TWAIN
(Towards) Integrated, Value-based, Multi-objective Wind Farm Control powered by AI

Tuhfe Göcmen
DTU Wind & Energy Systems

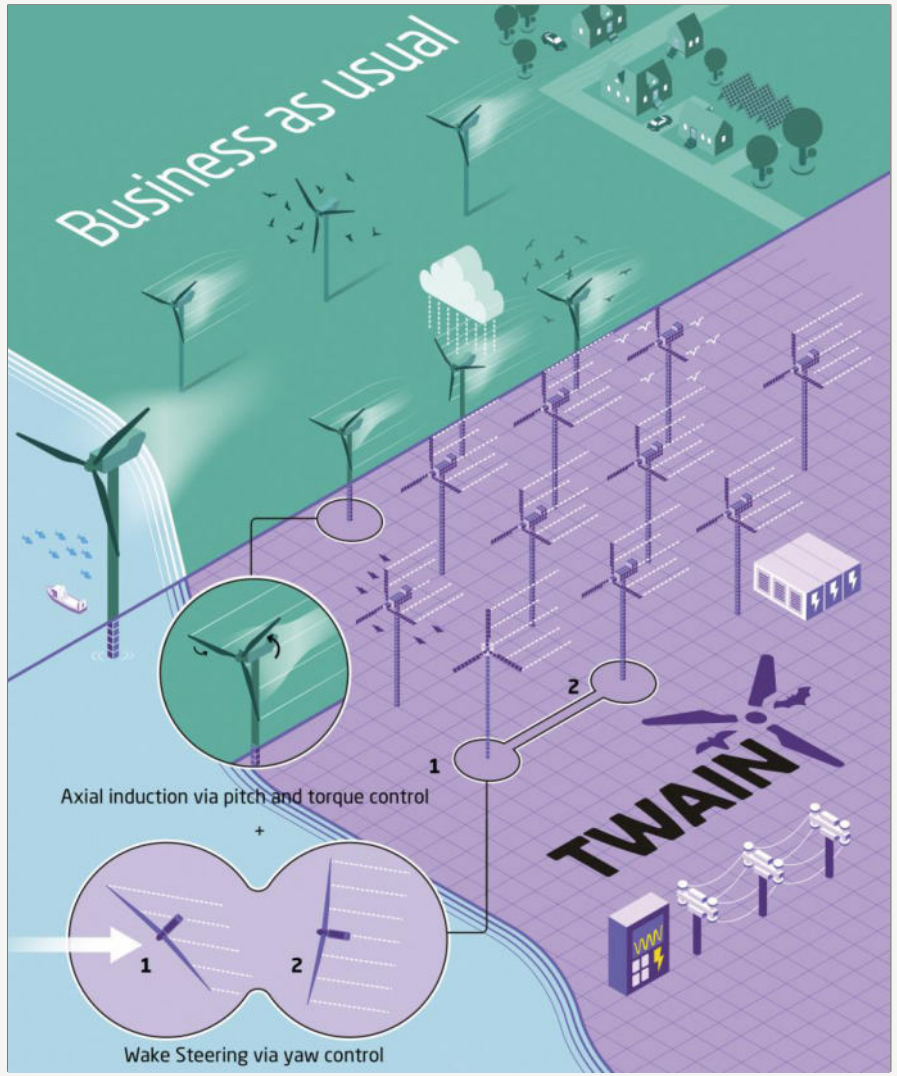
Funded by
the European Union

Consortium

CENER | CENTRO NACIONAL DE ENERGÍAS RENOVABLES

Technische Universität München

TWAIN Narrative



Turbines interact with each other & their environment

- Communication through turbine controllers
  - Greedy
- Aerodynamic interaction within the wind farm & interface with the environmental surroundings
  - Smart & Aware
    - Digitalisation of the processes & value
    - Operation management
    - Decision making
    - Integration at the design phase

Social Aspects

- Emitted, Propagated and perceived noise
- How can we mitigate for higher acceptability & affordability of green electricity?

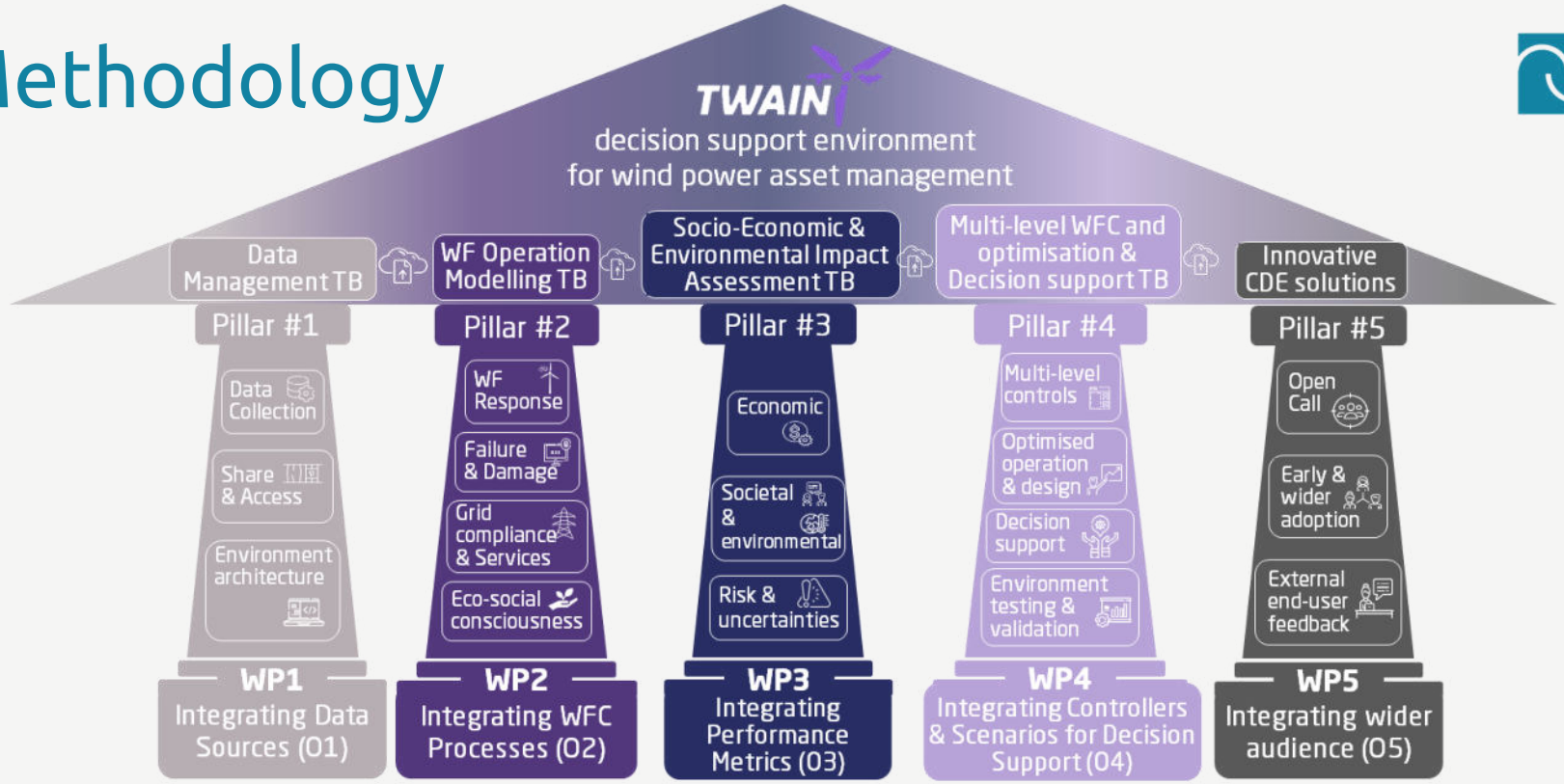
Wildlife

- Birds & bats around the turbines
  - Curtailed or interrupted operation
- How does it affect the revenue stream and optimum operation?

Precipitation & Rain

- Drivers of leading-edge erosion
  - (un)scheduled repairs higher O&M costs
  - Mitigated through torque control
- How can we include that in the controller hierarchy & value chain?

TWAIN Methodology



To support WF owners/operators to make better decisions for system-wide optimised performance, TWAIN's concept pivots on a **full-integration of WFC** at five different levels:

1) Integration of multi-source and multi-format data of varied nature from WFs in different life stages

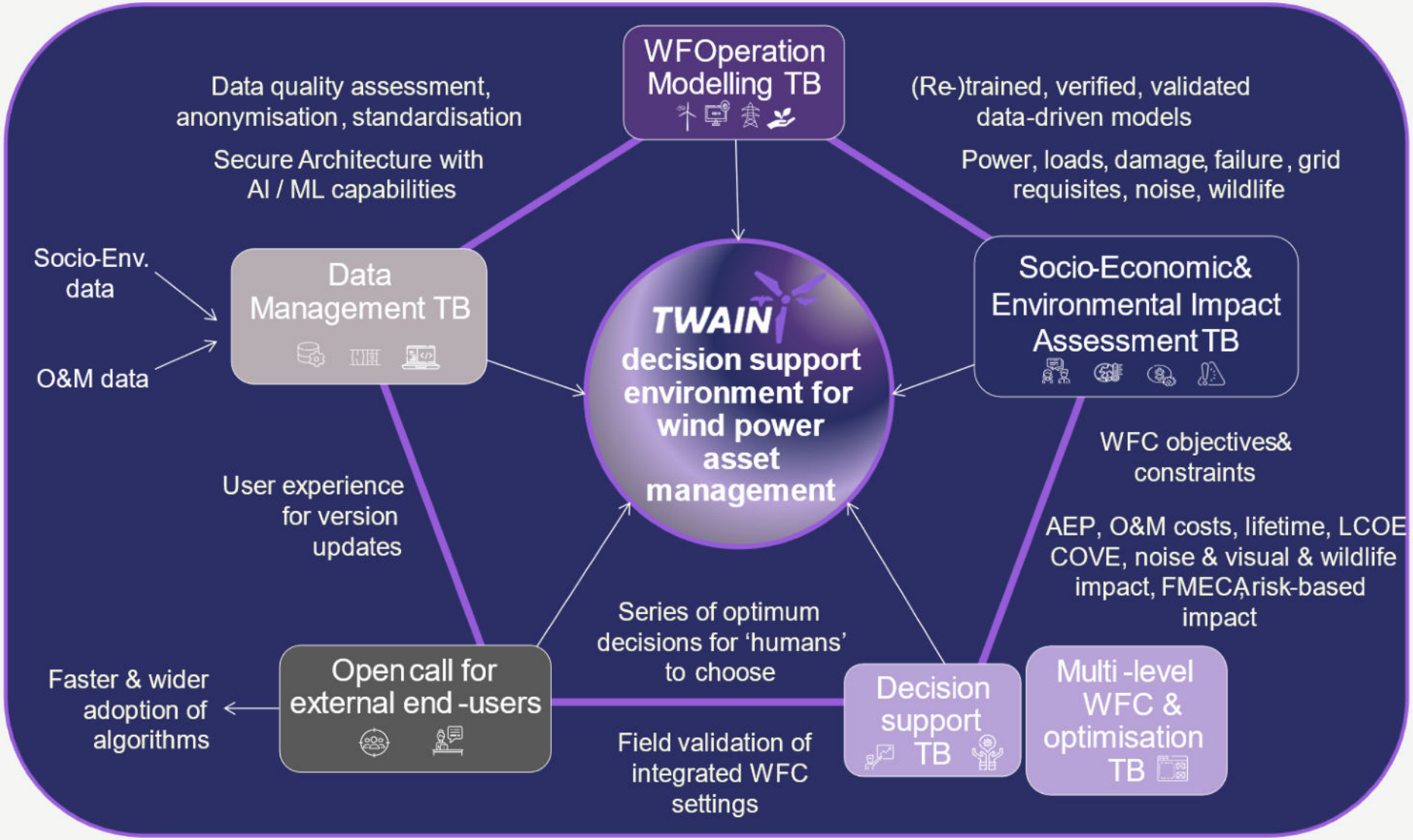
2) AI-enabled Integration of multi-disciplinary processes and phenomena affecting the WF operation

3) Integration of multi-objective prospects of WFC to assess the *true* added value of a certain operation mode

4) Integration of multi-level controllers and scenario analyses in decision support provision for harmonious co-existence of WPPs with their environment and society via optimised operation and design

5) Integration of wider audience to TWAIN outcomes

TWAIN Outcome & Interactions among toolboxes



TWAIN Case Studies

Environmental & Social Ramifications

Objectives	Constraints
Economic • ↓ LCOE • ↑ revenue Societal & Environmental • ↓ carbon footprint Risk & uncertainties • ↑ security, stability and reliability of electricity supply • ↓ integrated risk	Societal & Environmental • Noise constraints • Wildlife constraints (FR) Risk & uncertainties • ↑ resilience • Application to **ENGIE WF in France**

Adaptability to Offshore

Objectives	Constraints
Economic • ↓ LCOE • ↑ revenue Societal & Environmental • ↓ carbon footprint Risk & uncertainties • ↑ security, stability and reliability of electricity supply • ↓ integrated risk	Risk & uncertainties • ↑ resilience, adaptability and generalisability of AI for large offshore WFs • Application to **Vattenfall WF, Lillgrund in the Baltic Sea**

Layout co-design with WFC: next generation WTs

Objectives	Constraints
Economic • ↓ LCOE • ↑ revenue Societal & Environmental • ↓ carbon footprint Risk & uncertainties • ↑ security, stability and reliability of electricity supply • ↓ integrated risk with **20+MW WTs**	Societal & Environmental • ↓ use of land via closer spacing Risk & uncertainties • ↑ resilience under climate change and renewables-driven energy system & markets

Towards the end of life: Extension or Repowering?

Objectives	Constraints
Economic • ↓ LCOE • ↑ revenue Societal & Environmental • ↓ carbon footprint Risk & uncertainties • ↑ security, stability and reliability of electricity supply • ↓ integrated risk	Societal & Environmental • ↓ use of land via closer spacing • ↓ visual impact via repowering Risk & uncertainties • ↑ resilience • Application to **15+ years old ENGIE WF in Germany**

TWAIN Campaigns: Risø Field Tests

- DTU, supported by CENER and EDF, will perform the field test at Risø WF to **validate the expected gains** for
  - **power maximisation under structural load constraints** via wake control, and
  - **income maximisation** with variable market scenario under load constraints

  2 x Vestas V27 turbines

TWAIN Data Environment Overview

Objective:

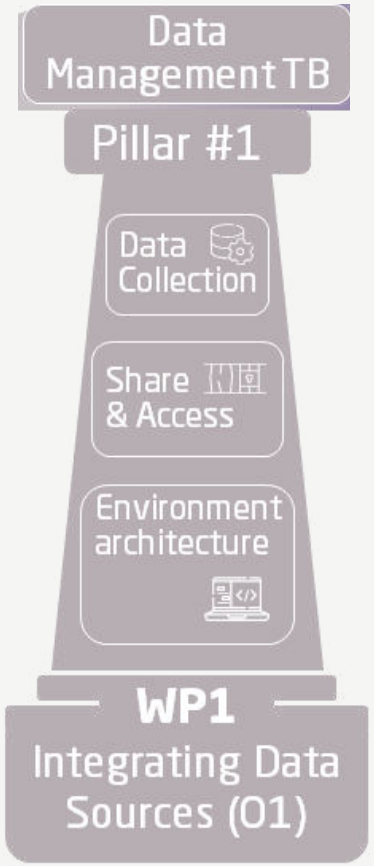
- Design a framework to integrate different data sources while meeting business and technical requirements
- Ensure data integrity, standardization, and compliance with regulations

Framework Features:

- Open-source: Encourages collaboration and transparency
- Interoperable: Seamlessly integrates with various data sources
- Secure: Implements multiple layers of security to protect data

Development Phases:

- Design Phase: Architecture vision development and framework assessment
- Implementation Phase: Technological setup and deployment of data environment components



TWAIN Data Env.: Key Components & Processes

Architecture Vision:

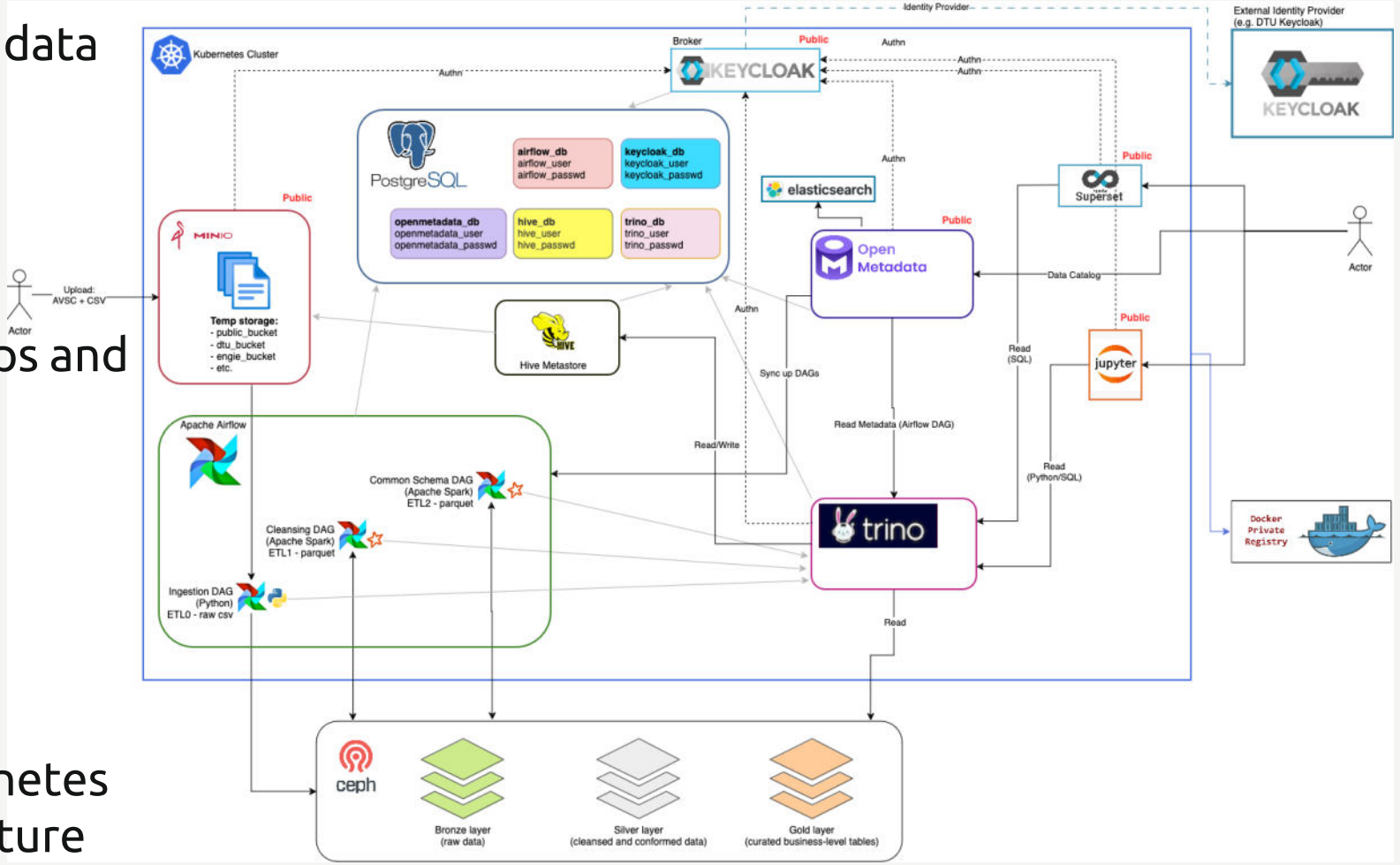
- Developed with input from data owners through workshops
- Includes security layers and constraints

Framework Features:

- Quality attributes workshops and use case validations
- Partner questionnaires and meetings to validate drafts

Implementation Highlights:

- End-to-end architecture components implemented
- Deployment to local Kubernetes clusters and DTU infrastructure
- Demonstrations for the consortium



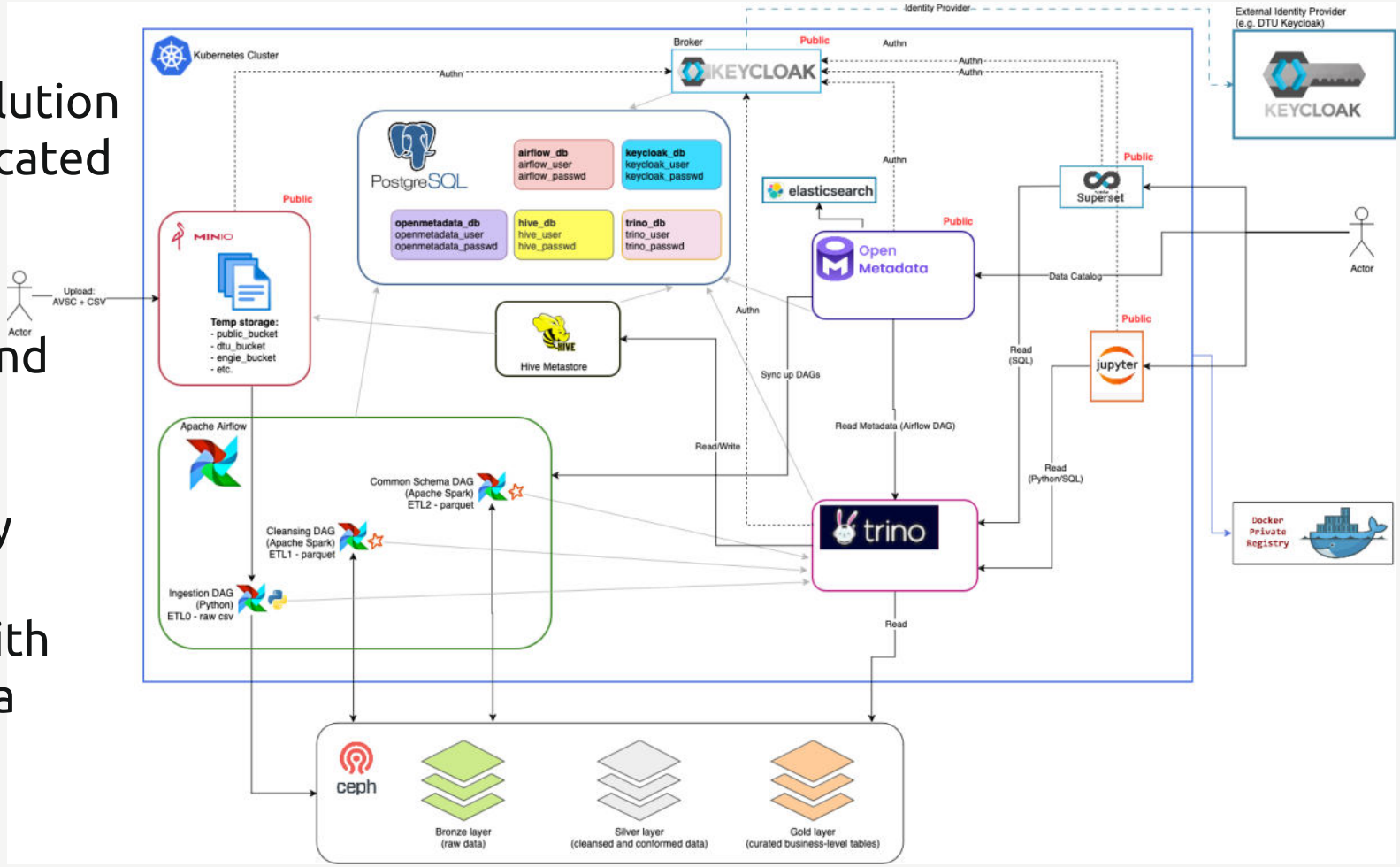
TWAIN Data Env.: Security & Data Management

Security Measures:

- Three levels of security: infrastructure, data, and solution
- Access control for authenticated and authorized users

Data Management:

- Data acquisition, storage, and processing
- Data standardization methodology with ontology integration rules
- Automated environment with security constraints for data access



Next Steps

- Conduct user testing with PUBLIC ACCESS and release MVP v.0

TWAIN

Thank you

Funded by
the European Union