Artificial Intelligence for Operation and Maintenance of PV Plants

Deliverable D4.1

Validation framework definition

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EXECUTIVE SUMMARY

This deliverable includes the main results obtained in the task **T4.1 Setup of descriptive and prescriptive systems in the validation framework** from the project AI4PV. The work carried out in the analysis of the situation regarding validation and the initial proposals and consideration for the formal validation of the results of the project.

As a result, a clear view of the complete validation process and its stages is presented, as well as an overview of the interaction and interfacing to consider for the final validation of the integrated system, as well as the data to consider in each of the scenarios of the project.

The designs and studies here included will set the baseline for the validation and evaluation of the results obtained in the developing process obtained from the rest of the tasks of the project, and will allow to further develop a validation plan in an integrated demo site for the formal and final validation of the system and platforms obtained as a result of the project.

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ABBREVIATIONS AND ACRONYMS

Acronym	Meaning
AEP	Annual Energy Production
AI4PV	Artificial Intelligence for Photovoltaic
AOI	Angle of incidence
API	Application Programming Interface
CAPEX	Capital Expenditure
HTTPS	HyperText Transfer Protocol Secure
O&M	Operations & Maintenance
PV	Photovoltaic
SB	String box
WP	Work Package

GLOSSARY OF KEY TERMS

(LCOE (Levelized Cost of Energy)	Levelised Cost of Energy represents the ratio of the capital and operational expenditures incurred over the lifetime of a project in relation to the annual energy produced over the operational life. Commonly used to compare energy generating technologies.
TRL (Technological Readiness Level)	The 9-point Technology Readiness Level scale is widely used to measure technology development.
Capital expenditures (CAPEX)	CAPEX costs are the investments made in the initial stages (development, consenting, production, installation, commission) of a project to buy project components, assets, or services.
Machine Learning	Machine learning is a method of data analysis that automates analytical model building. It is a branch of artificial intelligence based on the idea that systems can learn from data, identify patterns and make decisions with minimal human intervention.

1. INTRODUCTION

This document, deliverable **D4.1 Validation framework definition**, includes a summary of the results obtained in the process focused on the analysis of technologies, tools, mechanisms and methodologies for the initial validation process to be carried out in the context of the project AI4PV.

1.1 SCOPE OF REPORT

This deliverable focuses on the final stage of the project, since it aims at defining the initial framework for the validation of the system. The developments of the project - from data acquisition, storage and load, to the proper execution of algorithms and scripts for the detection of anomalies in the behaviour of PV operational data - will pass from several validation stages, starting at a simple isolated module validation, to a later testing as an integrated system.

The document includes a summary of the main results obtained in this initial definition process, considering the data available, the system integration and the requirements to fulfil the need previously defined.

The results here presented have been achieved in the development of task **T4. Setup of descriptive and prescriptive systems in the validation framework**, included in the context of the work package **WP4 Validation**. These advancements, in addition to those achieved in the other tasks of the work package (T4.2 and T4.3) will allow the deployment and validation of a system capable of modelling critical elements in PV plants and providing advanced recommendations to optimize the operation and maintenance.

1.2 OUTLINE OF REPORT

This report is structures as follows,

- ***Chapter 1 introduces the scope of the document***
- ***Chapter 2 focuses on the results obtained after analysing current trends and a proper definition of the objectives*** *from a high-level perspective*
- ***Chapter 3 digs into the specific validation plan*** *to implement in the context of the project.*
- ***Chapter 4 provides the data considerations*** *that have been considered for the validation process.*

2. VALIDATION PROCESS

This section provides a contextualization of the validation process, main activities to be carried out in the context of WP4 of the project. The validation of the developments and designs should follow a methodology that ensures a proper performance of the system and that the results (recommendations and detections made by the different modules from AI4P) are valuable and accurate.

A proper validation starts with a clearly stated set of needs. These needs are the basis for the system requirements. When the system is developed, the system is assessed against these needs. Three main activities can be identified in a proper validation plan [1]

- **Planning:** With stakeholder involvement planning starts at the beginning of the project timeline. The plan includes who will be involved, what will be validated, what is the schedule for validation, and where the validation will take place.
- **Validation strategy:** This defines how the validation will take place and what resources will be needed. For example, whether a before and/or an after study will be needed. If so, the before study will need to be done prior to deployment of the system.
- **Perform validation:** After the system has been accepted, the system should be assessed based on planning & strategy and the results documented.

As a research and development project, AI4PV has already described a set of requirements and an initial planning, using information from both technical experts and market actors. WP4 will use this preliminary information, gathered in the project proposal phase as well as in the previous stage of its design and development, to perform the other two main stages: i) the definition of a proper validation strategy, and ii) performing said validation.

The system's owner and stakeholders are responsible for the validation of the system. The primary systems engineering activity is to assist in development and execution of all three activities. In the context of the project, the data owner (EDPR) will act as the stakeholder, since they will use the developments, using their expertise and knowledge to identify hits and misses, and to polish the development.

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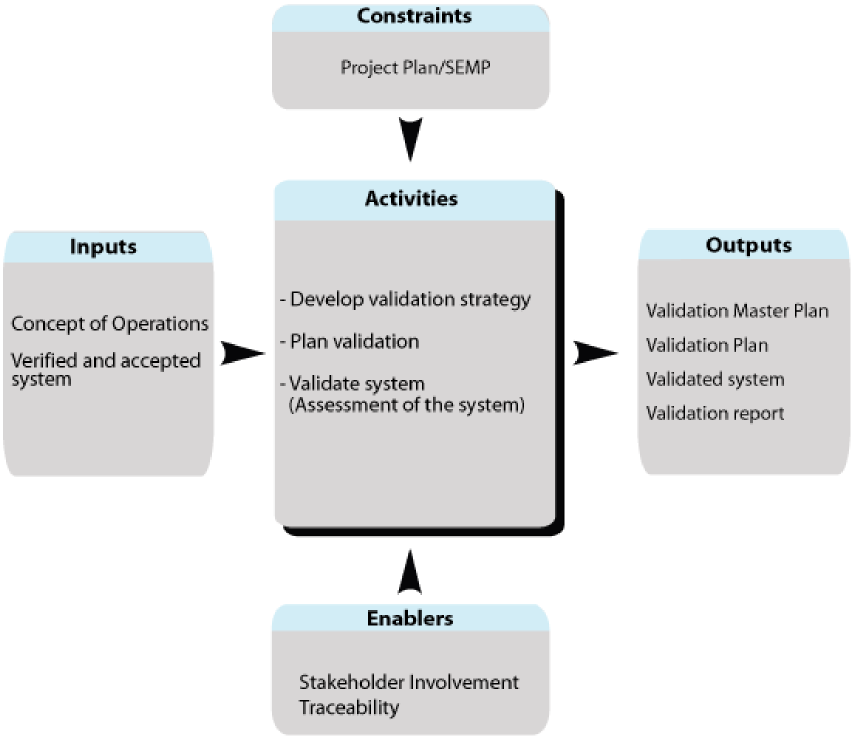

FIGURE 2-1: VALIDATION PROCESS INVOLVEMENT [1]

As for the time structure, the validation process will be implemented following a progressive approach, to be described in detail in the next sections, focused on a logical process, as presented in Figure 2-2:

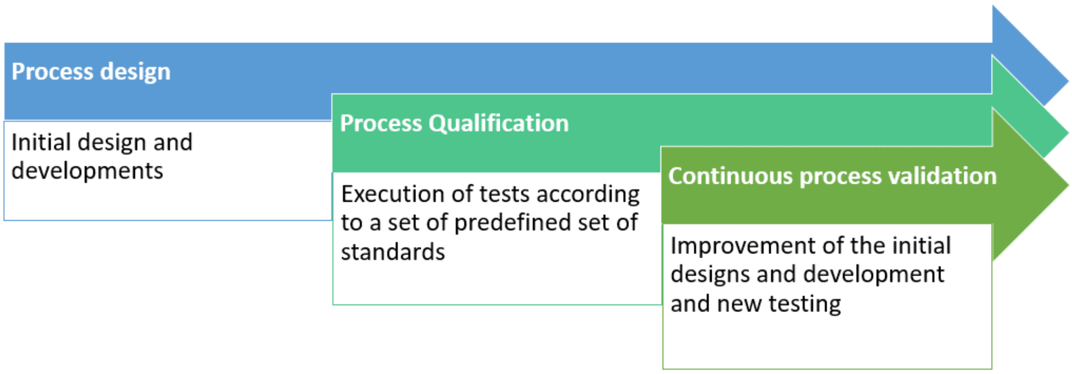

FIGURE 2-2: VALIDATION MECHANISMS

The process design has already been done, and the developments are being implemented by the different members of the consortium. The process qualification and the later continuous process validation will take place in the context of this WP4.

The key initial considerations to have present for the whole validation process are presented in the Table 2-1:

TABLE 2-1: INITIAL CONSIDERATIONS FOR THE VALIDATION PLAN

Validation procedure objective	The objective of each test case is to verify that each of the algorithms provides the results expected from them, meaning that the function for which they have been designed offers positive results in more than **80%** of the cases. To do this, it is necessary to carry out a global analysis of them and assign a percentage of the success cases in the case of detection of accidents, or see that the energy results are in accordance with the capacity of the inverter, in the case of the balance of energy. Finally, for other issues such as PR and degradation, it is necessary to check that the results obtained are within the range specified for them.
Previous requirements	Before the formal analysis, it is necessary to do the following check-ups: • Analyse the period to be studied, make sure that it is within the months with a low percentage of missing data. • Analyse preferably those inverters that have coherence in both data and power generation. • Fully understand the analysis procedure to follow. • Have all the information necessary to carry out the analysis, this means all the necessary signals (DCPower, ACPower, alarms, etc.). If not, it will be necessary to review the procedure.
General steps	The general steps to be taken into account to perform the algorithm status analysis are based on successful problem detection cases. The most important consideration is that the correct operation of the algorithm is verified, that is, that the detections are positive and the balances match the capacity of the inverter. If not, it is necessary to try to discover the reason for the problem. The next step to follow would be to detect cases in which the accidents conditions are met but for some reason the algorithm has not been able to detect it. This last step is applied when the positive cases have been finalized. In this situation, as simulation data will be used, it will be important to consider the potential effect of this, and data that represent faults will also need to be reviewed.
Expected results	The expected result should represent the efficiency status of the algorithm when detecting incidents or performing the energy balance. A percentage of positive cases within the case studies carried out above 80% must be provided. If not, the algorithm will be considered to require revision or improvement.

3. VALIDATION FRAMEWORK

3.1 COMPLETE VIEW

As a project developed by several entities collaborating among them, two clear stages can be identified in the project developing process:

1. A first **decoupled stage**, in which initial versions of each of the developments done by each member of the consortium will be evaluated in an isolated operation.
2. And a second **integrated stage**, in which each of the developments, created as independent modules, will be connected to fulfil the complete set of requirements and to create a final operating product which complies with all the preliminary presented characteristics.

In Figure 3-1, a clearer view of this distinction can be appreciated. As it can be seen, in the context of isolated developments, each specific module, including data cleansing algorithms and tools for specific problem detection, will have to be initially tested to ensure that it complies with the requirements specified. Then, the system will be integrated with all the tools previously developed and validated, to once again verify a proper operation in a real operational context.

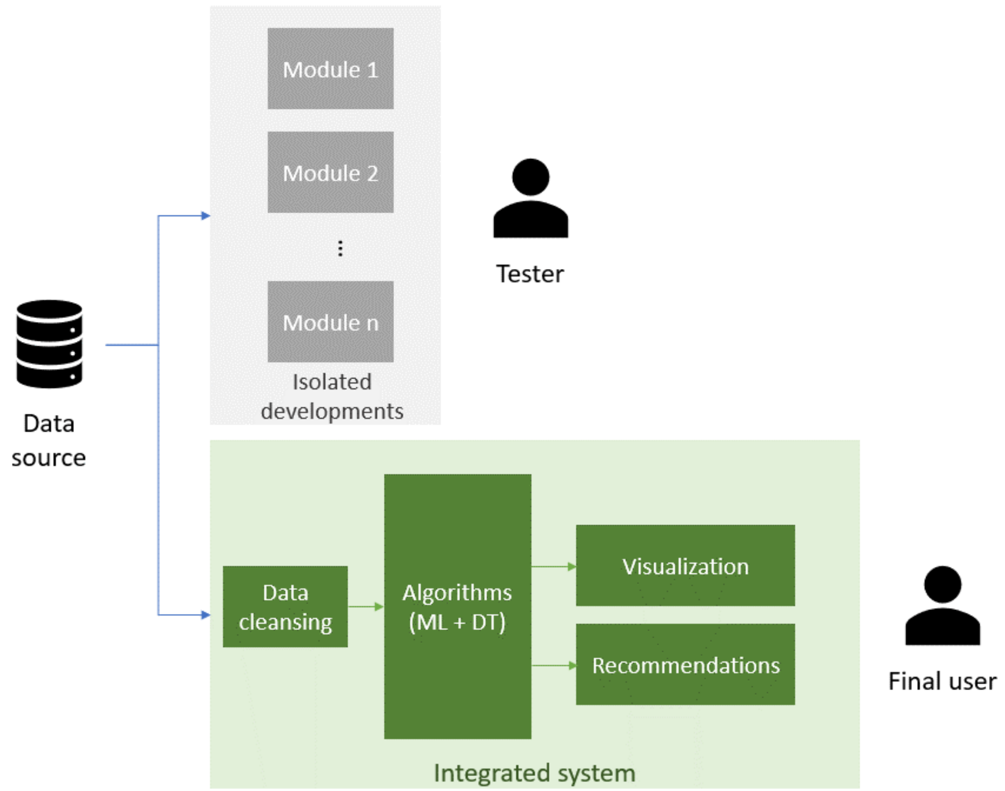

FIGURE 3-1: SYSTEM VALIDATION IN TWO STAGES

The validation of independent modules can be easily performed by Q&A personnel or developers, however, for the final validation of the integrated system, the best course of action would be to ensure that a potential end-user of the development actually participates, since they will be able to identify potential improvements or failures directly linked to what is expected to be done in the normal day-to-day operation.

The proposed integration process can be appreciated in Figure 3-2. The envisaged architecture will count with an automatic extraction of the data as a first stage, to then, proceed to clean the data and prepare it for its use for the later performance of advanced analytic algorithms to, finally, after assessing the results with a set of KPIs for O&M, provide a set of recommendations and representation of said results using visualization tools. In order to allow that the platform behaves in a coordinated and integrated manner, two main potential interconnection points have been defined:

- First, **the clean data** dataset, generated by the algorithms developed for this purpose, will be made accessible for every algorithm which might need to use it.
- Secondly, the **results of the analytic tools for failure and underperformance detection**, will be prepared in a consolidated format, to allow that the later generation of recommendations and the representation of the results in appealing and manageable graphs and dashboards can be achieved.

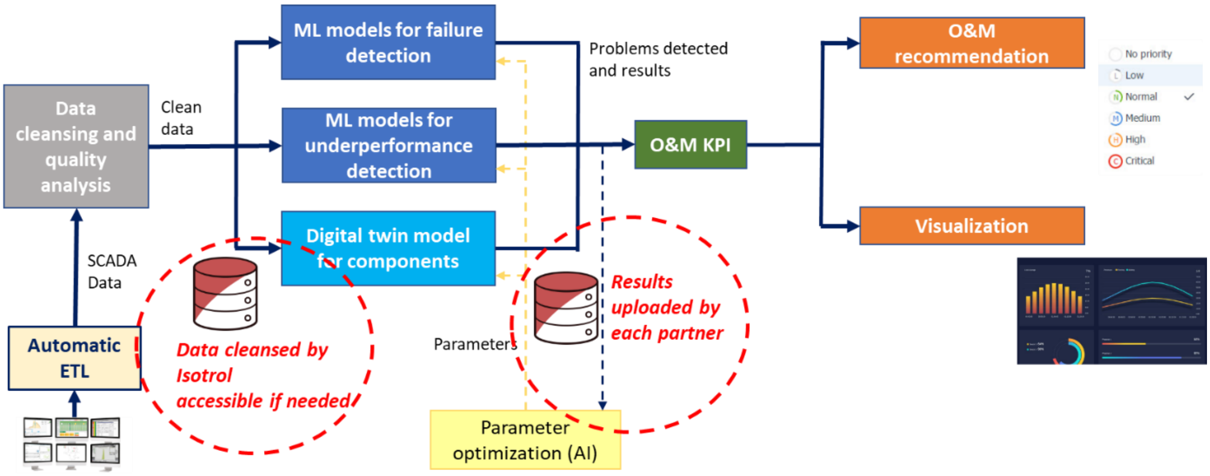

FIGURE 3-2: SYSTEM INTEGRATION PROPOSAL

In the end, the aim of the validation process will be to ensure that all of the use cases and applications that have been described in the project (which are presented in Table 4-2 and extensively described in D1.1) are successfully met. For this matter, in the initial modular validation, each of the developments will be tested by its developer to make sure that the described functionality is met and then, later, the complete performance in an integrated paradigm will be analysed, to see if any potential failure arises.

4. DATA REQUIREMENTS FOR THE DEMONSTRATION

4.1 FAILURES AND GENERAL CONSIDERATIONS

Table 4-1 present a description of the key areas of study to consider from the validation standpoint:

TABLE 4-1: KEY ELEMENTS TO CONSIDER

Component	Description
Inverter	The inverter category considers all the failures and problems that are going to be considered at the key power electronic component of PV generation systems, ranging from specific problems related to sub-components (such as the refrigeration systems or the power electronic switches powered by IGBTs).
Junction boxes	The junction box refers to the point at which the wiring between modules and the rest of the electric system takes place and is prone to several failures referring to the specific joints and the cables themselves.
PV panel	Mechanism responsible of transforming sunlight into electric energy. It may suffer several problems, such as degradation due to time or other factors, and soiling or the deposit of dirt and other substances in its surface.
Sensor	The sensors are located around the PV plant and are responsible of capturing data in form of signals which have to be transferred to control units. They are subject of numerous problems which can lead to failure in the calculations and can lead to harmful inaccurate decision making.
String/SB	Strings and string boxes (SB) are groups of generating elements that are analysed as a whole, and which usually are target of common control units, such as trackers.
Transformer	The transformer is the power element conformed of inductive elements and coils responsible of transforming the power output, making it suitable for the electric grid the PV plant is connected to.

The initial list of use cases and scenarios for the project has been analysed at the current stage of the process, paying attention to the specific list of signals and the availability of information to materialize the requirements into a specific set of problems to detect, which will be de cornerstone of the validation of the integrated process. The list of failures is presented in the Table 4-2:

TABLE 4-2: LIST OF FAILURES TO DETECT

Fault/Failures	Component	Partner
Switch/IGBT open circuit	Inverter	INESC TEC
Switch/IGBT short circuit	Inverter	INESC TEC

AC filter degradation	Inverter	INESC TEC
MPPT/control fault	Inverter	ISOTROL, INESC TEC
Gating signals misfiring	Inverter	INESC TEC
Inverter shutdown	Inverter	ISOTROL
Temperature disconnection	Inverter	ISOTROL
Maintenance stop	Inverter	ISOTROL
Late awakening	Inverter	ISOTROL
Clipping	Inverter	ISOTROL
Fan malfunction (ML prescription)	Inverter	INESC TEC
DSP/Sensors malfuncion (ML prescription)	Inverter	INESC TEC
DC cable degradation	Junction boxes	INESC TEC
DC cable open circuit	Junction boxes	INESC TEC
DC cable short circuit (line to line and line to ground)	Junction boxes	INESC TEC
Soiling	PV panel	EDP NEW, ISOTROL
Time degradation	PV panel	ISOTROL
Pyranometer sensor failure	Sensor	ISOTROL
Power sensor failure	Sensor	ISOTROL
String disconnection	String/SB	ISOTROL
Stringbox disconnection	String/SB	ISOTROL
Transformer underperformance	Transformer	EDP NEW

This table summarises the list of specific cases which are suitable attending to the data available, as well as the specific plant topology and configuration selected for piloting the results.

4.2 DATA INTEGRATION FRAMEWORK

Figure 4-1 shows a detail of the data acquisition process proposed for the project AI4PV, which will allow the implementation of the complete AI4PV platform and its automatic operation. As it can be appreciated, using a VPN for safe and secure interaction, data extraction will take place, in order for a preliminary normalization and transformation before the final load is done. Data will then be available for its use, and both the original data and the results will be accessible for developers and for operators and end users, which, using an API endpoint via HTTPS, will be able to validate the performance and results of the developments.

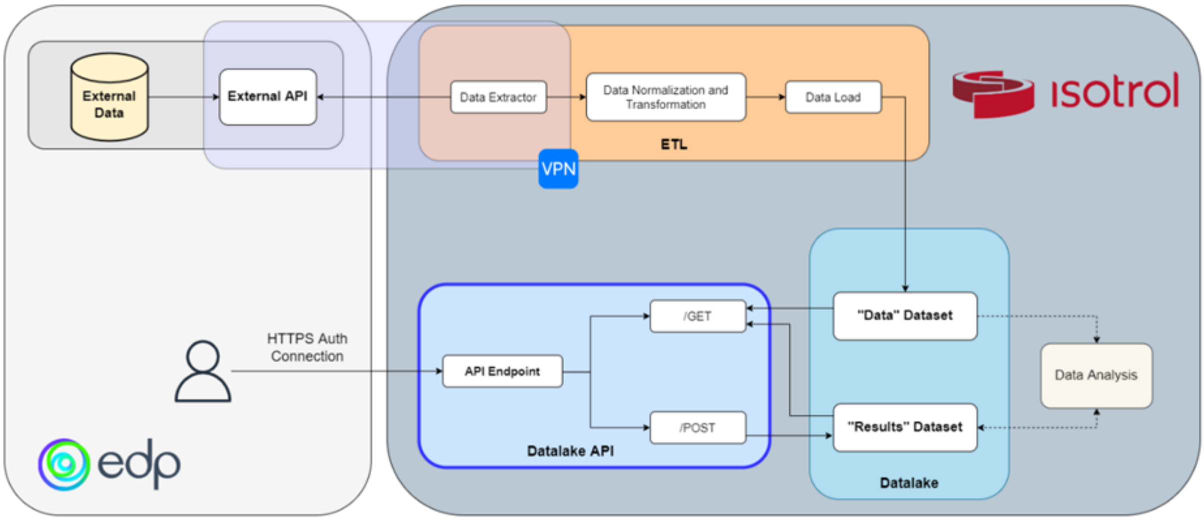

FIGURE 4-1: DATA ACQUISITION AND STORAGE PROCEDURE

The first storage will consist of a series of tables that include all the data that has been extracted, accessible by different authorized users. This will allow that different algorithms, models and systems are executed in different environments and virtual machines. The results that each analysis generate will later be stored in a different table in a structured manner, allowing the post-processing of the results obtained regarding the detection and prediction of failures, generating recommendations according to economic considerations related to O&M.

The extraction process will be configured in a way that ensures that all the signals are retrieved in a structured and usable manner. The data extraction and the initial transformation and load process will ensure, first of all, that all the necessary signals are retrieved and, secondly, that the data which is finally uploaded to the datalake follows the required timeframes. Data will be structured ensuring that timestamps are aggregated with a granularity of **5 minutes**.

As for the specific data retrieving and upload frequency, there are several considerations to keep in mind. Normal operation and daily reports generation will need a daily extraction of data, however, in order to empower digital twin results, lower frequencies, closer to the range of several minutes, will be considered. Depending on the final identified needs of operational systems, and the technical viability of the data extraction, a final frequency will be defined.

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5. CONCLUSIONS

This deliverable (D4.1 Validation framework definition) includes the main results obtained after the execution of task T4.1 Setup of descriptive and prescriptive systems in the validation framework. The main results obtained after the completion of the task are a list of considerations and definitions that will conform the first input to the validation plan of the project.

The main results are, first of all, a main overall description of the complete validation paradigm to consider in the context of the project and, secondly and more importantly, the description of the scope of the validation process, ranging from the description of the failure modes to include in the final scope of the project, to the description of the complete integration of the final system and the signals to consider for applying the advanced analytics that will allow the detection of said problems and failures.

The future work of the WP4 will focus on the formal final integration of the system and the implementation of this developments in the pilot to be used in the project, using the descriptions here included as the base for the validation plan to be carried out in said environment.

6. REFERENCES

[1] "Federal Highway Administration," 2016. [Online]. Available: https://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_7_1.cfm.