InterOpEnergy Project

The next step for Interoperability Tests in the Energy Sector

3rd Cross-Sector Symposium on Interoperability
26th June 2025

René Kuchenbuch, Project Coordinator
Meng Lin, Scientific Researcher

Agenda

- **Introduction to the InterOpEnergy Project**
- **Key insights from the Whitebook „Interoperability Tests in Energy“**
  - *Development of Technical Frameworks*
  - *IHE Gazelle in Energy Domain*
  - *IOP Testing with Data Space Connectors*
  - *AI-based Test Case Generation*
  - *Consideration of current interoperability topics*

Who are we?

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What is Interoperability?

Challenges

LEFT
EXIT 12
INTEROPERABLE SOLUTION
PROPRIETARY CHEAP STUFF
imgflip.com

An Example for Interoperability Challenge

Physical connections

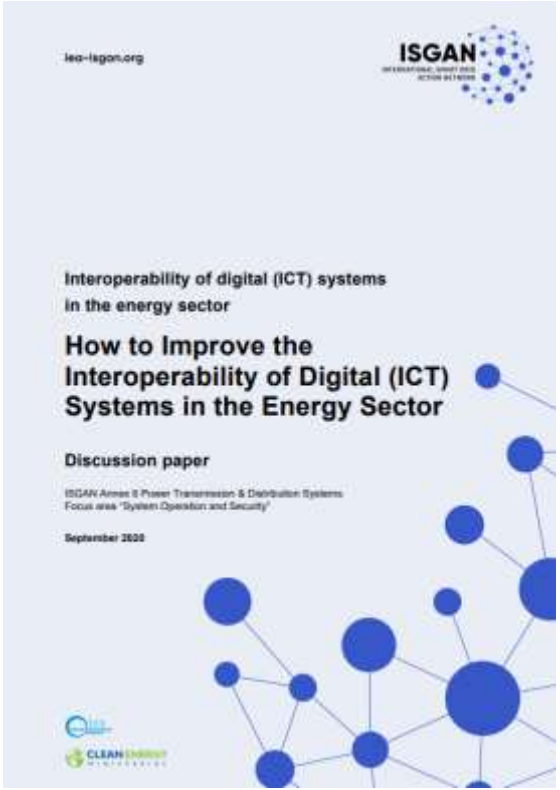
ISGAN Discussion Paper on Interoperability

What you would learn from this document?

1) Which approaches are commonly used to improve the interoperability of digital (ICT) systems in (electric) energy sector?
2) Which approaches to improve the interoperability of digital (ICT) systems in other sectors / domains can be learned from?
3) What can be learned from?

Case Studies

> Integrating the Energy System (IES) Austria
> CIM profiling and proof of interoperability within the scope of CIM IOP test activities (CIM Connectathons)
> SGILab of the Joint Research Centre (JRC) of the European Commission



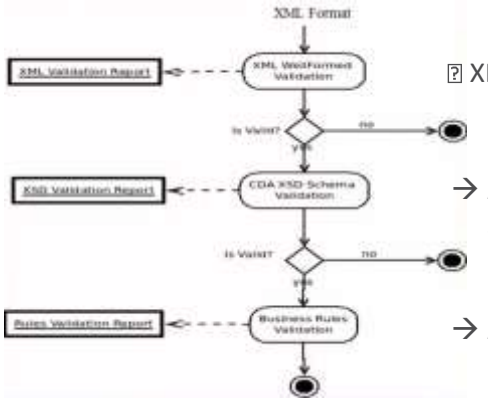
Interoperability Testing is more than Conformance…

Conformance Testing

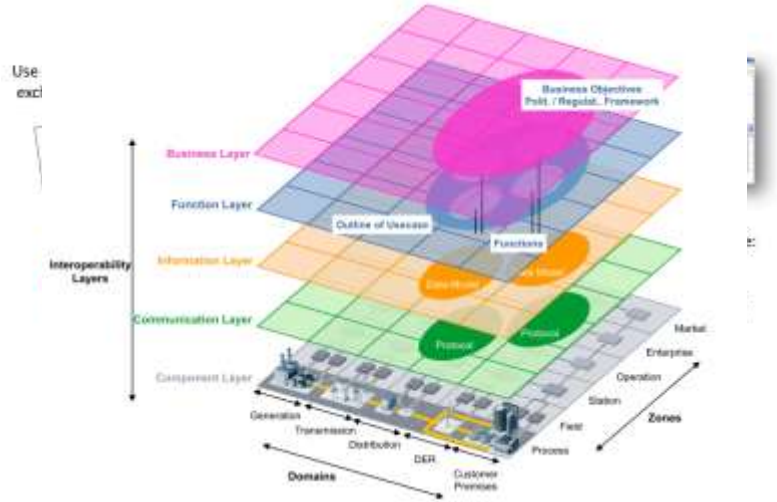
Is a standalone process to ensure that the implementation conforms to specified standards and profiles, i.e., the implementation's outputs and responses are checked against patterns and rules.

Interoperability Testing

Is assessing the ability of two or more systems to exchange information and to make mutual use of the information exchanged.



- XML Syntax Check
- → According XML Scheme (.xsd)
- → According Schematron Rules (.sch)



Smart Grid Architecture Model (SGAM)

[1] IES Cookbook: http://www.aico-software.at/media/files/IES_cookbook.pdf

Integrating the Energy System (IES) Approach

„Profiles“
Use case based, cooperative specification of data exchanges using existing standards

„Tests“ Test Event
vendors test their prototypes in an early stage of implementation

European Collaboration Network for Interoperability Testing

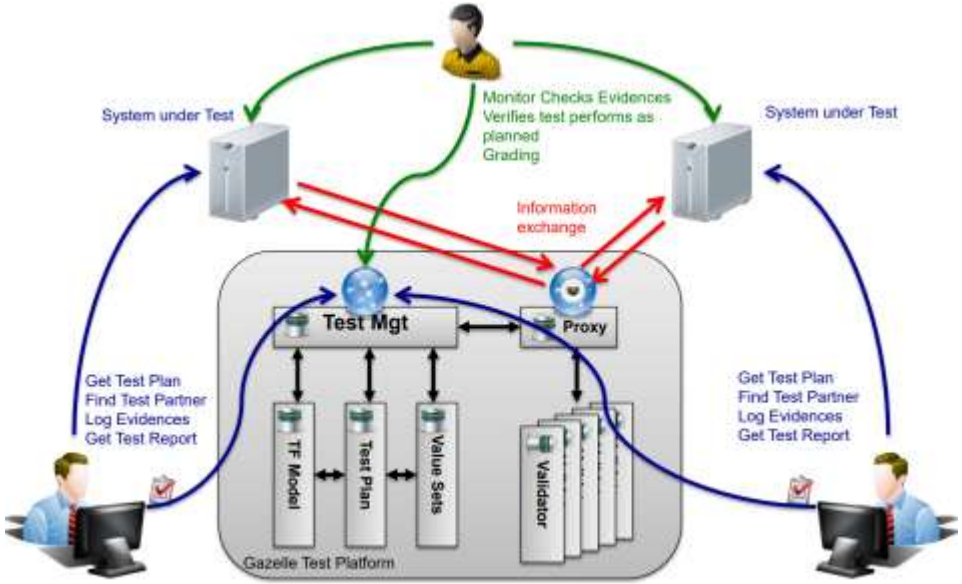
„Adoption“
building a community as process owner and share publicly accessible results (profiles, tests)

Interoperability Testing Tool

IHE GAZELLE eHealth test framework for interoperability

IES Connectathon Energy Vienna, January 2019

IHE Gazelle



Test Manager	Assertion Manager	Proxy	Security Suite	Validation Services	Simulators
manages test campaigns from start to finish.	manages **IHE Profile** specifications assertions and links them to test plans in **Test Manager**.	captures on-the-wire messages exchanged between products to validate conformance.	verifies conformance to **Security** protocols.	conformance verification of services, messages and documents.	emulate **IHE** actors and facilitate testing of stand-alone eHealth products.

InterOpEnergy

What is InterOpEnergy?

Project Name	InterOpEnergy
Project Duration	36 Months
Project Runtime	1st July 2024 – 30th June 2027
Funding Code	03EI6066E
Consortium	OFFIS BMIMI (as associated partner)
Budget	310.282,42 €

What is InterOpEnergy?

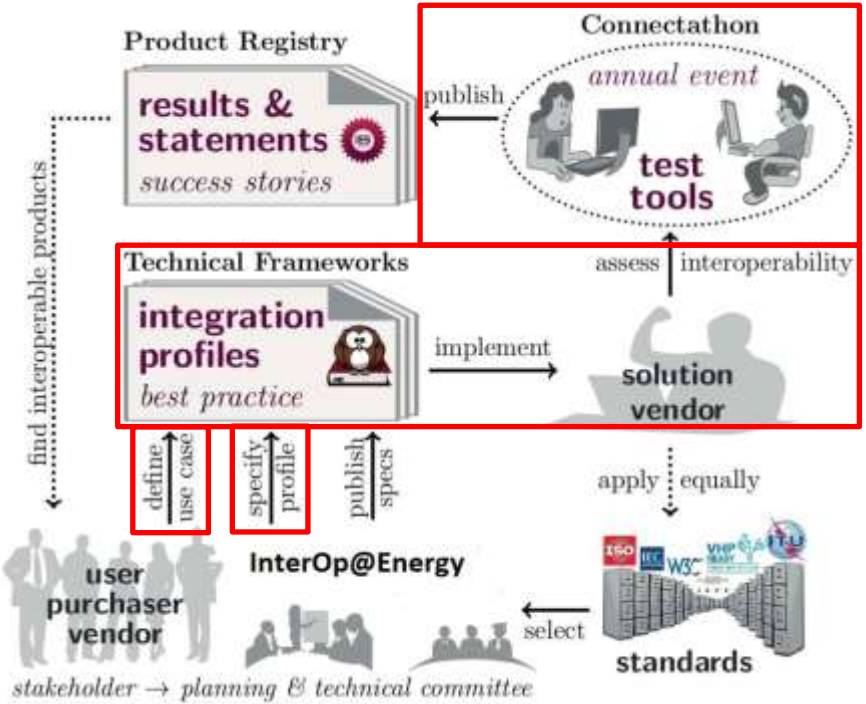
- **Improve Conformance and Interoperability Testing by adapting/expanding the IES Methodology with regard to IHE Gazelle**
  - Promotion of existing research and its adaptation with regard to the interoperability testing tool IHE Gazelle, which is established in the healthcare sector

- **Laying the foundation for future ENERGY Connectathons (Interoperability Testing Events)**
  - Events where system developers and suppliers come together and test their systems for interoperability
  - InterOpEnergy would like to enrich the execution and planning of Connectathons with providing Technical Frameworks for two concrete use cases (provided as open source)

- **Increase interoperability efforts, particularly the testing in the energy sector**
  - Provision of support for interoperability efforts on the part of InterOpEnergy, especially in testing
  - Cooperation and participations in networks, such as ISGAN or EraNET/CETP Channels

Objectives

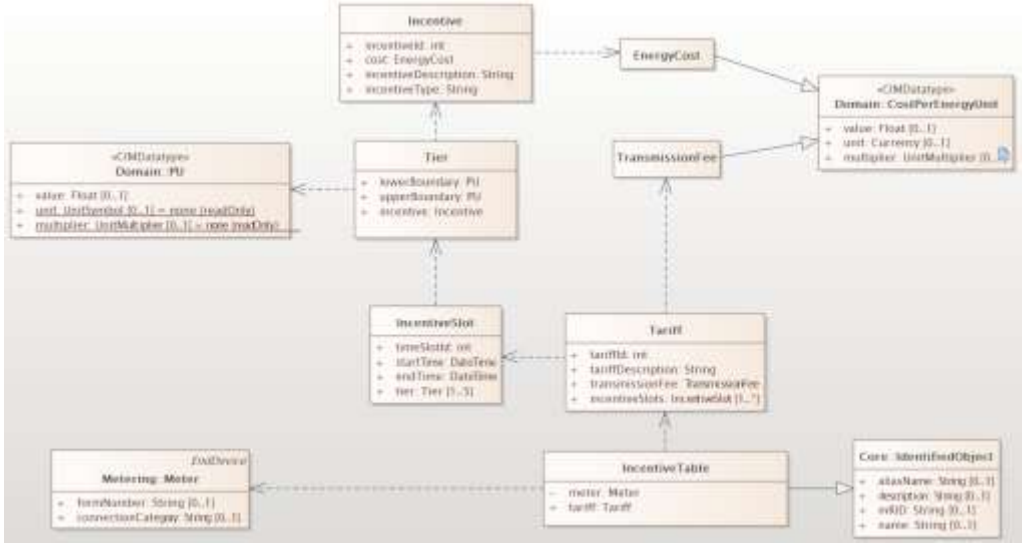
- **Selection and Definition of two Use Cases**
  - Time of Use Tariff for Smart Electric Vehicle Charging
  - CGMES Data Exchange
- **Development of Technical Frameworks**
  - Guidelines for implementing and testing interoperable solutions
- **Development of a Test Platform for Interoperability Testing**
  - Use of the IHE Gazelle from the healthcare sector
- **Definition and Integration of Test Scenarios**
  - Design and integrate test scenarios and sequences into the InterOpEnergy test platform
- **Efforts to improve the energy-related Connectathons**
  - Providing Technical Frameworks for the Use Cases
  - Publish results according to FAIR criteria (e.g., via GitHub or NFDI4Energy)



Use Case #1: Time-of-Use Tariff for Smart Electric Vehicle Charging

- **Relevant Actors/Standards:**
  - > Energy Broker/Delivery Broker
  - > Customer Energy Manager
  - > (Smart) Electric Vehicle Charging Station
  - > Electric Vehicles
  - > Common Information Model (CIM)
  - > IEC 63380
  - > Smart Grid Architecture Model, IEC 62559 Use Case-Methodology, IES Cookbook, …

- **Smart Charging of Electric Vehicles acc. Time of Use-Tariff**
  - > **Development of a CIM Profile for exchanging dynamic tariff data**
  - > **Establishing IHE Gazelle including a Technical Framework for the UC**

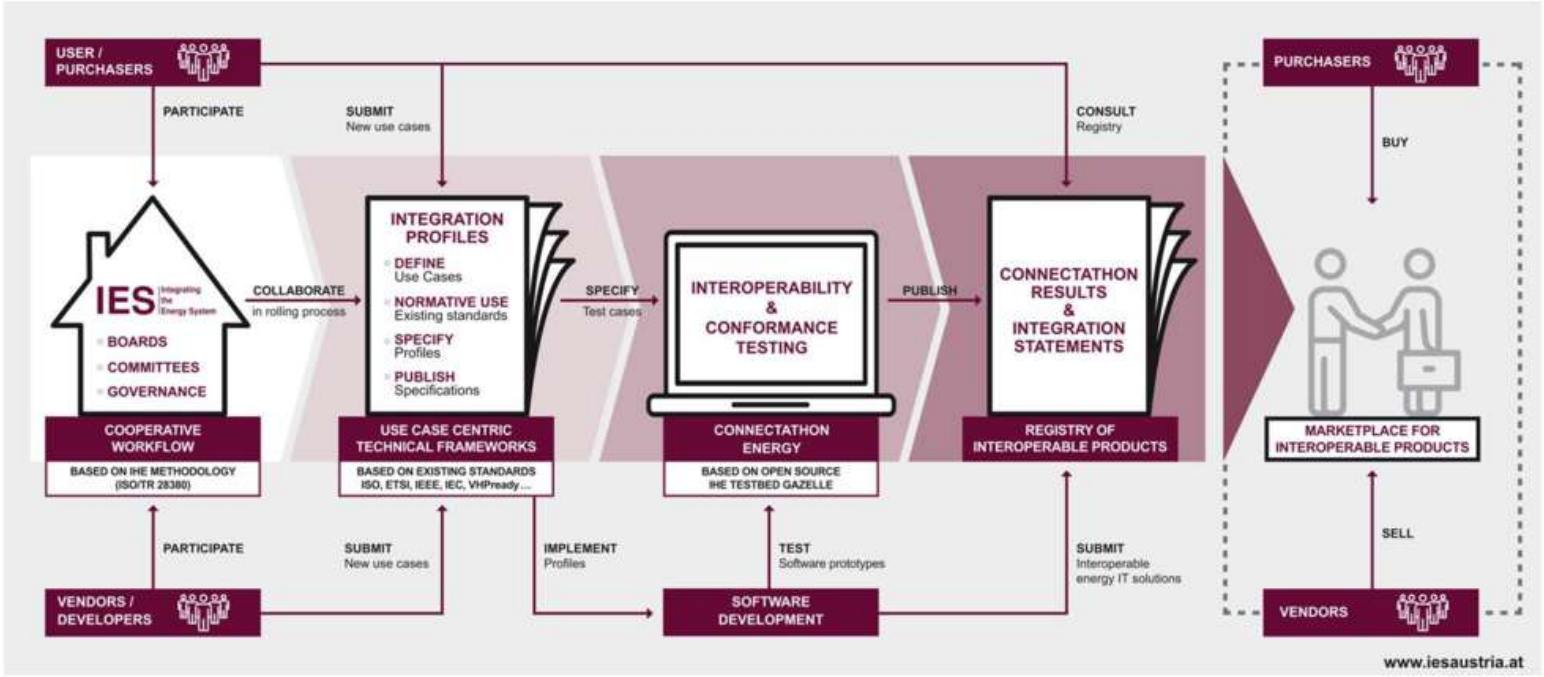


Use Case #2: CGMES Data Exchange

- **CGMES (IEC 61970:600) is an extension of CIM**
  - > **Network Codes Specifications** for Contingency, Equipment Reliability, Grid Disturbance, Remedial Action (Schedule)
  - > Defines the Data Exchanges between Transmission System Operators, Distribution System Operators, Software Vendors

- Our Focus (so far) will be on Grid Disturbance Profile

IES Workflow



[1] IES Cookbook: http://www.aico-software.at/media/files/IES_cookbook.pdf

Connectathon Energy

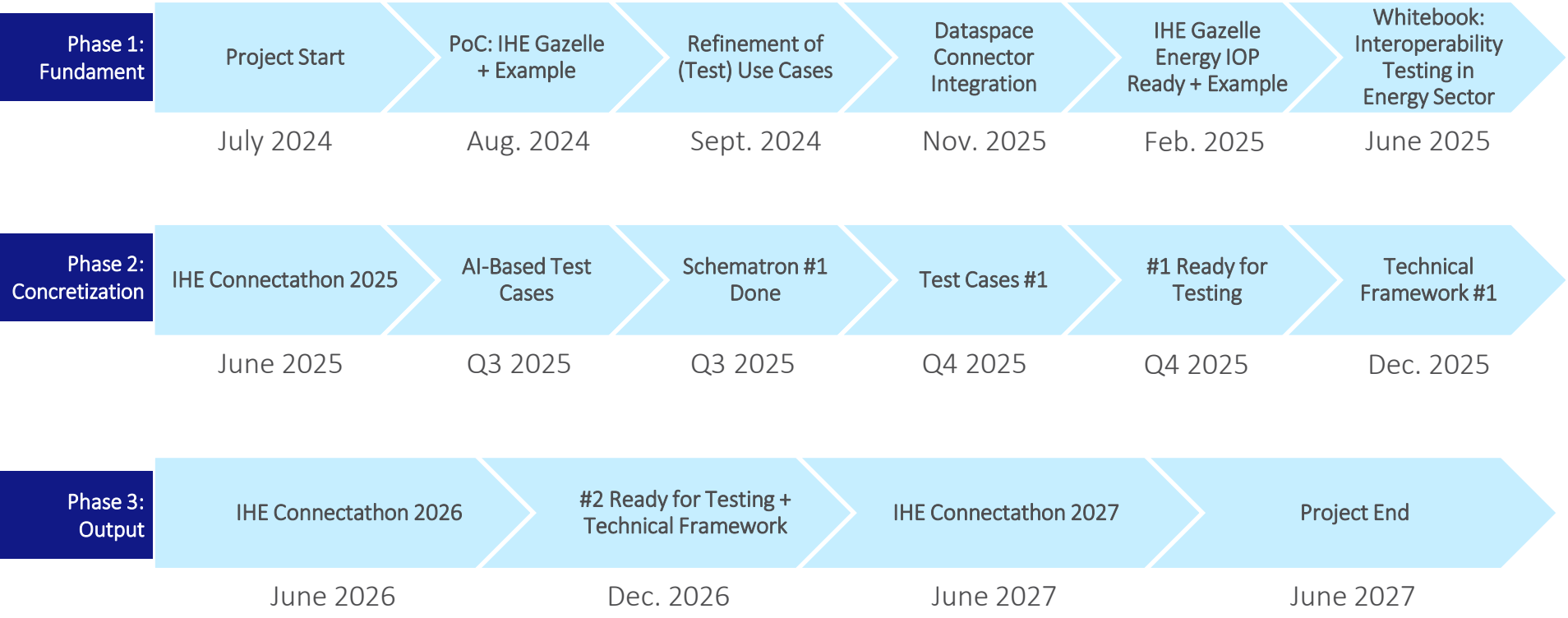
- Annually interoperability testing event for vendors to test their products at an early stage of development
- **Seven months prior the Connectathon Energy** the Integration Profiles have to be published and integrated in Gazelle to create test cases
- **Four month prior the Connectathon Energy** vendors can register their systems for being tested and can perform conformity tests
- **The Connectathon (Energy) should take one week** to have enough time to fix issues that were detected during the tests

Figure 4: IES timing is centred on the annual Connectathon Energy

[1] IES Cookbook: http://www.aico-software.at/media/files/IES_cookbook.pdf

Impression from Connectathon

Our Roadmap


Phase 1: Fundament
Project Start
PoC: IHE Gazelle + Example
Refinement of (Test) Use Cases
Dataspace Connector Integration
IHE Gazelle Energy IOP Ready + Example
Whitebook: Interoperability Testing in Energy Sector
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Aug. 2024
Sept. 2024
Nov. 2025
Feb. 2025
June 2025
Phase 2: Concretization
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Schematron #1 Done
Test Cases #1
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Technical Framework #1
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Q3 2025
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Q4 2025
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Phase 3: Output
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Project End
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June 2027
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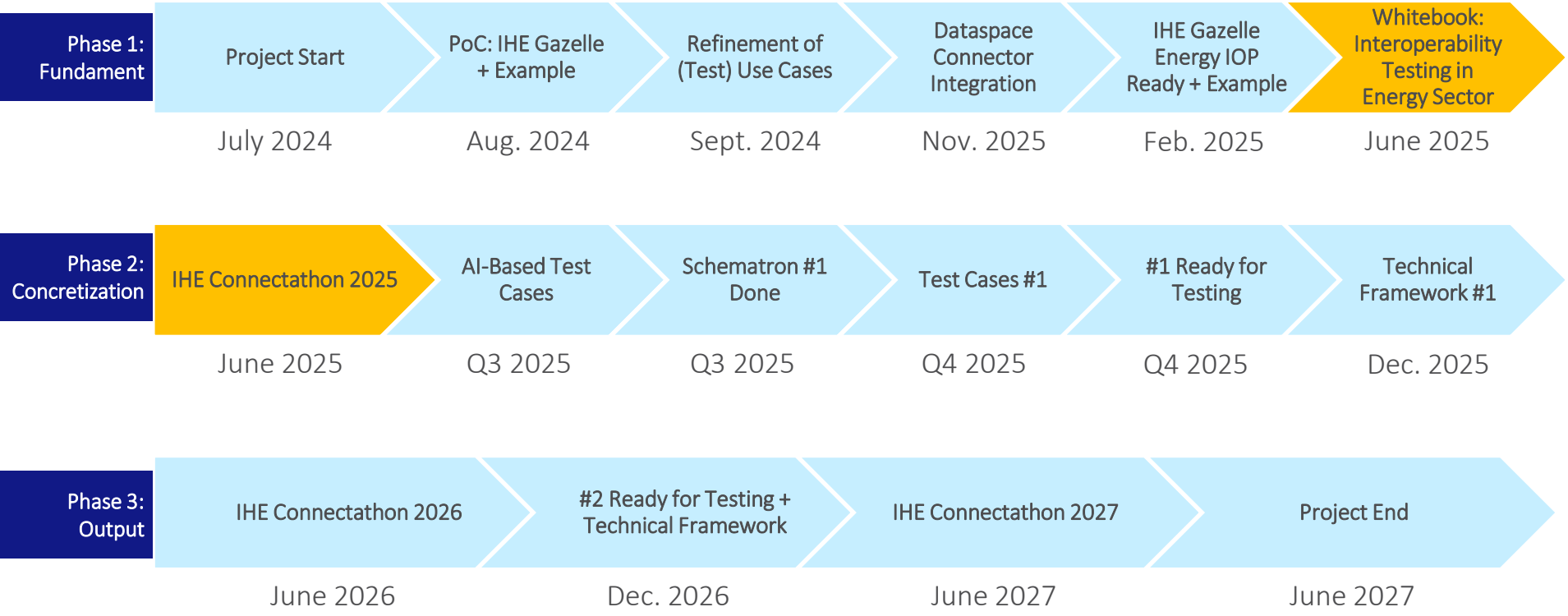
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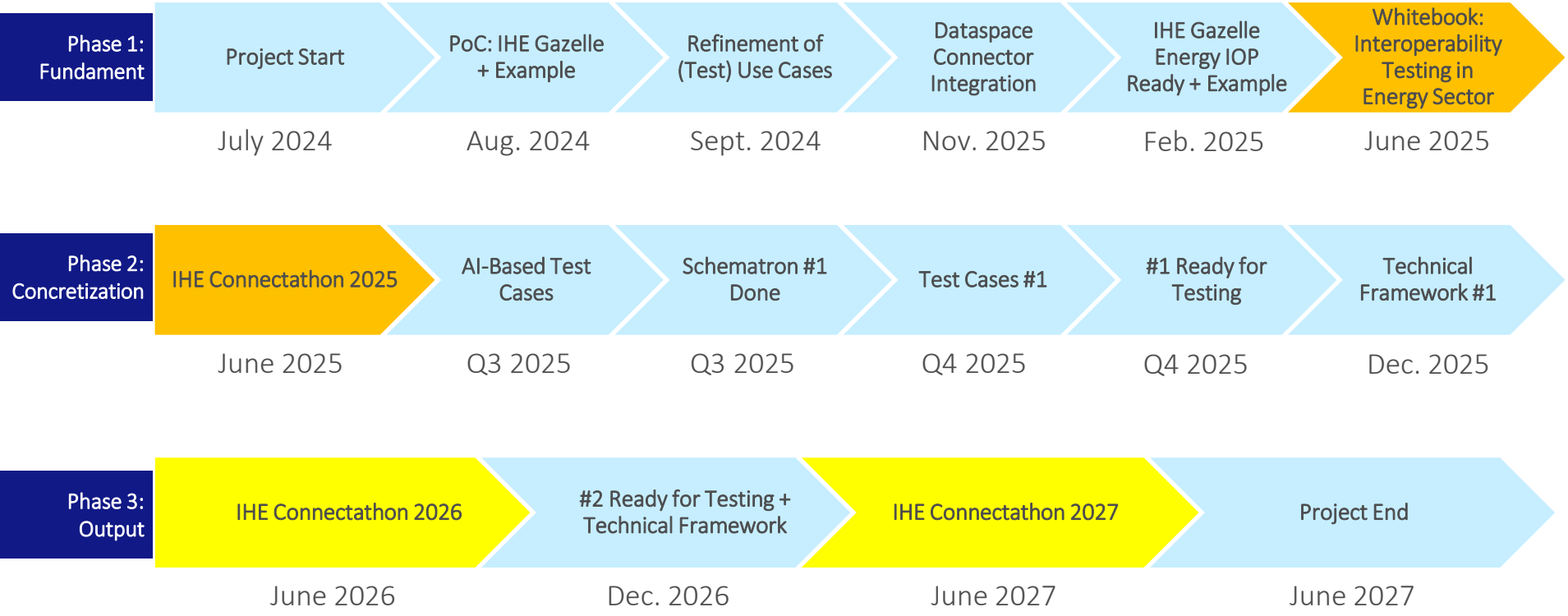
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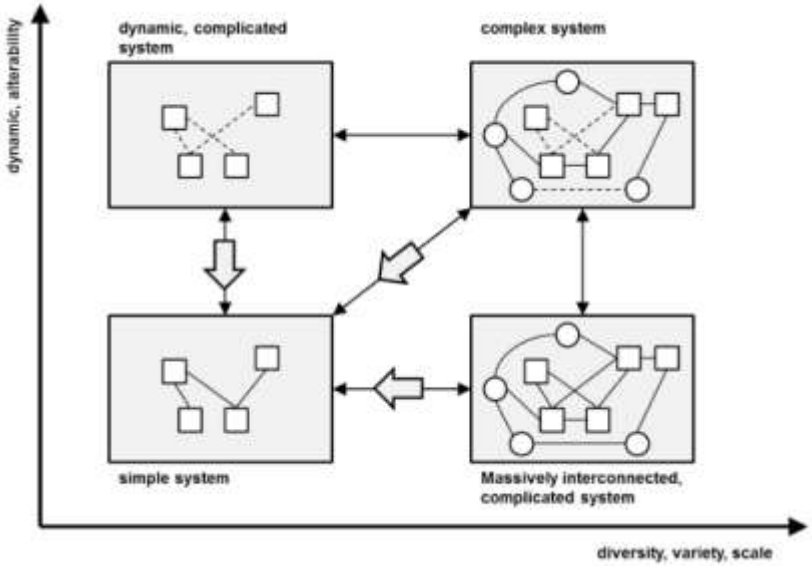
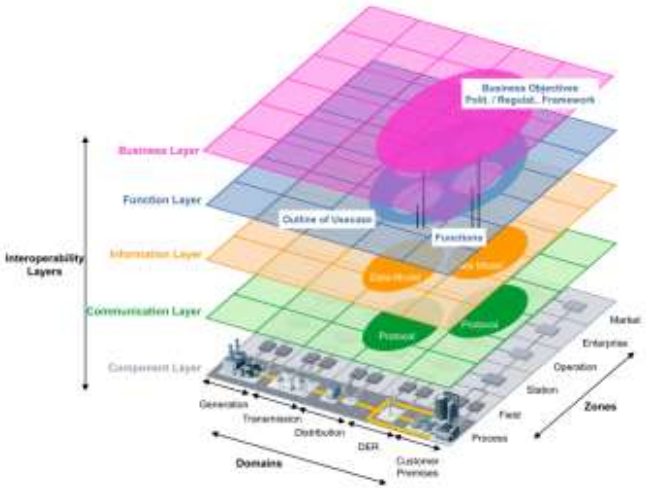
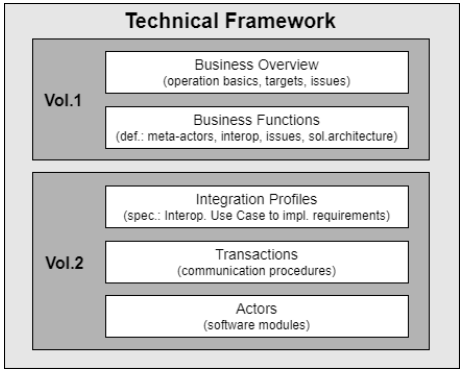
Key Insights from our Whitebook



- The **Smart Grid** are a prime example of a **System-of-Systems (SoS).**
- The following characteristics are be identified for a SoS:
  - **Autonomy:** SoS can adapt and function even if some systems fail.
  - **Belonging:** Participation is often based on mutual benefits.
  - **Connectivity:** Systems are connected in many ways to enhance collaboration and efficiency.
  - **Diversity:** The SoS benefits from having different kinds of systems working together
  - **Emergence:** New behaviors or abilities can appear when systems work together.

- **Structure of Technical Frameworks**

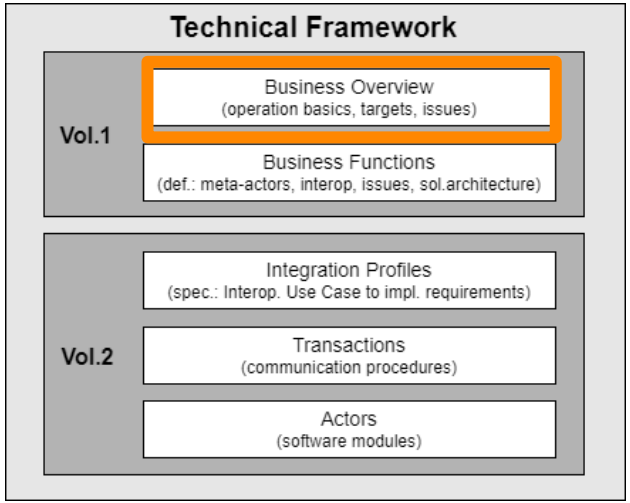




Our Technical Framework is based on the **SGAM** and **IES Technical Framework Template**, it defines how **interoperability** is to be implemented following a **Top-Down Business Logic**:

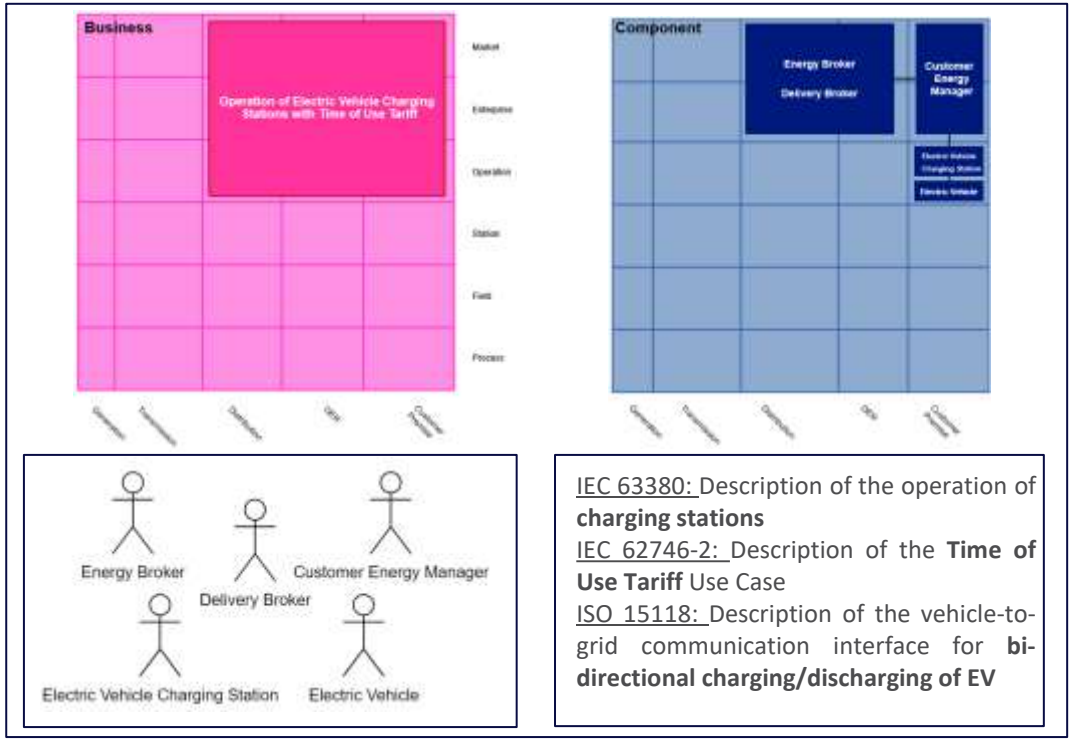
- It identifies the target audience and their needs.
- It clarifies the objectives and scope of interoperability testing.
- It provide a consistent basis for semantics, syntax and pragmatics in technical implementation.
- It describes the application of existing standards and best practices.

- **Volume 1 provides a high-level overview of interoperability:**



Business Case Overview (informative):

- ❖ Typical use cases
- ❖ Relevant meta-actors
- ❖ Related standards



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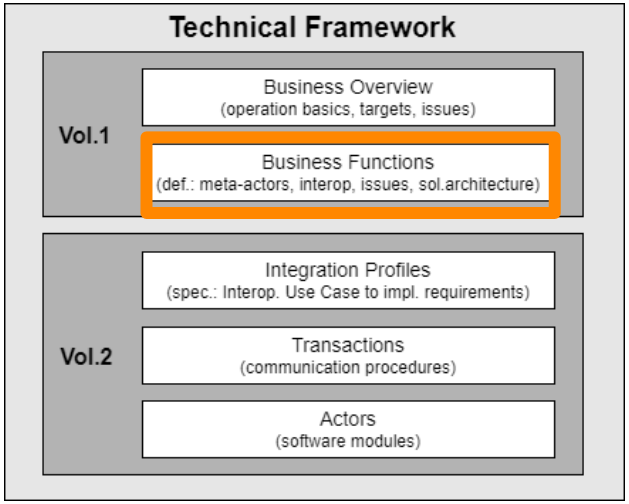
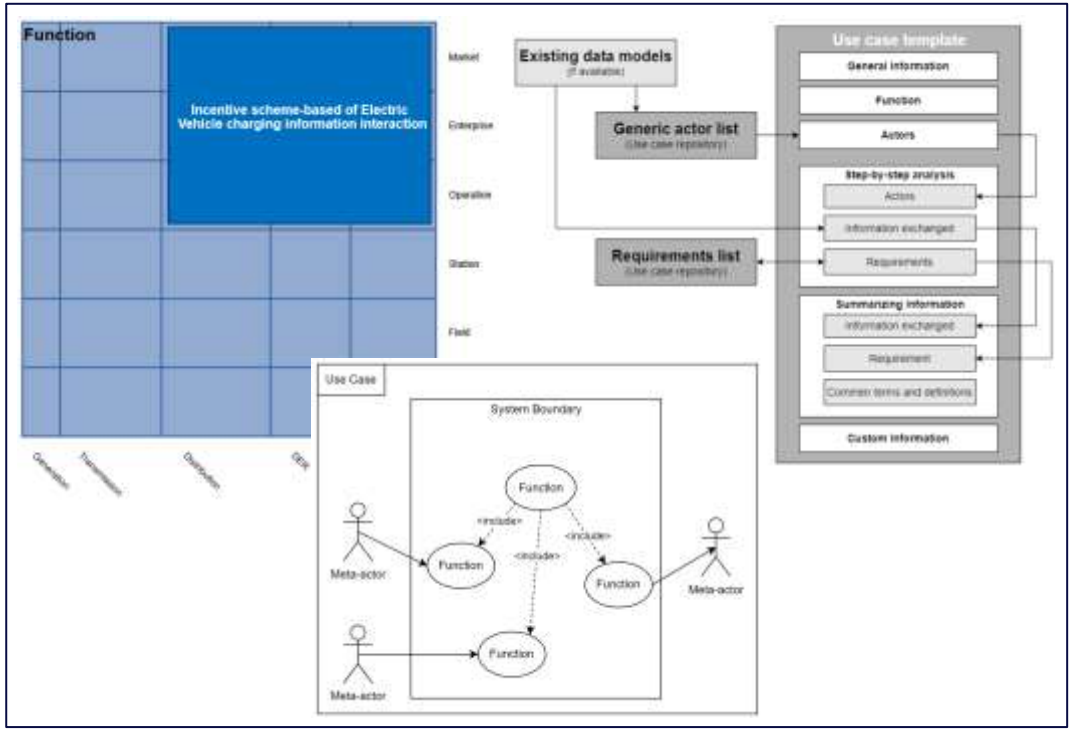
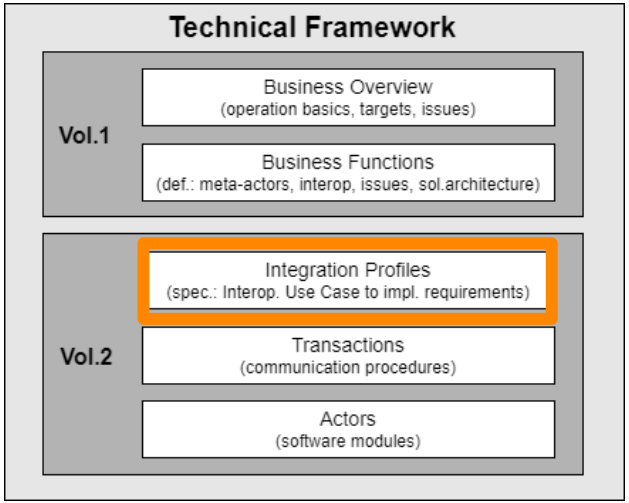


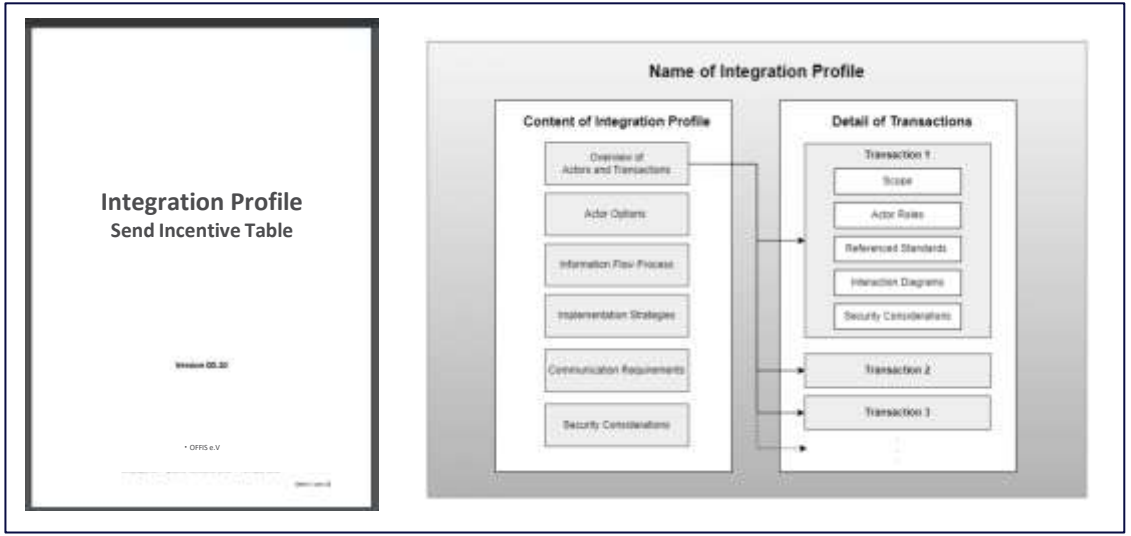
Business Functions (informative):

- ❖ Describe interoperability issues with IEC 62559 Use Case Methodology
- ❖ Use Case Diagrams



- **Volume 2 provides a low-level overview of interoperability:**

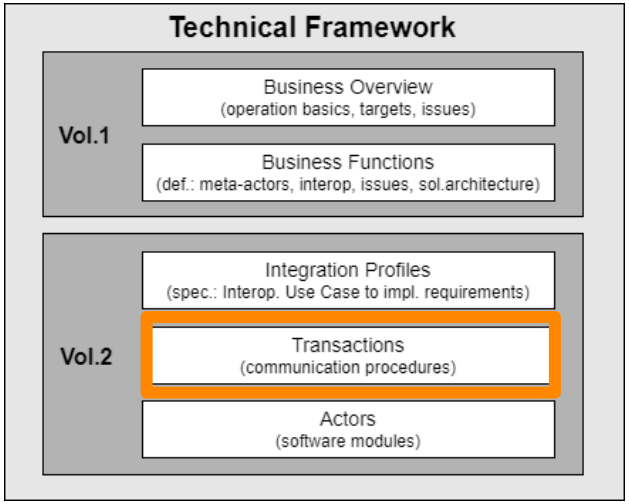


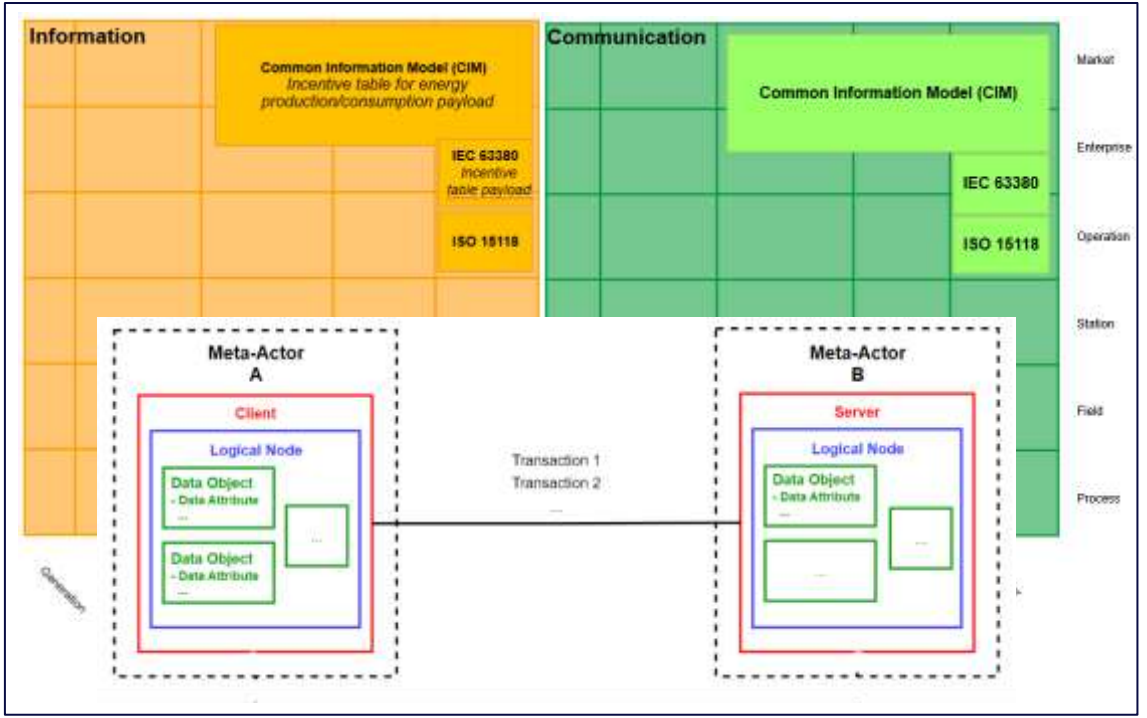


Integration Profiles (informative and normative):

- ❖ Technical solution for a specific interoperability issue from Business Function
- ❖ Definition of transactions
- ❖ Definition of the actors that are involved

- **Volume 2 provides a low-level overview of interoperability:**

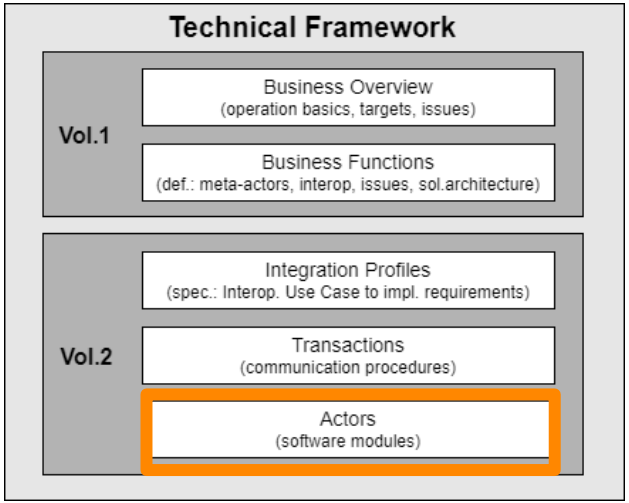




Transactions (normative):

- Procedures required for interoperable cooperation
- Specification of the actors
- Specification of the IT standards

- **Volume 2 provides a low-level overview of interoperability:**



Actors:

- Implementation examples to realize the actors that perform transactions
- Software tools/stacks/platforms that can be used
- Reference implementation(s)

- **Design and validate Use Case-related Test Cases:**

Test prototype solutions on annual **Connectathon** and **iteratively improve** the **Integration Profiles**:

- **Specify test cases** according to Integration Profile
- **Execute** test cases with at least two independent **peer vendors**
- **Add** test cases, procedures, description and criteria **to test environment** (Gazelle)
- **Implement conformity validation tools** (e.g., Schematron)
- **Capture data** transmitted during peer-to-peer communication (e.g., trace via proxy)

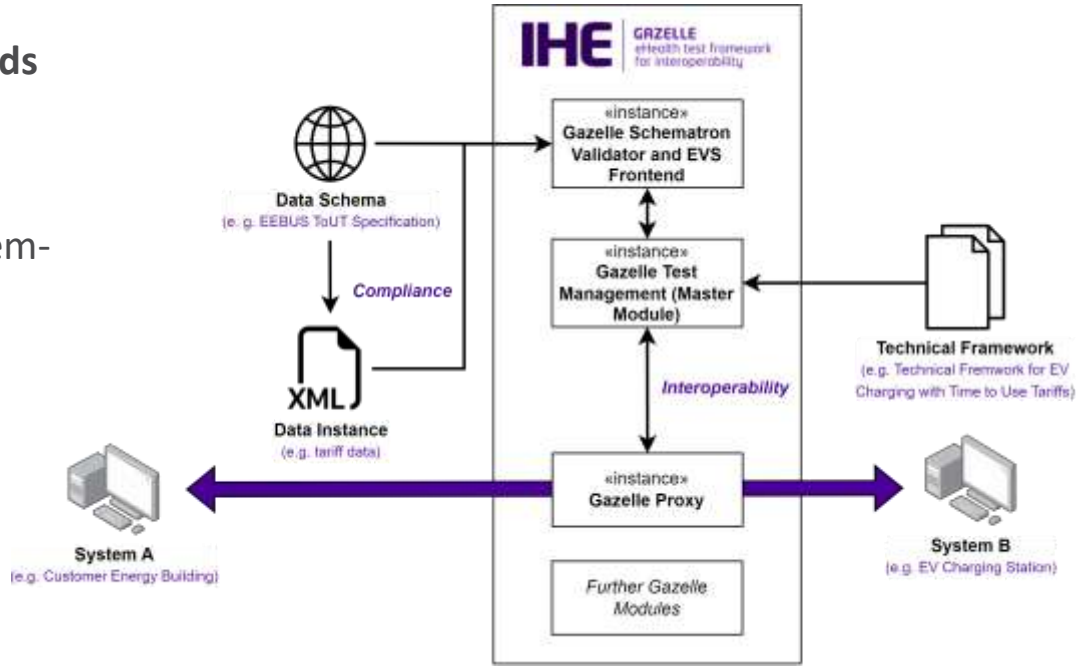
Test Case ID	TC-ToUT-001	**Title**	Validation of the Summer/Winter Time changeover in the Time-of-Use Tariff Use Case
Related IEC 62559 Use Case	ToUT_EV	**Related Information Exchanged**	Incentive-based table for energy production/consumption with price of energy and/or delivery fee
Test Priority	High	**Test Type**	Functional / Interoperability
Preconditions	• Energy Broker has an established connection to the Customer Energy Manager. Time is synchronized.		
Test Data	• examples/TC-ToUT-001_OK: Normal test file that should pass the test *Note: Special Case Check: Transition from 02:00 to 03:00 CEST* • …		
Expected Result	• The system automatically applies the correct tariff zone when the time changes.		
Testing Rules	• (Schematron Rule IDs could be mentioned here.)		
Test Step Nr.	**Action**		**Expected Result**
1.	Check conformity according the syntacts / semantics		Should be compliant to XSD and Basic Schematron Rules
2.	…		…
Organization	John Doe Ltd.	**System-under-Test ID**	Doe_Ltd_SUT_1
Actor	Energy Broker	**Scenario**	Transfer of Incentive Schemes to Electric Vehicles Charging Stations
Executed By	John Doe	**Peers:**	• Jane Roe Ltd: Roe_AG_SUT_2 *(Customer Energy Manager)* • James Doe Ltd: Doe_UG_SUT_3 *(Customer Energy Manager)*
Status	Passed		
Actual Result	Data successfully sent and interpreted; James Doe Ltd. had issues on the interpretation		
Environment	Simulated data used		
Execution Date	29. Feburary 2025		
Comments / Notes	-		
Attachments	Screenshots, Logs		

Whitebook

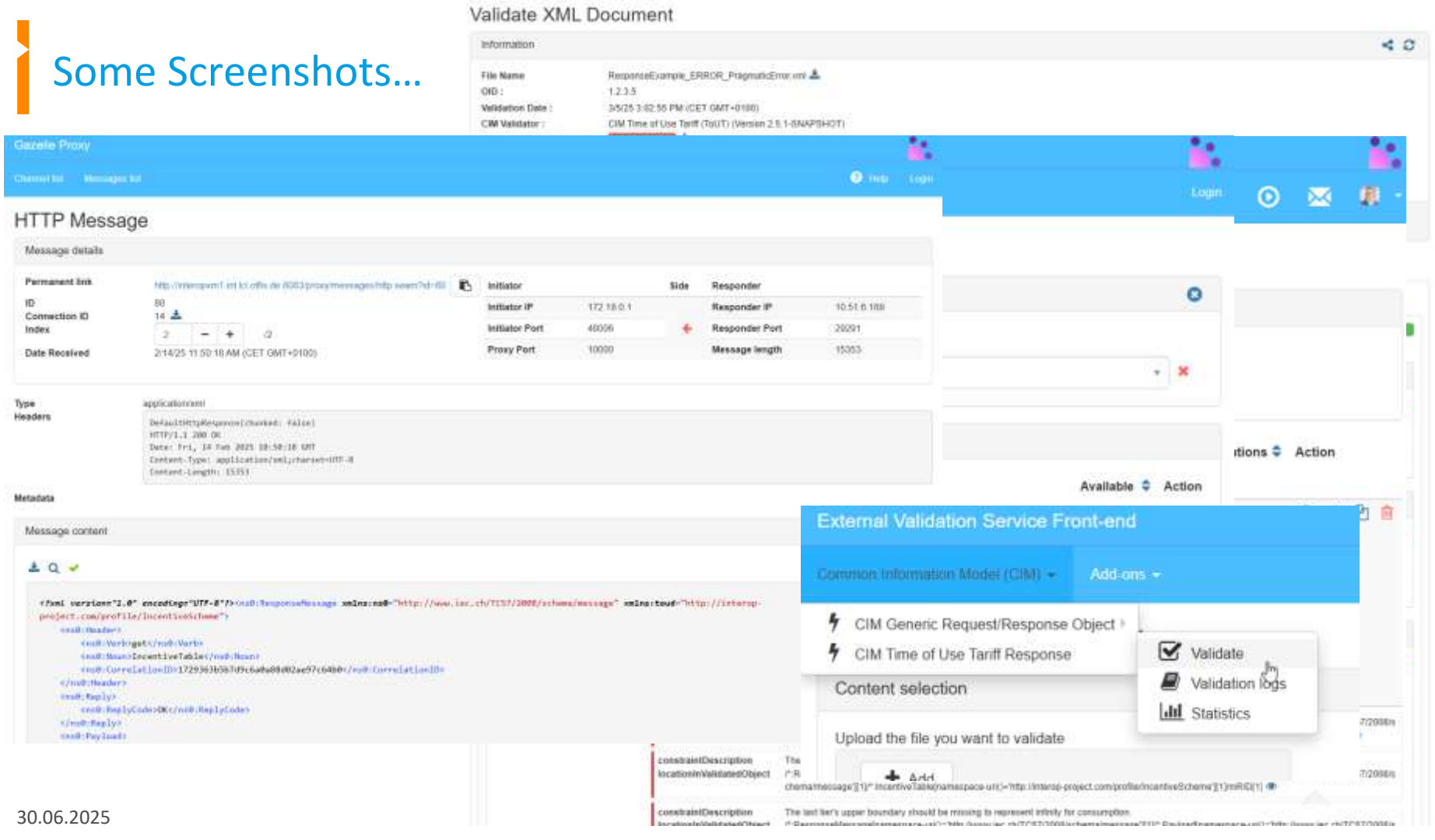
Integrating IHE Gazelle in Energy Sector

- **Conceptionalization and Adaption for energy-related Use Cases and Standards**
  - Usage of IHE Gazelle Ecosystem
  - Consideration of energy-related Problems and Conditions (e.g. System-of-Systems)

- **Supporting the Organization and Execution of energy-related Test Sessions and Connectathons**



Some Screenshots…



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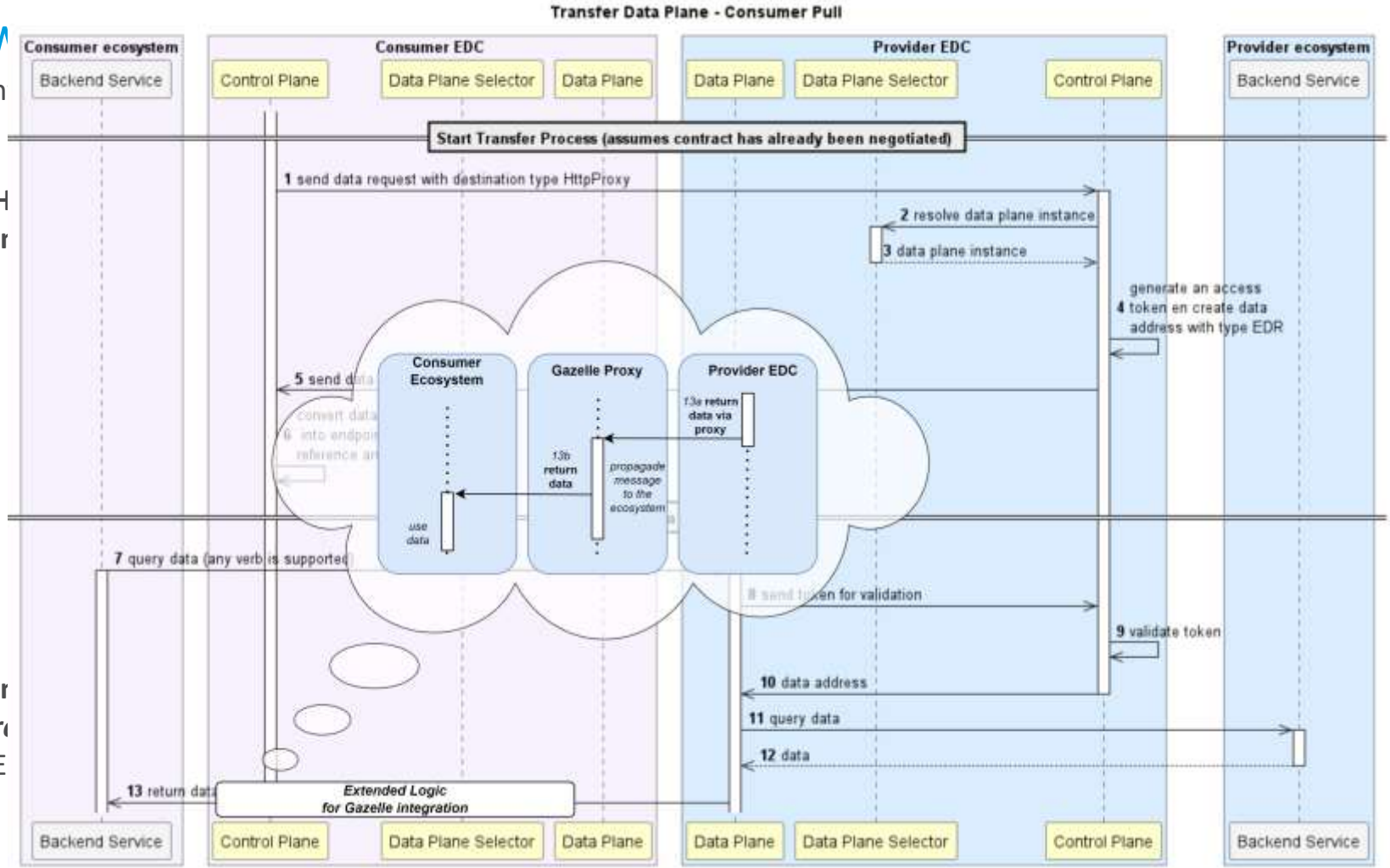
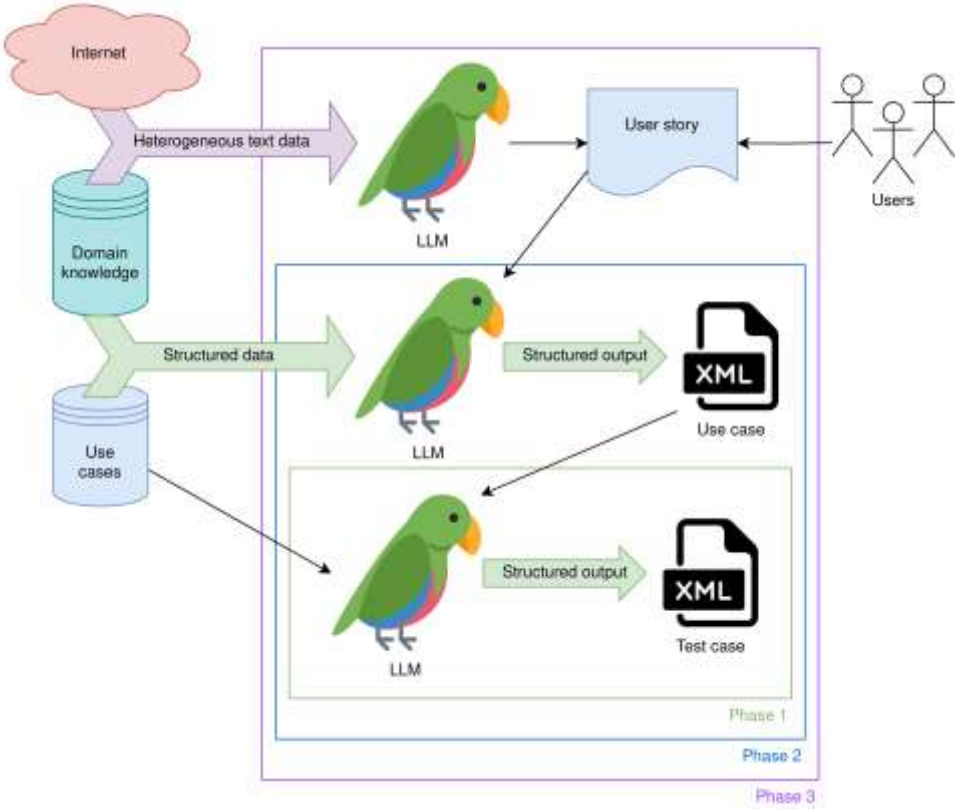

Transfer Data Plane - Consumer Pull
Consumer ecosystem
Backend Service
Consumer EDC
Control Plane
Data Plane Selector
Data Plane
Provider EDC
Data Plane
Data Plane Selector
Control Plane
Provider ecosystem
Backend Service
Start Transfer Process (assumes contract has already been negotiated)
1 send data request with destination type HttpProxy
2 resolve data plane instance
3 data plane instance
generate an access
4 token en create data
address with type EDR
5 send d
Consumer Ecosystem
Gazelle Proxy
Provider EDC
13a return data via proxy
13b return data
propagate message to the ecosystem
use data
7 query data (any verb is supported)
8 send token for validation
9 validate token
10 data address
11 query data
12 data
13 return data
Extended Logic for Gazelle integration
Backend Service
Control Plane
Data Plane Selector
Data Plane
Data Plane
Data Plane Selector
Control Plane
Backend Service

Whitebook

AI-based Test Case Generation

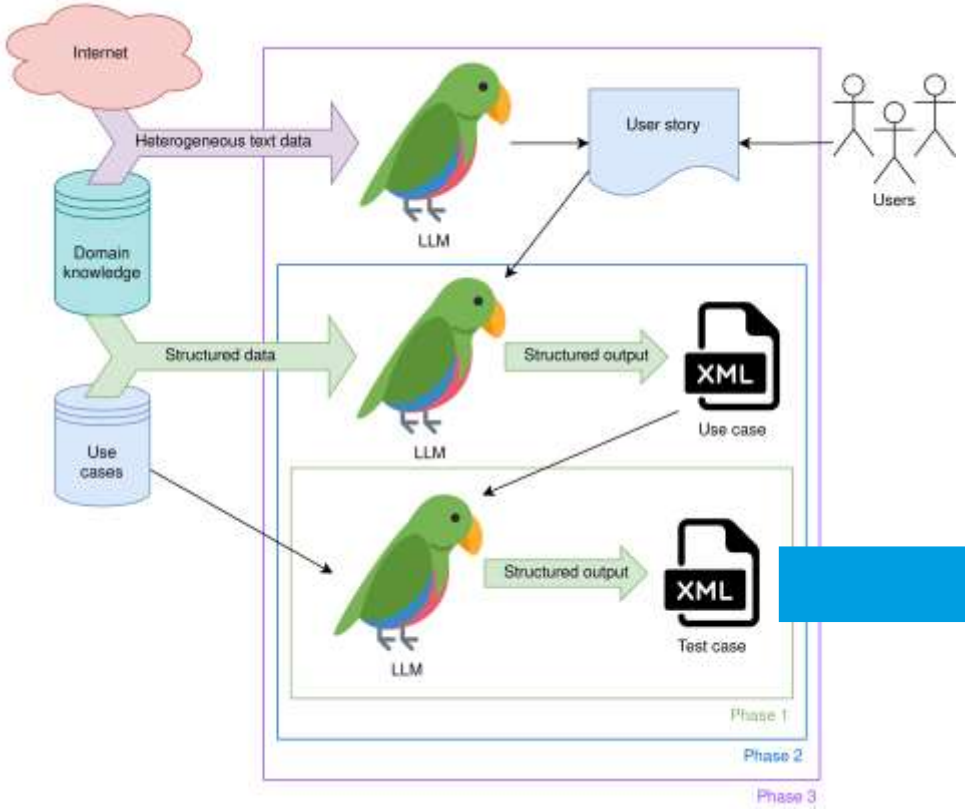
- Usage of **Large Language Models (LLaMA 3.2 and ChatGPT 4o)** and Retrieval Augmented Generation (RAG)
- Consideration of **Internet, Domain Knowledge and Use Cases**

- **Our Approach considers 3 Phases:**
  - **Phase 1:** Generating **Test Cases and Schematron** files from Use Case
  - **Phase 2:** Generating Use Cases from User Stories
  - **Phase 3:** Generating User Stories



Whitebook

AI-based Test Case Generation



Test Case ID	TC-ToUT-001	Title	Validation of the Summer/Winter Time changeover in the Time-of-Use Tariff Use Case
Related IEC 62559 Use Case	ToUT_EV	Related Information Exchanged	Incentive-based incentive table for energy production/consumption with price of energy and/or delivery fee
Test Priority	High	Test Type	Functional / Interoperability
Preconditions	• Energy Broker has an established connection to the Customer Energy Manager. • Time is synchronized.		
Test Data	• examples/TC-ToUT-001_OK: Normal test file that should pass the test *Note: Special Case Check: Transition from 02:00 to 03:00 CEST* • …		
Expected Result	• The system automatically applies the correct tariff zone when the time changes.		
Testing Rules	…		

Test Step Nr.	Action	Expected Result
1.	Check conformity according the syntacts / semantics	Should be compliant to XSD and Basic Schematron Rules
2.	Set an interval of a tier shortly before and after the time changeover	The exchanged data must clearly represent distinct and unambiguous time intervals, even during the DST transition: • Each timestamp must be unique and contextually clear (e.g., with time zone or DST indicator). • There must be no ambiguity between repeated or skipped time values (e.g., "02:00" during DST change).
3.	The interpreting system uses and understands this data in its context	The interpreting system must: • Correctly interpret and apply the time intervals as intended, accounting for the DST

…

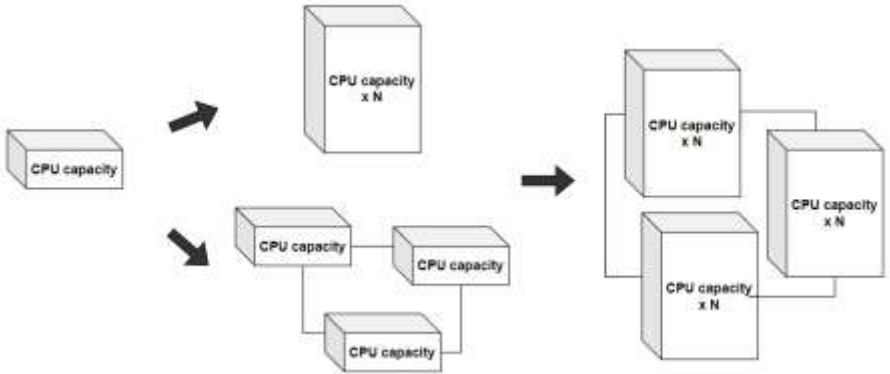
- **Two Major Challenges of Conformance Testing:**

  - **Reproducibility and Scalability**
    - Definition:
      - **Reproducibility** means results can be independently verified with the same setup.
      - **Scalability** is a system's ability to handle growth without losing performance or reliability.
    - Solution:
      - **Testing Profiles** used in one system should be interoperable with those in others, based on a **shared testing ontology**.

- **Three Different Stages of Reproducibility:**

1. **Same people** use the **same setup** to repeat results
2. **Different people** use the **same setup** to reproduce results
3. **Different people** use **different setups** to replicate results

- **Two Strategies of Scalability:**



1. **Vertical Scaling**, which involves enhancing existing hardware capabilities, such as increasing CPU capacity, memory, or storage.
2. **Horizon Scaling**, which involves adding more hardware or nodes to distribute workload and improve overall capacity.

Whitebook

Key considerations in data management for interoperability testing

- **FAIR Principles of Data Space:**
  - **F**indable: Each node in the Data Space from the participant connector can publish a self-description.
  - **A**ccessible: The Data Space Connector supports standardized access to data.
  - **I**nteroperable: An information model serves as the basis for metadata format and semantic interoperability.
  - **R**eusable: The usage policy based on data sovereignty.

- **Instances from Interoperability Testing:**

- Use of persistent identifiers like DOIs or URIs should be assigned to all datasets and metadata.

- Use of standardized formats, such as JSON, XML, or RDF, and annotated with controlled vocabularies or ontologies by the relevant community, such as CIM.

- High-quality metadata describes the content, structure, and provenance of data, such as Data Catalog Vocabulary (DCAT) or schema.org

- **Other Data Space-related Projects:**
  - int:net
  - NFDI4Energy in Germany
  - RISEnergy
  - ERIGRID 2.0

Conclusion

InterOpEnergy

- **Join us and bring your Systems and Solutions to the testing event!**
  - Especially relevant: Solutions for incentive-based EV Charging and Common Grid Model Exchange Standard (CGMES) Use Cases
  - Standards considered: EEBUS Specification, IEC 63380 (EV Charging Stations), IEC 15118, CIM, CGMES
  - ***Save the Date**: Test Session planned at 2026!*

Whitebook „Interoperability Testing in Energy“

- **The Whitebook is in release progress (Q4) – feel free to reach out for more details**
  - Advancing technical frameworks for interoperability
  - Leveraging IHE Gazelle in the energy domain
  - Enabling IOP testing with Data Space Connectors
  - Utilizing AI for automated test case generation
  - Perspective on current topics like FAIR data and Data Management

Check QR to find more information about InterOpEnergy and our Whitebook

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Thank you very much

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