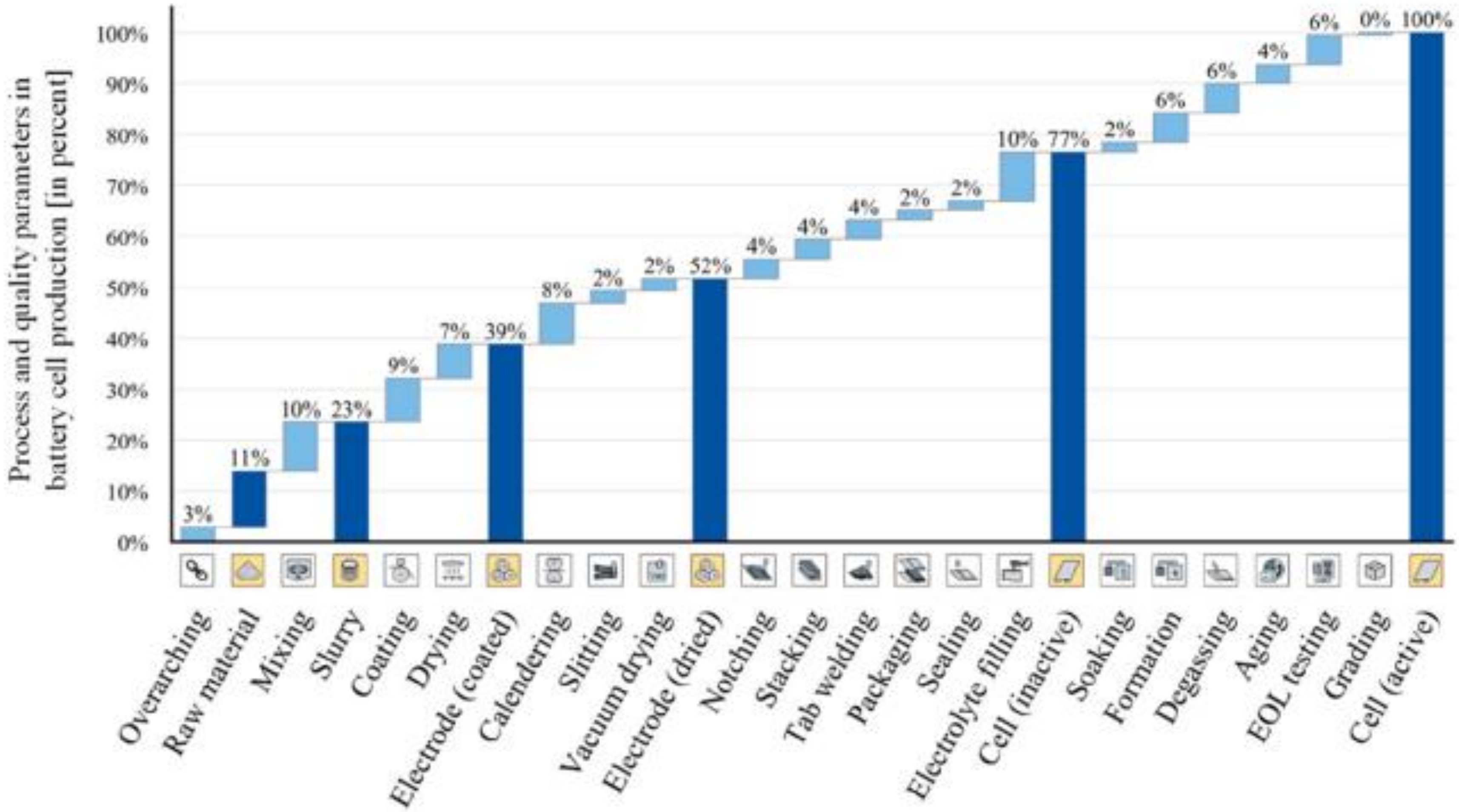


BACKUP SLIDE

Information Needed in the Battery‘s Digital Passport

BACKUP SLIDE

Distribution of the Parameters in the Battery Production Process

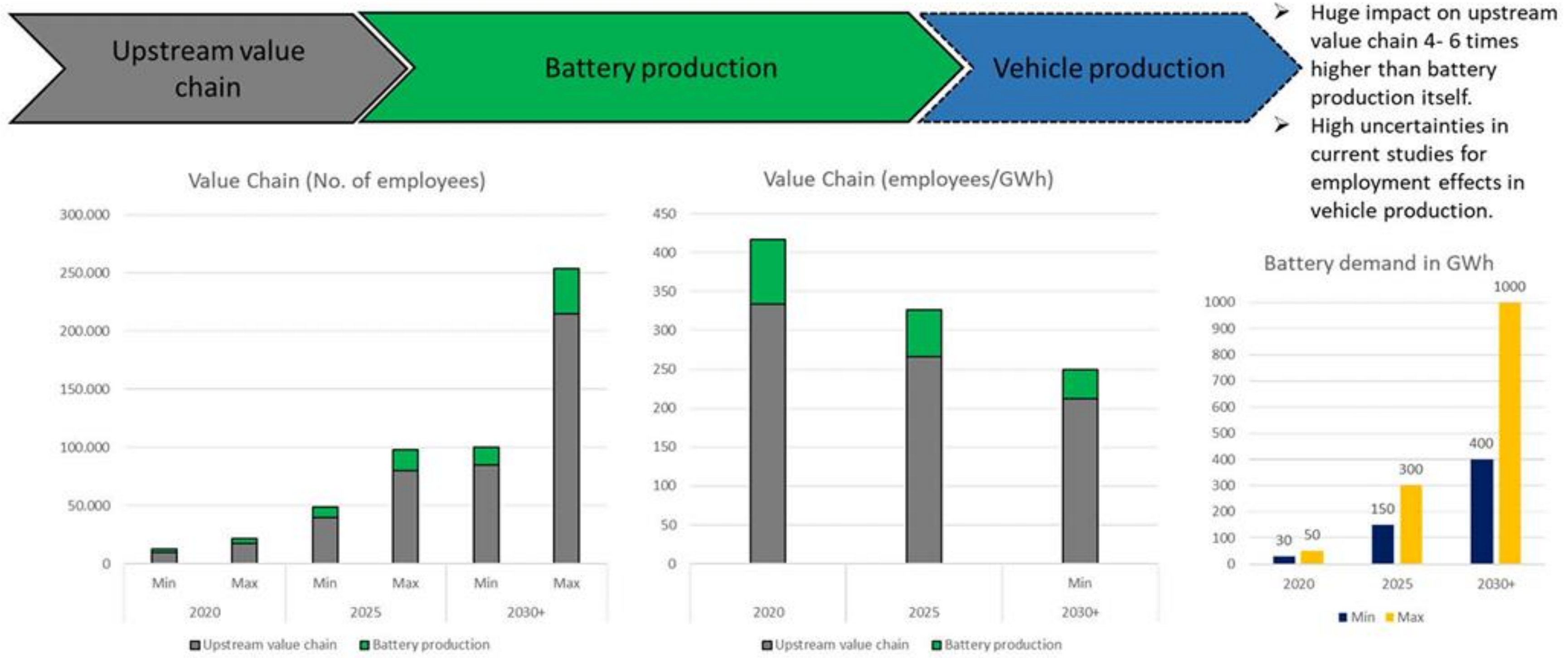


BACKUP SLIDE

- The mapping establishes a connection between the PLC variables and the OPC UA server (through the data model).
- It results in the same representation of data between the PLC and the OPC UA server.

BACKUP SLIDE

Employment effects and emerging expert needs



Source: Own calculations based on BatPac Model (ANL) & Hettesheimer et. al (2018): Employment effects and value chains in the battery machinery and plant engineering industries VDMA/Fraunhofer ISI (10/2018). Battery demand from Position Paper on Education and Skills

Figure 2: Absolute number of employees needed in Europe and employees per GWh connected with the battery (materials, cell to pack) production.