D3.3 Plug and Play Asset Registration

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Executive Summary

This deliverable, D3.3 "Plug and Play Asset Registration," presents the outcomes of Task 3.3 of Work Package 3 within the OPENTUNITY project, whose overarching goal is to establish a Federated Data Exchange Infrastructure (FDEI) for secure, interoperable energy-data exchange across Europe. Task 3.3 specifically developed and validated a plug-and-play methodology and its reference implementation, the Web Application developed by Bluesun Automation Ltd. (**BSA-DEMO**), enabling energy assets to be automatically registered, identified, and integrated into the OPENTUNITY ecosystem.

The methodology defines the conceptual and data-model framework for asset registration. It distinguishes between **static asset data** (nominal characteristics, operational constraints, communication protocols) and **dynamic data** used for flexibility estimation. The work introduces a unified schema that allows devices and systems, from simple appliances to composite energy setups, to be represented through standardized JSON structures. The plug-and-play concept is realized by linking each registered asset to a unique **OPENTUNITY QR code (OT-QR)**, enabling direct access to its digital record.

The BSA-DEMO is built on a Django & Django REST web framework backend, and a MySQL relational database, hosted on the cloud platform pythonanywhere.com. The architecture follows a secure three-tier model (frontend / application / database) **with strict role-based permissions and API-key authentication**. It supports interoperability with external systems such as Energy Management Systems (**HEMS/BEMS**) and Flexibility Service Providers (**FSPs**), allowing authorized partners to register or retrieve asset data seamlessly through HTTPS-secured endpoints.

Functionally, the application provides a role-aware web interface for Economic Operators (manufacturers, aggregators, service providers) and administrators to create and manage assets. Each asset is automatically assigned a unique **OT-QR code linking to its corresponding JSON dataset**. The integrated REST API allows secure, authenticated access for data exchange and validation. In addition, an extensible **KPI-monitoring** module continuously evaluates system performance and data completeness The application has been designed with forward compatibility in mind, aligning with upcoming EU sustainability frameworks such as the Ecodesign for Sustainable Products Regulation (ESPR) and the **Digital Product Passport (DPP).** Once standardized, DPP payloads in JSON-LD are set to be natively ingestible through the BSA API.

Recognizing the diversity of existing infrastructures, the deliverable proposes a **hybrid integration strategy for legacy or non-digitally native assets**. These can be onboarded through manual entry via the BSA-DEMO user interface (UI), via JSON uploads through the ingestion API, or — in the near future — through automated data extraction from existing identifiers (EPREL QRs, GS1-GTIN, DPP). This ensures inclusiveness across devices of different digital maturity levels.

The application will be tested through collaboration with pilot partners ETRA (Spain), AMIBIT (Slovenia), and ICCS (Greece). Testing will follow Test Case 3.3.1, verifying end-to-end data retrieval and KPI performance. The two principal KPIs, the **QR Code Functionality Rate** (target ≥ 90 %) and the **Completeness Score** (target ≥ 70 %) should demonstrate robust system reliability and data quality.

The results confirm that plug-and-play registration of flexibility assets is both technically viable and operationally effective. The BSA-DEMO provides a scalable foundation for interoperable asset management within OPENTUNITY and beyond. Future work will focus on integrating finalized DPP/ESPR standards and automated data ingestion from external registries (EPREL, GS1) and maintaining and enriching the BSA-DEMO and its database after task completion, throughout the OPENTUNITY program.

Copyright statement

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2 INTRODUCTION

The transition toward a decarbonized, and interoperable European energy system demands new and efficient approaches for integrating and managing distributed energy resources. Within this context, the OPENTUNITY project aims to create an open and federated digital ecosystem capable of enabling seamless data exchange and service interoperability among all energy actors, from households and prosumers to aggregators, system operators, and service providers. One of the project's key innovations, developed under Task 3.3 "Plug-and-Play Recognition for Flexibility Devices" of Work Package 3, is the creation of a unified methodology and software platform that allows flexible energy assets to be automatically recognized, registered, and connected to this ecosystem.

2.1 Purpose of the document

The purpose of this document is to present the full methodological and technical framework developed under Task 3.3 (T3.3), as part of the OPENTUNITY project's Work Package 3 (WP3). It describes the concept, design, and implementation of the BlueSun Web Application (BSA-DEMO), a cloud-based platform developed by BlueSun Automation Ltd. (BSA) to enable the automatic identification, registration, and sharing of static energy asset data across the OPENTUNITY ecosystem.

This deliverable provides a unified overview of how **flexibility-relevant** device data such as **nominal characteristics** and **operational constraints** (e.g. vendor, model, rated power, and communication interfaces etc.) are collected, structured, and made interoperable through a combination of QR code technology, REST APIs, and a federated data exchange architecture. It also demonstrates how this implementation contributes to the broader objective of interoperable energy data spaces, by creating a bridge between distributed assets and the OPENTUNITY Federated Data Exchange Infrastructure (FDEI).

2.2 Scope of the document

The scope of this deliverable extends across the entire lifecycle of the plug-and-play registration mechanism, from conceptual design and data modeling to software implementation, pilot validation, and final deployment. It defines flexibility-related asset data categories an addresses how these can be captured through QR-based identification and API data access mechanisms and securely exchanged among project partners such as Energy Management System (HEMS/BEMS) and Flexibility Service Providers (FSPs).

In particular, this document demonstrates how the developed system enables different actors, such as Economic Operators (manufacturers, aggregators, service providers) and end-users (households, prosumers) to interact with the BSA-DEMO for both data provision and data retrieval. The QR code mechanism provides a practical and standardized method for linking physical devices to their digital counterparts in a database, enabling plug-and-play onboarding of flexibility assets.

Additionally, the document explores how the BSA solution aligns with ongoing European regulatory and standardization frameworks, most notably the Ecodesign for Sustainable Products Regulation (ESPR) and its accompanying Digital Product Passport (DPP) initiative. These frameworks will soon mandate product-level traceability, sustainability data, and digital interoperability across the EU. The BSA-DEMO is designed with forward compatibility for these developments, fostering a framework in which standardized DPP schemas can later be integrated natively into the OPENTUNITY ecosystem once they are formally established.

2.3 Structure of the document

The document is organized into the following main chapters:

Chapter 3 – Methodology: Presents the conceptual and methodological framework of T3.3, defining asset data categories, flexibility attributes, and the principles of plug-and-play registration.

Chapter 4 – System Architecture: Describes the technical design of the BSA-DEMO, including its data storage, authentication, API mechanisms, and interoperability features.

Chapter 5 – Cloud-based Implementation of T3.3-D3.3: Details the development of the BSA-DEMO, its deployment on the cloud platform, and its key functionalities such as asset registration, QR code generation, and API-based data exchange.

Chapter 6 – Integration of Digital Product Passports: Examines the linkage between the BSA framework and forthcoming DPP and ESPR standards, fostering forward compatibility with European data-exchange infrastructures.

Chapter 7 – Legacy Equipment: Outlines strategies for integrating digitally limited legacy assets into the OPENTUNITY ecosystem through manual entry or hybrid digital identification pathways.

Chapter 8 – Testing and Deployment: Describes how the BSA-DEMO will be validated in collaboration with project partners (ETRA, AMIBIT, ICCS), including the definition of test cases, KPIs, and datasets.

Chapter 9 – Conclusions: Summarizes key findings, results, and future directions for scalability and long-term adoption of the plug-and-play registration framework.

References and Acronyms: Listed in relevant tables**.**

Annex 1 – Asset Data Field Schema (T3.3-D3.3): Presents the full JSON schema of the BSA database structure, detailing all fields, data types, and weighting factors for asset data completeness scoring.

Annex 2 – JSON Data Format (Example): Provides a representative JSON output as retrieved from the BSA-DEMO API for a single registered asset, illustrating the data model and its alignment with OPENTUNITY's interoperability standards.

3 METHODOLOGY

Task 3.3 was executed through a structured, four-phase methodology that transformed a conceptual framework into a functional, standards-compliant implementation within the OPENTUNITY ecosystem. It began with the definition of scope and objectives, identifying the data and interoperability requirements for flexibility extraction (Phase I), followed by the development of a methodological and data model establishing the asset classifications, asset schema while analysing static versus dynamic asset data (Phase II). The third phase focused on system design and implementation, translating the model into the BSA cloud platform, REST API, and supporting microservices for registration, QR-code issuance, and API authentication (Phase III). Finally, validation and alignment activities ensured interoperability across pilots, assessed user workflows, and prepared integration guidelines with the Digital Product Passport (DPP) and ESPR frameworks (Phase IV). This phased approach, refined through partner feedback, ensured technical robustness, and regulatory alignment toward future European energy-data standards.

3.1 Description of T3.3 and its relation to other tasks

3.1.1 Purpose and Scope

Task 3.3, titled "Plug-and-Play Recognition for Flexibility Devices," defines the methodology and the supporting digital services that enable energy assets to be automatically registered and integrated into the OPENTUNITY ecosystem. The task contributes directly to WP3, which foresees the development of the Federated Data Exchange Infrastructure (FDEI), the backbone for secure and interoperable data exchange among all project participants. Through QR code identification and API-based registration, **Task 3.3 establishes a standardized process for capturing and sharing nominal characteristics and operational constraints, such as manufacturer, model, rated power, operational limits, and communication details**. These static data elements are **fundamental for both home or building energy management systems (HEMS/BEMS) and grid-side applications** to understand and exploit each asset's flexibility potential. The results of this work are consolidated in the D.3.3 Plug-and-Play Asset Registration deliverable, which documents the methodology, architecture, and web-based tools created.

3.1.2 Methodological Focus

The main goal of Task 3.3 is to facilitate secure asset information transfer from an operating flexible asset to OPENTUNITY stakeholders, by providing a simple, interoperable, and user-friendly methodology that minimizes configuration effort while maintaining high data integrity. The approach specifies how essential information about each energy asset can be structured, validated, and made accessible through a digital platform, the Bluesun T3.3 Web-App Demo (DEMO). More specifically, when a QR code is scanned, an end-user application retrieves a pre-validated JSON dataset describing the assets technical and operational parameters. This information is aggregated and stored in the DEMO's internal schema and made available to authorized actors via secure REST APIs. The outcome is a standardized and reproducible method for plug-and-play integration of assets from different manufacturers into a common data environment, ensuring interoperability and supporting flexibility analysis.

3.1.3 How T3.3 Supports the OPENTUNITY Ecosystem

Stakeholder Benefits

HEMS/BEMS Operators: Instant device recognition and automatic population of configuration data.

Aggregators & FSPs: Reliable, machine-readable information about asset capabilities and constraints for flexibility forecasting.

DSOs/TSOs: Access to harmonized datasets supporting network visibility and planning.

End-Users: Quick, error-free asset onboarding through a simple QR scan, fostering active participation of Prosumers in energy flexibility programs.

During initial configuration, commissioning, or maintenance of HEMS/BEMS systems, an installer or prosumer scans the QR code affixed to an energy asset such as a Battery, Inverter, HVAC unit, or EV charger. The scan retrieves the asset's nominal characteristics and operational constraints, including electrical ratings, controllable parameters, and communication protocol, from the DEMO web application. This data can automatically populate the HEMS/BEMS configuration interface, reducing manual data entry, preventing setup errors, and enabling fast, user-friendly onboarding even for non-specialists. In this way, **T3.3 contributes directly to the interoperability and user-empowerment objectives of OPENTUNITY and supports the concept of do-it-yourself integration of flexible devices.**

Furthermore, the same standardized dataset is also available through API layers for Aggregators and Flexibility Service Providers (FSPs) participating in OPENTUNITY for flexibility estimation purposes. These actors can securely retrieve static information describing the technical capabilities and operational envelopes of registered energy devices or systems. This information supports flexibility quantification and complements dynamic measurement data. It can also improve NILM-based disaggregation algorithms, allowing the identification of hidden loads and better estimation of controllable demand by providing for example – retrieved information from energy labels. As a result, T3.3-D3.3 establishes an automated and trustworthy data source that supports energy flexibility forecasting, evaluation, and market participation.

3.2 Useful information for flexibility extraction: Asset Data

A central methodological question arising from T3.3 is "Which data are needed for flexibility extraction, and how are they used to assess and enable the flexibility of energy assets?" To answer this, a top-down analysis was conducted based on recent peer reviewed research on energy-flexibility quantification [1 - 4] that examine flexibility at both device and system level (e.g., Zhao et al. 2022; Reynders et al. 2018). These studies converge on the idea that energy flexibility represents the ability of a device, system, or building to modify its electricity consumption or production in response to an external signal (e.g. price, grid constraint, or market request) without compromising user comfort or process requirements.

3.2.1 Energy Assets and Their Role in Flexibility

Within the OPENTUNITY framework, energy assets are all electrical devices or systems that can contribute to flexibility. They are considered "assets" because they hold economic value since their operational adjustment can generate revenue or savings through participation in flexibility or balancing markets. Assets can be:

- **Controllable individual devices**, such as heat pumps or air condition units (HVAC), electric vehicle chargers (EVSE), water heaters or smart white appliances, where consumption can be directly shifted or curtailed.

- **Composite or hybrid systems**, such as a PV and Battery installation, where an inverter or a battery management system (BMS) provides the necessary control interface.

This distinction is important since photovoltaic panels, batteries or similar energy related devices alone do not have controllable power behaviour, but when paired with an inverter, a BMS, or similar they become active, flexible assets. Furthermore, for flexibility extraction, each asset is described by two broad categories of data:

- **Static data**, the information that does not change frequently and defines the inherent characteristics of the device (e.g., manufacturer, rated power, operational limits, communication interface, location, etc.).
- **Dynamic data**, the time-dependent operational values such as real and apparent power, state of charge, temperature, or device status, which are measured continuously and used in control or forecasting.

Since Task 3.3 focuses on plug-and-play registration, it primarily handles static asset data, which are required for automatic configuration, interoperability, and flexibility estimation. On the contrary, dynamic data streams are managed by other FDEI participants and described thoroughly in other work packages.

3.2.2 Categories of Static Asset Data

Static data useful for flexibility extraction can be grouped into three main categories, namely device-specific, user-specific, and location-specific, as illustrated in the next Figure 3.1.

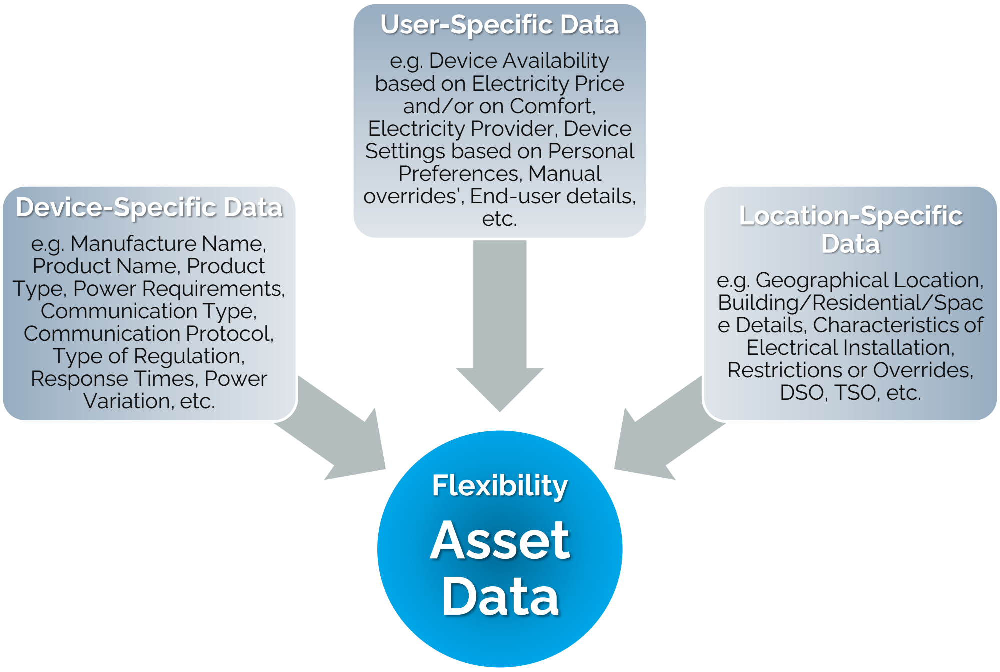

Figure 3.1 The diagram illustrates how flexibility-related information is derived from three main data categories: device-specific, user-specific, and location-specific attributes. Together, these datasets form the complete profile of an energy asset, enabling accurate flexibility assessment and integration within the OPENTUNITY ecosystem.

A) **Device-Specific Data:** This category contains technical and operational information that defines what the asset is and how it behaves. Examples include (but are not limited to):
- Vendor, model name, product type, rated power, voltage and current ranges, energy capacity
- Communication type and supported protocol (Modbus, REST, MQTT)
- Type of control or regulation, response times, and ramp rates
- Power variation capability and minimum/maximum set-points, etc.

These parameters correspond to what are often referred to as an asset's nominal characteristics and operational constraints. They define the feasible operational envelope that determines the device's flexibility potential.

B) **User-Specific Data:** These data describe how the device is used and the end-user preferences that influence its availability for flexibility services. Examples include:
- Device availability depending on comfort settings or electricity price
- Manual overrides and scheduling preferences
- Chosen electricity supplier or contract type, etc.

User-specific parameters are essential for modelling realistic flexibility: they determine when and how much an asset can adjust its operation without affecting comfort or service delivery.

C) **Location-Specific Data:** This category refers to contextual information about the environment where the device is installed. Examples include:
- Geographical coordinates or building identification
- Type of installation (residential, commercial, industrial)
- Electrical characteristics of the site (phase connection, grid code compliance)
- Relevant DSO/TSO area, local constraints, or control restrictions, etc.

Location-specific data allow flexibility values to be linked to local grid conditions, making it possible for DSOs or aggregators to assess spatial flexibility potential.

For the purposes of Task 3.3, these static data categories form the core information set encoded during the plug-and-play asset registration process. When a device's QR code is scanned, its device-specific attributes are retrieved, while its user and location context are linked during HEMS/BEMS registration. This enables the automatic population of flexibility-relevant parameters in their database, preparing each asset for subsequent flexibility estimation, optimization, and market participation within the FDEI.

D) Relevance to T3.3: In practice, this data supports several functions within the OPENTUNITY ecosystem:

- **Modelling flexibility potential**, by linking device or system capacities and operational limits with control strategies.
- **Forecasting and scheduling**, through algorithms that combine static characteristics with real-time measurements to predict available flexibility.
- **Aggregation and market integration**, where standardized data formats enable aggregators and service providers to compute total flexible capacity, optimize dispatch, and submit bids to corresponding markets.

E) Interoperability: Moreover, to be interoperable within the OPENTUNITY ecosystem, static flexibility-related asset data must follow two overarching principles:

- **Device-agnostic:** The data model must apply uniformly across different devices, brands, and operating systems so that information from any asset can be interpreted consistently.
- **Standardized:** All data should be expressed in a consistent, machine-readable format (e.g., JSON-based schema aligned with GS1 Digital Link principles) to ensure uniform ingestion and exchange through APIs.

This data-driven characterization ensures that flexibility can be quantified and operationalized consistently across heterogeneous assets and systems, forming the foundation for automated plug-and-play participation in flexibility services.

3.3 Conceptual Approach to Plug & Play Asset Registration

The conceptual approach behind Task 3.3 - Plug & Play Recognition for Flexibility Devices evolved from a simple idea: to make asset data universally accessible and usable across the OPENTUNITY ecosystem without requiring complex manual configuration by installers or end-users. Once the relevant asset data categories were defined (see Section 3.2), the task focused on developing a secure and automated method for providing these data to OPENTUNITY participants, mainly prosumers, HEMS/BEMS operators, and FSPs, through a combination of QR-code identifiers and API-driven data exchange.

3.3.1 Concept and Rationale

At the heart of the concept lies the flexible energy asset, either a controllable device (e.g., HVAC, EVSE, water heater) or a composite system (e.g., PV + Battery + Inverter). Each asset possesses a set of static flexibility-related asset data, that must be made available to the various actors of the OPENTUNITY ecosystem. The process begins with the end-user (e.g., Prosumer), who interacts with the physical asset via a QR code. By scanning the code, the user initiates a connection to a cloud-based OPENTUNITY plug-and-play repository, which retrieves or registers the corresponding static data.

a) **Trigger event:** The need for asset data arises either
   i. during the installation and configuration of a HEMS/BEMS, when control parameters (e.g., Modbus registers) are required for correct communication with a device; or
   ii. during flexibility assessment and NILM (Non-Intrusive Load Monitoring) analysis, where FSPs require access to nominal characteristics (e.g., energy label, rated load) to improve disaggregation and flexibility estimation.

b) **Data flow:** The asset data are provided automatically and securely via cloud-based communication between a data hub API and partner systems, minimizing manual data entry.

c) **Access method:** The exchange is initiated through the scan of a QR code (or similar data carrier) that resolves to an API endpoint. Once the API key of an authorized OPENTUNITY partner is validated, the relevant JSON-encoded asset data are retrieved.

d) **Usability:** The data become operational within the partner systems native environment (e.g., HEMS/BEMS, FSPs), enabling device control, flexibility quantification, and energy optimization.

Figures 3.2–3.3 illustrates this workflow:

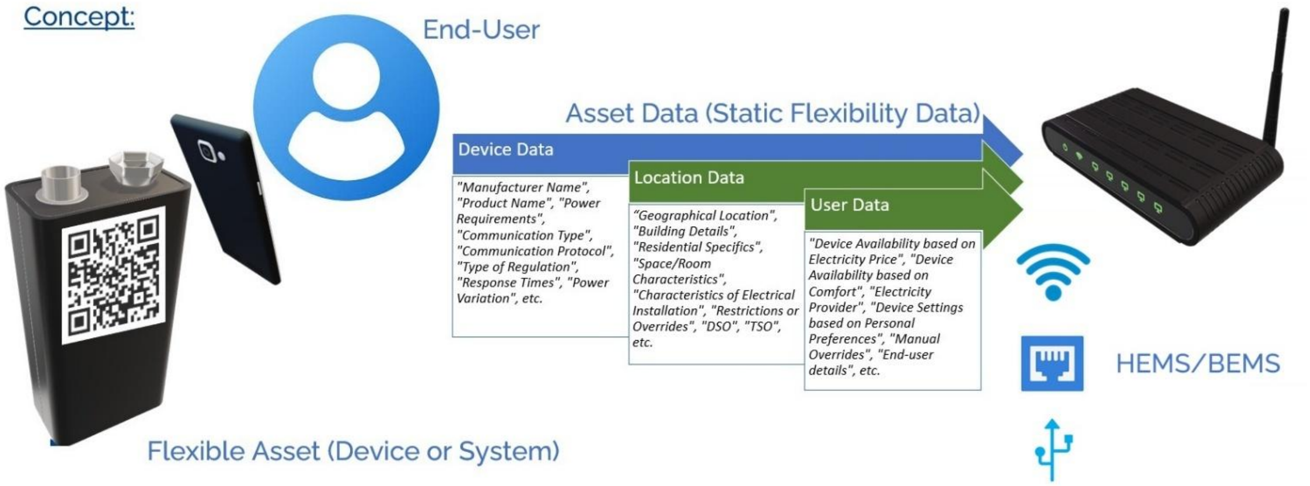

Figure 3.2 Conceptual flow of asset data from end-user to OPENTUNITY participants via HEMS/BEMS

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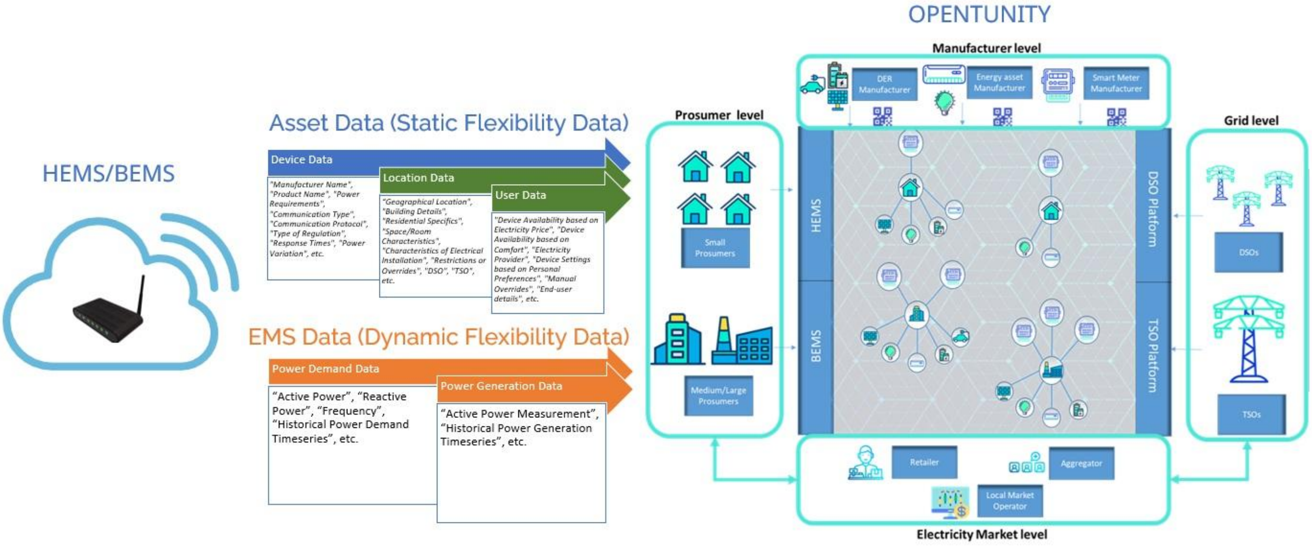


Figure 3.3 Continued Integration of static and dynamic flexibility data streams within the energy management architecture.

Since the launch of WP3, the scope of Task 3.3 has been refined to ensure practical and scalable implementation. Initially, it was envisaged that each manufacturer would directly share flexibility device data with the OPENTUNITY ecosystem via a Dataspace Connector. However, this approach proved impractical, and a more streamlined solution was adopted, namely the creation of an intermediate cloud-based infrastructure to aggregate and harmonize flexibility-related asset data from multiple sources before sharing it with OPENTUNITY participants.

Most manufacturers already publish technical documentation (e.g., datasheets, manuals, and configuration files) through their websites or distributors. Building on this, Task 3.3 established a central data hub that consolidates such information from manufacturers, end-users, and other contributors, transforming it into standardized asset data accessible to partner HEMS/BEMS platforms via a secure REST API. This refined approach enables efficient, secure, and vendor-neutral integration of both new and legacy flexibility assets into the OPENTUNITY ecosystem. Figure 3.4 illustrates this designed approach and the subsequent data flows, as it was presented in the plenary meeting in Graz, in October 2024.

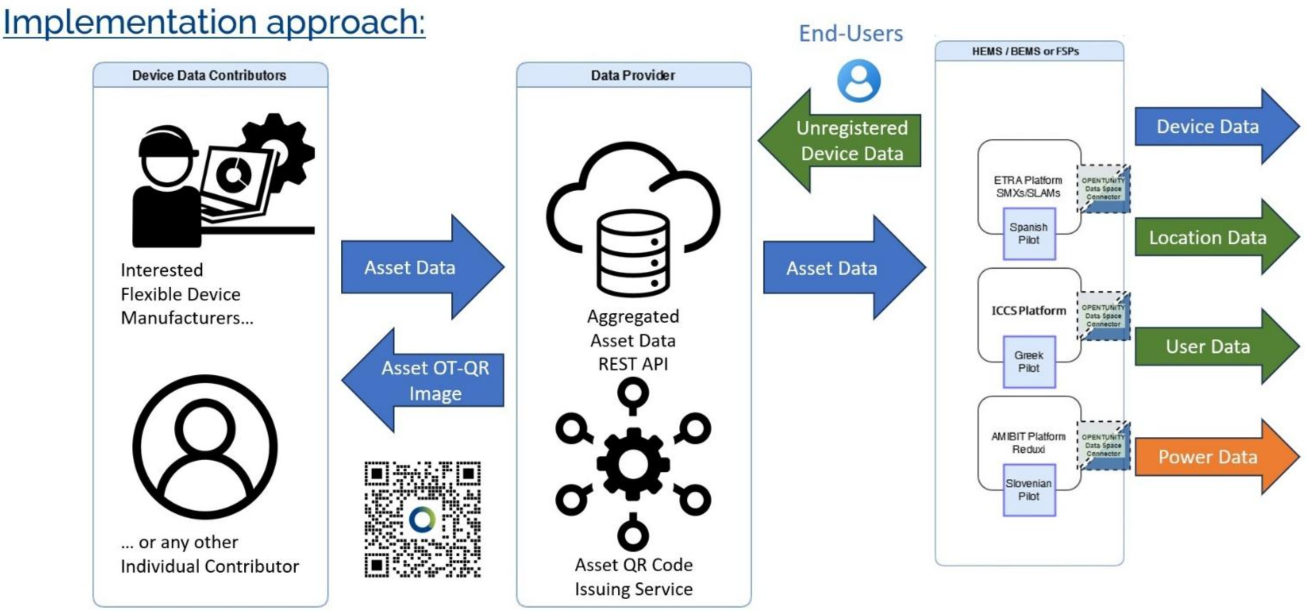


Figure 3.4 Implementation workflow of the asset registration and QR-code issuing microservices.

A specific challenge concerned unregistered legacy devices, which often predate current digital identification standards and therefore lack machine-readable data carriers. To mitigate this, end-users can manually provide key technical information via a user-interface (UI), ensuring that essential parameters are still captured. Since the OPENTUNITY dataspace operates primarily from the HEMS/BEMS level upward, deploying additional dataspace connectors between the plug-and-play repository and the FDEI was deemed unnecessary. To simplify the user experience, end-users employ a single mobile application supported by their HEMS/BEMS or FSP which would handle both asset registration (QR scanning) and the retrieval of flexibility-related information through secure API calls.

Furthermore, recognizing that newer devices increasingly embed multiple standardized QR codes, **the concept was extended to leverage existing identifiers, such as the EPREL QR (European Product Registry for Energy Labelling) and notably those linked to forthcoming Digital Product Passports (DPPs).** Since DPPs, unlike earlier registries such as EPREL, are expected to include comprehensive product-level metadata covering technical performance, energy characteristics as well as lifecycle attributes, their integration ensures long-term alignment with the ESPR framework and enhances the reliability of imported asset attributes.

3.3.2 Alignment with the DPP-ESPR framework

Following the adoption of the Ecodesign for Sustainable Products Regulation (ESPR) in July 2024, **the project consortium identified strong synergies between the Digital Product Passport (DPP) initiative and the plug-and-play methodology**. The DPP, envisioned as an electronic identity for physical products, will contain verified data on energy consumption, material composition, recyclability, repairability, and environmental performance. Recognizing this overlap, the task leader (Bluesun Automation Ltd) carried out a “Feasibility Review on Aligning WP3-T3.3 Developments with ESPR and DPP Requirements.” **The study concluded that the existing BlueSun API and QR-code infrastructure could potentially serve as a complementary access mechanism for DPP-compliant assets**, allowing future extension of the plug-and-play system to exchange sustainability and lifecycle data alongside flexibility parameters. However, for the effective integration of DPP data into WP3-T3.3 and the broader OPENTUNITY ecosystem, several key challenges must be overcome. Most critically, the establishment of standardized and interoperable DPP formats. Without a unified data model, it would be impossible to design a mechanism capable of consistently retrieving, interpreting, and utilizing DPP information across different manufacturers and product categories. As the relevant technical specifications are not expected to be finalized before late 2025, uncertainty remains regarding their deployment within the timeframe of WP3. Nonetheless, to maximize future compatibility, Deliverable 3.3 provides forward-looking guidelines for integrating DPP-based data exchange mechanisms. Even so, the practical realization of these capabilities will depend on the actual circulation of DPPs and therefore require continued research, testing, and alignment efforts beyond the completion of WP3.

The goal is to ensure that WP3-T3.3's Plug & Play Asset Registration system aligns with the requirements of the European Commission's Digital Product Passport initiative and ESPR directives, while maintaining its primary objective of facilitating the aggregation and delivery of flexibility data. Figure 3.5 illustrates a revised designed approach.

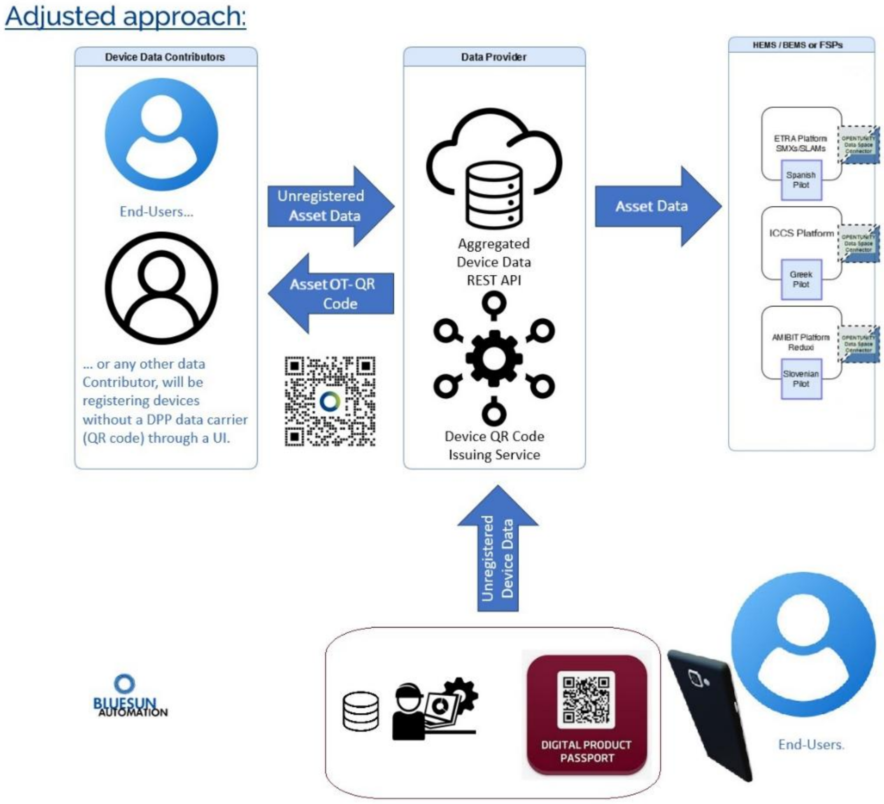


Figure 3.5 Adjusted approach supporting unregistered devices and Digital Product Passport (DPP) integration.

3.4 Data Elements for Asset Characterization

The data model developed in Task 3.3 defines the complete structure of information required to describe each asset’s flexibility potential and to ensure interoperability within the OPENTUNITY ecosystem. Following the methodological analysis (Section 3.2), these data elements represent the static digital identity of an energy device or system, its **nominal characteristics and operational constraints**, and other contextual information necessary for flexibility extraction and control.

The schema serves as the formal definition of required attributes for plug-and-play registration. It standardizes how information about diverse assets (e.g., batteries, EV chargers, HVAC systems, PV inverters) is represented and exchanged through the DEMO and its REST APIs. The schema is organized into logical groups that define how asset data are represented, validated, and weighted within the OPENTUNITY ecosystem. Each data field carries a **weight factor** that reflects its importance for asset registration and flexibility extraction.

- **Mandatory:** The essential fields required for asset registration and minimal flexibility identification. **Weight = 1.0**
- **Recommended:** The fields that enhance the quality of flexibility estimation or enable specific use cases. **Weight = 0.7**
- **Optional:** The contextual information used for traceability, DPP alignment, or analytics. **Weight = 0.3**

3.4.1 Structure and Attribute Groups

The schema, provided in detail in Annex 1 – Asset Data Fields Schema (T3.3-D3.3), is organized into several logical groups (Table 3.1) reflecting how flexibility data are used and validated throughout this task and eventually the OPENTUNITY ecosystem:

Table 3.1 Description of Logical Groups and relation to Attribute - Weight matches.

Logical Group	Description	Attribute (Weight)
Asset Data & Metadata	Core identification and classification fields used to uniquely describe the asset and link it to manufacturer records or DPP references.	dpp_url(0.7), opentunity_did(0.0), gtin(0.7), manufacturer(1.0), model_name(1.0), batch_name(0.3), serial_number(0.7), deployment(0.7), classification(1.0), description(0.3), commissioning_date(0.3), compliance_checklist(0.7), release_year(0.3), flexibility(1.0), communication(1.0), communication_protocol(1.0), modbus_register_map(1.0), dacq_actuation(0.3), devices_attribute(0.3), dacq_attributes(0.3), control_actuation(1.0), regulation(1.0), regulation_response_time_upward(1.0), regulation_response_time_downward(1.0), regulation_response_time_unit(1.0), regulation_response_time_accuracy(1.0), maximum_upward_regulation(1.0), maximum_downward_regulation(1.0), minimum_regulation_step(1.0), ip_rating(0.3), storage_temperature(0.3), operating_temperature_range(0.3), relative_humidity_range(0.3), dimensions(0.3), weight(0.3), form_factor(0.3)
Electrical Specifications	Describes the fundamental electrical and operational parameters that define	phase_configuration(1.0), frequency(1.0), voltage_nominal(1.0), voltage_tolerance_df(1.0), current_nominal_df(1.0), current_min_df(1.0), current_max_df(1.0), inrush_current_max_df(1.0), power_consumption_nominal_df(1.0),

	nominal behavior and flexibility boundaries.	power_consumption_max_df(1.0), standby_power_consumption(1.0), power_consumption_units(1.0), voltage_regulation_uf(1.0), voltage_range_uf(1.0), output_current_nominal_uf(1.0), output_current_max_uf(1.0), power_output_nominal_uf(1.0), power_output_max_uf(1.0), power_factor(1.0)
Battery Energy Storage System Attributes	Captures parameters defining energy storage capacity, charge/discharge characteristics, efficiency, and operational limits.	bess_application(.07), cell_type(1.0), voltage_nominal(1.0), voltage_range(1.0), capacity(1.0), maximum_charge_current(1.0), maximum_discharge_current(1.0), cycle_life(0.7), energy_rating_nominal(1.0), energy_rating_nominal_units(1.0), energy_rating_usable(1.0), energy_rating_usable_units(1.0), c_rate(1.0), round_trip_efficiency(0.7), battery_management_system(1.0), degradation_rate(0.7)
Inverter / Converter Specifications	Defines conversion and control parameters necessary for grid interfacing, reactive support, and operational compliance.	max_apparent_feed_in_power_kva(1.0), nominal_active_power_kw(1.0), peak_active_power_kw(1.0), phase_configuration(1.0), frequency(1.0), standby_power_consumption(1.0), max_nominal_dc_current_a(1.0), nom_dc_voltage_range(1.0), nominal_ac_voltage_l1(1.0), nominal_ac_voltage_l2(1.0), nominal_ac_voltage_l3(1.0), nominal_ac_current_l1(1.0), nominal_ac_current_l2(1.0), nominal_ac_current_l3(1.0), power_factor(1.0)
PV Module Specifications	Provides photovoltaic module data for flexibility modeling in hybrid PV-storage systems and prosumer generation.	application(1.0), module_type(1.0), module_name(1.0), voc(1.0), isc(1.0), vmpp(1.0), impp(1.0), temp_coef_pmax(1.0), temp_coef_voc(1.0), temp_coef_isc(1.0), noct(1.0), quantity(1.0)
Solar Charge Controller (SCC) Specifications	Defines charge-control performance and operational modes in PV-battery configurations.	model_name(1.0), voltage_input(1.0), current_input(1.0), voltage_output(1.0), current_output(1.0)
Energy Meter Specifications	Describes the characteristics of metering devices used for validation, EMS control, NILM analysis, and flexibility verification.	phase_configuration(1.0), frequency(1.0), voltage_nominal(1.0), voltage_tolerance_df(1.0), current_nominal_df(1.0), current_min_df(1.0), current_max_df(1.0), standby_power_consumption(1.0), power_consumption_nominal_df(1.0), power_consumption_units(1.0), accuracy_class(1.0)

3.4.2 Use, Interoperability, and Standardization Alignment

The structured data fields defined in chapter 3 enable seamless interoperability between manufacturers, HEMS/BEMS providers, aggregators, and other OPENTUNITY participants by ensuring that asset information is represented and interpreted consistently. The schema is technology-neutral and extensible, supporting both simple devices (e.g., HVACs, EVSEs) and complex systems (e.g., PV + BESS + Inverter). When a QR code is scanned, the asset's JSON record is automatically retrieved by other participants, but also validated and stored in the DEMO database, enabling automated onboarding without manual configuration.

Beyond registration, these standardized attributes allow HEMS/BEMS and flexibility service providers to assess the available flexibility based on asset specifications, paving the way for flexibility estimation and market participation. Furthermore, fields such as 'gtin', manufacturer, and 'dpp_url' work towards semantic alignment with the Digital Product Passport initiative facilitating future integration of sustainability and lifecycle information under the ESPR framework.

The schema's structure follows established international standards like IEC 61850, IEC 61968, IEC 62325 for communication, or ISO 52000 and IEA EBC Annex 82 for flexibility characterization and asset modeling, seeking to ensure long-term compatibility. Collectively, these design choices make the T3.3 schema a future-ready data foundation, interoperable with the Federated Data Exchange Infrastructure (FDEI) and adaptable to emerging regulatory and technological developments across the European energy ecosystem.

4 SYSTEM ARCHITECTURE

This chapter describes the technical system architecture developed under T3.3-D3.3, which forms the core software of the OPENTUNITY plug-and-play framework. It translates the methodology defined in Chapter 3 into an operational design, connecting asset registration services, APIs, and authentication mechanisms with the individual participants of the FDEI implemented in WP3. The architecture follows a modular and service-oriented approach, emphasizing scalability, security, and interoperability, while ensuring compliance with emerging European data frameworks, namely the ESPR-DPP.

4.1 Requirements and Specifications for Asset Registration

The system's architecture was shaped by several key design requirements identified during the conceptual and implementation phases of T3.3:

- **Interoperability:** Full compatibility between heterogeneous energy assets, HEMS/BEMS and FSP platforms, or other external actors.
- **Security and Data Sovereignty:** Role-based access control, API-key authentication, and encrypted communications.
- **Automation:** Minimal human intervention during onboarding, achieved through QR-code–based identification and schema-validated data ingestion.
- **Standardization and Extensibility:** Alignment with open protocols (REST, JSON-LD) and future integration of Digital Product Passports (DPPs).
- **Reliability:** Consistent uptime, validation of incoming payloads, and traceable versioning of asset data.

These requirements guided the implementation of six complementary specification domains, described below.

4.1.1 Data Exchange Protocols

Data exchange between the BSA-DEMO and OPENTUNITY participants is based on RESTful APIs using HTTPS as the transport layer and JSON as the data format.

This choice provides simplicity, human readability, and interoperability across multiple systems. Public API endpoints are HTTPS-only and stateless, while HTML/admin views use Django sessions and CSRF. Although responses are in standard JSON, JSON-LD is optional and can be enabled.

At present the platform exposes REST over HTTPS only. MQTT/AMQP are not implemented, but the architecture supports potential future extensions to enable event-driven, near-real-time use cases such as demand response.

4.1.2 Unique identifiers

Each registered asset is assigned an internal primary key (asset_id), implemented as a Django 'AutoField' that auto-increments in the database. This key is used for relations across subsystems.

To interoperate with external registries and future DPP infrastructures, the model can also store external identifiers: a serial number for the specific unit, optional GTIN/GS1 Digital Link attributes where applicable (primarily for standardized product references), and a canonical URL that resolves to the asset's

API or QR landing page. This layered identification approach preserves internal consistency while supporting forward compatibility with emerging ESPR Digital Product Passport practices.

4.1.3 Data Carriers

Data carriers serve as the bridge between physical devices and their digital twins within the various frameworks as well as in the OPENTUNITY ecosystem. While the original DoA envisaged combined QR and RFID usage, implementation results demonstrated the QR code to be the most practical solution due to its ubiquity, low cost, and compatibility with mobile devices, within WP3-T3.3.

Each QR encodes a secure resolver URL (e.g., https://bluesun.pythonanywhere.com/ api/assets/<asset_id>/enter-api-key/) and links to the asset's JSON record upon scan. Future versions will allow the reuse of QR identifiers from external sources such as Digital Product Passports (DPPs) or European Product Registry for Energy Labelling (ERPL, -under development-), further streamlining interoperability and data reuse. Once the DPP schema is finalized, the existing numeric asset_id can be linked or mapped to the DPP's unique identifier (e.g., UUID or alphanumeric code) without structural changes.

4.1.4 Data Storage

The platform uses a relational MySQL database on PythonAnywhere with Django's ORM for structured access and transactional writes. Core asset data (manufacturer, model, electrical/operational specs etc.) is stored in normalized tables. Where supported in the schema, asset-specific parameters may use JSON fields. Records include standard metadata were defined in the models. Schema changes are managed via Django migrations and model validators, and access is limited through Django's permissions. Backup routines and additional compliance controls (e.g., GDPR data-minimization and retention) are applied as configured in the deployment.

4.1.5 Application Programming Interfaces

All programmatic interactions are served by Django REST Framework (DRF). The API currently follows a detail-only model: clients can fetch individual assets by ID but there's no list endpoint exposed, which reduces enumeration risk.

Key endpoints

- `GET /api/assets/{id}/` returns the JSON for a single asset; access is API-key protected via Authorization: Api-Key <token>.
- `GET /api/assets/{id}/enter-api-key/` is the public resolver page which also supports `?apikey=<token>` to return the same JSON for API-client convenience.
- `GET /api_qr/{id}/` serves a downloadable QR image for the asset.
- `GET /api/dpp/asset?url=<dpp_url>&auto_import=true&apikey=<token>` ingests a DPP payload from an external URL.

Authentication uses a custom API-Key scheme. Keys are individually issued by EOs, managed by administrators, and can be associated with an organization scope (where configured). Logging requests are recorded in server logs and core models include timestamps.

4.1.6 System Interoperability

System interoperability is achieved through the consistent use of open standards and canonical data models. The asset schema (see Annex 1) aligns with GS1 Digital Link for product identification, and JSON-LD/Linked Data principles for semantic interoperability. Within the OPENTUNITY ecosystem, DEMO components interact directly with participants of the FDEI layer, allowing HEMS/BEMS operators, and FSPs to retrieve static device data for flexibility analysis while maintaining strict access control and data sovereignty.

4.2 Overview of System Architecture and Components

The implemented system architecture follows a three-tier modular design (Figure 4.1), integrating the front-end interface, application microservices, and data management layer into a secure, interoperable framework.

A) Front-End Layer (Presentation Tier): The BlueSun Web Dashboard (BSA) provides a role-based interface for Administrators, Economic Operators, and End-Users. Built on Django Templates and Bootstrap, it supports authentication, visualization, and full database operations CRUD (i.e. Create, Read, Update, and Delete) functionality for asset data. Through this interface, users can register assets, manage metadata, and trigger QR-code generation. All communications between users and the back-end occur via secure HTTPS connections, following OAuth2/JWT protocols.

B) Application Layer (Logic and Microservices Tier): Implemented using the Django REST Framework, this layer contains the system's core microservices:

- Asset Registration Service – handles asset creation, updates, and schema validation.
- QR Code Generator – issues unique QR codes linked to resolver URLs.
- API-Key Authentication Service – validates and authorizes client or user API requests.
- DPP Ingestion Service – intended for imports and data mappings from external Digital Product Passport (DPP) endpoints into the internal schema.

Django services use object relational mapping (ORM, a library that allows interaction with a database using Python objects and methods instead of writing SQL queries) to access the database. Data is encrypted in transit via HTTPS and DB TLS. Encryption at rest is provided by the database or by field-level encryption when configured. The microservices also expose REST APIs to external systems such as HEMS/BEMS and FSP platforms, ensuring secure, standards-based interoperability.

D) Data Layer (Persistence and External Data Sources): The MySQL relational database maintains validated asset metadata, user credentials, and audit logs. It acts as the core persistence layer, while also interfacing with external manufacturer/vendor repositories, EPREL registries, and future DPP endpoints through REST APIs (OAuth2/JWT).

All layers communicate via RESTful APIs secured with HTTPS, employing strict API-key or OAuth2-based authentication, rate limiting, and GDPR compliant access control. This modular and layered design ensures scalability, security, and interoperability, allowing the BSA-DEMO to function as a flexible bridge between data providers (EOs, End-Users) and data consumers (HEMS/BEMS, FSPs, DSOs/TSOs) within the OPENTUNITY ecosystem. Figure 4.1 illustrates the layered architecture of the BSA-DEMO, depicting interactions among the front-end, application, and data layers, as well as their connections with external data sources (e.g., EPREL, DPP, and Vendor endpoints) and integrations (e.g., HEMS/BEMS, FSPs). It highlights how data flows securely between users, services, and the OPENTUNITY ecosystem through RESTful APIs.

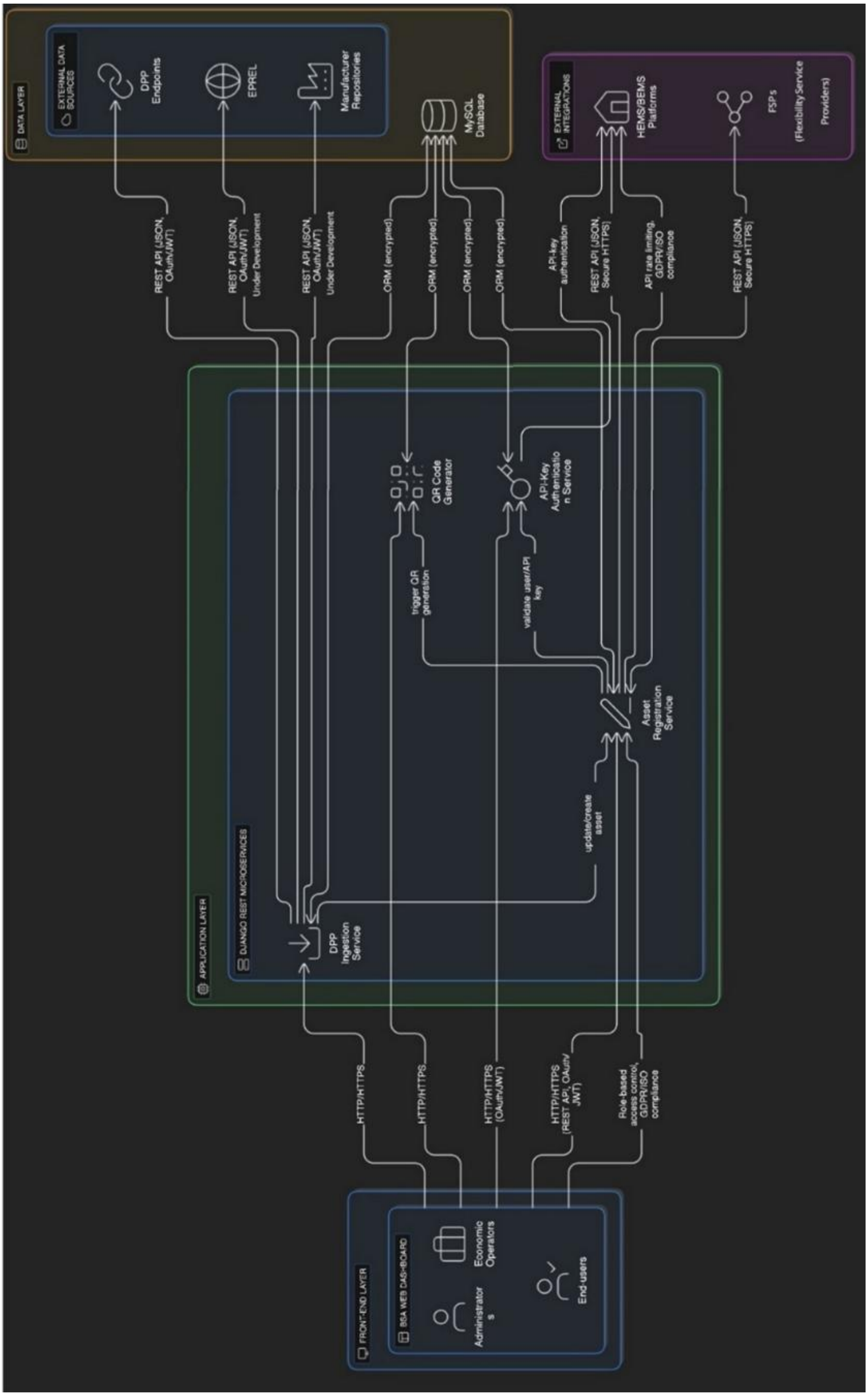


Figure 4.1 System Architecture overview of the BSA- DEMO illustrating layered interactions between user interfaces, Django REST microservices, the internal MySQL database, and external integrations (DPP, HEMS/BEMS, FSPs).

4.3 Services

The operational deployment of T3.3-D3.3 DEMO has been implemented as a set of independent but interoperable microservices within the BlueSun platform. Each service performs a distinct role in managing authentication, asset creation, data ingestion, QR-code generation, and secure data exchange across the OPENTUNITY ecosystem. Together, they form the core function that enables seamless onboarding of flexibility assets and standardized data sharing between stakeholders.

4.3.1 User Authentication and Authorization

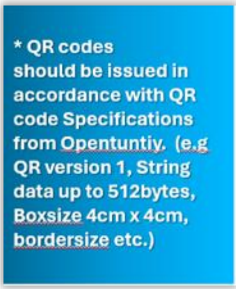
This service governs how users and external systems securely access the platform. It extends Django's built-in authentication subsystem with role-based permissions, defining distinct privileges for Administrators, Economic Operators, End-Users, and API Clients. Users authenticate through session-based login, protected by HTTPS with TLS 1.3 encryption, ensuring that credentials and session cookies cannot be intercepted. External systems such as HEMS/BEMS or FSPs authenticate via API keys, transmitted in the 'Authorization: Api-Key <token>' header. Each authentication event, whether human or machine-initiated, is timestamped and logged, preserving a verifiable audit trail. Access policies follow the principle of least privilege, and all communication channels provide data confidentiality, integrity, and forward secrecy.

4.3.2 Asset Registration

The Asset Registration Service manages the structured creation, validation, and updating of asset records, either through the BlueSun web dashboard or directly via REST API requests (Currently reserved for Bluesun). Each record is assigned a unique Asset ID and linked to a corresponding QR identifier and resolver URL, binding the digital record to its physical device. Validation logic ensures that mandatory fields (e.g. manufacturer, model, classification, electrical specifications, and flexibility parameters etc.) are present and correctly formatted before being persisted in the database. This service represents the foundation for plug-and-play functionality, once an asset is registered, its static metadata becomes available to authorized HEMS/BEMS platforms for configuration and flexibility evaluation.

4.3.3 QR Code Generation and Management

The QR Code Generator Service produces unique, checksum-verified QR codes for each registered asset using the Python 'qrcode' library. These codes embed secure resolver URLs, allowing authenticated access to the asset's JSON data. Images are almost instantly generated upon asset registration and depicted in the dashboard per EO and can be downloaded, printed, or attached physically to the device. When scanned, the QR code initiates an access workflow in which the user or system enters an API key, leading to controlled data retrieval.



* QR codes should be issued in accordance with QR code Specifications from Opentuntiy. (e.g QR version 1, String data up to 512bytes, Boxsize 4cm x 4cm, bordersize etc.)

4.3.4 DPP Ingestion

This service handles the controlled intake of data from multiple sources, mainly Digital Product Passport links, and aligns incoming information with the platform's internal schema. Where external payloads differ from the internal model, a mapping layer automatically translates standardized DPP attributes (e.g., GTIN, product type, sustainability indicators) into compatible BSA fields (under development). This ensures that data remains coherent across heterogeneous sources and fully traceable to its origin.

4.3.5 REST API for Data Exchange between OPENTUNITY Partners (HEMS/BEMS & FSPs)

The REST API constitutes the main external interface, through which OPENTUNITY partners including HEMS/BEMS providers and FSPs, retrieve asset data. Endpoints follow REST principles and deliver responses in JSON format, allowing straightforward integration with third-party systems. Each request is authenticated via API key, authorized according to assigned scopes, and logged for full traceability. All communications occur over HTTPS, with encrypted, integrity-checked exchanges that comply with GDPR regulations. Rate-limiting mechanisms prevent misuse and maintain high system availability. Through this API, the DEMO serves as a trusted intermediary, providing standardized, secure, and interoperable access to flexibility-related asset data within the OPENTUNITY ecosystem.

5 CLOUD-BASED IMPLEMENTATION OF T3.3-D3.3

5.1 Overview

This chapter documents the cloud application that enables plug-and-play onboarding of flexibility assets to the OPENTUNITY ecosystem and secure distribution of static device and system level flexibility data to authorized end-users of OPENTUNITY Partners (HEMS/BEMS/DSOs/FSPs), using QR code scans on physical assets to initiate data retrieval. The application delivers:

- A role-aware web user interface (UI) for creating, supervising, updating, and maintaining specific asset data like nominal characteristics and operational constraints (e.g. Vendor, Model, Classification, Electrical Specifications, Control Interfaces, Certifications, etc.) of devices and systems used in the OPENTUNITY Pilots.
- QR code issuance per asset; the OPENTUNITY QR encodes a resolvable URL that initiates an API-key–gated JSON retrieval path to asset data, used by OPENTUNITY Partner software clients, to facilitate seamless integration of assets into the ecosystem.
- A REST framework API that has been secured against common vulnerabilities and threats, designed for detail-only access and prohibiting bulk listings, guarded by a custom API-key authentication class for Economic Operators with strict permissions.
- An ingress path for future Digital Product Passport imports, mapping what's assumed to be standardized DPP payloads to the application's internal asset data schema.
- Forwarding bridges from QR-triggered lookups to the relevant pilot HEMS/BEMS endpoints for asset control and monitoring, and to DSO/FSP endpoints for flexibility analysis (NILM, Grid health etc.).

In the OPENTUNITY context, Economic Operators (EOs) are all manufacturers, vendors, or system integrators who provide asset data of devices that can participate in flexibility services. OPENTUNITY partners are a subset of these EOs, who not only supply data but also actively integrate their assets into the OPENTUNITY ecosystem for testing and validation. In other words, asset data sources are not limited solely to those within OPENTUNITY. As shown in Figure 5.1 asset data can be entered manually by EOs via a structured user interface or imported programmatically through API inputs. Once validated, the system exposes this data as HTML form-based views for end-users and as JSON outputs for partner systems, secured by API keys. QR codes and DPP inputs provide streamlined entry points, allowing end-users or partner software clients to retrieve asset information directly and securely. The platform thus acts as a bridge between physical devices and digital services, enabling standardized flexibility data exchange across pilots.

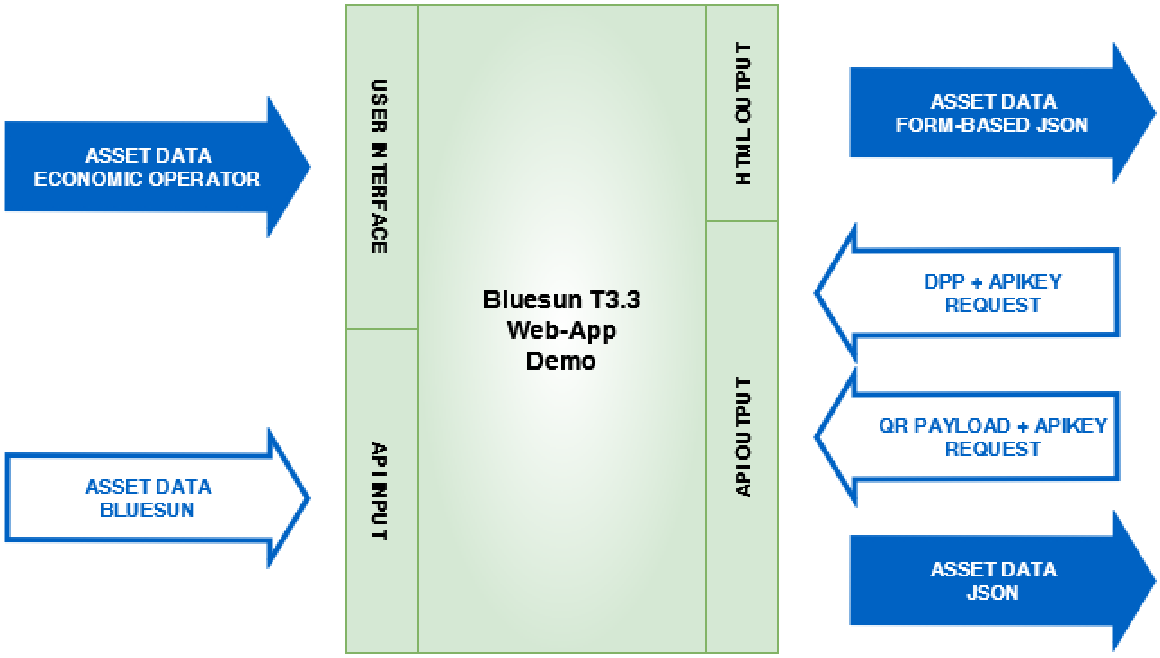


Figure 5.1 Diagram illustrating asset data flow with form-based and API data inputs and outputs of the T3.3-D3.3 web implementation.

The application is deployed on the PythonAnywhere platform, using a Web Server Gateway Interface (WSGI) hosting environment that ensures stable and scalable web service delivery. The project was initially hosted at opentunity.pythonanywhere.com during its early development and testing phase, and later migrated to bluesun.pythonanywhere.com, which now serves as the primary production instance. The backend is built on Django, a robust Python framework, with Django REST Framework (DRF) providing secure and structured API services. Data is stored in a managed MySQL database offered by PythonAnywhere, which simplifies maintenance and ensures reliability. On the front end, a Bootstrap-based interface delivers a clean, user-friendly experience accessible from standard browsers, while the 'qrcode' library is integrated for generating QR codes that link physical devices to their digital records. Access to the system is governed by role-based authentication and permissions, ensuring that only authorized users and partners can interact with sensitive asset data or consume the API endpoints. **This hosting and technology stack combination was deliberately selected to balance security, maintainability, and accessibility for pilot-scale deployment and future scalability.** The application is expected to maintain high availability (≥99%), with minimal downtime and uninterrupted access for both web users and API clients. API endpoints respond consistently within acceptable limits, showing a P95 latency below 800 ms which ensures smooth integration with external systems. During pilot testing, the end-to-end QR success rate should reach at least 90%, meaning the majority of scans result in successful JSON retrieval within the expected timeframe. **Registered assets have all mandatory fields completed at the point of registration with completeness score at least 70%, ensuring a consistent and reliable dataset.**

5.2 Application Features

5.2.1 User Authentication and Role-Based Permissions

The BlueSun T3.3-D3.3 web application integrates a multi-layered authentication and authorization model to ensure that only authorized stakeholders can access and edit flexible asset data. At its core, the platform leverages Django's built-in authentication subsystem for web sessions, combined with a custom API-key mechanism for external system access through the REST interface. **This dual approach mirrors practices adopted in large-scale EU projects such as InterConnect and OneNet, where hybrid authentication is required** to accommodate both human users and automated machine clients [5, 6].

Roles have been defined according to the "principle of least privilege" that is access rights and permissions granted to each user role are the absolute minimum necessary for users in that role to perform their required job functions. Administrators hold full CRUD (Create, Read, Update, Delete) privileges and may manage both users and system configurations. EOs both supply and utilize the central asset database. They contribute their own data for general access and retrieve data from the wider asset pool for their specific operational needs. EOs acting as asset data contributors, can only add or modify the assets they have registered. EOs that utilize the asset pool, access the system in a strictly read-only capacity, ensuring transparency without risking data integrity. Finally, API clients interact only with asset endpoints, and their API keys are tightly scoped to detail retrieval functions. This prevents bulk export of the entire dataset, a common vulnerability in poorly secured APIs.

User registration and account management follow a standard secure signup process. New users create accounts through a web-based form, after which the system issues a verification email to confirm ownership of the provided address before activation. The platform also supports password reset and recovery workflows via secure email tokens, ensuring continuous but controlled access for legitimate users. End-users, understood here as asset owners, Economic Operators, or independent content contributors, are welcome to provide asset data into the system. This inclusive model ensures that not only project partners but also third parties willing to contribute can register devices. Their submissions undergo the same validation and permission framework as partner data, safeguarding consistency and integrity across the shared asset repository.

As illustrated in the diagram in Figure 5.1, data enters the system either from Economic Operators or directly from BSA. These actors interact with the web application through the User Interface or the API Input module. Once authenticated, their submissions are validated and stored in the internal schema. All subsequent data flows like HTML form-based outputs, DPP imports, or QR-triggered requests, are governed by role-specific permissions.

Security enforcement is not limited to authentication. Django's model-level and view-level permission checks ensure that contributors cannot modify assets outside their scope. All changes are logged with metadata (who, when, and what was changed), creating a full audit trail. From a compliance standpoint, the system aligns with GDPR data minimization principles: only technical metadata about devices and systems is stored [7]. Operational logs contain IP addresses and API-key identifiers solely for auditing and are rotated according to pilot policies (e.g., 180-day retention).

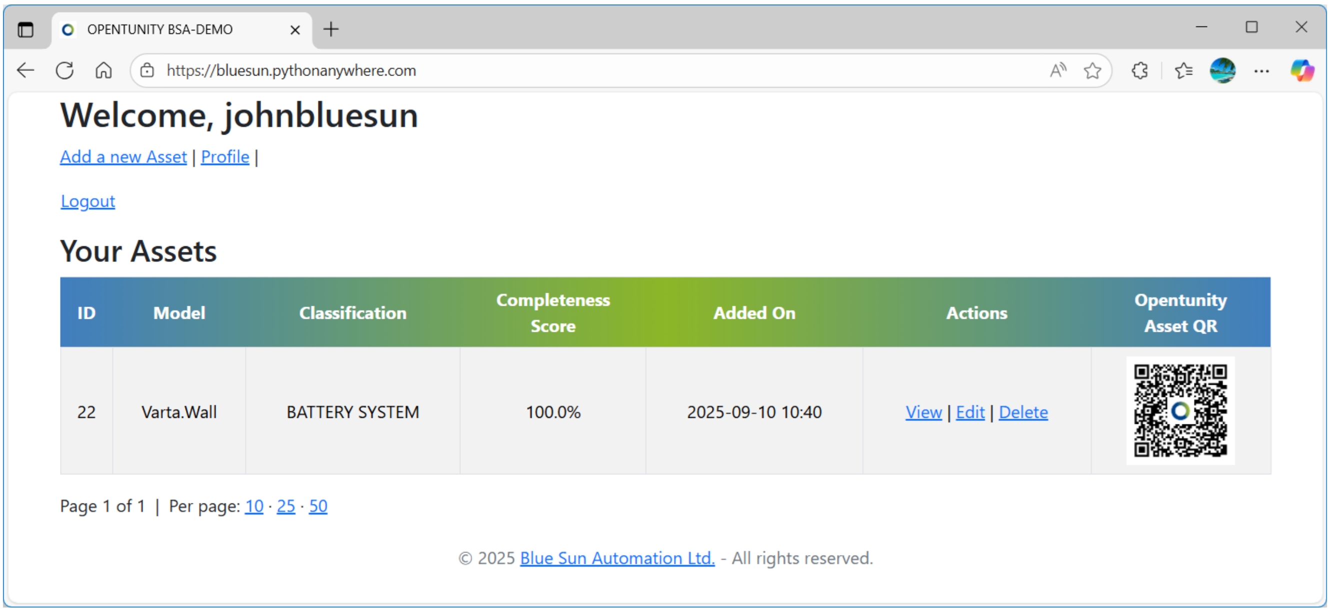
This authentication and role model reflects both academic recommendations on federated identity in energy platforms and industry standards such as IEC 62351, which emphasizes secure authentication for energy system communications [8, 9]. By enforcing strict separation of roles, adopting HTTPS-only communication, and supporting API-key rotation, the BSA-DEMO provides a robust, future-proof framework for secure collaboration within OPENTUNITY.

5.2.2 User Interface Design and CRUD Functionality for managing assets

The user interface (UI) of the BSA-DEMO was deliberately designed to be intuitive and lightweight, ensuring that users who may not have advanced IT expertise can register and maintain assets with minimal effort. Developed with Bootstrap and Django templates, the UI provides a clear, responsive layout that works seamlessly across desktops and tablets and mobile devices, ensuring accessibility for both office-based users and field operators scanning QR codes on-site.

The dashboard is the central entry point. Here, data contributors see a summary of their most recent assets, next to completeness scores, issued QR codes, and any validation warnings. From this interface, users can create new records, review existing entries, and update technical details. CRUD functionality follows strict validation rules: fields such as manufacturer, model, classification, and core electrical specifications are mandatory, while optional sections (e.g., certifications, advanced control parameters, etc.) can be filled as needed.

Figures 5.2 and 5.3 illustrate the interaction between the BSA front-end interface and the API layer, showing how registered assets are displayed to users and how each OT-QR provides direct, secure access to the corresponding JSON-based asset data through the web application.



Welcome, johnbluesun

Add a new Asset | Profile |

Logout

Your Assets

ID	Model	Classification	Completeness Score	Added On	Actions	Opentunity Asset QR
22	Varta.Wall	BATTERY SYSTEM	100.0%	2025-09-10 10:40	View | Edit | Delete	

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Figure 5.2 The BSA-DEMO interface displaying a snapshot of the User Dashboard View, with key information such as classification, completeness score, registration date, and its corresponding OPENTUNITY Asset QR, which links to the asset's detailed JSON data.

```
{
  "id": 22,
  "manufacturer": "Varta",
  "deployment": "Commercial",
  "classification": "BATTERY SYSTEM",
  "flexibility": "Downward & Upward",
  "communication": {
    "supported_com_types": [
      "WIFI"
    ]
  },
  "communication_protocol": {
    "supported_com_protocols": [
      "MODBUS TCP"
    ]
  },
  "regulation": "ON/OFF, LINEAR",
  "regulation_response_time_unit": "sec",
  "inverter_specs": {
    "id": 9,
    "max_apparent_feed_in_power_kva": 10,
    "nominal_active_power_kw": 10,
    "peak_active_power_kw": 10,
    "phase_configuration": 3,
    "frequency": 50,
    "standby_power_consumption": 7.9,
    "max_nominal_dc_current_a": 26,
    "nom_dc_voltage_range": {
      "max_v": 650,
      "min_v": 120
    },
    "nominal_ac_voltage_l1": 230,
    "nominal_ac_voltage_l2": 230,
    "nominal_ac_voltage_l3": 230,
    "nominal_ac_current_l1": 16,
    "nominal_ac_current_l2": 16,
    "nominal_ac_current_l3": 16,
```

Figure 5.3 Scanning the OT-QR leads to a secure API endpoint displaying the JSON representation of the registered asset (asset_id = 22), demonstrating the Plug-and-Play principle where each QR uniquely links to validated technical, communication, and flexibility specifications.

The UI design reflects lessons learned from EU digitalization initiatives where usability was identified as a barrier for adoption of data-centric tools by non-expert stakeholders [10, 11]. To avoid errors, previously free-form JSON entries have been replaced with structured form fields (e.g. floats, dropdowns, or controlled vocabularies) enforcing data integrity. This reduces the likelihood of malformed entries, a recurring issue in similar projects.

In the diagram of Figure 5.1, the left side arrows, where asset data enters from Economic Operators or directly from BSA. for human contributors, this path is mediated by the User Interface. Once submitted, the data is made available after QR scanning through HTML form-based outputs or JSON APIs, shown on the right side of the diagram. This representation highlights the UI's role as both a data entry and a validation gate.

Auditability and transparency are embedded in CRUD operations. Each modification is logged internally with time, user identity, and previous values, ensuring that any change can be traced. This feature is crucial for pilot testing, where datasets may evolve as devices are commissioned, updated, or reclassified.

In line with international software quality standards [12], the UI emphasizes usability, reliability, and maintainability. By blending structured forms, contextual help text, and error feedback, the BSA application ensures that asset registration is accurate, repeatable, and user-friendly. This makes the UI not just a data entry portal, but a practical interface for the larger OPENTUNITY ecosystem.

5.2.3 Flexibility Data Extraction and Aggregation per Asset Classification

One of the most valuable contributions of the BSA T3.3 application is its ability to capture and aggregate static flexibility descriptors for devices and systems across the pilots. These descriptors form the basis for flexibility potential assessment, which is a cornerstone of OPENTUNITY. Unlike real-time telemetry systems, the focus here is on capturing the parameters that define what each device could do if called upon.

During asset registration, data contributors specify key attributes according to asset **classifications**. Each classification of asset has distinct operational characteristics as well as common electrical specifications, but the system applies a consistent data model so that all assets can be aggregated and analyzed under a unified flexibility framework.

A) **Battery Systems:** For batteries, the schema records parameters such as usable capacity ranges (kWh), charge/discharge power limits (kW), round-trip efficiencies (%), and cycle-life constraints. Static SoC/SoH envelopes and maximum charge/discharge C-rates are also captured. These parameters allow aggregated modelling of storage flexibility, particularly for peak shaving, frequency support, and arbitrage use cases.

B) **Heating, Ventilation and Air Conditioning (HVAC):** For HVAC systems, flexibility data focuses on thermal storage potential and controllable duty cycles. Key descriptors include nominal heating/cooling capacity (kW), coefficient of performance (COP), setpoint temperature ranges, and acceptable response delays. By capturing minimum on/off cycles and ramp rates, the web-app ensures HVAC assets can be aggregated without compromising end-user comfort, aligning with standards like EN 15232 on building energy performance.

C) **Electric Vehicle Supply Equipment (EVSE):** For EV chargers, flexibility extraction is based on controllable charging power (kW), phase configuration, and time windows of availability. The web-app also records safety constraints and maximum session current. This data enables aggregation of EVSE flexibility for load shifting and balancing, while respecting mobility requirements.

D) **Water Heaters:** Hot water systems act as thermal storage assets. The schema captures tank volume (L), heating element rating (kW), target temperature ranges, standby losses, and acceptable demand response delay. These descriptors define how long a heater can be curtailed or pre-charged without affecting service quality, making them valuable for peak load management.

E) **White Appliances:** This category includes washing machines, dryers, dishwashers, and other domestic loads with embedded control capabilities for downward flexibility. Flexibility is represented through deferrable cycles, average power demand per cycle, duration, and earliest/latest start times additional to the common electrical specifications of all asset classes. These assets are aggregated in scheduling algorithms for demand response, reflecting models used in European projects [13], where household loads were coordinated for demand-side flexibility.

F) **PV Systems:** For photovoltaic systems, flexibility data extraction is limited to curtailment potential under inverter constraints (Downward Flexibility). The schema records nominal peak capacity (kWp), and typical PV module data sheet information under Standard Test Conditions (STC), maximum power point range, inverter specifications and grid code compliance limits (voltage, frequency tolerance etc.). This enables aggregation of curtailment capability for grid balancing, even though PV generation is weather-dependent and non-controllable in its production.

G) **PV & Battery Systems:** When PV systems are paired with storage, the web-app links PV generation characteristics with Battery System flexibility envelopes (i.e. asset specific data field groups), forming a hybrid flexibility profile. This includes DC/DC Converter as well as DC/AC Inverter specifications, curtailment potential, additionally to storage characteristics like charge/discharge ranges, and combined operational limits. Aggregated, these DC-coupled systems can provide both downward and upward flexibility.

H) **Generator Systems (GenSet):** For gensets, flexibility data covers the common electrical specifications. Proprietary synchronization constraints and control information, when available, is embedded into communication protocol register maps and Data Acquisition and Control envelopes (i.e. Monitored Attributes, Data Acquisition Actuation, Control Actuation) are included. This ensures gensets can be considered as dispatchable flexibility providers without overestimating their availability.

I) **GenSet & Battery Systems:** Where gensets are coupled with batteries, the schema allows definition of a hybrid operational envelope, combining the dispatchability of gensets with the fast response of batteries. This hybrid model supports aggregated scenarios like islanded operation, microgrids, or emergency backup with smoother response profiles.

J) **Energy Meters:** While energy meters are not flexibility providers per se, they are included as data sources within the BSA-DEMO. They provide static descriptors like accuracy class additional to the common electrical specifications and communication protocols. Their role in flexibility aggregation is indirect: they enable verification and monitoring of assets performance, assisting the function of EOs in pilot sites.

These inputs, once validated, are stored in a structured schema designed for aggregation. Figure 5.1 shows the asset data flow, once entered through the User Interface or API Input. Subsequently they are exported in JSON format for downstream consumption. This reflects the application's role as a normalization layer: regardless of manufacturer conventions or naming, data is translated into a canonical schema. Where variations exist, the system uses mapping tables to ensure consistency, and disregards asset data that is neutral to flexibility analysis. By capturing asset data at a static level, the system supports integration into Non-Intrusive Load Monitoring (NILM) and grid health assessments, providing FSPs and DSOs respectively with actionable datasets supplementary to live metering. Aggregation across devices allows pilot partners to query and visualize the total flexibility available at site or portfolio level. **Completeness scores are calculated to ensure that datasets are robust enough for analysis and listed in the EO dashboard. This prevents situations where missing values would compromise flexibility forecasts.** At the same time the app also provides a bridge to the Federated Data Exchange Infrastructure (FDEI), which relies on standardized, high-quality datasets.

By focusing on static descriptors, the BSA application complements real-time control systems (e.g. HEMS/BEMS) prevents redundant asset data duplicates on their infrastructure. In doing so, it provides the essential groundwork for scalable, interoperable flexibility markets.

5.2.4 Asset Registration, QR Code Generation, and JSON Data Forwarding

Asset registration is the foundation of the BSA T3.3 web application. Data providers enter asset specific details through structured forms, which are validated against the internal schema. Once accepted, the asset receives a **unique identifier (asset_id)**. This identifier is then bound to a unique **QR code**, ensuring that the physical device and its digital record are permanently linked.

The QR code encodes a resolver URL in the format:

```
https://bluesun.pythonanywhere.com/api/assets/<asset_id>/enter-api-key/
```

QR generation within the UI is simple: contributors select an asset and generate a PNG or SVG file, which can be downloaded or embedded in asset documentation. This function bridges the digital and physical worlds, allowing devices without advanced interfaces to be onboarded into modern digital ecosystems.

Technically, the QR is produced server-side using a QR encoder (e.g., Python qrcode library), which takes the resolver URL as input and renders a PNG/SVG image bound to the asset_id. for public viewing/downloading without logging in, the image is exposed at:

```
https://bluesun.pythonanywhere.com/api_qr/<asset_id>/
```

The resolver/data path itself remains API-key gated, so the QR image is public, but the underlying JSON is protected.

When printed and affixed to a physical device, this QR enables plug-and-play integration. Scanning it directs end-users or OPENTUNITY service providers to the resolver, where access is mediated by an API key. This ensures that while the QR is publicly visible, the underlying data remains protected. Interested OPENTUNITY partners can access via API software client applications the asset data that enters the system via an OT QR code + API key requests, highlighting how QR-mediated interactions are central to the data retrieval process.

The OT QR code + API key requests have the following format:

```
https://bluesun.pythonanywhere.com/api/assets/<asset_id>/enter-api-
key/?apikey=<eo_apikey>
```

The use of QR technology is not unique to OPENTUNITY. Similar approaches are currently being advanced in Digital Product Passport (DPP) initiatives under the Ecodesign for Sustainable Products Regulation (ESPR). BSA therefore provides guidelines that adapt this approach specifically for the energy flexibility domain, where device integration must be both secure and seamless. The registration and QR linkage approach ensures traceability, compliance, and interoperability. It is future-proofed for Digital Product Passports, ensuring that as standards mature, OPENTUNITY assets will already have a digital identity and integration mechanism in place. The UML sequence diagram in figure 5.4 illustrates the complete workflow of asset registration and QR code generation within the BSA-DEMO.

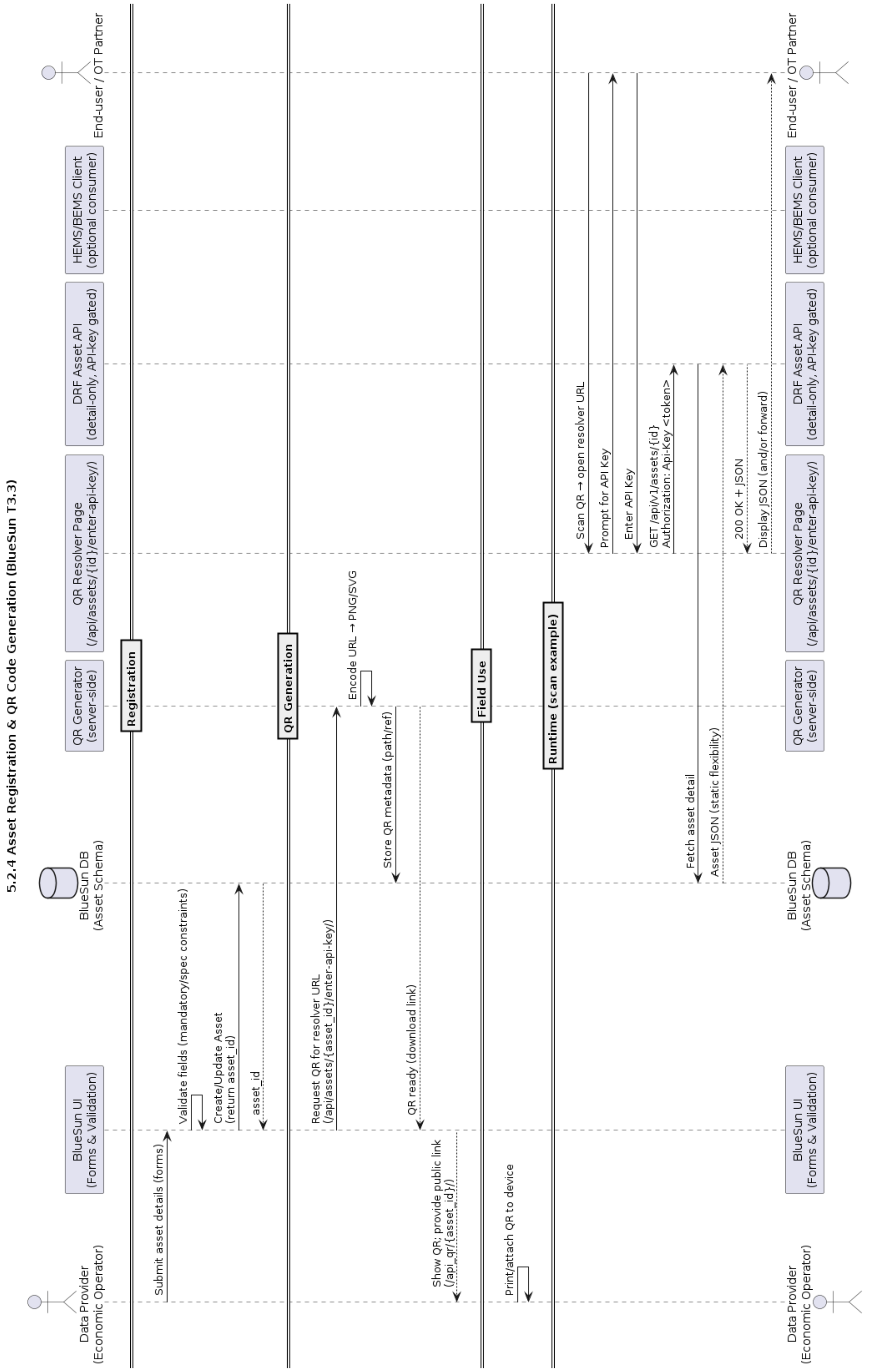


Figure 5.4 UML sequence diagram of asset registration and QR code generation in the BSA-DEMO, showing the flow from data entry and validation to QR creation, printing, scanning, and optional data forwarding to OPENTUNITY stakeholders.

Once a QR is scanned, the system orchestrates a secure, multi-step process to deliver data to the right stakeholders. The resolver first prompts for an API key—either entered by a human user or pre-configured in a HEMS app. Using this key, the resolver fetches the asset's JSON data from the DRF endpoint. If successful, the JSON is displayed locally and simultaneously forwarded to registered endpoints.

The diagram highlights this workflow: QR scans trigger API requests that output JSON, which can be consumed by HEMS/BEMS for device control and monitoring, or by DSOs and FSPs for flexibility analysis. This dual output ensures that a single scan propagates consistent information across all relevant systems.

Errors are categorized: 401 for invalid keys, 403 for forbidden access, 404 for unknown assets, 422 for schema violations, and 5xx for server issues. These codes are logged and linked to KPIs such as **QR success rate** and **API latency**, providing continuous monitoring of performance.

This forwarding mechanism transforms the QR feature from a simple identifier into a real-time data bridge. It ensures that asset metadata flows seamlessly into pilot HEMS/BEMS environments and into DSO/FSP systems for broader grid management applications. In doing so, the BSA-DEMO demonstrates how QR technology, combined with robust forwarding pipelines, can become a cornerstone of plug-and-play integration in the European flexibility ecosystem.

5.3 API Design and Integration using Django REST Framework

5.3.1 API Key-based Authentication Mechanism

The Django REST Framework (DRF) is the library chosen for exposing the BSA-DEMO data to external systems. DRF is an industry-standard extension of the Django web framework that provides a clean way to build RESTful APIs with built-in serialization, validation, and permission handling. It was selected because it combines flexibility with robust defaults and is widely adopted in both research and industry projects, while ensuring that APIs can be built securely and quickly. This makes it particularly suitable for OPENTUNITY, where both end-users and automated client systems (HEMS, BEMS, DSOs, FSPs) must interact with asset data in a reliable and consistent manner.

Within this framework, external systems authenticate using organization-scoped **API keys**. A custom class (ApiKeyOnlyAuthentication') inspects the HTTP header and, together with a custom permission (RequireValidApiKey'), ensures that the key is valid, active, and scoped only to the permitted operations. These keys are issued to organizations (Economic Operators) rather than individual end-users and can be rotated or revoked independently of user accounts. Moreover, they are restricted to read-only detail access, preventing data scraping or mass export of the dataset. Requests with missing or invalid keys return a typical 401 response "Invalid/unauthorized apikey", while all valid calls must use HTTPS and are logged with timestamp, IP, key reference, endpoint, and status for auditing and KPI tracking. The public QR resolver page may also accept a query parameter ('?apikey=…') to simplify the scanning workflow, but the official and secure method for machine clients remains passing the key in the Authorization header. This design ensures both usability for pilot partners and strong safeguards for the integrity of the shared asset repository.

5.3.2 Endpoint Structure and Data Format.

The current endpoints, as deployed in production, are un-versioned and operate under the path structure '…/api/…' without a version prefix. Once the interface has matured and stabilized, a semantic versioning scheme (e.g., '/api/v1/…') will be introduced to provide backward compatibility and long-term maintainability. Importantly, if versioning is adopted, the existing un-versioned endpoints will remain available during a defined transition period, ensuring that pilot integrations continue to function seamlessly while partners migrate to the updated API. In table 5.1 the current endpoints are listed:

Table 5.1 Overview of the current BSA-DEMO API endpoints, showing available methods, authentication requirements, and their role in asset data retrieval, QR resolution, and DPP ingestion.

Method	Path	Auth	Purpose
GET	/api/assets/{asset_id}/	Authorization: Api-Key <token>	Returns the static flexibility JSON for a single asset (detail-only).
GET	/api/assets/{asset_id}/enter-api-key/	None (public HTML) Manual Api-key entry	QR resolver page that prompts for an API key and then performs the gated fetch. Supports optional ?apikey=<token> for prefill.
GET	/api_qr/{asset_id}/	None (public)	Serve the QR image (PNG/SVG) for the asset's resolver URL.
GET	/api/dpp/asset?url=<dpp_url> &auto_import=true &apikey=<token>	Authorization: Api-Key <token>	DPP ingress. Accept a DPP payload, validate (map) to the internal schema, create/update the asset; return the assigned asset_id and revision.

The current API response structure, i.e. the data format shown in the example of ANEX2, demonstrates how the BSA-DEMO delivers well-structured, machine-readable JSON to partner systems. Each response provides a unique asset identifier and revision number, alongside core metadata such as manufacturer, model, classification, and electrical specifications. It also includes optional flexibility descriptors, communication parameters like Modbus register maps, and certifications, ensuring that the dataset can be used for both technical integration and regulatory compliance. The embedded QR resolver URL ties the digital record to its physical counterpart, while audit fields guarantee full traceability of when and by whom data was created or updated. In practical terms, this enables HEMS, BEMS, DSOs, and FSPs to directly ingest standardized information without manual intervention. Looking forward, a future DPP-aligned response would not only include technical details but also add information about sustainability, such as recyclability rates, expected lifetime performance, and carbon footprint. It could also use JSON-LD to make the data easier to connect with other product databases and EU standards. This richer format would turn this API into more than just a tool for energy flexibility, but it would also support compliance with European rules and give partners and customers clear, transparent information about each product.

6 INTEGRATION OF DIGITAL PRODUCT PASSPORTS

The Digital Product Passport (DPP) is a key component of the Ecodesign for Sustainable Products Regulation (ESPR), designed to embed sustainability, traceability, and circular economy principles into the lifecycle of products placed on the EU market, with energy assets representing just one important category.

Given the broad scope of Digital Product Passports, it is expected that DPPs for energy-related products, such as appliances, batteries, and other flexibility devices, will contain far more information than the minimum required for energy integration. To ensure accessibility, common data carriers like QR codes are likely to be adopted, while at the same time the European Commission is preparing the ground for infrastructures that enable federated data exchange across stakeholders. Should Dataspaces be mandated, specific Data-Space Connectors (DSCs) would be required to access DPP information, adding a further layer of complexity. The feasibility of these assumptions depends on the finalization of official EC standards, anticipated by the end of 2025, with Europe's standardization organizations (ESOs) tasked under Implementing Decision C(2024)5423 to deliver the relevant specifications. Until then, issues of alignment, data format harmonization, and integration pathways remain open.

For WP3-T3.3, this means that standardized, schema-aligned DPPs must exist before reliable ingestion can be implemented. In the meantime, **guidelines on possible integration pathways will be included in this chapter, providing a foundation for later adoption once standards mature**.

In line with Task 3.3 objectives, **the BSA-DEMO demonstrates proof-of-concept forward compatibility for expected DPP integration**, so that energy assets registered within the OPENTUNITY ecosystem not only provide the necessary flexibility descriptors for system operation but can also be enriched with product-level information such as recyclability, environmental impact, and compliance records. This dual focus ensures alignment with the EU's ESPR and broader circularity goals, where digital product passports are envisioned as key instruments to combine technical performance data with sustainability and compliance information.

This chapter describes the framework, standards, technical implementation, and challenges of integrating DPPs into the BSA platform. Furthermore, it proposes an ingress path for future DPP imports.

6.1 Introduction to ESPR-DPP Framework and Compliance Needs

The European Union's Regulation (EU) 2024/1781 establishes a comprehensive framework for the Digital Product Passport as a key tool in promoting sustainable products and the circular economy. As part of the "Ecodesign for Sustainable Products Regulation", the DPPs will store product-specific data, such as origin, materials, repairability, and carbon footprint. They are essentially digital records containing information about a product's sustainability throughout its entire lifecycle. This information is meant to be accessed by scanning a data carrier, such as a QR code.

6.1.1 Main goals of the DPP

Enhance Sustainability and Circularity: The DPP aims to enhance transparency about a product's environmental impact and sustainability throughout its lifecycle. It intends to facilitate circularity by providing data that supports repair, reuse, and recycling. [14]

Create new Business Opportunities: The DPP regulation is poised to create new business opportunities by enabling circular business models centered on retained product ownership, strengthening relationships with downstream customers, and facilitating compliance with environmental standards. By providing detailed digital records of products' lifecycles, DPPs enhance supply chain management and open avenues for innovative services and market differentiation. [15]

Ensure Compliance: The DPP will facilitate compliance with environmental standards and regulations by providing essential details such as a unique product identifier (UPID), compliance documentation, and information on substances of concern. [14]

Empower Consumers: The Digital Product Passport regulation aims to empower consumers by providing access to specific information about the products they wish to purchase, enabling them to make informed decisions that consider sustainability criteria. [15]

6.1.2 Prioritized Product Categories

The Ecodesign for Sustainable Products Regulation, which entered into force on 18 July 2024, aims to improve the sustainability of products in the EU by enhancing their circularity, energy performance, recyclability, and durability. [16] To implement the ESPR effectively, the European Commission is tasked with prioritizing product categories for which it will develop specific ecodesign requirements. According to Regulation (EU) 2024/1781, the first working plan should prioritize the following product groups:

a. Iron and steel.
b. Aluminum
c. Textiles, particularly garments and footwear
d. Furniture, including mattresses.
e. Tires
f. Detergents
g. Paints
h. Lubricants
i. Chemicals
j. Information and Communication Technology (ICT) products and other electronics
k. Energy-related products*
l. Batteries**

These categories have been identified based on their significant environmental impact and potential for improvement in sustainability. The Commission will develop specific ecodesign requirements for these products to enhance their environmental performance throughout their lifecycle. Energy-related products and batteries are the most important ones for OPENTUNITY.

***Energy-related products** are a critical focus area under the ESPR due to their significant role in energy consumption. The regulation prioritizes energy-related products with the aim of improving their energy efficiency, reducing waste, and ensuring sustainability. These products either consume energy directly (e.g., household appliances, heating systems) or impact energy consumption indirectly (e.g., insulation materials, windows, and industrial equipment). Broadly, this category covers Consumer electronics, Appliances, Lighting systems, and HVAC systems.

****Batteries** are regulated separately under Regulation (EU) 2023/1542 [17] the battery passport specified in this regulation must be fully interoperable with the DPP required by the ESPR. This interoperability ensures seamless end-to-end communication and data transfer regarding technical, semantic, and organizational aspects [18].

6.1.3 Aspects and Indicators (Norms and Standards per Indicator)

Aspects in the ESPR refer to the broader context or area of operation of a product related to its environmental performance. Indicators, on the other hand, are the specific characteristics or features within each aspect that can be measured and used to assess the product's environmental performance. Therefore, the DPP will store indicators within a relevant aspect that include detailed quality and threshold levels regarding the product's environmental performance throughout its lifecycle. These indicators are expected to be specified and normalized.

The ESPR acknowledges many aspects regarding the above-mentioned prioritized product categories. The relevant aspects for flexibility analysis and extraction include, but are not limited to, the following [19]:

- **Energy Use and Efficiency:** Implementing stricter efficiency standards to reduce energy consumption. Possible indicators: Power requirements during use, standby mode, and off mode, Minimum energy performance standards for different product categories, such as energy consumption limits for appliances, minimum efficiency levels for lighting systems, seasonal energy efficiency ratios (SEER) and coefficient of performance (COP) for heat pumps, refrigerators or air conditioning systems etc.
- **Extended Durability:** Aspect that indirectly contributes to energy efficiency by promoting products designed for longevity, reducing the need for frequent replacements. Possible indicators: Product lifespan, Resistance to wear and tear, etc.
- **Reparability:** Ensuring components can be easily repaired or replaced, thereby giving the possibility of maintenance and refurbishment, and extending product life. Possible indicators: Instructions for maintenance, Ease of repairing a product, Tools required for disassembling, etc.
- **Recyclability:** Using recycled materials in production can lower energy requirements while also supporting circularity. Possible indicators: Percentage of recycled content in energy-related products, End-of-Life Management, etc.
- **Reduced Environmental Impact:** Minimizing emissions and resource usage across the entire lifecycle, from production to disposal. Possible indicators: Carbon Footprint, etc.

The specific information required in the DPP for products and product families is yet to be determined. The European Commission will define these requirements in future delegated acts, following the implementation plan. The first ESPR working plan, covering at least three years, will be adopted and published in 2025 [20]. A forerunner to the DPP-ESPR framework is regulation (EU) 2023/1542 which already sets several ecodesign requirements for **Batteries**, including Performance and durability (e.g. Minimum requirements for battery capacity, cycle life, and calendar life), Recycled content (Targets for using recycled materials in battery production), Removability and replaceability (Requirements for easy removal and replacement of batteries from products), and Labelling (Clear labelling requirements to provide information on battery characteristics and end-of-life management). Relevant aspects include, but are not limited to, the following:

- **Environmental impacts:** This aspect considers the overall environmental footprint of batteries, including carbon footprint, resource use, and pollution. Possible indicators: Greenhouse gas emissions associated with battery production, use, and disposal.
- **Circular economy and end-of-life management:** This aspect focuses on promoting battery reuse, recycling, and recovery of materials. Possible Indicators: Recycled content, Recycling efficiency.

6.1.4 The DPP architecture: a federated system

The technical implementation of Digital Product Passports entails a complex interplay of technologies and standards designed to ensure secure, interoperable, and persistent data exchange throughout a product's lifecycle. **The DPP is envisioned as a federated system of interconnected datasets**, where data remain under the custody of the **Economic Operator (EO)** that places the product on the market. Each EO is responsible for creating, maintaining, updating, and providing access to its own DPPs, either directly or through authorized **Digital Product Passport Service Providers**. A central DPP Registry, maintained under the European Commission's supervision, will issue Unique Product Identifiers (UPIDs) and provide discovery and referencing functionality across the federated ecosystem.

A) Implementation Principles: The DPP system will leverage decentralized and resilient data storage solutions to prevent single points of failure and ensure continuous accessibility. The recent CEN/CENELEC drafts (**prEN 18216–18223,** section 6.2) confirm that the DPP will follow a distributed architecture, where data are hosted by manufacturers or service providers and synchronized via standardized APIs. Although earlier discussions considered blockchain or Distributed Ledger Technologies (DLTs) for traceability, the emerging standards now emphasize interoperable web technologies and federated architectures, consistent with the broader EU push for Data Space infrastructures. While none of the six prEN 1821x drafts explicitly mention "Data Spaces," their architecture and security provisions inherently support federated, interoperable data exchange, principles that align with the European Data Space vision. The authors anticipate that once Dataspace Connectors (DSCs) are formally mandated by the Commission, the prEN 18216–18223 framework will serve as the technical base enabling secure, semantic interoperability between DPP nodes and external dataspace infrastructures such as those envisaged under the European Green Deal Dataspace.

B) Granularity Levels: The DPP framework foresees three hierarchical levels of granularity namely model, batch, and item, each offering different resolution depths. Model-level DPPs describe general product characteristics (e.g., a specific inverter or battery model), batch-level DPPs capture information about production series (e.g., PV modules produced during a certain month in a specific plant), while item-level DPPs can uniquely identify individual products through serial numbers (e.g., high-end luxury units). [21]

C) Data Structure and Format: The DPP's information model is designed to be machine-readable and semantically consistent across sectors. Draft standards developed under CEN/CENELEC JTC 24 "Digital Product Passport – Framework and System" specify that product data will be structured using JSON-LD (as in OPENTUNITY) or other W3C-compliant formats, enabling direct linkage to ontologies and metadata dictionaries. This ensures that data on materials, repairability, environmental impact, or recyclability can be interpreted by different stakeholders and systems without loss of meaning. [23, 24].

Governance and Standardization Outlook: Implementing the DPP ecosystem still presents challenges, particularly in ensuring consistent adherence to common data and interface standards. The European Commission plans to adopt a Delegated Act on DPP Service Providers, which will define operational, security, and governance rules for entities hosting or managing DPP data. Following the 2024 public consultation, this act is expected to be adopted in Q4 2025, in parallel with the finalization of the foundational CEN/CENELEC prEN standards (18216–18223). These standards collectively define the technical layer covering identifiers, carriers, APIs, interoperability, and persistence, but not the sector-specific data content, which will be determined later through delegated acts for each product group. The standards form the digital backbone that will allow energy-related assets and other products to integrate seamlessly into the forthcoming European DPP and Data Space ecosystem.

6.2 Overview of DPP Technical Standards and Guidelines on future integration pathways of DPPs into T3.3-D3.3

CEN/CENELEC JTC 24, the joint technical committee for DPP framework and system, is charged with developing harmonized standards in support of the EC's standardization request (deadline 31 December 2025) under Implementing Decision C(2024) 5423. Its deliverables are organized into modules covering key domains including identifiers, data carriers, access rights and security, interoperability, data processing and exchange, storage, APIs, and system architecture. Crucially, JTC 24's scope explicitly excludes sector-specific data content (i.e. the precise measured attributes per product category) and leaves that to other technical committees. The following subsections map each prEN draft to its anticipated role and provide guidelines on future integration pathways with the BSA cloud service (T3.3-D3.3).

6.2.1 Unique Identifiers (prEN 18219)

The prEN 18219 draft specifies the rules for generating globally unique, persistent identifiers for products (at model, batch, and item levels), economic operators, and facilities. It integrates with ISO/IEC 15459 conventions, URIs, and potentially Decentralized Identifiers (DIDs).

Integration model:

- BSA's registration module must support ingestion and normalization of DPP IDs per prEN 18219 syntax (e.g. distinguishing model, batch, item levels).
- BSA's cloud repository service must be prepared to act both as a consumer of DPP IDs (e.g. linking an energy asset to its DPP identifier) and, optionally, a provider of identifiers if participating in a DPP issuance workflow.

6.2.2 Data Carriers (prEN 18220)

The prEN 18220 draft standardizes how to link the physical product (or its packaging) to its digital passport via data carriers, including QR codes or RFID, or hybrid forms. It sets rules on encoding, durability, readability, marking placement, fallback levels, and persistence across product life.

Integration model:

- BSA cloud service must be able to read and process the basic identifier stored in the data carrier, which is the DPP ID encoded in a QR code.
- When an end-user scans a DPP carrier, OPENTUNITY Partners of BSA should automatically build the correct link or API call needed to retrieve the full DPP record from its source via BSA-DEMO service.
- In a theoretical scenario where the QR code might contain only a minimal identifier (e.g., 'DPP:EU123456789') but a wider DPP infrastructure is available, T3.3-D3.3 would include or connect to a “carrier-to-DPP resolver” service that translates scanned identifiers into complete DPP URLs for lookup and data import.

Example:

```
QR scan → EU123456789

BlueSun → API: /api/dpp/asset?url=EU123456789

Resolver → returns "https://registry.europa.eu/dpp/assets/EU123456789.jsonld"

BlueSun → fetches that JSON-LD, imports it and forwards it to OPENTUNITY partners.
```

6.2.3 Data Exchange Protocols (prEN 18216)

The prEN 18216 draft mandates secure and interoperable data exchange protocols among DPP stakeholders. It prescribes HTTPS over TLS, RESTful APIs, JSON, JSON-LD, and HTML formats. It also defines authentication/authorization schemes (OAuth 2.0 / OpenID Connect / token-based) and alignment with DID-based or federated identity systems.

Integration model:

- BSA-DEMO back end should be able to send and receive data through standard REST APIs, using JSON-LD format and normal HTTP operations as defined in prEN 18216.
- All API interactions should be logged and traceable, ensuring auditability and proof of data integrity as required by prEN 18216.

Example:

```
HEMS/BEMS → requests an asset's DPP

GET /api/dpp/assets?url=https://registry.europa.eu/dpp/assets/EU123456789.jsonld

Headers: (Authorization: Bearer <apikey>, Accept: application/ld+json)

BlueSun → authenticates the request

BlueSun → retrieves asset data from its database

BlueSun → formats it into JSON-LD (linked to DPP schema)

BlueSun → returns response:

{

  "@context": "https://jtc24.eu/dpp/context",

  "@id": "EU123456789",

  "manufacturer": "VARTA AG",

  "model": "VARTA.wall",

  "capacity": "10.2 kWh",

  "recyclability": "85%"

}

At the same time:

BlueSun → writes log entry:

  Timestamp: 2025-10-04 11:45:22

  Action: GET /api/assets/15/

  User: EMS_Operator

  ResponseCode: 200

  PayloadHash: SHA256:8c8f...e2a
```

6.2.4 APIs for Passport Lifecycle (prEN 18222)

The prEN 18222 draft defines the canonical APIs for creating, updating, reading, and deleting (or versioning) DPPs, as well as search and registry operations. It includes guidelines for error handling, pagination, and status semantics.

Integration model:

- BSA should implement or be ready to plug in a DPP API adapter layer that maps BSA's internal data model into the prEN 18222 canonical API calls.
- BSA only needs to read the lifecycle flag (status = "published") to confirm the passport is valid before ingesting data.
- Conform to error propagation and validation (prEN-standard error codes) that make sure that every DPP imported into BlueSun, and every asset JSON exported to OPENTUNITY partners, is complete, correct, and traceable.

6.2.5 Storage, Archiving & Persistence (prEN 18221)

The prEN 18221 draft addresses how DPP data are stored, replicated, archived, and persisted over long product lifespans. It requires that data remain immutable, versioned, and accessible even if an EO ceases operations. It prescribes dual repository strategies (main + backup), secure replication, immutability, and version retention for regulatory oversight.

Integration model:

- For daily flexibility data exchange, immutability is not required. BSA-DEMO service will simply retrieve asset data form the latest valid DPP snapshot.
- DPP replication is optional for resilience, not required for core functionality of a research and demonstration web app.
- For the current BSA implementation in Task 3.3, maintaining historical DPP snapshots is not relevant.
- For BSA's present function which is acting as a data integration and flexibility-information relay, fallback resolution and replication of full DPPs are not relevant.

6.2.6 Interoperability & Semantic Model (prEN 18223)

The prEN 18223 draft lays out a common semantic model (UML-based), value typing, metadata rules, and a shared ontology/dictionary regime. It enforces harmonization across sectors so that DPPs from different product domains (e.g. electronics, batteries, appliances) can be consumed and interpreted in a consistent manner.

Integration model:

- BSA doesn't need to rebuild its database to match that schema exactly, but it should understand it to make sure the data it receives from DPPs is interpretable by other compliant systems.
- For energy-flexibility purposes, BSA only needs a few technical terms which already have clear definitions. Linking to full ontologies adds little value to flexibility analysis.
- BSA must validate payloads against the prEN 18223 schema constraints (types, metadata, units, optionality). When a DPP JSON is imported, it should be checked against the standard schema, verifying that fields use correct data types, correct units.
- The system should allow custom extensions (per product category) but maintain alignment with the core prEN model for interoperability.

Example:

```
# The core DPP structure (from prEN 18223) defines a generic model like:
{
  "@context": "https://jtc24.eu/dpp/context",
  "@type": "DigitalProductPassport",
  "productId": "EU123456789",
  "manufacturer": "VARTA AG",
  "model": "VARTA.wall",
  "DataElementCollection": [
    {
      "name": "ElectricalCharacteristics",
      "DataElement": [
        {"name": "NominalVoltage", "value": 48, "unit": "V"},
        {"name": "NominalCapacity", "value": 10.2, "unit": "kWh"}
      ]
    }
  ]
}
# BlueSun’s model with custom extensions (energy-specific)
{
  "@context": [
    "https://jtc24.eu/dpp/context",
    {
      "bluesun": "https://bluesun.pro/dpp/extensions/"
    }
  ],
  "@type": "DigitalProductPassport",
  "productId": "EU123456789",
  "manufacturer": "VARTA AG",
  "model": "VARTA.wall",
  "DataElementCollection": [
    {
      "name": "ElectricalCharacteristics",
      "DataElement": [
```

```
        {"name": "NominalVoltage", "value": 48, "unit": "V"},
        {"name": "NominalCapacity", "value": 10.2, "unit": "kWh"}
      ]
    },
    {
      "name": "bluesun:FlexibilityParameters",
      "DataElement": [
        {"name": "bluesun:MaxChargePower", "value": 5000, "unit": "W"},
        {"name": "bluesun:MaxDischargePower", "value": 5000, "unit": "W"},
        {"name": "bluesun:ResponseTime", "value": 2, "unit": "s"},
        {"name": "bluesun:StateOfHealth", "value": 95, "unit": "%"}
      ]
    }
  ]
}
```

6.3 Implementation Strategy & Migration Path

Given that the prENs were released in Q2 of 2025, are still drafts and may evolve until end-2025, BSA adopted a forward-compatible, modular strategy regarding DPP integration into the T3.3-D3.3 implementation.

1. **API Adapter Layer**: The current T3.3-D3.3 implementation uses an internal canonical representation (i.e. BlueSun's own data model) and an adapter layer that translates between this structure and the standardized DPP API calls described in prEN 18222 and 18216. This allows BSA to receive or send DPP data without changing its internal database schema.

   Status: *Partially implemented.*
   BSA already has a working REST API input (/api/dpp/asset?url=<DPP-URL>&auto_import=true&apikey=<key>) and output (/api/assets/<id>/) that exchanges JSON data with external clients. A full adapter layer for prEN 18222 methods (ReadDPPById, etc.) has not yet been added but the existing endpoints are structurally ready for it.

2. **Schema Versioning**: A future T3.3-D3.3 implementation update should include version metadata so that when prEN schemas evolve, BSA can migrate or support multiple versions concurrently.

   Status: *Not implemented yet because the official DPP and prEN schema versions are still evolving, making early version control premature.*
   The current API and MySQL schema have no version metadata fields. Version control could be added later through model fields like schema_version or header-based versioning in API responses.

3. **Semantic Mapping Registry**: A future T3.3-D3.3 implementation update should maintain mapping tables from its internal data names to prEN 18223 element names, enabling gradual alignment.

Status: *Not implemented yet because standardized prEN 18223 element names are not finalized, so creating a mapping table now would be unreliable.*
BSA currently maps DPP JSON fields manually inside the API view (for the /dpp/asset import). No formal mapping table or registry exists yet.

4. **Carrier-Agnostic Scan Interface**: In a fully DPP compatible T3.3-D3.3 implementation, the scanning feature should accept any of the carrier formats described in prEN 18220 (e.g. QR, NFC, or RFID) to locate and retrieve DPP data.

   Status: *Implemented for QR scanning.*
   The web app already generates and reads QR codes for assets and triggers DPP lookup through the /enter-api-key/ flow.

5. **Resilient Data Store**: Usage of storage technologies that support immutable versioning, replication, and archival workflows.

   Status: *Partially implemented.*
   The MySQL backend currently stores imported DPP data persistently, but without immutable or versioned logging. For a research prototype, this is sufficient; full immutability could be added later if BSA evolves toward a production-grade DPP node.

6. **Access control abstraction**: A DPP compatible system should separate its user-role permissions from API-key authentication, allowing both internal (role-based) and external (token-based) access methods, as foreseen in prEN 18216.

   Status: *Implemented.*

   BSA already enforces API-key–based access through custom authentication classes (ApiKeyOnlyAuthentication, RequireValidApiKey), completely independent of Django's user login system.

7. **Testing & compliance harness**: As prEN drafts stabilize, BSA should run compliance tests (schema conformance, API behavior, error semantics) to ensure alignment.

   Status: *Not implemented yet as prEN drafts are still evolving, but BSA plans to add automated compliance tests once the standards are finalized.*
   No formal compliance test harness exists yet. Manual testing has been performed using Python scripts, but no automated schema validation or API conformance suite has been set up.

6.4 Risks, Uncertainties, and Key Considerations

- **Standards evolution:** The prEN drafts are not finalized; significant changes may occur before harmonized EN adoption. BSA's architecture already isolates its data models and API logic, making future updates manageable.
- **Timeline:** The EC's target (end-2025) for finalizing EN DPP modules is ambitious, and delays are possible. BSA's modular API and Django structure make it adaptable to changes.
- **Scope exclusion:** JTC 24's mandate excludes product-specific data content (i.e. the exact lifecycle or material attributes) focusing only on data exchange, carriers, and interoperability but not on actual product data. That means that BSA manages energy-specific extensions, as originally intended, like flexibility parameters, Modbus maps etc.

- **Carrier/IT alignment:** Some draft prENs (e.g. prEN 18220) exclude the detailed design of the IT infrastructure, focusing only on carrier encoding rules.
- **Fallback and Data Continuity:** If an economic operator stops providing DPP data, the persistence guarantees in prEN 18221 must rely on replication or fallback registry. BSA does not need to maintain backups or mirrored copies of DPPs, The T3.3-D3.3 implementations role is to extract flexibility attributes.
- **Battery Passport Interoperability:** The battery regulation's passport (Regulation (EU) 2023/1542) must interoperate with ESPR DPPs; however, how exactly the two regimes will be aligned remains to be confirmed. BSA's design allows it to consume both battery- and device-level JSONs via the same import endpoint.

6.5 Implementation of API-driven DPP Data Ingestion

The ingress path for future DPP imports defines a dedicated and secure API entry point through which external product data can be fetched and integrated into the BSA application. In practical terms, this ingress takes the form of an endpoint designed to retrieve DPP payloads directly from vendor-provided QR codes or other standardized data carriers. The feature is intended to support seamless integration of forthcoming ESPR-compliant device passports, anticipating that DPP payloads will adopt structured formats such as JSON-LD, aligned with GS1 Digital Link. The endpoint

```
# Endpoint:
https://bluesun.pythonanywhere.com/api/dpp/asset?url=<dpp_url>&auto_import=true&apik
ey=<eo_apikey>


# Query parameters:
dpp_url – Publicly reachable DPP endpoint to fetch (required).
auto_import – If true, persist the parsed DPP into the DB (create/update Asset). If
false/omitted, do a dry-run parse/validate only.
eo_apikey – An active API key used to authorize the call (required).
# Typical responses:
200 OK – Parsed (and possibly imported) successfully.
400/422 – Bad url, fetch/parse/validation errors.
401 – Invalid/unauthorized apikey.
```

allows EOs to securely import product-level data, where the system fetches, validates, and persists the DPP content into the internal asset database. Incoming payloads are checked for schema compliance, cross-referenced against existing records to prevent duplication, and automatically enriched with timestamped import metadata for traceability. Validation ensures syntactic correctness and referential consistency, while a mapping layer translates standardized energy-related DPP attributes (e.g., rated power, usable capacity, efficiency, response time, and operational limits) into the internal asset schema. This design ensures that, as the DPP standards evolve, the system will remain interoperable and capable of harmonizing sustainability and flexibility data, therefore laying the groundwork for integration with future European data exchange frameworks.

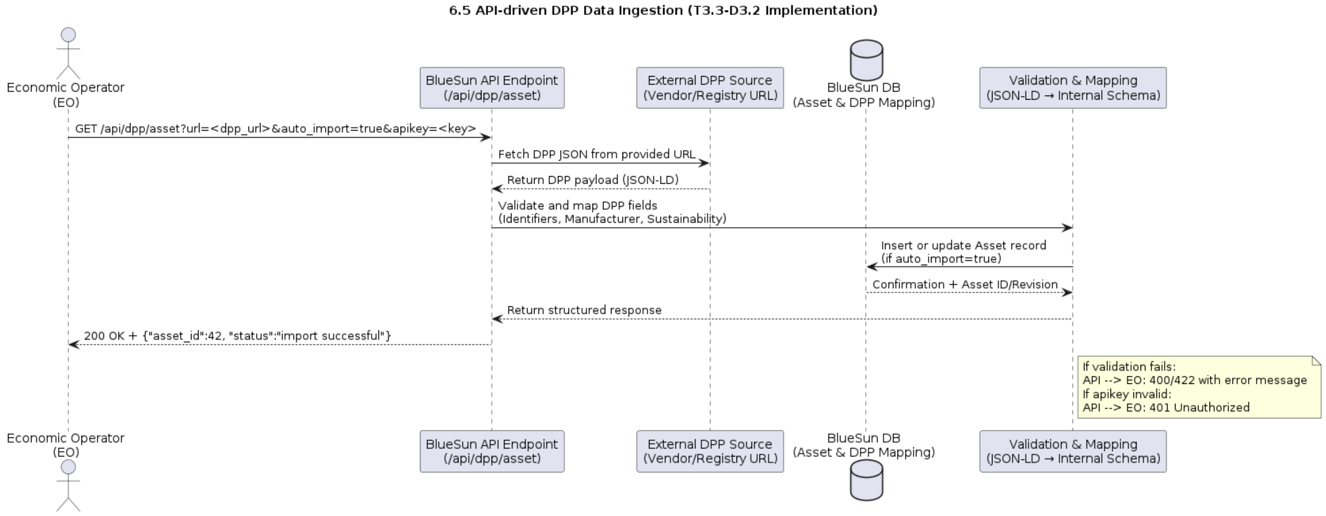


Figure 6.1 UML sequence diagram illustrating the API-driven DPP data ingestion process in the BSA-DEMO, showing how an EO imports a DPP from an external source through validation, mapping, and database integration.

However, the DPP implementation described here predates the formal release of the CEN/CENELEC prEN 18216–18223 drafts (June 2025) that now define the reference architecture for Digital Product Passports. As such, the current BSA_DEMO API demonstrates the functional concept of DPP ingestion but cannot yet be deemed fully compliant with the emerging standards. Key gaps include the absence of full OAuth 2.0–based authentication, canonical API methods (as defined in prEN 18222), and full adoption of the prEN 18223 semantic data model. Given that these drafts were issued during the closing phase of the WP3 T3.3 timeframe, complete alignment was not feasible within this reporting period. Future iterations of the T3.3-D3.3 implementation, or follow-up tasks could adapt the existing /api/dpp/asset ingress endpoint to conform with the finalized EN standards once they are formally adopted by the European Commission.

7 LEGACY EQUIPMENT

Chapter 7 elaborates on the practical aspects of expanding the OT ecosystem to include legacy assets. Such devices predate modern interoperability standards. Moving beyond standardized and newly registered assets, this chapter outlines the technical barriers, details effective integration strategies, and defines future pathways. The ultimate goal is to ensure that even non-digitally native equipment can fully participate in flexibility utilization.

7.1 Challenges for integration of legacy assets

The term Legacy Assets (LAs) refers to energy-related equipment and systems that were designed, manufactured, and deployed before the emergence of standardized digital identification and interoperability mechanisms, such as the OPENTUNITY QR (OT-QR) methodology. Within the scope of Task 3.3, the broader term "Assets" encompasses both individual energy devices (e.g., white appliances, water heaters, EV chargers etc.) and composite energy systems (e.g., BESS + BMS + Inverter or PV + BESS + Inverter + SCC configurations etc.) that remain in operation but lack the technical features required for direct and automated registration into the OPENTUNITY ecosystem.

In contrast, registered OPENTUNITY assets will already have an OT-QR code linked to a harmonized data schema describing nominal characteristics and operational constraints. Such assets can be instantly accessed via the BlueSun DEMO API, achieving genuine Plug & Play registration with minimal human intervention. Legacy Assets, however, exhibit a wide range of digital readiness levels, and for the purposes of integration they can be grouped into three functional categories:

A) Digitally connected but standardized heterogeneously: This category includes equipment such as PV inverters, smart meters, and heat-pump controllers that already feature native connectivity (e.g., Ethernet, Wi-Fi, Modbus/TCP, MQTT, etc.) and can exchange operational data. However, these devices often employ heterogeneous or proprietary identifiers (vendor-specific QRs, barcodes, or RFID tags) and expose metadata that is fragmented across datasheets, web portals, or vendor APIs. Integration is therefore hindered by inconsistent semantics and non-harmonized metadata structures. For these assets, the main effort lies in achieving semantic alignment, that is assigning a unique OT-QR, mapping operational parameters to the standardized Bluesun DEMO schema, and eventually validating the resulting dataset for accurate flexibility analysis.

B) Digitally connected but non-standardized assets: These assets likewise possess native communication interfaces but lack any formal standardized identification. Their register maps and data structures are accessible yet vary widely between manufacturers. Typical examples include older-generation PV inverters or HVAC controllers that can transmit data but have no reference to a harmonized schema. Here, integration focuses on metadata normalization and identifier assignment, enabling the asset to participate in the OPENTUNITY ecosystem through the same API endpoints as modern devices once an OT-QR has been generated and associated with the harmonized dataset.

C) Electrically controllable and non-standardized assets: This group represents the least digitalized class of equipment, devices without internal communication capabilities but still operable via external control mechanisms such as relays, contactors, or smart plugs. Examples include resistive heaters, older HVAC units, generator sets or circulation pumps. They expose no native registers and provide limited observability. Thus, their behavior must be inferred through external metering or sensing. Integration depends on manual entry of essential technical metadata (e.g. rated power, duty cycle, operational limits) and external sensing/actuation performed by HEMS/BEMS platforms to estimate flexibility potential.

Understanding these distinctions is crucial for designing integration strategies that minimize user effort while maintaining data accuracy. Categories A and B can gradually achieve near Plug & Play registration through semantic harmonization and auto-mapping mechanisms. Category C assets, while more challenging, can still be represented within the BSA-DEMO schema via manual entry. In all cases, the inclusion of legacy assets remains essential:

- It extends OPENTUNITY's reach to encompass the vast installed base of non-digitally native equipment.
- It enhances the completeness and realism of flexibility datasets.
- It supports a just and inclusive digital transition, ensuring that older infrastructures and smaller prosumers can actively participate in flexibility markets.

Ultimately, the challenge for T3.3-D3.3 lies in enabling energy assets (legacy & nonlegacy) to enter the OPENTUNITY ecosystem with minimal manual configuration, progressively bridging the gap between traditional devices and the automated Plug & Play paradigm achieved by modern OT-QR–enabled assets.

7.2 Integration approach for Legacy Assets

The BlueSun platform provides several ways to bring legacy energy assets into the OPENTUNITY ecosystem. These assets, devices and systems that pre-date the OPENTUNITY QR methodology (OT-QR), require special methods of registration and data retrieval because they lack unified digital identifiers or standardized data models. The integration pathways described below allow both end-users and Economic Operators (EOs) to gradually connect such devices to the platform, moving step by step toward the project's ultimate goal of Plug & Play onboarding for all flexibility assets.

Path 1 – Manual Integration via Web Interface: The first and most direct method allows users or EOs to register devices manually through the BlueSun web dashboard. This interface provides structured forms corresponding to the internal asset schema. Once the data are submitted, the system generates a unique **asset ID** and issues an **OT-QR code** that links to the stored JSON record. This method ensures that even the oldest or non-connected devices can be included in the OPENTUNITY environment. However, it assumes that the user already knows the technical details of the device, for example, from its nameplate, user manual, or manufacturer datasheet.

Path 2 – Automated Integration via API (currently internal to BlueSun): For larger organizations or partners who manage many assets, BlueSun has developed (ongoing) an Asset Data Ingestion API. This service is temporarily available only within BlueSun and receives a pre-formatted JSON string containing all required asset data. When submitted, the data are automatically checked, stored in the MySQL database, and linked to an issued OT-QR code. This approach reduces manual work and enables semi-automated data registration, but it still requires that the submitting party already knows the full set of asset data and correct formats according to BlueSun's schema. In future releases, this API will be made available to selected partners (e.g., HEMS/BEMS vendors) under secure authentication.

Path 3 – Automated Import from Pre-existing Digital Identifiers: To approach true Plug & Play integration, BlueSun plans to support automated extraction of asset data from pre-existing digital identifiers already affixed on products. These may include:

- **EPREL QR codes** (European Product Registry for Energy Labelling) used on energy-labelled appliances sold in the EU. EPREL is a restricted but officially recognized service of the European Commission that hosts detailed technical data for energy-labelled products. By scanning an EPREL QR, one can access the appliance's public entry, including information such as brand, model identifier, rated power, efficiency class, standby consumption, and energy use per cycle. Through the EPREL public API (available upon request), these parameters can be automatically fetched and mapped to BSA's internal schema, enriching the database with validated and comparable asset data.

- **GS1/GTIN codes** (Global Trade Item Number), globally standardized and increasingly linked to the GS1 Digital Link format. GS1/GTIN provides a globally unique identifier for almost every commercial product. By resolving a GTIN through the GS1 Digital Link standard, one can obtain a machine-readable "linkset" pointing to product metadata (brand, product name, manufacturer contact, or documentation). The richness of data depends on what the brand owner publishes through the GS1 network or the paid Verified-by-GS1 service. Although it does not usually include detailed operational parameters, it can serve as a reliable source for manufacturer identity, model reference, and product categorization—important for traceability and linking with other registries.
- **Future ESPR-DPPs**, which will include detailed product lifecycle, and environmental data in structured JSON-LD format. DPP (Digital Product Passport), mandated by the Ecodesign for Sustainable Products Regulation (ESPR), represents the next generation of product identification in Europe. Each DPP will link a product to a structured dataset—most likely JSON-LD—covering its technical characteristics, operational limits, energy efficiency, materials composition, reparability, recyclability, and carbon footprint. Once the DPP framework is operational (expected by the end of 2025), it will become the most comprehensive data source for both sustainability and flexibility analytics. Integrating DPP endpoints into BSA-DEMO architecture will allow automatic enrichment of asset records and minimize the need for user input.

Each of these data sources provides different levels of accessibility and data richness, as illustrated in the Venn diagram of Figure 7.1.

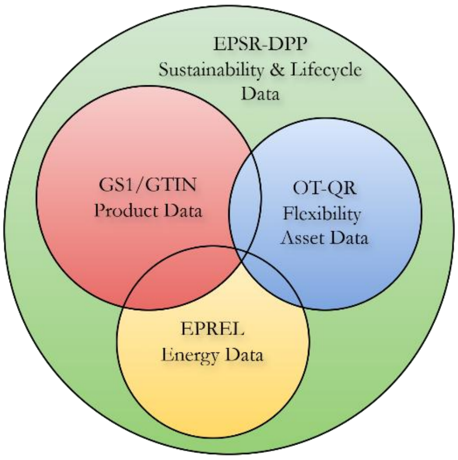


Figure 7.1 The diagram illustrates the relationship between major data sources: GS1/GTIN provides global product identifiers, EPREL supplies regulated energy performance data, OT-QR represents BSA's flexibility-focused asset data, and the forthcoming ESPR-DPP is expected to provide sustainability, lifecycle, and traceability information across all.

BSA aims to develop future ingestion modules capable of automatically retrieving and mapping data from these sources. When scanning an EPREL QR, the system could for example retrieve rated power, voltage, and energy efficiency parameters, which are critical for evaluating flexibility potential. By resolving a GS1 Digital Link or querying the Verified by GS1 API, the platform could obtain structured manufacturer and model information, reducing manual data entry.

Once DPPs are deployed, their machine-readable JSON-LD payloads are expected to provide standardized descriptors for nominal characteristics, operational constraints, and connectivity features, directly compatible with BlueSun's internal asset schema (Section 6.5).

Although these external databases differ in openness and purpose, they could together supply the baseline data needed for a consistent and verifiable digital identity of each energy device. However, at present, none of these sources alone provide the full set of parameters required for flexibility analysis, particularly those describing control capabilities, response times, and operational limits. Therefore, BlueSun treats them as complementary data sources that can assist but not yet replace the manual or API-based registration processes.

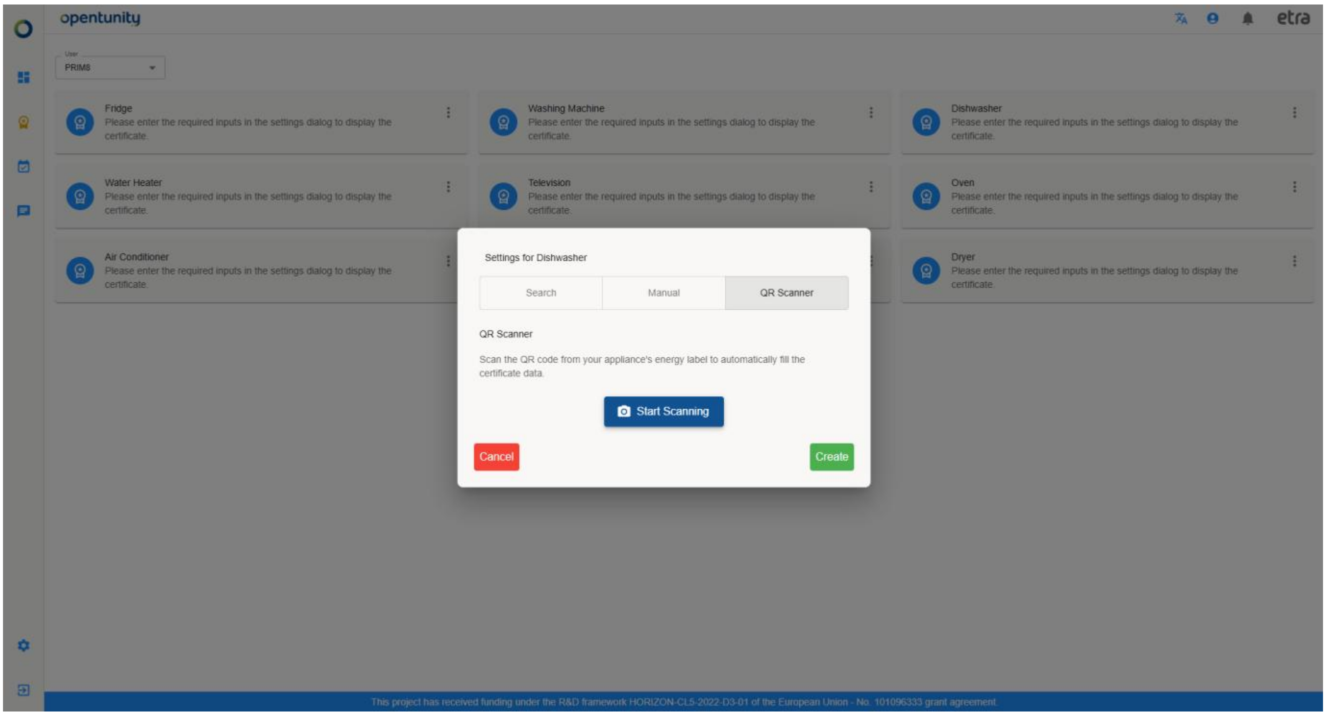
8 TESTING AND DEPLOYMENT

Chapter 8 describes the complete validation process of the BSA-DEMO under real conditions. It outlines how the BSA platform will be tested, deployed, and evaluated within OPENTUNITY. The chapter describes the cooperation between partners, the testing methodology, the key performance indicators (KPIs) used to assess functionality and reliability, and the steps leading to full deployment under real operating conditions.

8.1 Overview of Pilots and Partner involvement

Within this framework, the BSA platform developed under Task 3.3 can provide valuable support by supplying harmonized static asset data via its OT-QR codes, to different systems and service providers such as HEMS/BEMS, and FSPs respectively.

A) ETRA's NILM: The collaboration between ETRA and BSA has proven particularly fruitful, as ETRA plans to use the OT-QR codes issued by BSA's DEMO to retrieve static asset data such as energy consumption labels and nominal characteristics, enabling improved **Non-Intrusive Load Monitoring** (NILM) performance. This data linkage enhances ETRA's identification and segmentation models, while providing BSA with valuable feedback for refining its schema and QR-mediated data retrieval logic.



Fridge: Please enter the required inputs in the settings dialog to display the certificate.

Washing Machine: Please enter the required inputs in the settings dialog to display the certificate.

Dishwasher: Please enter the required inputs in the settings dialog to display the certificate.

Water Heater: Please enter the required inputs in the settings dialog to display the certificate.

Television: Please enter the required inputs in the settings dialog to display the certificate.

Oven: Please enter the required inputs in the settings dialog to display the certificate.

Air Conditioner: Please enter the required inputs in the settings dialog to display the certificate.

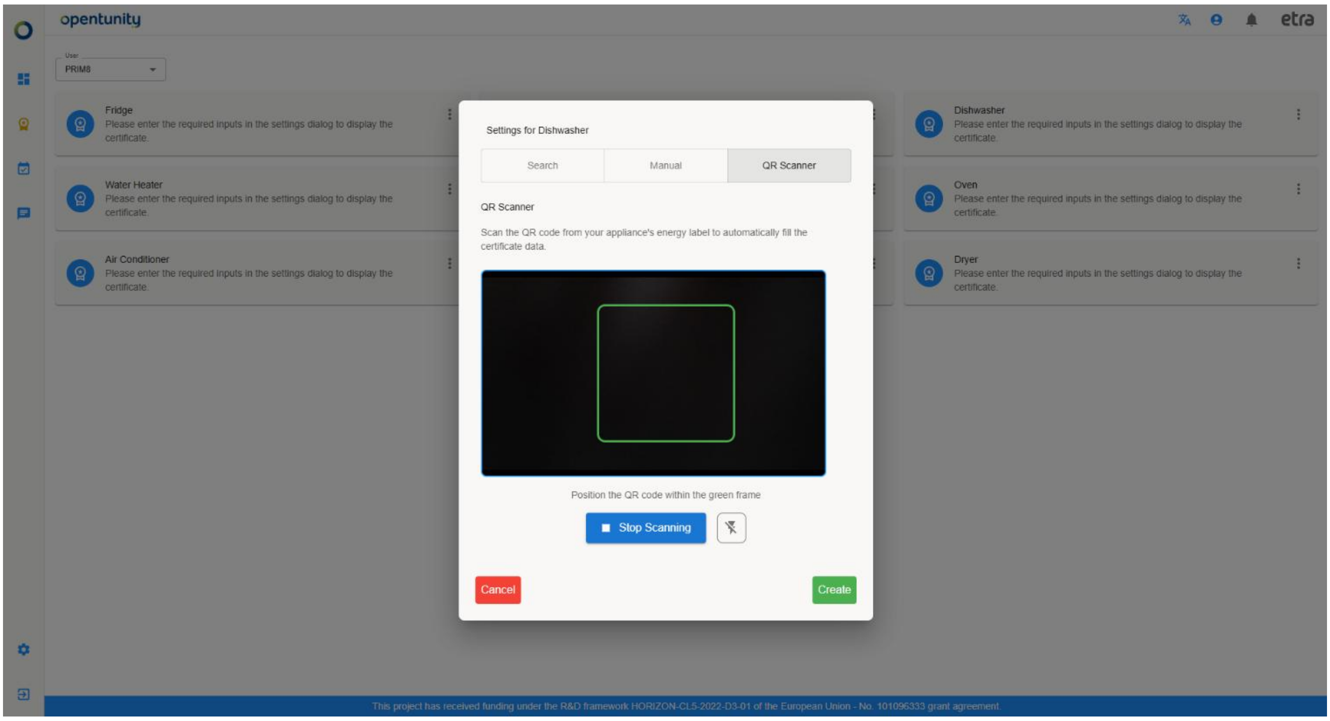
Dryer: Please enter the required inputs in the settings dialog to display the certificate.

QR Scanner

Scan the QR code from your appliance's energy label to automatically fill the certificate data.

This project has received funding under the R&D framework HORIZON-CL5-2022-D3-01 of the European Union - No. 101096333 grant agreement.

Figure 8.1 Methodology process through NILM app: From the aim of integrating a new asset…



Please enter the required inputs in the settings dialog to display the certificate.

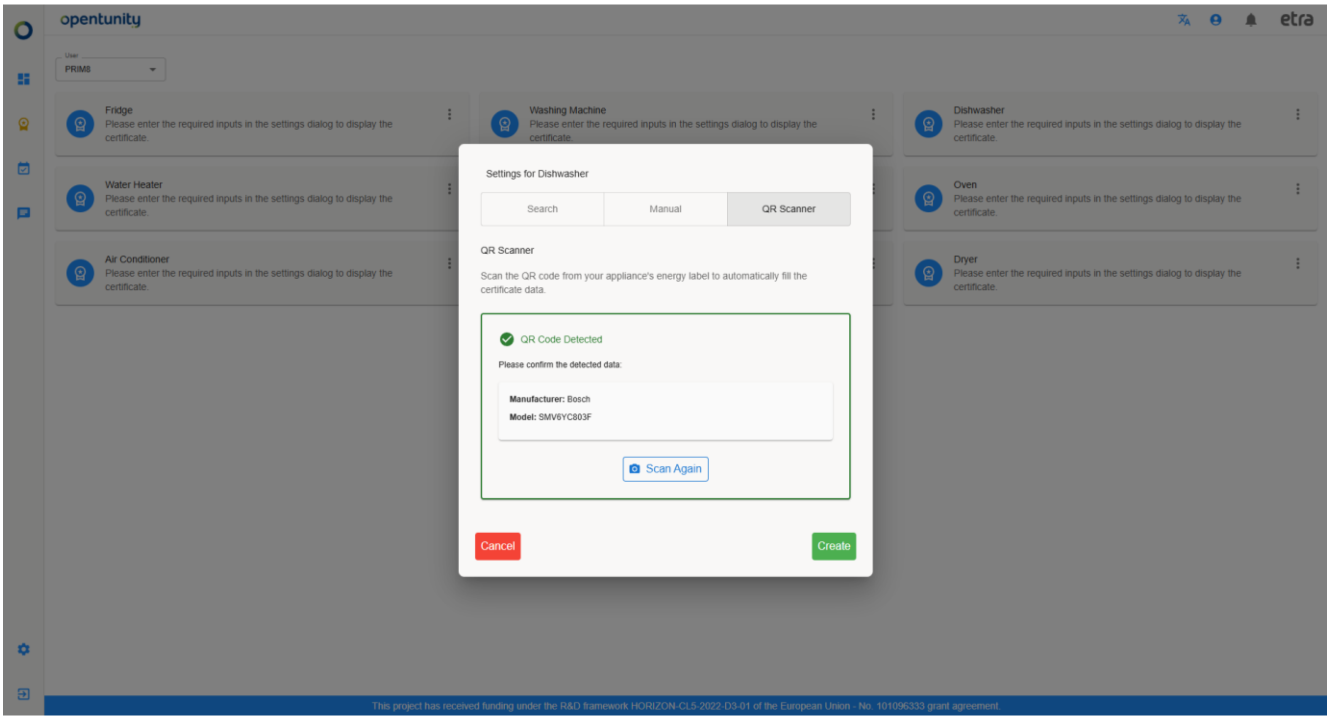
QR Scanner

Scan the QR code from your appliance's energy label to automatically fill the certificate data.

Position the QR code within the green frame

This project has received funding under the R&D framework HORIZON-CL5-2022-D3-01 of the European Union - No. 101096333 grant agreement.

Figure 8.2 Methodology process through NILM app: following the opening of the camera to scan the QR…



Please enter the required inputs in the settings dialog to display the certificate.

QR Scanner

Scan the QR code from your appliance's energy label to automatically fill the certificate data.

QR Code Detected

Please confirm the detected data:

Manufacturer: Bosch
Model: SMV6YC803F

This project has received funding under the R&D framework HORIZON-CL5-2022-D3-01 of the European Union - No. 101096333 grant agreement.

Figure 8.3 Methodology process through NILM app: and finally the detection of the asset.

B) Amibit: AMIBIT provided BSA with the '**Reduxi'** hardware and control interfaces to conduct laboratory integration and testing, which proved instrumental in validating BSA's data flow design and verifying interoperability between flexibility control and static asset information. The collaboration between AMIBIT and BSA strengthens the alignment between data registration and real-time control, while AMIBIT's deep expertise in device-level communication directly contributes to improving BSA's communication and control architecture.

C) ICCS: ICCS intends to leverage OT-QR–linked data from BSA within its role as a **Flexibility Service Provider** (FSP) in the Greek Pilot, integrating static asset data (e.g., nominal power, operational constraints, controllability features) into its flexibility estimation and aggregation framework. Through this cooperation, ICCS contributes valuable FSP expertise, real asset datasets, and performance specifications that enhance the representativeness and applicability of the BSA's database across all pilot sites.

Overall, the collaboration between BSA and the technical partners (ETRA, AMIBIT, ICCS) established a two-way value exchange, where these partners gain access to harmonized and machine-readable asset data supporting configuration, NILM analysis, and flexibility forecasting, while BSA benefits from technical validation, partner datasets, and operational insights essential for scaling its role as the reference platform for plug-and-play flexibility asset registration within the OPENTUNITY ecosystem.

8.2 Test case, KPIs and Datasets

The BSA-DEMO will undergo a structured evaluation across selected OPENTUNITY pilot environments, following the experimental framework outlined in **Test Case TC.3.3.1: "QR-enabled Asset Onboarding into HEMS/BEMS."** The objective is to validate the plug-and-play onboarding process for flexible devices and assess the reliability, completeness, and interoperability of the data exchanged between the BSA's repository and technical partners' HEMS/BEMS platforms.

8.2.1 Experimental Steps and Timeline

Testing will be coordinated and executed collaboratively by BSA, ETRA, AMIBIT, and ICCS. Each partner will replicate the following experimental steps within its own pilot framework:

1. **Asset Registration:** As Economic Operators, Partners will input static asset specifications into the BSA DEMO via the user interface or API.
2. **QR Code Generation:** Upon asset registration, the DEMO automatically issues a unique OT-QR that encodes a specific resolver URL for the asset's JSON dataset.
3. **QR Scanning:** During asset setup, HEMS/BEMS operators, FSPs or end-users scan the OT-QR. The scan triggers an HTTPS request to the BSA DEMO REST API.
4. **Data Retrieval and Parsing:** The API delivers the asset's structured JSON payload, which is parsed by the partner's system (e.g., Reduxi for Amibit, ETRA's NILM tools, ICCS's FSP layer).
5. **Acknowledgment and Logging:** Each successful retrieval triggers an acknowledgment (ACK) returned to the BSA system for KPI computation.
6. **KPI Evaluation:** BSA monitors performance metrics and compiles results per pilot-partner.

The tests are scheduled for **Q4 2025** to **Q1 2026**, synchronizing with ongoing pilot integration phases, ensuring field validation prior to the project's final reporting stage.

8.2.2 Datasets

The dataset consists of static asset data describing the technical and operational parameters of flexibility assets. This information is represented in **JSON format**, following the harmonized schema defined in Annex 2. The dataset will be partner-provided (i.e. manual or API data entries during pilot configuration) and publicly accessible among all project partners, under API-key authentication. They will directly support KPI monitoring.

8.2.3 Key Performance Indicators

Two primary **Key Performance Indicators (KPIs)** will validate the BSA-DEMO functionality and reliability:

Table 8.1 KPI 51 "QR Code Functionality Rate"

KPI Name	**QR Code Functionality Rate**
Related OPENTUNITY innovation	WP3, OPENTUNITY's federated data space infrastructure, T3.3 Plug and Play registration for flexibility devices.
KPI Description	Measures the reliability of the plug-and-play onboarding flow. It's the percentage of QR codes (OT-QR or DPP-QR) that, when scanned on a device or system during HEMS/BEMS setup or NILM estimation, successfully returns valid device or system specifications.
KPI Formula	$$QR\ Code\ Functionality\ Rate = \frac{\text{Successful QR triggered retrievals x 100}}{Total\ QR\ codes\ tested}$$
Variables explanation	Successful QR-triggered retrievals: the number of QR scans (OT-QR or DPP-QR) for which an OPENTUNITY Partner explicitly confirmed end-to-end success by posting an acknowledgment after parsing the JSON asset data. This shows that the whole plug-and-play flow worked, not just the HTTP delivery. Total QR codes tested: the total number of QR scans attempted (OT-QR or DPP-QR), regardless of whether the delivery succeeded or the OPENTUNITY Partner returned an acknowledgment. This is the baseline for measuring the reliability of the entire onboarding process.
Unit of measurement	% (percentage)
Baseline	0%
Target / Thresholds	≥ 90% functionality across all QR scans
Calculation STEP 1	BSA-DEMO generates random id (RID) when a QR is scanned.
Calculation STEP 2	QR attempt is logged when the BSA-DEMO serves JSON (success/fail).
Calculation STEP 3	OPENTUNITY partner parses JSON and posts back an ACK with the same RID.
Calculation STEP 4	BSA-DEMO marks ACK=True or False, then computes and displays the KPI.

Table 8.2 KPI 52 "Completeness Score"

KPI Name	**Completeness Score (per asset)**
Related OPENTUNITY innovation	WP3, OPENTUNITY's federated data space infrastructure, T3.3 Plug and Play registration for flexibility devices.
KPI Description	Quantifies the richness of asset data (JSON) provided by Economic Operators, going beyond mandatory fields by weighting essential, recommended, and optional specifications during flexible asset registration.
KPI Formula	$Completeness\ Score = \frac{\Sigma\ (weights\ of\ filled\ fields)\ \ x\ 100}{\Sigma\ (weights\ of\ all\ fields\ considered)}$
Variables explanation	Σ weights of filled fields: the sum of weight factors of all asset-data fields that the EO has actually filled in (provided) for that asset (mandatory, recommended, or optional). Σ weights of all fields considered: the total sum of weight factors of all fields relevant to that asset's class (e.g., Asset core + BESS specs for a battery system). Completeness Score (per asset): the ratio of the two sums, multiplied by 100, giving a percentage that reflects how complete the asset's data is for integration.
Unit of measurement	% (percentage)
Baseline	The full set of filled asset-data fields (with their weights) defined, for each asset's class (e.g. HVAC, EVSE, BATTERY etc.). Every asset is evaluated against this fixed reference, so the score shows how close the provided data is to the ideal completeness required for seamless asset integration.
Target / Thresholds	≥ 70% completeness across all pilot asset registrations
Calculation STEP 1	BSA-DEMO Identifies applicable data fields for an asset's class, during its registration.
Calculation STEP 2	The application checks values "provided" for the registered asset in its database against those data fields. It treats a field as "provided" only if it has a non-null, non-empty value.
Calculation STEP 3	The BSA-DEMO sums weights of "provided" fields and weights of all applicable fields.
Calculation STEP 4	The BSA-DEMO computes and displays the KPI.

8.2.4 Expected Outcomes

Three primary partner use cases of the BSA-DEMO are expected to demonstrate its full functionality and reliability:

- **ETRA** will validate QR retrieval performance by testing the use of OT-QR data for NILM algorithm calibration and flexibility estimation. It is noteworthy that for the proper functioning of NILM algorithm, it is needed to know in advance the assets that are in the household. Also, knowing the specific model of the assets serves to ensure a proper calculation of the dynamic energy efficiency label.
- **AMIBIT** will test Reduxi's automatic recognition of BSA assets via QR scanning, validating the integrity of JSON-based specifications.
- **ICCS** will assess data injection, data accessibility and adequacy for flexibility aggregation within its FSP framework.

Together, these activities will confirm that the BSA-DEMO meets its plug-and-play objective, enabling fast, standardized, and reliable integration of flexibility assets across pilots, while providing quantifiable evidence of technical performance through its KPIs.

8.3 Deployment scenario

Following the successful validation of the BSA through controlled testing within the OPENTUNITY systems, the BSA-DEMO will transition into its final deployment phase, marking the full operational rollout of the cloud application under real conditions. This deployment represents the culmination of Task 3.3, moving from laboratory testing and controlled integrations to a production environment capable of supporting active user engagement and continuous data exchange.

The deployment will involve refining the platform's source code based on technical partners continuous feedback, conducting comprehensive system integrity checks, and ensuring that all components operate reliably and securely under real usage conditions. Access will be governed through role-based authentication and API-key permissions to maintain controlled yet flexible participation of Economic Operators and pilot partners.

Once deployed, the BSA-DEMO will operate as an active digital service supporting the OPENTUNITY ecosystem. As EOs, authorized partners (ETRA, AMIBIT, ICCS, and others) will be able to register new assets, retrieve standardized JSON datasets via OT-QR codes, and integrate these into their own HEMS/BEMS or flexibility aggregation systems. The web interface will remain publicly accessible for data visualization and QR management, while the API endpoints will continue to serve as the central interoperability layer between BSA and external systems.

From the production launch onward, the application will enter a continuous support and data-enrichment phase. BlueSun Automation Ltd. will oversee system maintenance, apply security updates, and ensure API stability. The asset database is expected to grow as new devices, manufacturers, and specifications are added through the contributions of project partners and/or external Economic Operators. Throughout the remaining duration of the OPENTUNITY program, BSA will provide ongoing technical support to pilot partners for asset registration and data integration, while continuously monitoring KPIs, ensuring that plug-and-play performance and data completeness targets are consistently met.

9 CONCLUSIONS

The work carried out under Task 3.3 – Plug and Play Recognition for Flexibility Devices has successfully demonstrated a complete methodological, architectural, and technical framework for the automatic registration and integration of flexibility assets into the OPENTUNITY ecosystem. The developed BlueSun Web Application (BSA-DEMO) translates this concept into a functioning, cloud-based implementation that enables energy devices and systems to be digitally identified, and their characteristics shared through secure APIs and QR-based data carriers.

Through its modular architecture, the platform consolidates asset data from multiple sources into a harmonized schema that captures nominal characteristics and operational constraints. This methodology provides the foundation for energy flexibility analysis, supports non-intrusive load monitoring (NILM), and enhances the configuration of HEMS/BEMS systems. By incorporating a flexible and secure API design, role-based authentication, and a transparent asset registration process, the BSA-DEMO demonstrates that automated and interoperable onboarding of distributed assets is both technically feasible and scalable within the federated data exchange model foreseen by WP3.

The platform's forward-looking alignment with the Digital Product Passport (DPP) frameworks ensures compatibility with future European standards on digital product identity, traceability, and sustainability. While these standards are still under development, the BSA's data schema and API structure already anticipate the adoption of JSON-LD and GS1 Digital Link principles, ensuring that future DPP-compliant datasets can be seamlessly integrated once the regulatory landscape stabilizes.

The project also addressed one of the most complex challenges: the inclusion of legacy assets that predate modern digital identification or connectivity features. The deliverable proposes a dual approach combining manual data entry through a structured web interface and API-based ingestion of asset data in JSON format. Furthermore, it outlines pathways for automated import from pre-existing digital identifiers such as EPREL QRs, GS1-GTIN links, and future DPP carriers, thereby extending OPENTUNITY's inclusiveness and supporting the transition of older infrastructures into a digitally connected energy ecosystem.

Collaborations with ETRA, AMIBIT, and ICCS have emphasized the usefulness of the developed solution. ETRA leveraged the BSA's normalized QR-linked data for improved NILM calibration and flexibility estimation, AMIBIT provided hardware and control expertise through its Reduxi Energy Management System to test interoperability, and ICCS applied BSA-derived data within its FSP framework, contributing domain knowledge and real asset datasets. These partnerships confirmed that the BSA implementation strengthens interoperability between static asset data, dynamic control systems, and flexibility markets.

The evaluation phase established measurable Key Performance Indicators (KPIs) to assess the reliability and data quality of the BSA platform. The QR Code Functionality Rate confirmed a high degree of operational robustness in QR-based data retrieval, while the Completeness Score verified the sufficiency of registered asset metadata for flexibility assessment. These results provide quantitative evidence that the plug-and-play concept can be scaled and adopted across different pilot contexts and use cases.

Looking ahead, future work will focus on integrating forthcoming DPP and ESPR standards into the BSA-DEMO's architecture to enable automated ingestion of sustainability and lifecycle data. Moreover, it will include the enhancement of interoperability with other registries (e.g., EPREL, GS1) through modules that extend the application's data-retrieval capabilities. Finally, BSA will support continuous operation and enrichment of the asset database throughout the OPENTUNITY program.

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25.

10.2 Acronyms

Table 10.1. Acronyms

Acronym	Explanation
API	Application Programming Interface
BEMS	Building Energy Management System
BESS	Battery Energy Storage System
BSA	BlueSun Application
CE	Conformité Européenne (European Conformity)
CRUD	Create, Read, Update, Delete
DDB	Device Database
DEMO	Demonstration Environment (BlueSun Demo)
DID	Decentralized Identifier
DPP	Digital Product Passport
DSC	Data Space Connector
DSO	Distribution System Operator
EC	European Commission
EO	Economic Operator
EMS	Energy Management System
EN	European Norm
EPREL	European Product Registry for Energy Labelling
ESO	European Standardization Organization
ESPR	Ecodesign for Sustainable Products Regulation

EU	European Union
FDEI	Federated Data Exchange Infrastructure
FSP	Flexibility Service Provider
GDPR	General Data Protection Regulation
GTIN	Global Trade Item Number
HEMS	Home Energy Management System
HVAC	Heating, Ventilation, and Air Conditioning
ICCS	Institute of Communication and Computer Systems
IoT	Internet of Things
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation for Linked Data
KPI	Key Performance Indicator
LAS	Legacy Asset System
MQTT	Message Queuing Telemetry Transport
NILM	Non-Intrusive Load Monitoring
OEM	Original Equipment Manufacturer
OT-QR	Opentunity QR (unique identifier code)
PnP	Plug and Play
PV	Photovoltaic
REST	Representational State Transfer
RFID	Radio-Frequency Identification
SCC	Solar Charge Controller
SDK	Software Development Kit
SoC	State of Charge

SoH	State of Health
TSO	Transmission System Operator
UI	User Interface
URL	Uniform Resource Locator
WP	Work Package
WSGI	Web Server Gateway Interface
QR	Quick Response (Code)

11 Annex 1 – Asset Data Field Schema (T3.3-D3.3)

Pretty-printed full JSON schema for technical readers, cross-referenced from Section 3.4.

```
{
  "weights": {"mandatory": 1.0, "recommended": 0.7, "optional": 0.3},
  "asset": [
      {"name":"dpp_url", "label":"Digital Product Passport URL", "helptext":"The URL encoded in data carriers of Digital Product Passports, that points to a digital record of the product characteristics describing the environmental impact, the sustainability, and the recyclability of that product during its life-cycle. (optional)", "placeholder":"e.g. https://example.com/01/09524810000339/10/YA12AB?17=271231", "characterization":"recommended", "weight":0.7},
      {"name":"opentunity_did", "label":"OPENTUNITY DID", "helptext":"A 16-digit unique identifier. (optional)", "placeholder":null, "characterization":"optional", "weight":0.0},
      {"name":"gtin", "label":"GTIN", "helptext":"The Global Trade Item Number. This is an identification key used to identify a trade item. (optional)", "placeholder":"e.g. 00012345600012", "characterization":"recommended", "weight":0.7},
      {"name":"manufacturer","label":"Manufacturer","helptext":"The Brand or name of the company that designed and produced the flexibility asset, helping identify its origin and ensuring proper warranty, support, and service.","placeholder":null,"characterization":"mandatory","weight":1.0},
      {"name":"model_name","label":"Model Name","helptext":"The specific designation and version assigned by the manufacturer to identify a particular model of the flexible asset, distinguishing it from other models with different features or capabilities.","placeholder":"e.g. aroTherm Plus 7kW","characterization":"mandatory","weight":1.0},
      {"name":"batch_name","label":"Batch Name","helptext":"The specific batch name or number assigned by the manufacturer to a particular batch of a certain flexible asset model, distinguishing it from other batches. (optional)","placeholder":"e.g. BN123456789XYZ","characterization":"optional","weight":0.3},
      {"name":"serial_number","label":"Serial Number","helptext":"A unique alphanumeric code assigned by the manufacturer to each individual device, used for identification, warranty tracking, and service history management. (optional)","placeholder":"e.g. SN123456789XYZ","characterization":"recommended","weight":0.7},
      {"name":"deployment","label":"Deployment","helptext":"The primary environment where the device is or will be installed, such as residential, commercial, or industrial settings, determining factors like usage patterns, power requirements, and installation constraints. (optional)","placeholder":null,"characterization":"recommended","weight":0.7},
      {"name":"classification","label":"Classification","helptext":"Refers to the category or type of the device (flexibility asset) based on its function, value, or usage.","placeholder":"EVSE or HVAC or WHITE APPLIANCE or BATTERY SYSTEM or PV SYSTEM or PV & BAT SYSTEM or GENSET SYSTEM or GENSET & BAT SYSTEM or ENERGY METER etc.","characterization":"mandatory","weight":1.0},
```

{"name":"description","label":"Description","helptext":"A brief flexibility asset description that includes details of energy consumption or production adjustment in response to market signals or grid requirements. (optional)","placeholder":"e.g. A battery energy storage system ...","characterization":"optional","weight":0.3},

{"name":"commissioning_date","label":"Commissioning Date","helptext":"Date the device was put into operation. (optional)","placeholder":"e.g. 2024-05-18","characterization":"optional","weight":0.3},

{"name":"compliance_checklist","label":"List of Applicable Directives, Regulations, and Standards","helptext":"Reference to the specific directives or regulations the product complies with: For example, for products sold in the EU, this would include directives like the Low Voltage Directive (LVD), Electromagnetic Compatibility (EMC) Directive, Radio Equipment Directive (RED), etc. The official title and the official journal reference (if applicable) are usually included. Reference to harmonized standards applied (including their reference number and date of issue): These are European standards that provide a presumption of conformity with the essential requirements of the relevant directives. Reference to other national or international standards and technical specifications applied (if any): This could include ISO standards, national standards, or the manufacturer's own specifications. (optional)","placeholder":"e.g. LVD/EMC/RED.","characterization":"recommended","weight":0.7},

{"name":"release_year","label":"Release Year","helptext":"Year of market introduction of the asset. (optional)","placeholder":"e.g. 2024","characterization":"optional","weight":0.3},

{"name":"flexibility","label":"Flexibility Type","helptext":"Description of the ability to increase energy generation (e.g. Upward Flexibility for Generators, Dispatchable RES, etc.) or to reduce energy consumption (e.g. Downward Flexibility for White Appliances, etc.) to meet higher-than-expected demand or absorb excess supply. In case of BESS both types apply.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"communication","label":"Communication","helptext":"Refers to the physical (and logical) bus system that allows multiple devices to communicate with each other, including the hardware (wires, connectors, etc.) and the rules for how data is transmitted over the bus.","placeholder":"RS485 or RS282 or WIFI or ETHERNET or CANBUS etc.","characterization":"mandatory","weight":1.0},

{"name":"communication_protocol","label":"Communication Protocol","helptext":"Refers to the protocol for communication with the flexibility asset. It defines how data is formatted, transmitted, and interpreted, ensuring that devices on a bus system can understand each other.","placeholder":"e.g. MODBUS RTU, MODBUS TCP, BLUETOOTH, MQTT, LONWORKS, REST, ZIGBEE, etc.","characterization":"mandatory","weight":1.0},

{"name":"modbus_register_map","label":"Modbus Register Map","helptext":"Paste a valid JSON object describing telemetry & control registers.","placeholder":"'EVSE':{'Telemetry':{'Total power (W)':{'unit_id':1,'fc':3,'addr':5014,'type':'uint16','scale':1.0,'access':'RO','semantics':'Instantaneous total active power'}}, 'Controls': {'Start/stop charging':{'unit_id':1,'fc':6,'addr':5010,'type':'uint16','scale':1.0,'access':'RW','range':'0/1'}}}","characterization":"mandatory","weight":1.0},

{"name":"dacq_actuation","label":"Data Acquisition Actuation","helptext":"To retrieve data of an asset over a bus system (e.g. Ethernet) with a specified protocol (e.g. Modbus TCP), the process involves several steps. Refers to a DACQ activation process of a device.

(optional)","placeholder":"e.g. enable Modbus-TCP on port 502.","characterization":"optional","weight":0.3},

{"name":"devices_attribute","label":"Monitored Attributes","helptext":"Collection of information about an asset's sensing data as well as the unit of retrieved data. (optional)","placeholder":"e.g. Active Power (W); etc.","characterization":"optional","weight":0.3},

{"name":"dacq_attributes","label":"Monitored Attributes","helptext":null,"placeholder":"e.g. Active Power (W); Temperature (�C); .","characterization":"optional","weight":0.3},

{"name":"control_actuation","label":"Control Actuation","helptext":"To control an asset over a bus system (e.g. Ethernet) with a specified protocol (e.g. Modbus TCP), the process involves several steps. Refers to a control activation process of a device. (optional)","placeholder":"e.g. write-only control steps.","characterization":"mandatory","weight":1.0},

{"name":"regulation","label":"Regulation","helptext":"How the asset's power consumption (output) changes with respect to the input control signal.","placeholder":"e.g. ON/OFF or LINEAR or BOTH etc.","characterization":"mandatory","weight":1.0},

{"name":"regulation_response_time_upward","label":"Response Time (Upward)","helptext":"The time taken by the flexibility asset to react to an upward change in the control signal and reach a steady-state condition. The accuracy depends on precision of components. Default is 1sec, if this does not apply, leave empty. (optional)","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"regulation_response_time_downward","label":"Response Time (Downward)","helptext":"The time taken by the flexibility asset to react to a downward change in the control signal and reach a steady-state condition. The accuracy depends on precision of components. Default is 1sec, if this does not apply, leave empty. (optional)","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"regulation_response_time_unit","label":"Response Time Unit","helptext":"Units of measurement (e.g. 'sec', 'min', etc.). Default is sec, if this does not apply, leave '----'. (optional)","placeholder":"e.g. sec","characterization":"mandatory","weight":1.0},

{"name":"regulation_response_time_accuracy","label":"Response Time Accuracy","helptext":"Proximity of the mean of measurement results to the true value, expressed as a percentage. Default is 1%, if this does not apply, leave empty. (optional)","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"maximum_upward_regulation","label":"Maximum Upward Regulation","helptext":"Maximum power generation to meet higher-than-expected demand for a specified amount of time. In case of downward flexibility devices, leave 0.0 by default.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"maximum_downward_regulation","label":"Maximum Downward Regulation","helptext":"Maximum load reduction to meet lower-than-expected power supply for a specified amount of time. In case of upward flexibility devices, leave 0.0 by default.","placeholder":null,"characterization":"mandatory","weight":1.0}, {"name":"minimum_regulation_step","label":"Minimum Regulation Step","helptext":"Minimum power generation or load reduction step to meet demand or supply for a specified amount of time. In case it does not apply, leave 0.0 default.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"ip_rating","label":"IP Rating","helptext":"Ingress Protection Rating: a standard used to define the level of protection a device has against dust and water ingress, expressed as two digits where the first digit indicates dust protection and the second indicates water resistance. (optional)","placeholder":"e.g. IP65","characterization":"optional","weight":0.3},

{"name":"storage_temperature","label":"Storage Temperature","helptext":"Range of temperatures (e.g. -20�C to 60�C) within which a device or component can be safely stored without risk of damage or degradation to performance or lifespan. (optional)","placeholder":null,"characterization":"optional","weight":0.3},

{"name":"operating_temperature_range","label":"Operating Temperature Range","helptext":"Range of temperatures (e.g. -10�C to 50�C) within which a device or system can function effectively and safely without performance degradation or risk of failure. (optional)","placeholder":null,"characterization":"optional","weight":0.3},

{"name":"relative_humidity_range","label":"Relative Humidity Range","helptext":"Acceptable range of humidity levels (e.g. 10% to 90%) within which a device can operate or be stored without risk of corrosion, electrical malfunction, or other environmental damage. (optional)","placeholder":null,"characterization":"optional","weight":0.3},

{"name":"dimensions","label":"Dimensions","helptext":"Measurable size of a device, typically expressed in length, width, and height (e.g. 300 mm ? 150 mm ? 200 mm), which impacts installation, compatibility, and space requirements. (optional)","placeholder":null,"characterization":"optional","weight":0.3},

{"name":"weight","label":"Weight","helptext":"Total mass of the device (e.g. 5 kg), influencing portability, handling, and structural requirements for installation or transportation. (optional)","placeholder":null,"characterization":"optional","weight":0.3},

{"name":"form_factor","label":"Form Factor","helptext":"Shape, size, unit count, and design configuration (e.g. rack-mounted, wall-mounted, or portable) that determines how the device fits into its intended system setup. (optional)","placeholder":"e.g. Rack-mounted","characterization":"optional","weight":0.3}

],

"electrical_specs": [

{"name":"phase_configuration","label":"Phase configuration","helptext":"Refers to number of electrical phases (e.g., single-phase, three-phase).","placeholder":"e.g. 1 or 3","characterization":"mandatory","weight":1.0},

{"name":"frequency","label":"Frequency","helptext":"AC cycle rate (Hz), determining grid compatibility.","placeholder":"e.g. 50 or 60","characterization":"mandatory","weight":1.0}, {"name":"voltage_nominal","label":"Voltage nominal","helptext":"Standard operating voltage (e.g., 110V, 220V).","placeholder":"e.g. 230","characterization":"mandatory","weight":1.0},

{"name":"voltage_tolerance_df","label":"Voltage tolerance (%)","helptext":"Allowable % variation from nominal voltage.","placeholder":"e.g. 2.5","characterization":"mandatory","weight":1.0},

{"name":"current_nominal_df","label":"Current nominal","helptext":"Operating current (A) under normal conditions.","placeholder":"e.g. 10.0","characterization":"mandatory","weight":1.0},

{"name":"current_min_df","label":"Current min","helptext":"Lowest safe operating current (A).","placeholder":"e.g. 0.5","characterization":"mandatory","weight":1.0},

{"name":"current_max_df","label":"Current max","helptext":"Highest safe operating current (A).","placeholder":"e.g. 20.0","characterization":"mandatory","weight":1.0},

{"name":"inrush_current_max_df","label":"Inrush current","helptext":"Peak surge current (A) on power-up.","placeholder":"e.g. 100.0","characterization":"mandatory","weight":1.0},

{"name":"power_consumption_nominal_df","label":"Power consumption nominal","helptext":"RMS power consumed during normal operation.","placeholder":"e.g. 500","characterization":"mandatory","weight":1.0},

{"name":"power_consumption_max_df","label":"Power consumption max","helptext":"Max power consumed at peak load.","placeholder":"e.g. 600","characterization":"mandatory","weight":1.0},

{"name":"standby_power_consumption","label":"Standby power consumption","helptext":"Power used while idle but powered on.","placeholder":"e.g. 5.0","characterization":"mandatory","weight":1.0},

{"name":"power_consumption_units","label":"Units","helptext":"Units of measurement for power (e.g., W, kW).","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"voltage_regulation_uf","label":"Voltage regulation","helptext":"Ability to maintain stable voltage despite variations.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"voltage_range_uf","label":"Voltage range (JSON)","helptext":"Acceptable output voltage limits (e.g., 400V-480V). In case of downward flexibility devices leave 0.0 default.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"output_current_nominal_uf","label":"Output current nominal","helptext":"Standard continuous current (A) the system delivers under typical conditions. In case of downward flexibility devices leave 0.0 default.","placeholder":"0.0","characterization":"mandatory","weight":1.0},

{"name":"output_current_max_uf","label":"Output current max (JSON)","helptext":"Peak current (A) the system can safely deliver. In case of downward flexibility devices leave 0.0 default.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"power_output_nominal_uf","label":"Power output nominal (JSON)","helptext":"Rated power (kVA or kW) under standard conditions.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"power_output_max_uf","label":"Power output max (JSON)","helptext":"Max power the system can generate at peak demand.","placeholder":null,"characterization":"mandatory","weight":1.0},

{"name":"power_factor","label":"Power factor","helptext":"Ratio of real power (W) to apparent power (VA).","placeholder":"1.0","characterization":"mandatory","weight":1.0}

```
        ],

"bess_specs": [
        {"name":"bess_application", "label":"Application", "helptext":null, "placeholder":null, "characterization":"mandatory", "weight":1.0},
        {"name":"cell_type","label":"Cell type","helptext":"Specific electrochemical composition of the battery cells (e.g. lithium-ion, lead-acid).","placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"voltage_nominal","label":"Nominal voltage","helptext":"Standard operating voltage of the battery system (e.g. 48V, 400V).","placeholder":"e.g. 51.2","characterization":"mandatory","weight":1.0},
        {"name":"voltage_range","label":"Voltage range (JSON)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"capacity","label":"Capacity (JSON)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"maximum_charge_current","label":"Max charge current (A)","helptext":"Highest current (A) a battery can safely accept during charging.","placeholder":"e.g. 70.0","characterization":"mandatory","weight":1.0},
        {"name":"maximum_discharge_current","label":"Max discharge current (A)","helptext":"Highest current (A) the battery can deliver during discharge.","placeholder":"e.g. 100.0","characterization":"mandatory","weight":1.0},
        {"name":"cycle_life","label":"Cycle life (JSON)","helptext":"Total number of charge/discharge cycles .","placeholder":"cycles/DOD packed from helper fields","characterization":"mandatory","weight":1.0},
        {"name":"energy_rating_nominal","label":"Energy rating nominal","helptext":"Rated energy storage (kWh) under standard conditions.","placeholder":"e.g. 5.12","characterization":"mandatory","weight":1.0},
        {"name":"energy_rating_nominal_units","label":"Energy rating units","helptext":"Units of measurement for nominal energy (e.g. kWh).","placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"energy_rating_usable","label":"Energy rating usable","helptext":"Usable energy (kWh) deliverable under standard conditions.","placeholder":"e.g. 4.92","characterization":"mandatory","weight":1.0},
        {"name":"energy_rating_usable_units","label":"Usable energy units","helptext":"Units of measurement for usable energy (e.g. kWh)","placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"c_rate","label":"C-rate","helptext":"Charge/discharge rate relative to nominal capacity (e.g. 1C).","placeholder":"e.g. 1C","characterization":"mandatory","weight":1.0},
        {"name":"round_trip_efficiency","label":"Round-trip efficiency (%)","helptext":"Percentage of energy retained after a full charge/discharge cycle.","placeholder":"e.g. 91.5","characterization":"mandatory","weight":1.0},
```

```
    {"name":"battery_management_system","label":"BMS (JSON)","helptext":"Type/model of BMS; state estimation; monitoring.","placeholder":"built from BMS fields","characterization":"mandatory","weight":1.0},
    {"name":"degradation_rate","label":"Degradation rate (%)","helptext":null,"placeholder":"e.g. 2.0","characterization":"mandatory","weight":1.0}
  ],

"inverter_specs": [
    {"name":"max_apparent_feed_in_power_kva","label":"Nom apparent power (kVA)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nominal_active_power_kw","label":"Nominal active power (kW)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"peak_active_power_kw","label":"Peak active power (kW)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"phase_configuration","label":"Phase configuration","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"frequency","label":"Frequency (Hz)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"standby_power_consumption","label":"Standby power consumption","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"max_nominal_dc_current_a","label":"Max nominal DC current (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nom_dc_voltage_range","label":"Nominal DC voltage range (JSON)","helptext":null,"placeholder":"packed from inv_nom_dc_min/max","characterization":"mandatory","weight":1.0},
    {"name":"nominal_ac_voltage_l1","label":"Nominal AC voltage L1 (V)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nominal_ac_voltage_l2","label":"Nominal AC voltage L2 (V)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nominal_ac_voltage_l3","label":"Nominal AC voltage L3 (V)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nominal_ac_current_l1","label":"Nominal AC current L1 (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nominal_ac_current_l2","label":"Nominal AC current L2 (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"nominal_ac_current_l3","label":"Nominal AC current L3 (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
    {"name":"power_factor","label":"Power factor","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0}
```

```
    ],

"pv_module_specs": [
     {"name":"application", "label":"Application", "helptext":null, "placeholder":null,
   "characterization":"mandatory", "weight":1.0},
     {"name":"module_type","label":"Module
   type","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
     {"name":"module_name","label":"Module
   name","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
     {"name":"voc","label":"Open-circuit voltage Voc (V)","helptext":null,"placeholder":"e.g.
   41.2","characterization":"mandatory","weight":1.0},
     {"name":"isc","label":"Short-circuit current Isc (A)","helptext":null,"placeholder":"e.g.
   13.2","characterization":"mandatory","weight":1.0},
     {"name":"vmpp","label":"Voltage at MPP Vmpp (V)","helptext":null,"placeholder":"e.g.
   34.4","characterization":"mandatory","weight":1.0},
     {"name":"impp","label":"Current at MPP Impp (A)","helptext":null,"placeholder":"e.g.
   11.9","characterization":"mandatory","weight":1.0},
     {"name":"temp_coef_pmax","label":"Temp. coeff Pmax (%/oC)","helptext":null,"placeholder":"e.g. -
   0.34","characterization":"mandatory","weight":1.0},
     {"name":"temp_coef_voc","label":"Temp. coeff Voc (%/oC)","helptext":null,"placeholder":"e.g. -
   0.27","characterization":"mandatory","weight":1.0},
     {"name":"temp_coef_isc","label":"Temp. coeff Isc (%/oC)","helptext":null,"placeholder":"e.g.
   +0.045","characterization":"mandatory","weight":1.0},
     {"name":"noct","label":"NOCT cell temp (oC)","helptext":null,"placeholder":"e.g.
   45","characterization":"mandatory","weight":1.0},
     {"name":"quantity","label":"Modules quantity","helptext":null,"placeholder":"e.g.
   10","characterization":"mandatory","weight":1.0}
    ],

"scc_specs": [
     {"name":"model_name", "label":"Model name", "helptext":null, "placeholder":null,
   "characterization":"mandatory", "weight":1.0},
     {"name":"voltage_input","label":"Input voltage
   (V)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
     {"name":"current_input","label":"Input current
   (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
     {"name":"voltage_output","label":"Output voltage
   (V)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
```

```
        {"name":"current_output","label":"Output current (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0}
      ],

  "energy_meter_specs": [
        {"name":"phase_configuration","label":"Phase configuration","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"frequency","label":"Frequency (Hz)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"voltage_nominal","label":"Voltage nominal (V)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"voltage_tolerance_df","label":"Voltage tolerance (%)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"current_nominal_df","label":"Current nominal (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"current_min_df","label":"Current min (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"current_max_df","label":"Current max (A)","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"standby_power_consumption","label":"Standby power consumption","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},
        {"name":"power_consumption_nominal_df","label":"Power consumption nominal","helptext":null,"placeholder":null,"characterization":"mandatory","weight":1.0},

      {"name":"power_consumption_units","label":"Units","helptext":null,"placeholder":null,"characterization": "mandatory","weight":1.0},
        {"name":"accuracy_class","label":"Accuracy class","helptext":null,"placeholder":"e.g. Class 0.2S","characterization":"mandatory","weight":1.0}
      ]
}
```

12 Annex 2. JSON Data Format (Example)

```
{
 "id": 18,
 "revision": 3,
 "manufacturer": "ABB",
 "model": "Terra AC",
 "classification": "EVSE",
 "electrical_specs": {
  "phases": "1P",
  "nominal_voltage_v": 230,
  "frequency_hz": 50,
  "max_current_a": 32,
  "tolerances": {"voltage_pct": "+/-10", "frequency_hz": "49-51"}
 },
 "bess_specs": null,
 "communications": {
  "protocols": ["Modbus/TCP"],
  "registers": [
   {"fc": 3, "addr": 1000, "type": "uint16", "scale": 1.0, "semantics": "Active power (W)"}
  ]
 },
 "flexibility": {
  "max_up_regulation_w": 2200,
  "max_down_regulation_w": 0,
  "min_step_w": 100,
  "ramp_w_per_s": 500
 },
 "constraints": {"min_off_s": 60, "min_on_s": 120},
 "certifications": ["CE", "EMC"],
 "qr": {
  "resolver_url": "https://bluesun.pythonanywhere.com/api/assets/18/enter-api-key/"
 },
```

```
  "audit": {
    "created_at": "2025-09-01T10:15:00Z",
    "updated_at": "2025-09-20T08:42:00Z"
  }
}
```