# Federated Architecture - Technical specifications for the EnerTEF reference architecture (ED)

## Introduction

This section presents the architectural foundation of the EnerTEF digital ecosystem. It outlines the key software components and their functional roles, the application scenario they support, and the system-wide logic that orchestrates their interactions. The architecture is structured to provide a modular interoperable, and scalable environment capable of supporting secure experimentation and deployment of AI services in the energy domain.

Key input for the Reference Architecture design is the creation of a Components Catalogue, describing each core building block of the EnerTEF platform in terms of its function, interfaces, and information flows. This is followed by the Application Scenario, which exemplifies how users interact with the platform to fulfil the representative operational objective.

To illustrate system behaviour, we then describe how the components interconnect to realize the scenario, identifying key integration pathways, control flows, and data exchange mechanisms. A set of Generic System Use Cases (GSUC) is introduced to abstract recurring patterns of user-platform interaction, providing a foundation for functional validation and requirements mapping.

Finally, we present the architecture mapped onto the Smart Grid Architecture Model (SGAM) framework, offering a structured and standards-aligned view of the system across the five SGAM layers: Business, Function, Information, Communication, and Component. This mapping facilitates the alignment of the EnerTEF architecture with EU energy and digital interoperability standards and supports future extensions toward compliance with frameworks such as IDSA, GAIA-X, and BDVA.

## Reference Architecture Design Methodology

The initial Reference Architecture of the EnerTEF digital ecosystem has been designed through a structured, layered, and standards-informed methodology to ensure modularity, interoperability, scalability, and compliance with European digital, energy and Data Space initiatives.

The design approach followed these guiding principles:

* **User-Centric and Use Case-Driven:** Architecture requirements were derived from the needs of key user groups, AI service developers, energy sector end-users, and TEF node operators through representative business application scenario.
* **Layered Architectural Decomposition (SGAM-based):** The Smart Grid Architecture Model (SGAM) was adopted for the design of the 1st EnerTEF logical concept model to ensure alignment with EU best practices in the digitalization of energy systems. SGAM enabled a multi-layered breakdown—Business, Function, Information, Communication, Component—to clearly separate concerns and map system roles to standardized domains and zones.
* **Interoperability and Standards Alignment:** The design incorporated components such as Dataspace Connectors and standardized data models to enforce semantic and technical interoperability. It also considered alignment with frameworks such as IDSA, GAIA-X, and BDVA, laying the foundation for future compliance.
* **Modularity and Federation:** The architecture supports the federation of independent TEF nodes, allowing them to contribute assets (e.g., datasets, DTs, HPC resources) in a modular manner. Centralized components (e.g., the Portal, IAM, Orchestrator) interoperate with decentralized local assets through well-defined interfaces.
* **Security and Access Control by Design:** Identity and Access Management (IAM) principles were embedded from the start, with integration to systems such as Keycloak for authentication and Role-Based Access Control (RBAC) across all modules and user roles.
* **Iterative and Incremental Development:** The architecture was refined through iterations with the entire EnerTEF consortium. Component capabilities were continuously validated against real-world workflows, ensuring traceability from user needs to technical design.

This methodology ensures that the resulting architecture is not only business sound but also responsive to the needs of stakeholders, scalable for future extensions, and capable of supporting secure and trustworthy AI experimentation within the European energy ecosystem. This first version of the Reference Architecture will also form the basis for the Technical Reference (Software) Architecture which will be the outcome of the continuous T2.5 efforts.

## Architecture Models & Initiatives Alignment

The EnerTEF architecture is designed to align with key European frameworks and digitalization initiatives to ensure interoperability, trustworthiness, and regulatory coherence across the energy and AI experimentation domains.

* **Smart Grid Architecture Model (SGAM):** The architecture adopts SGAM to ensure layered clarity (Business, Function, Information, Communication, and Component) and maps actors, domains, and zones consistently. This alignment facilitates integration with energy systems and compliance with EU energy digitalization strategies.
* **IDSA (International Data Spaces Association):** The use of Dataspace Connectors and data governance mechanisms ensures alignment with IDSA principles, including data sovereignty, secure data exchange, and trusted data usage.
* **GAIA-X:** The platform design supports federated data infrastructure with decentralized control, trust frameworks, and interoperable services—key tenets of GAIA-X. Integration of identity and access management, transparency, and policy enforcement enables alignment.
* **Common European Energy Data Space (CEEDS):** The EnerTEF architecture aligns with CEEDS principles by adopting mechanisms for bilateral data exchange through standardized APIs and incorporating data and control plane protocols that ensure secure and interoperable communication across nodes. Furthermore, the architecture envisions the use of catalogues for the registration, publication, and discovery of data, services, and assets, supporting seamless integration, governance, and findability of resources.
* **BDVA (Big Data Value Association):** The EnerTEF platform fosters AI and big data experimentation, promoting data-driven innovation while adhering to principles like FAIR data (Findable, Accessible, Interoperable, Reusable) and secure AI model usage, in line with BDVA objectives.
* **AIOTI, AIoD, and DOME:** The platform promotes collaboration between AI developers and infrastructure providers, contributing to AI and IoT experimentation environments that are open, federated, and modular, reflecting AIOTI and AIoD principles.

This alignment ensures that EnerTEF is not only technically robust and modular but also adheres to strategic European digital frameworks, maximizing its relevance, sustainability, and potential for cross-border collaboration.

## Component Catalogue

This section describes the components that will be developed in the context of the EnerTEF project and will form the EnerTEF building blocks for establishing the reference architecture. For each component the technological enabler (TE) is provided, the basic functionality, the I/O method, the actors to use it and the responsible partner. The tables below provide information of the EnerTEF central platform components and not the local assets, DTs and digital platforms (TE-10, TE-11, TE-12, TE-13) to be provided by TEF providers.

Table 44 Energy Data Models component details

|  |  |
| --- | --- |
|  | Energy Data Models |
| Technological enabler | TE-1 |
| Description | Ensure interoperability and homogenization by extending energy ontologies. |
| Functionalities | * Ontology development * Data annotation |
| Subcomponents | * Ontology development submodule * Data annotation submodule |
| Input data description | Energy-specific data |
| Input data format | Structured (databases, tables, spreadsheets) |
| Data input method | API input, file upload |
| Data output method | API output, file export |
| Actors (roles) | * Data consumers: End-Users * Data providers: TEF Asset Providers |
| Related software components | Interoperability Middleware |
| WP/Task | WP3/T3.1.1 |
| Leader | RWTH |

Table 45 Dataspace Connector component details

|  |  |
| --- | --- |
|  | Dataspace connector |
| Technological enabler | TE-2 |
| Description | Ensure seamless, secure data exchange and sovereignty. |
| Functionalities | * Secure Data transfer between a provider and a consumer * Support policy enforcement * Identity verification * Register available datasets and expose metadata |
| Subcomponents | * Data connector GUI * Middleware integration APIs |
| Input data description | TEF dataset to be transferred |
| Input data format | Semi-structured (JSON, XML, YAML) |
| Data input method | Through GUI or API allow users to provide data to be published |
| Data output method | Through GUI or API show transferred data and procedure (interrogation, contract agreement) |
| Actors (roles) | * Data provider: TEF Asset Provider (TEF provider administers data sources) * Data consumer (queries, agrees and consumes data): End-Users |
| Related software components | Interoperability Middleware |
| WP/Task | WP3/ T3.1.2 |
| Leader | ED |

Table 46 IAM Module component details

|  |  |
| --- | --- |
|  | Identity Access Management Module |
| Technological enabler | TE-3 |
| Description | Secure Access to TEF resources by applying identity access policies |
| Functionalities | * Authentication * Authorization * Role based access control (RBAC) |
| Subcomponents |  |
| Input data description | * User information * Organization access policies * RBAC Data |
| Input data format | Standardised data exchanged (OAuth, LDAP etc.) |
| Data input method | Through GUI or API allow users to enter data to be published |
| Data output method | Through GUI or API show transferred data and procedure (interrogation, contract agreement) |
| Actors/ Roles | All EnerTEF Users |
| Related software components | * EnerTEF portal * TEF providers * TEF services and |
| WP/Task | WP3/ T3.2 |
| Leader | COMS |

Table 47 HPC Orchestrator component details

|  |  |
| --- | --- |
|  | HPC Orchestrator |
| Technological enabler | TE-4 |
| Description | Coordinate and monitor access to TEF resources |
| Functionalities | * Monitor TEF resource allocation * Schedule and prioritize access to TEF resources |
| Subcomponents | * Resource monitoring module * Resource access prioritization module |
| Input data description | * TEF node Telemetry Data * Resource list |
| Input data format | * Telemetry Data (semi-structured, JSON) * Resources list (semi-structured, JSON) * Access priorities (semi-structured, JSON) |
| Data input method | Through GUI receive experiment resource requirements |
| Data output method | DB I/O for persisting access history, scheduling priorities |
| Actors (Roles) | TEF Asset provider/Node admins: Monitor HPC resources, register assets |
| Related software components | * EnerTEF Portal * Experimentation GUI |
| WP/Task | WP3/T3.3 |
| Leader | ED |

Table 48 Experimentation Workbench component details

|  |  |
| --- | --- |
|  | Experimentation Workbench |
| Technological enabler | TE-5, TE-6, TE-7, TE-8 |
| Description | Execute AI experiments |
| Functionalities | * Data preprocessing * Run services from the service catalogue * Train AI models * Track performance of AI models * Serve AI models |
| Subcomponents | * Experimentation Suite: GUI for designing and experiment datasets * Model registry: store AI models for reusability |
| Input data description | * Datasets (CSV, JSON) or dataset address in database * APIs for services, needed for input features * API for AI model and python code to train AI model * HPC resources available for experiment * Experiment information and metrics (JOSN, CSV) |
| Input data format | * Trained model in object * Metrics in relative database |
| Data input method | * Dataset (csv, json) or dataset address in database * APIs for services, needed input features for service * API for AI model and/ or python code via Jupyter notebook to train AI model * API for HPC resources availability * Experiment information, tracking metrics via Jupyter notebook input |
| Data output method | * API AI model (pkl) * Tracking information (CSV) * Giving back resources to HPC (Structured) |
| Actors/ Roles | AI service providers |
| Related software components | * Data connector * TEF nodes * HPC Orchestration * Marketplace |
| WP/Task | WP3/T3.3 |
| Leader | RWTH |

Table 49 EnerTEF Portal component details

|  |  |
| --- | --- |
|  | EnerTEF Portal |
| Technological enabler | TE-9 |
| Description | One-stop-shop for listing, purchasing and executing services on TEF nodes |
| Functionalities | * Register and authenticate users * Register services, assets, resources * Purchase services, assets, resources * Access resources * Design experiments |
| Subcomponents | * Marketplace GUI * Transaction mechanism * Training material |
| Input data description | * Service list: structured (DB) * Resource list: structured (DB) |
| Input data format | User forms through porta GUI |
| Data input method | Structured (database) |
| Data output method | Through portal GUI show purchases services |
| Actors/ Roles | * End-Users: Access services * AI service developers: Access service catalogue, request resources, design experiments * TEF Asset provider: provide and monitor resources |
| Related software components | Experimentation workbench  HPC orchestrator  IAM module |
| WP/Task | WP3/T3.5 |
| Leader | ED |

Table 50 Regulatory Sandboxes Component Catalogue

|  |  |
| --- | --- |
|  | Regulatory Sandboxes |
| Technological enabler | TE-14 |
| Description | Sandbox for supporting AI testing on legal and regulatory standards |
| Functionalities | * Description of Regulatory Sandboxes * Linking to compliance level * Classification, if application requires Sandboxing * Sandbox workflow report |
| Subcomponents | * Template for developers * Template for regulatory persons |
| Input data description | Manual, User forms |
| Input data format | Descriptive (free text) and choice |
| Data input method | Input in template document of portal |
| Data output method | List of TEF/Sandboxes mapped to the regulations  Document |
| Actors/ Roles | Users  Administrators  Project Manager, Lead developers |
| Related software components | Catalogue, Staging environment. |
| WP/Task | WP2/T2 |
| Leader | COMS, JSI |

Table 51 Recommendation Toolbox Component Catalogue

|  |  |
| --- | --- |
|  | Recommendation Toolbox |
| Technological enabler | TE-15 |
| Description | Offer content-based suggestions to end-users, linking them with top-tier services |
| Functionalities | Organization of services  Recommendation of services based on the user |
| Subcomponents | Catalogue |
| Input data description | Text box, possible free text |
| Input data format | Free text |
| Data input method | Chat or multiple choices |
| Data output method | List of recommendation |
| Actors/ Roles | Users |
| Related software components | Recommendation eengine or GPT software |
| WP/Task | WP7/T7.4 |
| Leader | COMS |

## Business Application Scenario & Business Flow

This section describes a business application scenario on the EnerTEF Platform. The section will begin with the flow of actions for each category of users and then present the complete application scenario demonstrating the interaction of users between them on the EnerTEF integrated platform.

Table 52 AI Service Developers flow of actions

|  |  |
| --- | --- |
|  | AI Service Developers |
| Actor Description | Startups, SMEs, research teams, or technology providers offering AI-based solutions applicable to the energy sector. |
| Flow of actions | * Register and authenticate through the EnerTEF Portal’s Access Management System (TE-3). * Access and browse the EnerTEF Services Catalogue, identify expertise-related challenges, and propose solutions to the relevant end-users. * Request access to EnerTEF Assets (Datasets, Digital Twins, Virtual Assets (TE-13). * Configure and run experiments through the EnerTEF AI Experiment Workbench, request HPC resources, all via the Transaction Manager (TE-9). * Collect experiment outputs, refine solutions if necessary, and prepare intermediate validation reports aligned with the established KPIs. * Receive feedback from the end user and proceed with the implementation. * Present the final AI service on the Experiment Dashboard and notify the Transaction Manager upon submission. |
| Flow Diagram | A diagram of a software company  AI-generated content may be incorrect. |

Table 53 End-Users flow of actions

|  |  |
| --- | --- |
|  | End-Users |
| Actor Description | Stakeholders from the energy sector, including Transmission System Operators (TSOs), Distribution System Operators (DSOs), utilities, Renewable Energy Source (RES) operators, aggregators, and other energy-related entities. End-users may also have assets to provide, making them potential Asset Providers as well. |
| Flow of actions | * Register and authenticate through the EnerTEF Portal’s Access Management System (TE-3). * Access the EnerTEF Services Catalogue, which contains the existing set of validated AI service needs and testing opportunities, initially defined during the Co-Creation AI Living Labs. * Submit new service needs (or modify the already defined services) directly through the Portal if additional or emerging challenges arise. * Assign the implementation of the solution to the Startup/SME that has expressed interest in carrying it out. * Provide feedback to AI service developers based on their interim reports * Approve or reject the validation of solutions based on test results and business/operational relevance via the Transaction Manager. * Provide feedback to the AI Service Developers |
| Flow Diagram | A diagram of a person with text  AI-generated content may be incorrect. |

Table 54 TEF Node Administrators flow of actions

|  |  |
| --- | --- |
|  | TEF Node Administrators |
| Actor name | TEF Asset providers/Node administrators |
| Actor Description | Entities responsible for operating and maintaining the physical infrastructures, virtual environments, datasets, digital twins, and high-performance computing (HPC) resources federated into the EnerTEF Portal. |
| Flow of actions | * Register and onboard their managed assets into the EnerTEF Portal, ensuring proper metadata documentation (capabilities, access policies, operational parameters). * Maintain operational availability, and performance of: Physical testing infrastructures, Digital assets (datasets, simulators, digital twins), HPC resources and cloud environments. * Integrate with the EnerTEF HPC Orchestrator (TE-4) to enable dynamic and seamless resource allocation to AI Service Developers conducting experiments. * Apply data governance and interoperability standards as required by the Data Governance, Data Space, Data Access and Semantic Interoperability Layer (TE-1, TE-2). * Support the secure and permissioned sharing of datasets and system telemetry with AI experiments, under GDPR and cybersecurity regulations. |
| Flow Diagram | A diagram of a software company  AI-generated content may be incorrect. |

The figure below displays the entire application scenario to demonstrate the interaction of the different category of users between them on the EnerTEF Portal. End-users request the implementation of services and validate the results, Startups and SMEs develop services using EnerTEF resources and prepare reports and finally TEF asset providers provide assets and HPC resources. The EnerTEF Platform ensures smooth coordination among these roles to maintain a seamless workflow.

A diagram of a diagram

AI-generated content may be incorrect.

Figure 2 EnerTEF Application Scenario

The figure below illustrates the logical data flow and interaction between the core EnerTEF building blocks (interoperable interfaces), highlighting how telemetry, control, and identity-related information traverses the system. This interconnection architecture enables seamless integration and orchestration of physical and virtual resources across TEF nodes. It captures the mechanisms required to fulfil key user capabilities, including resource discovery, access management, prioritised scheduling, service creation and validation, and execution of AI-enhanced services. Each component plays a pivotal role in ensuring coordinated, efficient, and secure access to TEF infrastructure.A diagram of a company

AI-generated content may be incorrect.

Figure 3 EnerTEF Platform logical business flow

* **EnerTEF Portal:** is the highest-level user interface and single-entry point of access for the EnerTEF modules. The EnerTEF Portal consists of the following submodules:
  + **User Access Management Module:** allows the user form registration and authentication. The User Access Management system will be integrated with the Identity Access Management (IAM) module for the creation and enforcement of access policies and role-based access control (RBAC, AI service developers, End-Users, Node admins).
  + **Services Catalogue Management Module:** it provides basic Service Catalogue operation management with functionalities such as, creation of service requests, proposing solutions and assigning the solution development to startups and SMEs.
  + **Recommendation toolbox:** suggests top tier services to users, providing all necessary details for an informed selection.
  + **Asset Management module:** allows every operation on the Asset List, registering new assets (local platforms and DTs), their parameters and access policies in the EnerTEF platform.
  + **Asset Access Management Module:** allows users to access EnerTEF assets: i) firstly to access EnerTEF local assets (DTs and platforms) by checking the asset’s access policies with the IAM module and then redirecting users to the local platforms and DTs for using them, and ii) secondly to negotiate and consume TEF datasets by utilizing the Dataspace Connector.
  + **Transaction Mechanism:** allows stakeholders to purchase EnerTEF resources, including local assets, platforms and DTs, HPC resources for conducting experiments and access to experimentation workbench for implementing services.
  + **Experimentation Dashboard:** allows users to design their experiments, provide necessary description of the experiment (title, description, date, steps), request the datasets they would like to use.
  + **Orchestrator Dashboard:** displays and performs analytics on TEF resource monitoring data, resource allocation and service execution status.
  + **Validation Dashboard:** allows users to provide feedback, monitor and validate service results, and finally validate the services according to their standards and KPIs.
  + **Analytics Module:** collects data and performs analytics regarding the portal usage, transactions and services usage analytics.
  + **Support Module:** allows end-users to create tickets regarding technical issues they are experiencing in the Portal, access issues, resource conflicts and disputes. It will also allow users and admins to track the progress of the issues and their status.
* **Interoperability Middleware:**
  + **Dataspace connector:** Dataspace Connector allows the interrogation of a TEF datasets between the data provider (TEF provider) and data consumer (Portal’s end users) ensuring data sovereignty and secure data exchange according to IDSA principles.
  + **Connector GUI:** The connector front-end responsible for all user dataspace interactions.
  + **Semantic Interoperability Enablers:** Transforms and homogenizes data across heterogeneous sources, ensuring semantic alignment and consistency. Supports standardized data representation (ontologies) for interoperability and integration.
* **HPC Orchestrator:** monitors, prioritizes and schedules access to HPC resources for executing services and performing experiments in the Experimentation Workbench.
* **Experimentation Workbench:** allows users to perform experiments. Consists of firstly, the experimentation suite that allows users to perform their experiment step by step and, secondly, the model registry which allows users to store the trained models and the achieved KPIs.
* **TEF Nodes:**
  + **TEF datasets:** data to be shared with end users for conducting experiments and training models.
  + **HPC resources:** for conducting experiments, training models and execute services.
  + **TEF assets:** includes TEF local platforms and DTs providing services that Portal’s end-users can access.

The following figure depicts the development view displaying the component interconnection to achieve the desired functionalities of the application scenario based on the same logical business flow:

A diagram of a computer network

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Figure 4 EnerTEF Platform development logical business flow

## General System Use Cases from Business Flow

From the business flow and application scenario mentioned in the previous section the following general system use cases (GSUCs) are derived that will be elaborated in the sequent deliverable D2.2 – “Final version of the AI-based services catalogue and EnerTEF’s federated architecture”.

Table 55 EnerTEF Platform GSUCs

|  |  |  |
| --- | --- | --- |
| System Use case Title | Actors | Components |
| User Registration | All | EnerTEF Portal, IAM |
| User Authentication | All | EnerTEF Portal, IAM |
| Access Service Catalogue | AI service developers, End-Users | EnerTEF Portal, Service Catalogue Management Module |
| Submit new service request | End-Users | EnerTEF Portal, Service Catalogue Management Module |
| Propose solutions | AI service developers | EnerTEF Portal, Service Catalogue Management Module |
| Perform transactions | AI service developers | Portal, Transaction Mechanism |
| Request access to assets | AI service developers | EnerTEF Portal, Transaction Mechanism, Asset Access Management Module, IAM |
| Request access to HPC resources | AI service developers | EnerTEF Portal, Transaction Mechanism, HPC orchestrator |
| Configure and perform experiments | AI service developers | EnerTEF Portal, Transaction mechanism, Experimentation Dashboard, Experimentation Workbench |
| Create validation reports | AI service developers | EnerTEF Portal, Validation Dashboard |
| Receive feedback from users | AI service developers | EnerTEF Portal, Validation Dashboard |
| Assign service implementation to startup SME | End-Users | EnerTEF Portal, Service Catalogue Management module |
| Provide feedback to service developers | End-Users | EnerTEF Portal, Validation Dashboard |
| Approve or reject validation of solution | End-Users | EnerTEF Portal, Validation Dashboard |
| Register assets | Node Administrators/TEF Asset Providers | EnerTEF Portal, Asset Management Module, IAM |
| Monitor assets | Node Administrators/TEF Asset Providers | EnerTEF Portal, Asset Management Module, HPC orchestrator |

## SGAM oriented EnerTEF RA

EnerTEF aims to establish a Common European-scale Energy AI Federated Testing and Experimentation Facility (TEF), facilitating extensive adaptation validation and upscale of AI tools and services across the energy sector so as to bridge the gap between demand and limited availability of rigorously tested AI products. The EnerTEF platform will bridge AI Service Developers (Startups, SMEs, researchers) with End-Users (Energy sector stakeholders such as TSOs, DSOs, RES operators, utilities, aggregators) to accelerate the deployment of trustworthy AI solutions in real and near-real environments.

**SGAM Model**

The SGAM[[1]](#footnote-1) was initially developed under the M/490 mandate from the European Commission (EC) to the European standardization organizations, CEN, CENELEC, and ETSI. Its primary goal was to identify existing technical standards relevant to Smart Grids and to highlight any gaps in current technologies and standardization efforts. SGAM serves as a framework to harmonize terminology, technologies, and objectives by providing a reference model that functions as a blueprint for designing future Smart Grid architectures.

The conceptual SGAM model consisting of five interoperability layers, each comprising six domains and five zones, is shown in the figure below.

A diagram of a multicolored diagram

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Figure 5 SGAM Model

The SGAM Domains reflect the stages of the energy conversion process, as outlined in the widely recognized NIST Conceptual Model[[2]](#footnote-2). These domains are defined as follows[[3]](#footnote-3):

* **Bulk Generation:** Refers to the large-scale production of electricity using sources such as fossil fuels, nuclear energy, hydroelectric plants, offshore wind farms, and extensive solar facilities like photovoltaic (PV) and concentrated solar power (CSP) plants. These are typically linked to the transmission grid.
* **Transmission:** Involves the high-voltage infrastructure used to transport electricity across long distances.
* **Distribution:** Covers the systems responsible for delivering electricity from the transmission network to end users.
* **Distribution Energy Resources (DER):** Encompasses small-scale, decentralized electricity generation units connected to the public distribution network, usually ranging from 3 to 10 MW. These units can be managed directly by a Distribution System Operator (DSO).
* **Customer Premises:** Includes all locations where electricity is consumed and potentially generated. These range from industrial and commercial sites to residential homes (e.g., factories, airports, shopping malls, and households). They may also host energy technologies like PV systems, electric vehicles (EVs), battery storage, and microturbines.

The Zones, which intersect with the SGAM Domains, represent the ICT-based control layers that manage the energy conversion process. Structured according to the automation pyramid, the Zones are defined as follows:

* **Market:** Represents the various market-related activities across the energy value chain, including energy trading, retail, and mass markets.
* **Enterprise:** Covers business and organizational operations, services, and infrastructure for stakeholders like utilities and energy providers. This includes functions such as asset management, logistics, workforce planning, training, billing, and customer relationship management.
* **Operation:** Focuses on the control and monitoring of power systems within each domain. Examples include Distribution Management Systems (DMS), Energy Management Systems (EMS) for generation and transmission, microgrid controllers, virtual power plant management platforms, and EV fleet charging coordination systems.
* **Station:** Acts as the aggregation point at the local level, responsible for tasks like data collection, function integration, substation automation, local SCADA systems, and plant-level supervision.
* **Field:** Involves devices used for real-time monitoring, protection, and control of the power system. This includes protection relays, bay controllers, and Intelligent Electronic Devices (IEDs) that collect and use data from the physical infrastructure.
* **Process:** Represents the actual physical and chemical processes in energy conversion—such as generating, transmitting, or consuming electricity. It includes all physical components directly involved, like generators, transformers, circuit breakers, lines, cables, loads, sensors, and actuators.

The following layers of the SGAM models are defined for the EnerTEF platform:

1. **Business Layer:** provides a business view of the EnerTEF platform and consists of all the end users along with their objectives. Particularly:
   * AI service developers: Startups, SMEs, research teams, or technology providers offering AI-based solutions applicable to the energy sector.
   * End users: Stakeholders from the energy sector consuming services, including TSOs, DSOs, utilities, RES operators, aggregators, and other energy-related entities.
   * TEF Asset providers-Node administrators: TEF providers, AI factories, entities responsible for providing assets, operating and maintaining the physical infrastructures, virtual environments, datasets, digital twins, and high-performance computing (HPC) resources federated into the EnerTEF Portal.
2. **Function Layer:** describes the services of the EnerTEF platform. Particularly:
   * Registration and authentication,
   * Access to EnerTEF services catalogue, submit new service needs, assign implementation, approve or reject validation,
   * Access to EnerTEF Assets (Datasets, DTs, digital platforms),
   * AI Experiment design and conduction,
   * Experiment validation,
   * Regulatory compliance,
   * Feedback on services and experiments,
   * Maintain operational availability of assets HPC resources and testing infrastructures.
3. **Information Layer:** provides the necessary mechanism for data modelling and homogenization ensuring data integrity. Consists of all the syntax in an effort to describe the appropriate semantic vocabularies and design the needed metadata repository and data interoperability process. Our methodology will focus on SAREF4ENER, SAREF4BLDG.
4. **Communication Layer:** provides all the necessary protocols for securing data transfer between entities ensuring data sovereignty and protection. Particularly, Dataspaces will be leveraged that enable secure and controlled data exchange between participants. They enforce usage policies, manage data access, and ensure interoperability across systems. Data space Connectors are key to maintaining data sovereignty and trust in distributed environments. The Governance framework will be defined that sets the rules, policies, and structures that manage data sharing, access, and responsibilities among participants. It ensures trust, compliance, and alignment with legal and ethical standards. Effective governance enables secure and fair collaboration.
5. **Component Layer:** Consists of all the components that will be developed. Particularly:
   * **EnerTEF central platform components:** including Portal, Experimentation module, HPC orchestrator, IAM module.
   * **EnerTEF local assets:** offerings from TEF nodes, datasets, DTs, Platforms, HPC Resources.

And finally, the EnerTEF reference architecture based on SGAM is visualized below. The full detailed EnerTEF reference architecture will be elaborated in D2.2 – “Final version of the AI-based services catalogue and EnerTEF’s federated architecture”.

**A screenshot of a computer screen

AI-generated content may be incorrect.**

Figure 6 EnerTEF SGAM RA

## Conclusion & Future steps

The work conducted in this deliverable has established the foundational architectural design of the EnerTEF platform. Through a detailed component catalogue, application scenario, generic system use case outline, and a layered SGAM-based representation, we have laid the groundwork for an interoperable, modular, and federated experimentation ecosystem aligned with key European digital and data initiatives.

At this stage, the architecture serves as a functional baseline to guide the implementation of the platform's core components and services. However, several technical elements remain under active development, particularly in the areas of interoperability, orchestration, secure data access, and standardized service interactions. In this phase (M10), the EnerTEF architecture demonstrates alignment with three key reference architecture standards: the Smart Grid Architecture Model (SGAM), the International Data Spaces Association (IDSA) reference architecture, and the GAIA-X framework. This ensures compliance with the project KPI for this milestone. Moving forward, the architecture will evolve to integrate additional standards, aiming to reach adherence to at least seven reference architectures by M18, ensuring robustness, interoperability, and European alignment.

Looking ahead, the next critical milestone will be the formulation of the final EnerTEF Reference Architecture to be delivered in D2.2 – “Final version of the AI-based services catalogue and EnerTEF’s federated architecture”. This architecture will go beyond the current SGAM abstraction and offer a comprehensive, implementation-ready model capturing the platform’s refined component interactions, data flows, governance, and compliance layers. The final reference architecture will be validated against relevant European and international standards and initiatives (e.g., IDSA, GAIA-X, DOME, BDVA, AIoD).

In parallel, the use cases introduced in this deliverable will be further developed and formally analysed in Deliverable D2.2 – “Final version of the AI-based services catalogue and EnerTEF’s federated architecture”, where they will be used to validate the architecture and demonstrate its applicability, completeness, and extensibility across real-world scenarios.

Through this iterative refinement, EnerTEF aims to deliver a scalable and standards-aligned architecture that facilitates trusted AI experimentation in the energy sector, while ensuring openness, compliance, and reusability across TEF nodes and stakeholders.

1. URL: <https://syc-se.iec.ch/deliveries/sgam-basics/> [↑](#footnote-ref-1)
2. Office of the National Coordinator for Smart Grid Interoperability. NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0; Technical Report; National Institute of Standards and Technology (NIST): Gaithersburg, MD, USA, 2014. [↑](#footnote-ref-2)
3. Smart Grid Coordination Group. Smart Grid Reference Architecture; Technical Report; CEN-CENELEC-ETSI: Brussels, Belgium, 2012 [↑](#footnote-ref-3)