TWAIN
Advancing Wind Farm Control through AI-Driven Multidisciplinary Process Modelling and Data Integration

Tuhfe Göçmen
DTU Wind & Energy Systems

Funded by
the European Union

Consortium

TWAIN

DTU

CENER | CENTRO NACIONAL DE ENERGÍAS RENOVABLES

TUM
Technische Universität München

TU Delft

softserve

EDF

ENGIE Green

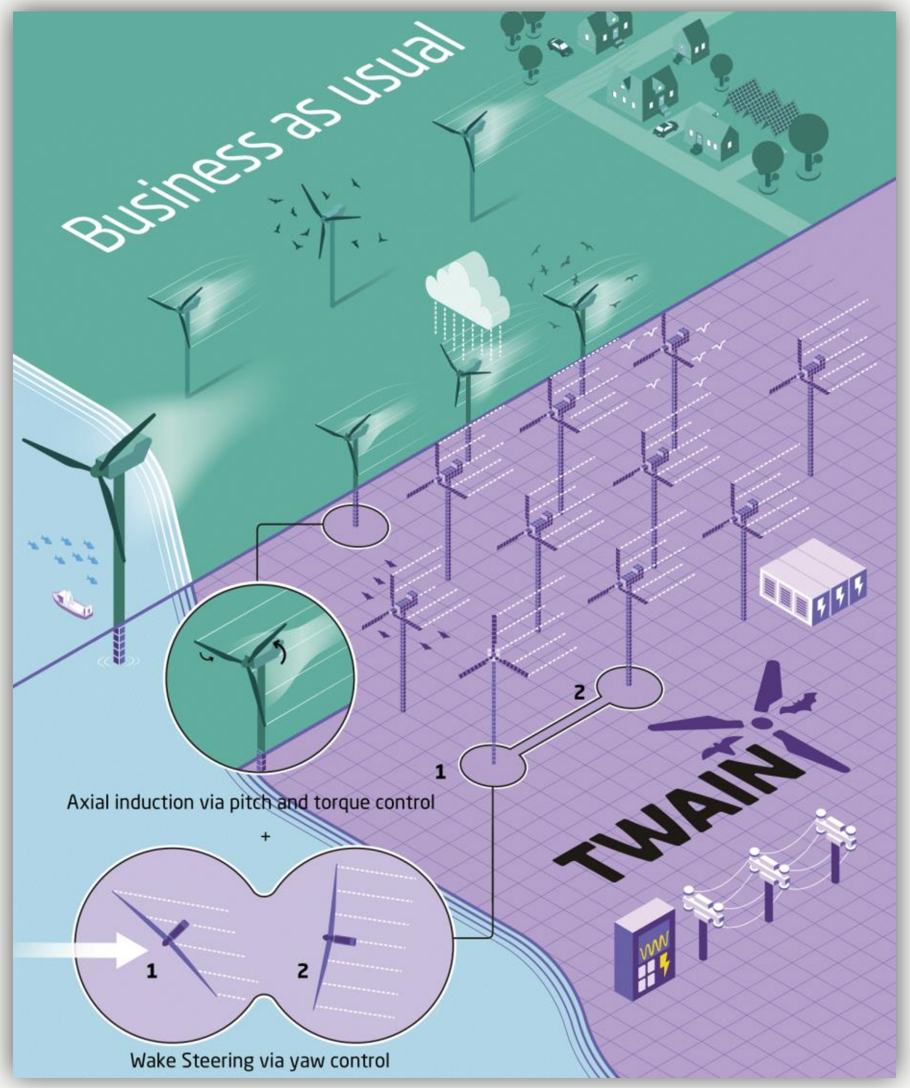
ENGIE Laborelec

RAMBOLL

F6S

VATTENFALL

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?

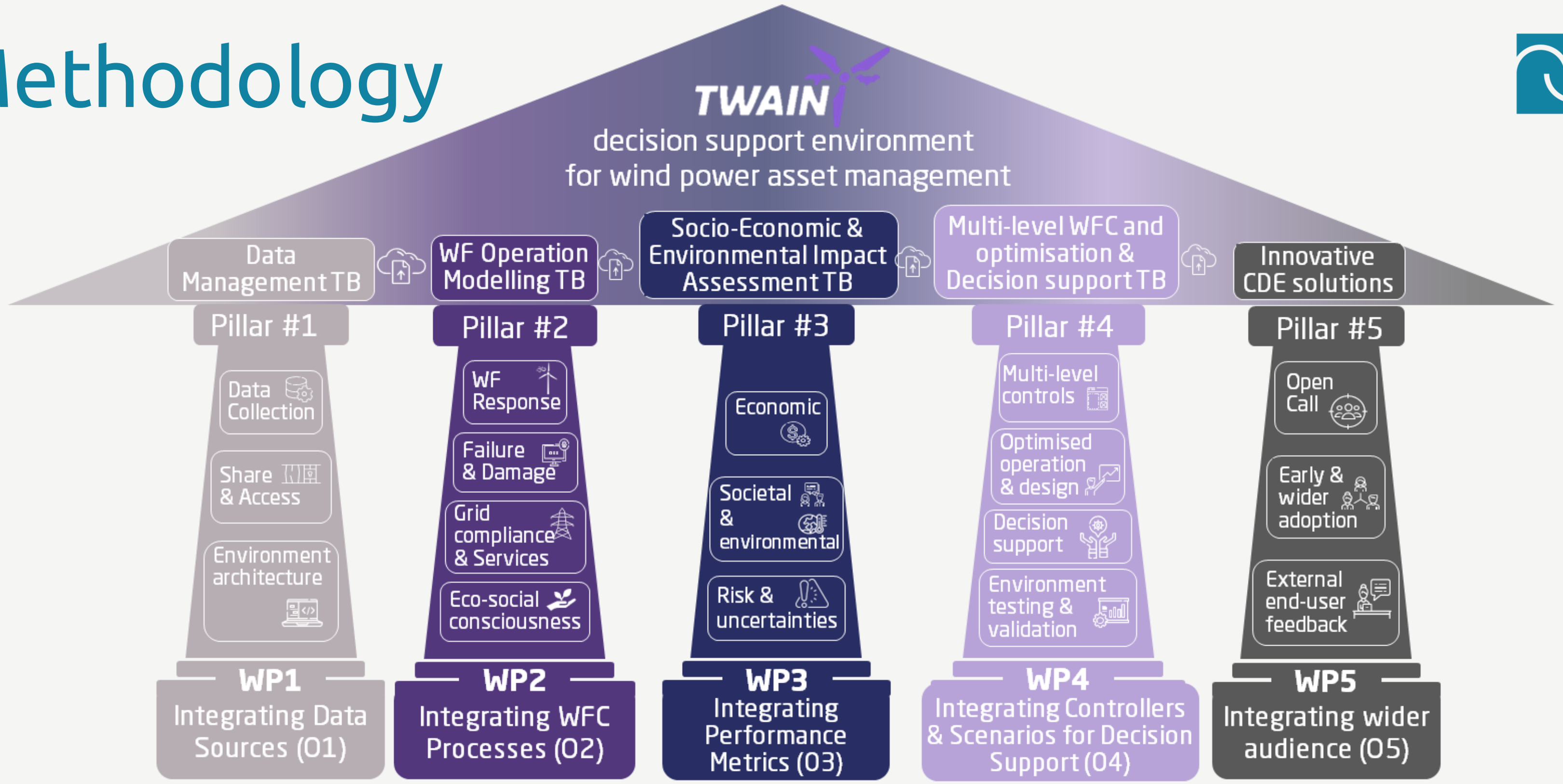
Wildlife

- 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 Case Studies

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Environmental & Social Ramifications

Objectives

Economic
- ↓LCOE
- ↑revenue

Societal & Environmental
- ↓carbon footprint

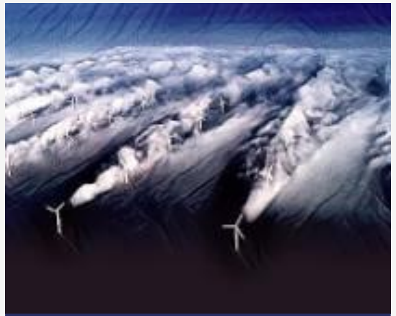
Risk & uncertainties
- ↑security, stability and reliability of electricity supply
- ↓integrated risk

Constraints

Societal & Environmental
- Noise constraints
- Wildlife constraints (FR)

Risk & uncertainties
- ↑resilience

- Application to **ENGIE WF in France**



Adaptability to Offshore

Objectives

Economic
- ↓LCOE
- ↑revenue

Societal & Environmental
- ↓carbon footprint

Risk & uncertainties
- ↑security, stability and reliability of electricity supply
- ↓integrated risk

Constraints

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

Economic
- ↓LCOE
- ↑revenue

Societal & Environmental
- ↓carbon footprint

Risk & uncertainties
- ↑security, stability and reliability of electricity supply
- ↓integrated risk with **20+MW WTs**

Constraints

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

Economic
- ↓LCOE
- ↑revenue

Societal & Environmental
- ↓carbon footprint

Risk & uncertainties
- ↑security, stability and reliability of electricity supply
- ↓integrated risk

Constraints

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 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**

Social Aspects

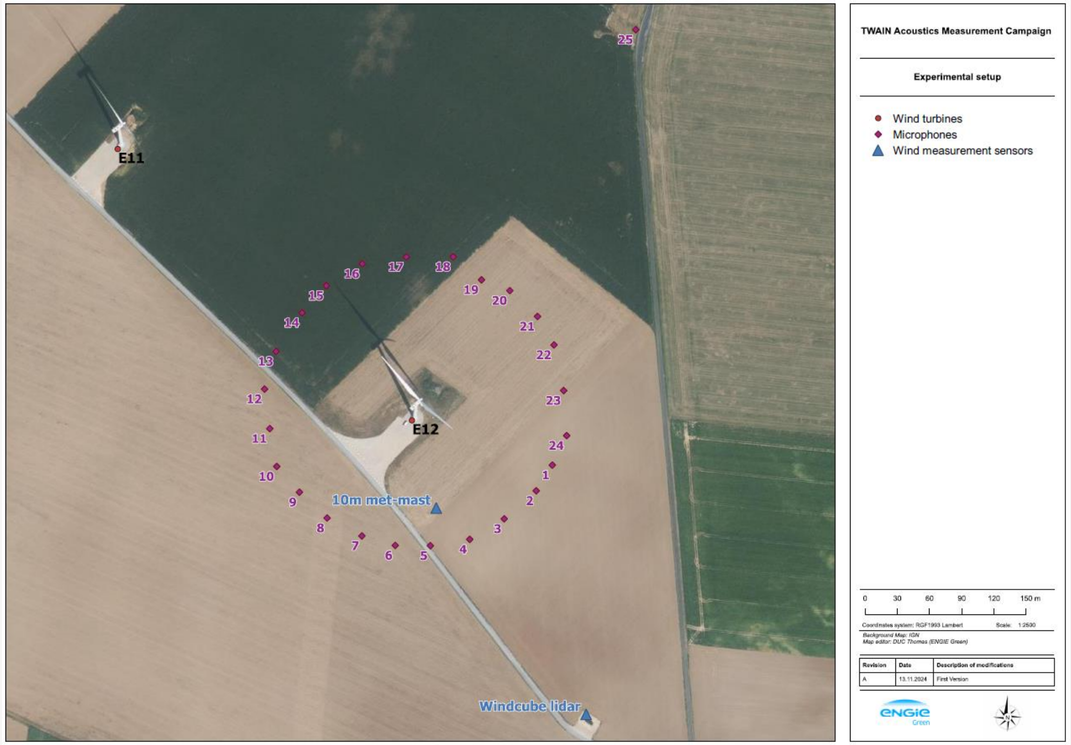
- Emitted, Propagated and perceived noise
- Acoustic measurement campaign by ENGIE Green

Wind turbine characteristics:

- Vestas V110-2.2 MW Mk10
- Hub height : 80 m
- Commissioning date : February 2021

Experimental setup:

- 24 microphones located at ~ 135 m from the wind turbine
- 1 far field microphone
- 10m met mast
- 1 ground-based lidar Windcube v2
- 1 nacelle-mounted lidar WindCube nacelle (4 beams pulsed lidar)



TWAIN Case Studies

Environmental & Social Ramifications

Objectives	Constraints
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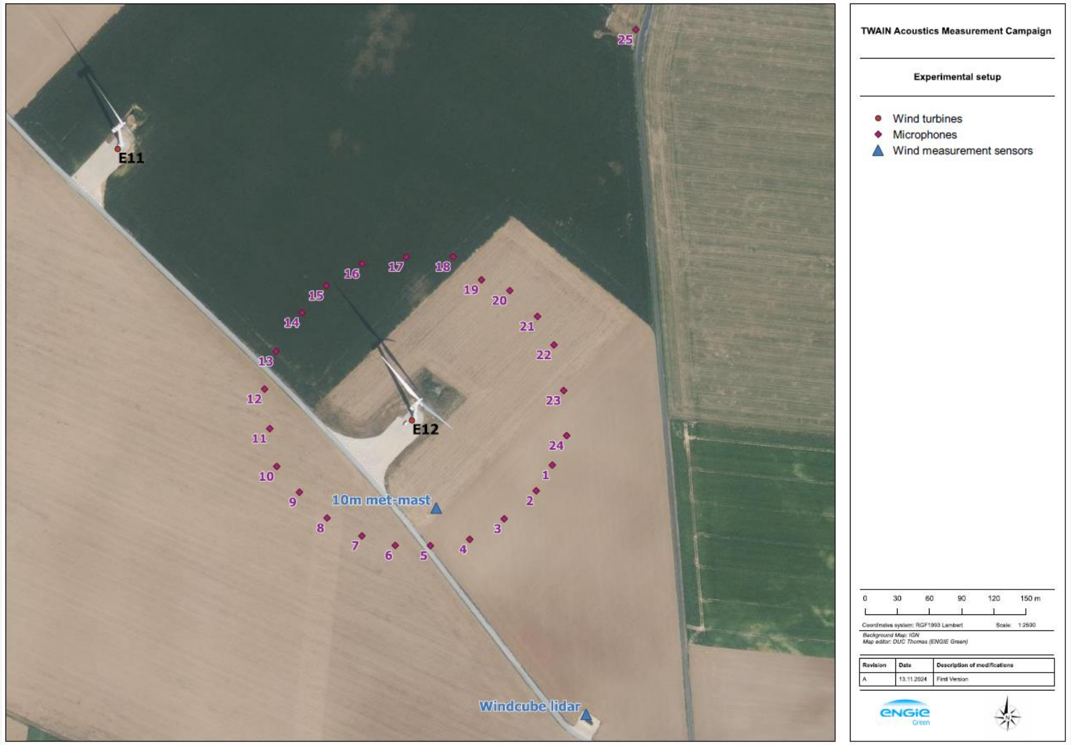
Social Aspects

- Emitted, Propagated and perceived noise
- Acoustic measurement campaign by ENGIE Green

5 yaw positions were tested during the campaign, from +20° to -20 ° by steps of 10°

- Toggle regularly between each yaw position so that similar wind conditions could be observed for each position
- Referring back to Reference yaw position 0° (baseline) between toggles

- Aim is to validate high-fidelity tools for noise emission under wake steering
  - To be used to generate synthetic database for noise surrogates → WFC optimisation
- Final results in WESC 2025 ☺



TWAIN Case Studies

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Environmental & Social Ramifications

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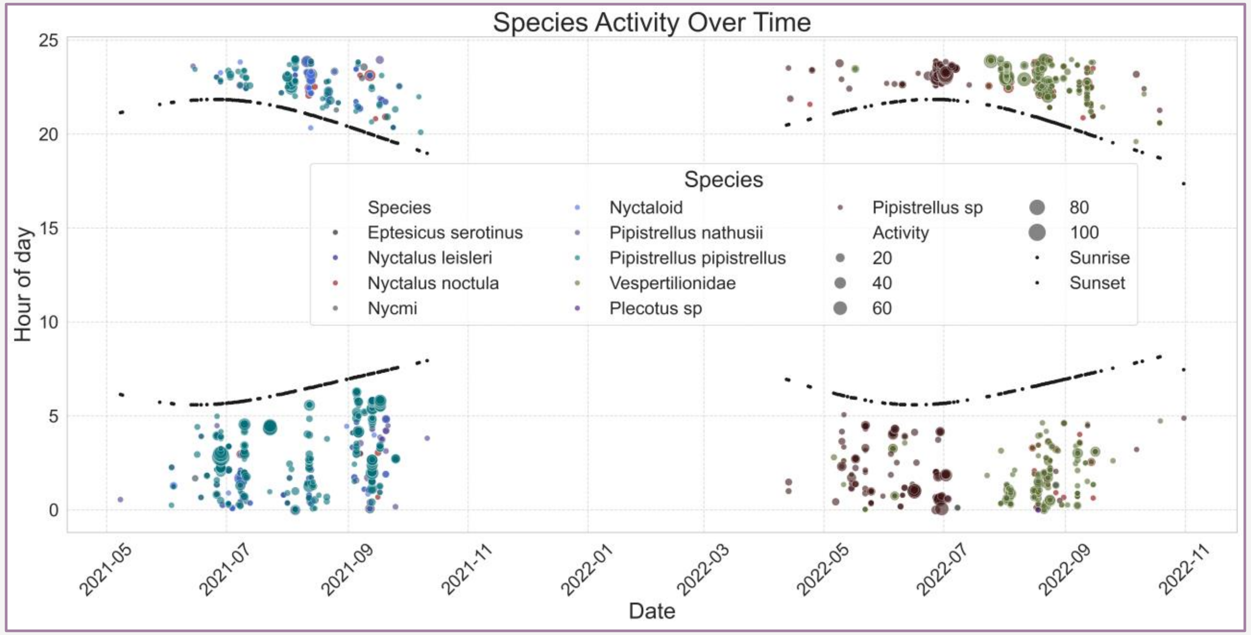
Wildlife

- Bats around the turbines
  - Curtailed or interrupted operation



Case 2: Dynamic Curtailment

- Method: Based on activity sensor
- Control actuation: shut-down / start-up + **yaw strategy**
- Focus: AEP increase, load constraints / minimisation

Case 0 : Business as usual

- Method: Static curtailment based on ambient conditions
  - Time of year (~May – Oct)
  - Time of day (sunrise – sunset)
  - Temperature
- Control actuation: shut-down / start-up
- Focus: Effect on power & loads

Case 1 : Dynamic Curtailment

- Method: Based on activity sensor
  - Single sensor as a reference for the entire wind farm
- Control actuation: shut-down / start-up
  - Sensitivity analysis wrt on/off period 10mins / 30mins / 1h
- Focus: Effect on power & loads

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

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Objective:

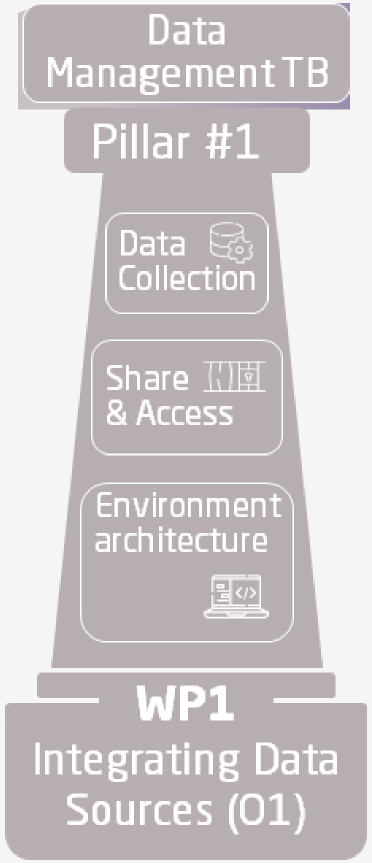
- Design a framework to integrate different data sources while meeting business and technical requirements
- Ensure data integrity, standardization, and compliance with regulations

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



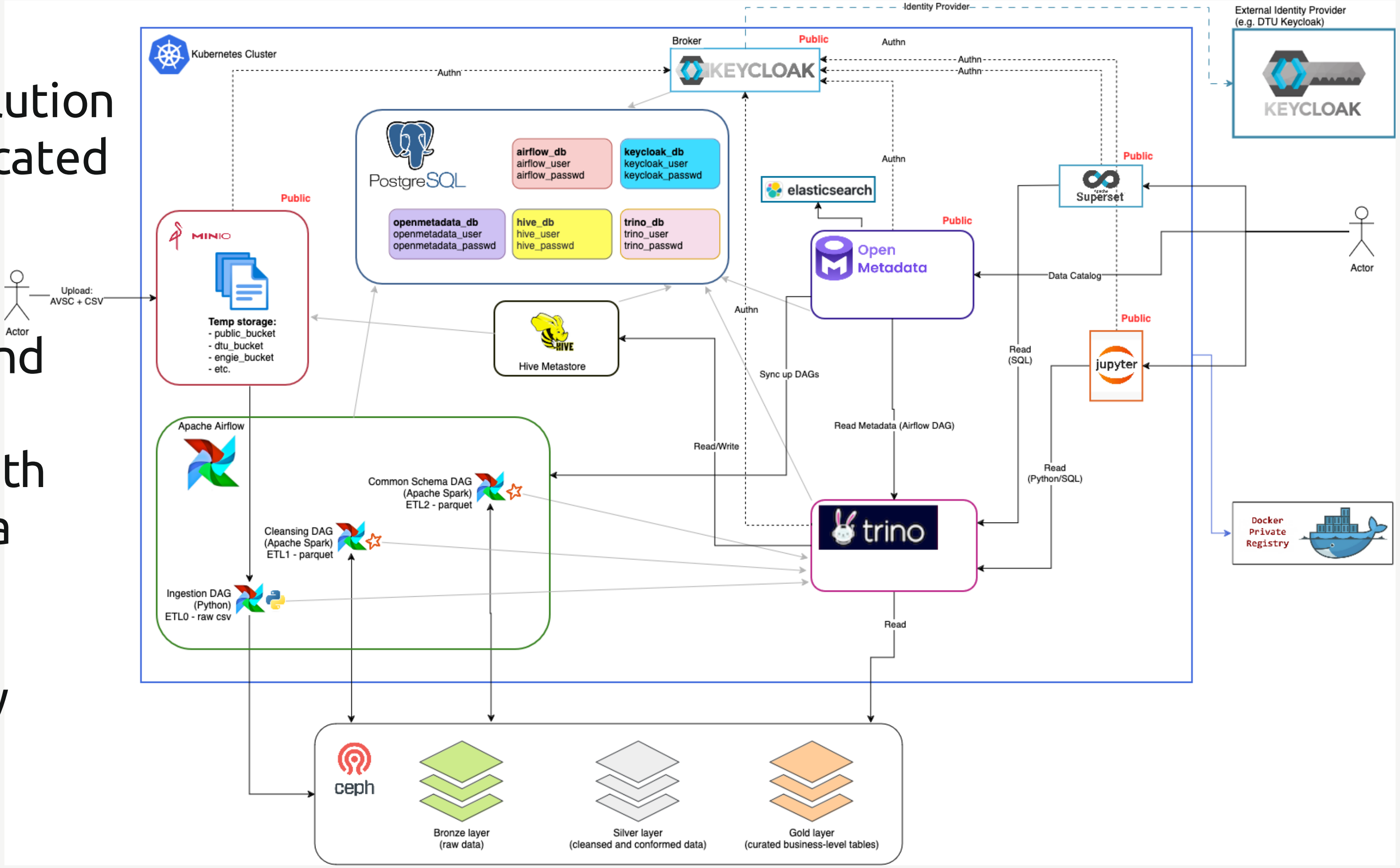
TWAIN Data Env.: Security & Data Management

Security Measures:

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

Data Management:

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



Main user Interface

https://jupyterhub.twainproject.app → demo @ WESC2025

TWAIN @ WESC 2025 : Mini-symposium

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MS#06.1 Data Synergies in Wind: Process Modelling Beyond Power Generation

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[1] DTU Wind and Energy Systems | [2] CENER

Reliability, monitoring and sensing, O&M

The session is open to all interested in the following topics:

1. **Data Fusion Techniques for Comprehensive Wind Farm Performance Assessment**
   Exploring methods to integrate diverse data sources (SCADA, environmental, operational – both physical and computational data) for a holistic understanding of wind farm performance beyond power output.
2. **Data-Driven Risk Analysis and Failure Mode Prognosis**
   Leveraging advanced analytics to evaluate the effects of different wind farm operation on wind turbine component failure rates, comparing them to baseline scenarios, and providing critical inputs for lifecycle assessments.
3. **Virtual Sensor Development and augmentation of physical data**
   Exploring the potential of virtual sensors to reduce hardware costs, improve reliability, and enable more sophisticated monitoring and operation strategies in wind energy systems.
4. **Data-Enabled Social and Environmental Impact Modelling**
   Addressing how various data types can be leveraged to model and mitigate the social and environmental impacts of wind farm operations.
5. **Advanced Data Quality Control and Assurance for Wind Farm Operations**
   Examining techniques for ensuring data integrity and reliability in wind farm monitoring and analysis, including real-time and historical data processing methods.

This mini-symposium is organised as part of the TWAIN project (Integrated, Value-based, and Multi-objective Wind Farm Control powered by Artificial Intelligence). TWAIN is funded by the European Union's Horizon Europe research and innovation programme under grant agreement No. 101122194. For more information about TWAIN, please visit: https://twainproject.eu

The call for abstracts is open up to 15 January 2025.
See instructions and submit your abstract here

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Thank you

Funded by
the European Union