Integrated Development Platform for Customer and Aggregator Energy Management Systems (Grant Agreement No 101172675)

D2.2 Initial Validation Framework and Plans

Date: 2025-04-30

Version 1.0

Published by the INDEPENDENT Consortium

Dissemination Level: PU - Public

Co-funded by the European Union

Document control page

Document file:	D2_2_Initial_Validation_Framework_and_Plans.docx
Document version:	1.0
Document owner:	**AMIBIT**
Work package:	WP2 Requirements and Common System Architecture
Deliverable type:	R - Document, report
Document status:	☒ Approved by the document owner for internal review ☒ Approved for submission to the EC

Document history:

Version	Author(s)	Date	Summary of changes made
0.1	Matija Kosin (AMIBIT)	2025-02-03	ToC proposal
0.2	Matija Kosin (AMIBIT)	2025-02-18	Initial contribution and work plan
0.3	Matija Kosin (AMIBIT)	2025-04-24	Version submitted to internal review
1.0	Matija Kosin (AMIBIT)	2025-04-29	Final version submitted to the European Commission

Internal review history:

Reviewed by	Date	Summary of comments
Arso Savanovic (SCOM)	2025-04-25	Accepted with minor corrections and comments.
Amir Safdarian (Volue)	2025-04-25	Accepted with minor updates.

INDEPENDENT is funded by the European Union's Horizon Europe Framework Programme for Research and Innovation under Grant Agreement No 101172675. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor CINEA can be held responsible for them.

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1 Executive summary

This document defines the initial validation framework and plans for the Integrated Development and Operations Platform (IDOP) within the INDEPENDENT project, forming a key output of WP2. The validation strategy is implemented in two phases. This report focuses on the first phase and includes contributions from T2.4 – Validation framework design. The goal is to ensure that IDOP-based Customer and Aggregator Energy Management Systems (CEMS and AEMS) meet the functional, technical, and business requirements derived from earlier use case and architecture work (T2.1–T2.3 in D2.1).

The validation framework includes four interrelated domains: end-user validation, technical validation, business validation, and KPI-based evaluation. The approach integrates both qualitative and quantitative methods, covering feedback from real-world pilot deployments in four countries. Validation focuses on system usability, performance metrics (e.g., response time, scalability), market compliance, and trust/security features including GDPR-compliance.

The technical validation assesses system integration with legacy infrastructure, performance of demand response functions, forecasting accuracy, and real-time control capabilities. Pilot-specific validation criteria are defined for German, Finnish, Swedish, and Slovenian implementations. These validate core features like price forecasting, flexibility activation, system optimization, and secure communications.

The end-user validation evaluates usability, acceptance, and privacy from user perspectives using questionnaires, focus groups, and UX tools such as the System Usability Scale. The business validation confirms that the IDOP aligns with stakeholder needs, market demands, and value co-creation principles. The KPI validation ensures the solution delivers measurable impact in energy savings, CO_2 reduction, market participation, and scalability.

This framework serves as a baseline for the second phase, where validation plans will be refined based on feedback and findings from the phase-one pilots.

2 Introduction

2.1 Purpose, context and scope

Requirements engineering and architecture design of the IDOP are implemented in two phases. This document describes the requirements and the initial system architecture of the IDOP. The final requirements and architecture are described later in the INDEPENDENT project.

This document gathers the work implemented in the following task:

- T2.4 - Validation framework design

The purpose of this task is to ensure that the IDOP meets the requirements of its users by designing a common validation framework to be implemented in WP6. The project pilots will play a central role in the validation as they provide the means to validate IDOP-based solutions at TRL 8. Therefore, important part of this task focuses on specifying how the pilots should be implemented to ensure proper validation and qualification of complete CEMS deployed in buildings and industrial sites and connected to operational flexibility and energy wholesale markets via AEMS. Both quantitative and qualitative research methods will be employed to gather feedback from all stakeholders, aiming to assess the effectiveness of the IDOP-based CEMS and AEMS. The validation will encompass end-user, technical, and business validation and covers the validation of the project's KPIs. This task is responsible for making the validation framework for both phase 1 and phase 2 pilots (to be implemented in T6.2 and T6.3). The framework will be iterated for phase 2 based on the findings from the first phase pilots. Additionally, particular emphasis will be placed on validating the market readiness, scalability, and replicability of the IDOP (to be carried out in T6.4)

2.2 Content and structure

The common validation framework and plan specify the content (what), methodologies and methods (how), and planning (when) of the evaluation. As a framework plan it is not intended to be prescriptive or restrictive; it will set the boundaries for the validation while being flexible to accommodate to changing shape and needs of the project.

A comprehensive validation plan is crucial for ensuring the successful implementation and deployment of any system or application. It serves as a structured approach to verify that the developed solution meets the specified requirements, adheres to industry standards, and delivers the desired functionality and performance. The validation framework outlined in this document encompasses four key aspects:

1) **End user validation:** The end user validation concentrates on evaluating the end users’ experience, based on their satisfaction and acceptance and perceived usability of the system/solution. Particular attention will be given to user needs and challenges, incentives and barriers, privacy issues or concerns, and functionalities and usability of the user interface (where relevant).
2) **Technical validation:** The technical validation focuses on assessing the system/solution's compliance with technical specifications, architectural design, coding standards, and performance requirements as per the INDEPENDENT project. This aspect ensures that the INDEPENDENT framework and its solution is built on a solid technical foundation and adheres to best practices in software development.
3) **Business validation:** The business validation involves verifying that the system/solution meets the defined business requirements, supports the intended business processes, and aligns with the INDEPENDENT project’s goals and objectives. This aspect ensures that the solution delivers the expected business value and supports the organization’s strategic initiatives.
4) **KPIs validation:** The KPI validation focuses on measuring the system/solution’s performance, effectiveness, and impact based on predefined key performance indicators. This aspect ensures that the solution meets the project’s quantifiable objectives and delivers measurable value. It involves evaluating technical performance, user satisfaction, business impact, and overall project success against the defined KPIs, ensuring continuous monitoring and optimization throughout the project lifecycle.

3 Technical validation plan

3.1 General

Table 1: Common technical validation by common requirements from D2.1

ID	Requirement	Validation criteria (related KPIs if any)
CR1	Integration with legacy automation and metering infrastructure	Verify CEMS collects data from smart meters and automation systems and sends control signals successfully.
CR2	Optimization of energy consumption	Validate CEMS optimizes consumption based on user preferences, dynamic prices, and PV generation.
CR3	Baseline power forecast	Compare CEMS baseline power forecast with actual consumption to assess accuracy.
CR4	Flexibility forecast/estimate	Compare forecasted flexibility with actual available flexibility and validate cost estimations.
CR5	React to explicit flexibility activations	Test CEMS response time and accuracy when executing flexibility activation requests.
CR6	User interaction and visualization	Ensure users can input preferences and visualize energy data, cost savings, and CO2 reduction.
AR1	Integration with energy and flexibility markets	Test AEMS integration with day-ahead, intraday, and flexibility markets for automated bidding.
AR2	Market price forecasting	Validate accuracy of day-ahead and intraday market price predictions.
AR3	Aggregated flexibility management	Ensure correct aggregation of flexibility data from multiple sources.
AR4	Flexibility bidding	Confirm AEMS optimizes and submits flexibility bids correctly.
AR5	User interaction for aggregators	Verify that aggregators can set goals, monitor performance, and access system reports via UI.
AR6	Support for sub-aggregation	Test that AEMS supports separation of aggregation and market integration functions.

3.2 Key Requirements and Validation Criteria

Table 2: Validation of DevSecOps

ID	Requirement	Validation criteria (related KPIs if any)
DR1	Secure deployment and operations	Secure deployment is enforced by integrating external secret management solutions and implementing a CI/CD pipeline that includes dependency vulnerability checks, container image scanning, infrastructure security scans, and compliance validation. This will be validated by executing the tests and analyzing the resulting data through automated reporting and visualization tools.
DR2	Secure and privacy-aware data sharing	Secure and privacy-aware Data Spaces for buildings are deployed and made available for pilots. Over 1000 data points from the project pilots can be discovered and accessed via Data Space (see KPI14 for details).
DR3	Support for investment planning	To ensure the proper functioning of the simulation program, thorough user validation and testing must be conducted. The simulation program for investment planning should be robust against non-standard input data and tested in various extreme scenarios, such as low or high electricity consumption and low or high electricity production. The final simulation results should be compared with expected values to ensure their accuracy and reliability.

3.3 Data Security Measures

3.3.1 Trust and Security

Table 3: Validation of security

ID	Requirement	Validation criteria
TR1	Manage identities	The user identities are managed in a privacy preserving manner: • Privacy preserving management like SSI is used for identity management, • Communication requires X.509 framework to be used for entities communication with the communication server. The impact on privacy should be minimised, X.509 identifiers should be pseudonymised, the scope of X.509 management should be limited to the technical aggregator scope, Identity management scalability: • Performance of the identity management should be fit for the intended purpose and usage. Estimate the performance of the trust management services and validate according to the scope of the pilot and later full-scale deployment, e.g. in Celje area.
TR2	Manage trust between system entities	Identify the needed but minimal set of relationships between the system entities and validate the suitability of the planned and implemented system services for this set. Evaluate if the privacy sensitive data is kept within the intended relationship boundaries.

ID	Requirement	Validation criteria
SR1	Secure communication	All the communication between system entities is secured. Performance of the secure communication is suitable for intended IDOP use. Standardised protocols are used for secure communication.
SR2	Access control sensitive assets and data	All sensitive data is subject to access control. The performance of access control mechanisms is suitable for intended IDOP usage. Authorization policies are fine grained so various system access policies can be implemented.

3.3.2 Privacy Considerations and Regulatory Compliance

Table 4: Validation of privacy and regulatory compliance

ID	Requirement	Validation criteria
PR1	Compliance	Ensure compliance with EU privacy regulations: the security and privacy mechanisms are checked for compliance with GDPR. Ethics guidelines and set in D1.2 Ethics plan will be followed. he compliance should be as full as possible.
PR2	Explicit data flows	Based on IDOP architecture specified in the deliverable D2.1, the data flows need to be checked and validated for rightfulness of the data processing of the system entities. All data flows should be checked.
PR3	Explicit consent	Check if the explicit consent has been given for data processing in the pilots as well if the current IDOP system does take the requirement into the account. All processing in the pilots should be based on explicit consent given by the pilots participants or based on other legal rights of the data controller/processor.
PR4	Data minimization	Assess a need to process the data by the IDOP system components and roles needed to get the access. All the data flows are checked for the data minimization principle.
PR5	Transparency	Make sure the data flows, data usage and processing are presented in a clear and understandable manner in the project deliverables and documentation. Transparency aspects are presented to the end users in end user workshops or direct communication with the end users.
PR6	By design	Evaluate the involvement of privacy by design in the case of IDOP system design and development. Implement checking milestones at each system design deliverable and evaluate how the privacy by design paradigm has been taken into account.

3.4 Pilot Specific Validation

3.4.1 Validation for the German Pilot

Table 5: German pilot specific validation plan

ID	Requirement	Related Common Requirements	Validation criteria (related KPIs if any)
GER_R1	Integration with day-ahead and intra-day markets	CR2	The CEM will fetch the electricity price forecast for day-ahead and intra-day markets via APIs (KPI7)
GER_R2	Optimization at the CEM level	CR2	CEM (Fortiss) is able to optimize the power envelopes of up to three Resource Managers with respect to the communicated power constraints and the electricity price forecast (KPI1, KPI16)
GER_R3	Flexibility forecast	CR3, CR4, AR3	PEBC Power constraints are aggregated at the CEM level and converted into a baseline and flexibility information for AEMS (KPI1, KPI19)
GER_R4	Collect user preferences	CR6, CR2	Optimization goal at CEM level can be selected via user input

3.4.2 Validation for the Finnish Pilot

Table 6: Finnish pilot specific validation plan

ID	Requirement	Related Common Requirements	Validation criteria (related KPIs if any)
FIN_R1	Integration of external data sources	CR1	In the phase 1, the system needs to be integrated into the following data sources in apartment building and supermarket pilots: • Finnish Meteorological Institute (FMI) (both sites): Weather forecast data • Fingrid data service (both sites): CO2 emission data
FIN_R2	Apartment building measurement data	CR1	Data collection tested and demonstrated for sensor data of the demo sites EMS/BMS/Smart meters. This includes identifying and adding sensor points needed, if necessary. In the phase 1, the system needs to be integrated into the following automation and metering infrastructures: • AtmosCare EMS: District heating measurements, total electricity consumption, exhaust air heat pump state • Atmoscare EMS: average indoor air temperature in the apartments, Apartment-specific temperature, humidity, and CO2 measurements
FIN_R3	Supermarket measurement data	CR1	Data collection tested and demonstrated for sensor data of the demo sites EMS/BMS/Smart meters. This

			includes identifying and adding sensor points needed, if necessary. In the phase 1, the system needs to be integrated into the following automation and metering infrastructures: • Fidelix BMS: Heat pump power, Total electricity consumption, space heating power (two different metering points), several indoor air measurements • Green & Cool
FIN_R4	Apartment building control signals	CR1	The ability to send control signals to BMS/smart meters and other metering infrastructure is tested and demonstrated. In phase 1, the RMs need to be able to send commands to following control points. The external system is presented in parentheses. • Exhaust air heat pump on/off control point (AtmosCare EMS) • Space heating supply water temperature (AtmosCare EMS)
FIN_R5	Supermarket control signals	CR1	The ability to send control signals to BMS/smart meters and other metering infrastructure is tested and demonstrated. In phase 1, the RMs need to be able to send commands to following control points. The external system is presented in parentheses. • Refrigeration system pressure (temperature) and mass flow control points (Green & Cool) • Water temperatures, water circulation pump, ventilation machines supply air temperature, etc. (Fidelix BAS)
FIN_R6	Price forecast for day-ahead market	AR2	Creation of the two-day price forecast for the day-ahead market is tested and demonstrated. CEMS can access the price forecast via an HTTP interface.
FIN_R7	HVAC system optimization at the CEM level	CR2	CEM (supermarket) is able to optimize the HVAC system control points with respect to the price forecast, coefficient of performance and location production. The apartment building CEM is able to optimize the HVAC system by keeping the indoor temperature closer to the set point (energy efficiency).
FIN_R8	Baseline forecast	CR3	Creation of the baseline power forecasts. The CEMS baseline forecast needs to be sent to Volue's AEMS via API interface.
FIN_R9	Flexibility forecast	CR4	Creation of the flexibility forecasts tested and demonstrated. The CEMS baseline forecast needs to be sent to Volue's AEMS via API interface.
FIN_R10	Integration with energy and flexibility markets	AR1	The Volue's AEMS needs to be integrated with the following markets: • Nord Pool day-ahead market • FCR-N market • FCR-D up market • FCR-D down market Optional markets to be considered: • FFR market

			• aFRR capacity up market • aFRR energy activation up market • aFRR capacity down market • aFRR energy activation down market • mFRR capacity up market • mFRR energy activation up market • mFRR capacity down market • mFRR energy activation down market
FIN_R11	Multi-market bidding	AR4	The multi-market bidding tested and demonstrated in Nord Pool day-ahead and intra-day markets.
FIN_R12	Aggregated flexibility management	AR3	The Volue's AEMS needs to be able to aggregate the baseline and flexibility data coming from the supermarkets.
FIN_R13	Flexibility activation	CR5, AR3	Flexibility activation tested and demonstrated. Volue's AEMS creates a flexibility activation message that is sent to CEMS via a message. The CEM reoptimizes the HVAC system (see FIN_R4) and then sends a control command to the RM
FIN_R14	Resource management for HVAC systems	CR2, CR4	Following resource management functionality tested and demonstrated for HVAC systems. • The RM is able to follow the load profile provided by the CEM as defined in the Power Envelope Based control. • The RM provides CEM with power measurements.
FIN_R15	Resource management for PV system	CR2, CR3	Following resource management functionality tested and demonstrated for PV systems. • The RM provides a power forecast for the CEM as defined in the S2 interface. • The RM provides CEM with power measurements.

FIN_R16	Interaction with End-User interface	CR6	Collection of user preferences, limits and goals is tested and demonstrated. Following resources and preferences, limits and goals associated with them are to be collected:
			• Heating system/ HVAC
			• Heat Pump
			• EV charging
			• PVs
			• Industrial processes
			• Optimization goals & fixed tariff data
			    ○ Costs
			    ○ Production
			    ○ Self-consumption
			    ○ Emissions
			Simultaneously, CEMS is able to provide visualizations and resource schedules that are available to the user via end-user interface. Also, the possibility for the user to override settings provided by the CEMS is demonstrated.

FIN_R17	Interaction with aggregators	AR5	Collection of user preferences and showcasing the results and operation status including but not limited to the following items: • List of markets to be considered for offering flexibility potential enabling the user select among them • Export option to enable the user to export results

			• Market specific caps for flexibility offerings that enable the user to diversify and alleviate the potential risk • Value sharing mechanism to enable the user select among different mechanisms for allocating revenue among the flexibility potential providers • Presenting expected revenue, participation in different markets and status of different markets
FIN_R18	Secure end-to-end communication	DR1	Secure end-to-end communication for the whole solution is tested and demonstrated (i.e. AEMS is able to communicate with CEMS, CEMS with RMs and UI with CEMS). All communication is secured with TLS and/or VPN.

3.4.3 Validation for the Swedish Pilot

Table 7: Swedish pilot specific validation plan

ID	Requirement	Related Common Requirements	Validation criteria (related KPIs if any)
SE_R1	Integration of external data sources	CR1	In the phase 1, the system needs to be integrated into the following data sources: • Weather forecast data
SE_R2	Price forecast for day-ahead market	AR2	Creation of the two-day price forecast for the day-ahead market for mFRR is tested and demonstrated. CEMS can access the price forecast via an HTTP interface.
SE_R3	Baseline forecast	CR3	Creation of the baseline power forecasts on an hourly basis. The CEMS baseline forecast needs to be sent to CWATT's AEMS via a MQTT/HTTP interface.
SE_R4	Flexibility short term forecast	CR4	Creation of the flexibility forecasts on an hourly basis tested and demonstrated. The CEMS baseline forecast needs to be sent to CWATT's AEMS via a MQTT/HTTP interface.
SE_R5	Flexibility day ahead forecast	CR4	Heat pump creates flexibility forecasts on a daily basis and CWATT's AEMS maintains a continuous model of available flexibility.
SE-R6	Power Tariff Model with Dynamic Updates	CR2	For each resource, the AEMS should maintain a Power Tariff Model (PTM) per the electricity provider that the resources at a site are connected to. The PTM must include all parameters required to enable a cost optimized usage of the grid connection. Moreover, the PTM must be dynamically updated over the relevant periods (e.g. monthly) to reflect actual peak levels reached enabling adjusted power limits and control strategies.
SE_R7	Integration with energy and flexibility markets	AR1	The CWATT's AEMS needs to be integrated with the following markets: • Nord Pool day-ahead market • mFRR capacity up market • mFRR energy activation up market • mFRR capacity down market

			• mFRR energy activation down market
SE_R8	Multi-market bidding	AR4	The multi-market bidding tested and demonstrated in Nord Pool day-ahead and intra-day markets.
SE_R9	Aggregated flexibility management	AR3	The CWATT's AEMS needs to be able to aggregate the baseline and flexibility data coming from the NIBE heatpumps.
SE_R10	Flexibility activation	CR5, AR3	Flexibility activation tested and demonstrated. CWATT 's AEMS creates a flexibility activation message that is sent to CEMS via a MQTT message. The CEM reoptimizes the NIBE system.
SE_R11	Interaction with End-User interface	CR6	Collection of user preferences, limits and goals is tested and demonstrated. Following resources and preferences, limits and goals associated with them are to be collected: • Heat Pump • EV charging • PVs • Optimization goals & fixed tariff data o Costs o Production o Self-consumption o Emissions Simultaneously, CEMS is able to provide visualisations and resource schedules that are available to the user via end-user interface. Also, the possibility for the user to override settings provided by the CEMS is demonstrated.
SE_R12	Interaction with aggregators	AR5	Collection of user preferences and showcasing the results and operation status including but not limited to the following items: • List of markets to be considered for offering flexibility potential enabling the user select among them • Export option to enable the user to export results • Market specific caps for flexibility offerings that enable the user to diversify and alleviate the potential risk • Value sharing mechanism to enable the user select among different mechanisms for allocating revenue among the flexibility potential providers • Presenting expected revenue, participation in different markets and status of different markets

SE_R13	Secure end-to-end communication	DR1	Secure end-to-end communication for the whole solution is tested and demonstrated (i.e. AEMS is able to communicate with CEMS, CEMS with RMs and UI with CEMS). All communication is secured with TLS and/or VPN.

3.4.4 Validation for the Slovenian Pilot

Table 8: Slovenian pilot specific validation plan

ID	Requirement	Related Common Requirements	Description
SLO_R1	Integration with legacy automation and metering infrastructure.	CR1	CEMS should be integrated with: • Reduxi controller • PCS CEMS should be able to connect with different types of assets: • solar inverters • hybrid inverters • EV chargers • smart meters • HVACs • etc. CEMS should be able to communicate with assets and collect measurement data: • power • energy • voltage • current • etc. CEMS should be able to send control signals to the operating assets: • power setpoint • EMS mode switching • temperature setpoint • etc.
SLO_R2	Optimize energy consumptions	CR2	CEMS should have ability to optimize energy consumption either automatically by predefined procedures or manually defined by user. It should have options as: • schedules • export/import power limits • EMS mode switching (self-consumption, peak-shaving, max consumption, max production) • AI algorithms • Dynamic prices
SLO_R3	Baseline power forecast	CR3	CEMS need to be able to provide the AEMS with baseline power forecast (i.e., optimized load profile).
SLO_R4	Flexibility forecast/estimate	CR4	CEMS should be able to estimate its flexibility forecast and provide this information to the market or some other aggregation platform.
SLO_R5	React to explicit flexibility activations	CR5	CEMS need to be able to activate the offered flexibility when requested by the AEMS.
SLO_R6	User interaction	CR6	CEMS need to be able to collect user preferences, limits, and goals. CEMS need to be able to provide users with visualisations on energy consumption, system state, and results of DSFM actions (e.g. costs savings and CO2 emission reductions).

SLO_R7	Integration with energy and flexibility markets	AR1	AEMS need to be integrated with relevant energy (day-ahead and intraday) and flexibility markets (e.g. TSO reserve and DSO local flexibility markets) to perform automated bidding.
SLO_R8	Market price forecasting	AR2	The AEMS need to provide CEMS with day-ahead price forecast. Additionally, price forecasts for the intraday and flexibility markets are required in the multi-market bidding.
SLO_R9	Aggregated flexibility management	AR3	AEMS need to be able to aggregate the baseline and flexibility
SLO_R10	Flexibility bidding	AR4	The AEMS need to be able to optimize the flexibility when bidding in energy and flexibility markets.
SLO_R11	User interaction	AR5	The AEMS need to provide aggregators with user interface to manage their goals and preferences, and view performance reports and system status information.

4 End User Validation Plan

The end user validation plan presented here specifies the content (what), methodologies and methods (how), and planning (when) of the end user validation activities. It is a common plan which will be adapted to each pilot's specific objectives, implemented solutions and services, type of end users, buildings and assets, and type of end user engagement. It is therefore not intended to be fixedly prescriptive nor restrictive, but it will set the boundaries for the validation while being flexible to accommodate to changing shape and needs of the pilots (the iterative approach) and its end-users.

4.1 End User Characteristics

Each INDEPENDENT pilot targets a specific type of end users as well as type of buildings which subsequently influences the type of solution or service that has been implemented. Table 9 below provides an overview of the users and buildings involved in each pilot.

Table 9: End user and buildings overview

Pilot	End user	Type of Building	Flexibility Resources
Finland	Building Manager/Building Owner	Commercial (Supermarket)	Heat pump
	Building Manager	Residential (Apartments)	Heat pump
Germany	Building Manager	Industrial (glass production)	HVAC system (heat pump)
	Consumer/Prosumer	Single family house	Solar production, heat pumps, and EV-chargers
Slovenia	Consumer/Prosumer	Single family house	Heat pumps, EVs, PVs, white goods, and batteries
		Apartment	Heating sources (electricity and gas)
	Building Manager	Industrial (dairy farm)	Cold storage, various industrial processing equipment, a PV, and a battery
Sweden	Consumer/Prosumer	Single family houses	Batteries, solar panels, heat pumps (ground source, air/water and exhaust air) and EV-chargers

4.2 Key Objective of End User Validation

When carrying out end user validation, the overall research question is: *Have we built the right product?* It thus focuses on assessing how well user requirements and needs have been met by allowing end users to test and validate the product.

The end user validation will focus on end users' experiences with testing and using the solution and/or service and collect qualitative and quantitative data on key factors (i.e. the validation metrics) which has formed their perspective and experiences. The key validation metrics are satisfaction, acceptance, and usability which are intrinsically interrelated and multifaceted. Particular attention will be given to user needs and challenges, incentives and barriers, privacy issues or concerns, and functionalities and usability of the user interface (where relevant). The primary objective of end user validation is thus to assess the user satisfaction, acceptance and usability of the IDOP-based solutions and services that have been implemented in the pilots.

4.3 Methodology, Tools and Success Criteria

The end users involved in pilots will test and use the implemented solutions and services, and the pilots are thus extremely valuable for collecting data directly on the end user perspectives and aspects; in essence pilots can be considered as the user acceptance testing ground where the developed services and solutions are tested in a real-world environment.

Pilot specific questionnaires and/or focus groups will be designed to gather qualitative data (i.e. interpretation-based and descriptive) on end users' overall experiences and perceptions of the solutions tested in the pilot. Standard questionnaires on user experience will be used to collect quantitative data and will primarily be used as supplementary to the qualitative data.

The qualitative data will be analysed to identify themes and commonalities that have shaped and affected the user experience (positively or negatively), thereby contributing to a deeper understanding of what shapes user experience and the meaning or significance user attribute to it. Quantitative data will, on the other hand, be used to analyse how end users rate the service/solution, how often they have used a UI and for what purposes.

As some business and technical validation activities involve end user it will often make sense to combine all aspect into one joint event, e.g. a focus group can be used to address both end user experiences and business aspects. Business and technical aspects are indeed relevant aspects to consider in the context of user acceptance and satisfaction, and it is therefore natural to create a joint event to address all three aspects. This way we also make better and more efficient use of end users' time.

All end users in a particular pilot will be invited to participate in a validation activity. Participation is voluntary but efforts will be made to encourage participation and engagement.

4.3.1 Pilot Specific Questionnaires

Pilot specific questionnaires will primarily consist of open-ended questions to elicit long-form written feedback from end users on their experiences, perspectives, and opinions using their own words. Closed-ended questions will either provide a set of possible answers or ask the respondents to rate a statement, in which case the 5-point Likert Scale will be used. All questions will be carefully designed and reviewed to avoid using biased or value-laden words that implicitly prompt or influence respondents to answer in a certain way.

Questionnaires will be created online using a GDPR approved platform. The questionnaire will be made accessible via a customized link and it must be possible to collect responses anonymously, i.e. without collecting IP addresses.

4.3.2 Focus Groups

The main aim of a focus group is to learn from the participants' experiences and perceptions. A moderator will present some trigger questions or discussion points for participants to discuss together. The focus group will have a flexible and informal format to resemble a conversation between participants. The moderator should only step in with a new trigger question if the conversation stalls or needs to be redirected.

Focus groups will have a maximum number ten to twelve of participants and this group should be made up of different end user with different sociodemographic profiles. A selection process may thus need to be implemented for which the inclusion/criteria will be transparent and directly related to the purposes of the validation.

4.3.3 The System Usability Scale

The System Usability Scale (SUS) was initially presented as “A ‘quick and dirty’ usability scale” (Brooke, 1996) and is today is a standardised well-known, reliable, and simple scale for assessing the perceived usability of a system. It focuses on the pragmatic aspects. It can be used as a post-test questionnaire for the assessment of perceived usability as well as for a retrospective evaluation of products and services (Grier, 2013).

It consists of ten short statements (items) that describe five classical usability criteria that focus on the pragmatic quality of a system/product: ease of use, usefulness, perceived complexity, consistency, and ease of learning. Using the 5-point Likert Scale, respondents indicate their disagreement or agreement with each statement. The SUS score for a system can range from 0 to 100. The score should be compared to a benchmark to give it more value. The benchmark we will use derive from (Lewis, 2018).

The SUS will be relevant for the pilots where a new (or a significantly extended version of an existing) user interface or app has been actively used by the end user to interact with the implemented service or solution.

4.3.4 The User Experience Questionnaire

The User Experience Questionnaire (UEQ) was constructed to allow for a “comprehensive impression of user experience” (Laugwitz, 2008) combing pragmatic and hedonic user experience aspects. The inclusion of the hedonic aspect is the main difference between the UEQ and the SUS. Similar to SUS, respondents indicate their agreement with each item (statement) on the questionnaire, however the UEQ uses a 7-point Likert scale. The UEQ contains 26 items which are grouped into six scales: Attractiveness, Efficiency, Perspicuity, Dependability, Stimulation, and Novelty. The UEQ comes with a unique scoring system with benchmark data which allows for an automatic calculation of the scoring by using the provided Excel scoring sheet (Schrepp, 2014).

A short version of the UEQ (the UEQ-S) was later developed to account for scenarios where a shorter questionnaire would be more appropriate, for example in case of where the UEQ is integrated into an existing questionnaire about the entire product experience (Hinderks, 2018). Since this will be the case in INDEPENDENT, we intend to use the UEQ-S to allow us to keep all questionnaires short, knowing that lengthy questionnaires can easily put users off from responding.

The UEQ-S only contains eight items equally divided into a pragmatic quality scale and a hedonic quality scale. The overall user experience value is calculated using the mean value of the eight items. Evaluation of the UEQ-S showed that it generates very similar results to the UEQ for pragmatic and hedonic quality, and the UEQ benchmark data set can still be applied to the UEQ-S (ibid.).

The UEQ-S will be used where the pilot wishes to include the hedonic aspect in the evaluation of the INDEPENDENT-based user interface or app that end users have used actively in the pilot (thus using the UEQ-S instead of the SUS).

4.3.5 Success Criteria

When we determine the success criteria for end user validation, we need to distinguish between qualitative and quantitative data. Qualitative data is by its very nature harder to organise and tabulate compared to quantitative data, and the purpose of the analysis or evaluation of data is also not to assign a value or level. Qualitative data will thus be interpreted to identify main themes, language use and narratives that relate to how positive or negative end users’ perceptions and experiences are. Quantitative data, on the other hand, will be evaluated against validated benchmarks for SUS and UEQ-S respectively.

4.4 Personal Data and Ethics

Personal data collected in questionnaires will be protected as prescribed by the GDPR. Online questionnaires will not collect any directly identifiable information such as name or address except in case where respondents can participate in a prize draw; this may be considered by some pilots to encourage pilot participants to fill in questionnaires. Sociodemographic data will only be collected when it will be processed for analytical purposes. Questionnaires collecting sociodemographic data will be subject to GDPR; combining sociodemographic data with e.g. information on buildings (type of residence) and assets could potentially be used to identify an individual and the data must therefore be protected. In these cases, a GPDR-compliant privacy notice will be issued together with the questionnaire and the processing will be based on informed consent.

All issues discussed in focus groups will be anonymised and participants will be informed hereof in the invitation to participate. It will be made clear that the focus group is a confidential and safe space where participants can freely express their opinions without fear of any repercussions, e.g. from their electricity provider, app provider or any other provider/supplier connected to the pilot.

4.5 End User Validation Plan

The following table presents an overview of the common end user validation plan. It leaves room for modifying the methodology and metrics to fit each pilot's specifications in order to make a detailed and complete pilot specific plan of validation activities. It is also worth noting that should the general and informal communication with end users during the pilot's lifetime (e.g. during installations, troubleshooting or general enquiries) indicate that a particular or unforeseen issue or aspect may have a significant effect on the user experience, it will be included as a validation metric.

Table 10: End user validation plan

ID	Objective	Product/service	Metrics	Tool	Method	Acceptance Criteria/KPI	Timing	**Lead Partner**
EUV1	User acceptance	Implemented service and/or solution	• Experience • Satisfaction • Usability • Trust	Survey using one of more methods, e.g. questionnaire, focus group and/or interviews	Qualitative analysis	Predominantly positive feedback	Iterative: 1. End Phase 1 (M16-M18) 2. End Phase 2 (M34-M36)	• Pilot clusters • In-JeT
EUV2	Usability	End user interface/app	Pragmatic quality	System Usability Scale (SUS)	Benchmark analysis	SUS: ≥80[1]	End Phase 2 (M34-M36)	• Relevant pilot clusters • In-JeT
EUV3	User experience	End user interface/app	• Pragmatic quality • Hedonic quality	The Short Version of the User Experience Questionnaire (UEQ-S)	Benchmark analysis	UEQ-S: ≥ Good[2]	End Phase 2 (M34-M36)	• Relevant pilot clusters • In-JeT

(Lewis, Item benchmarks for the System Usability Scale (SUS), 2018)
(Hinderks, A Benchmark for the Short Version of the User Experience Questionnaire, 2018)

5 Business Validation Plan

The Business Validation Plan aims to assess the effectiveness and impact DSFM and CEMS initiatives. The following KPIs ensure that the developed business models are viable and aligned with market needs:

- **KPI7**: Number of wholesale and flexibility markets supported.
- **KPI8**: Increase in profits from DSFM with multi-market operation.
- **KPI15**: Return on Investment in DSFM business models. This is based on a discounted cash flow analysis for IDOP users
- **KPI16**: Annual energy cost reductions for consumers with CEMS.

Data Requirements
To measure these KPIs, we will need:

1. **Market Data**: Historical and current prices from wholesale and flexibility markets, along with participation rates.
2. **Financial Data**. Since these data is confidential for single companies (e.g. profit margins, revenue streams from DSFM operations, and investment costs) we'll use publicly available data and cost structures from relevant studies.
3. **Consumer Data**: Historical energy consumption and cost data before and after CEMS implementation. Here we'll use data from the pilots and publicly available data. Assumptions on customer willingness to pay will be made.
4. **Scenario Data**: Weather data and future price estimates for energy and flexibility markets.

Data Collection Methods
Data will be collected through:

1. **Monitoring** of the energy consumption in the pilots, before and after the deployment of the INDEPENDENT platform.
2. **Surveys and Interviews**: Engaging stakeholders to gather qualitative insights on market participation and value perception. Organize co-creation workshops for value models with consortium partners,
3. **Market Analysis Reports**: Utilizing existing reports for historical and current market data.
4. **Collaboration with Tasks T5.3 and T5.4**: Integrating data from the investment analysis tool and business model development.

Contributions of Tasks T5.3 and T5.4
Task T5.3: Data-driven Tool for Investment Analysis

- **Investment Analysis Tool**: This tool will evaluate the feasibility and profitability of investments in DSFM by simulating various price and weather scenarios, directly impacting KPI8 and KPI16.
- **Historical Data Integration**: Fitting models to historical consumption data ensures accurate results, aiding in KPI16 measurement.
- **Scenario Simulation**: Stakeholders can visualize investment outcomes under different conditions, supporting strategic decision-making.
- **Iterative Updates**: Continuous integration of updated models keeps the tool relevant and reflective of market trends.
- **Data-Driven Insights**: The tool will provide empirical evidence to support business validation.

Task T5.4: Business Models and Value Sharing Mechanisms

- **Business Model Identification**: This task will identify relevant business models based on use cases documented in Deliverable D2.1, ensuring alignment with stakeholder needs.
- **Value Sharing Framework**: Establishing fair value-sharing mechanisms promotes collaboration among stakeholders. Create value models using dedicated tools and co-creation workshops.
- **Market Analysis**: Using SWOT and TOWS methodologies will identify barriers and drivers for implementing business models.
- **Established Methodologies**: Utilizing frameworks like the Value Network and Business Model Canvas will help articulate value creation and sharing.
- **Barriers and Drivers Analysis**: Identifying these factors will inform strategies to mitigate risks and leverage opportunities.

Conclusion

The Business Validation Plan integrates insights from Tasks T5.3 and T5.4 to effectively measure the project's impact against defined KPIs. Task T5.3 provides analytical tools for evaluating investment feasibility, while Task T5.4 focuses on developing relevant business models and equitable value-sharing mechanisms. This comprehensive approach ensures that DSFM and CEMS initiatives are validated, sustainable, and aligned with market needs, ultimately contributing to the successful implementation of the project's outcomes in the energy market.

6 KPIs Validation Plan

ID	Key performance indicator	Target	Description and validation measures	Validation methods and input data
KPI1	Compliance with key DSFM standards	100%	Compliance of the IDOP with key DSFM standards (presented in section 1.2.1.2 of the DoA).	Qualitative Analysis of the IDOP system architecture (D2.1 and D2.3) and IDOP-based DSFM systems demonstrated and validated in the project pilots (D6.1 and D6.2). Additional inputs include the module specifications and implementations of the CEMS and AEMS Packages (D3.1, D3.2, D4.1 and D4.2).
KPI2	Compliance with security standards and GDPR	100%	Compliance of the IDOP architecture and IDOP based pilot implementations with relevant EU regulations and standards.	The KPI validation will follow a set of requirements and validations as are proposed in Section 3.3 and in DevSecOps part in Section **Fejl! Henvisningskilde ikke fundet.**. Compliance will be checked for project based IDOP.
KPI3	Number of smart appliance vendors supported.	60	Count of vendors per appliance/device type whose SA are interoperable with the IDOP. These numbers will be reached by integrating the platforms provided by project partners into the IDOP and extending the support for new EMS and SA vendors	The interoperability of different devices is tested as part of the T6.1 (D6.1 and D6.2). The count will include devices in pilots and also other devices supported for replication purposes.
KPI4	Number of building and industrial EMS vendors supported.	40	Count of vendors per EMS type whose EMS (i.e., BAS, HEMS, AEMS, PV systems, etc.) are interoperable with the IDOP. These numbers will be reached by integrating the platforms provided by project partners into the IDOP and extending the support for new EMS/BAS/AEMS.	The interoperability of different EMS is tested as part of the T6.1 (D6.1 and D6.2). The count will include devices in pilots and also other devices supported for replication purposes.
KPI5	Increased accuracy and robustness of resource models, aggregated demand and flexibility forecasts	13%	Results from pilots are compared to SotA forecasting models.	The novel models including Neural Ordinary Differential Equations and probabilistic forecasting (documented in D3.1, D3.2 and will be compared to SotA models using the data collected from the project pilots (D6.1 and D6.2).

KPI6	Flexibility potential coverage in buildings and industrial sites	90%	Calculated by dividing the flexible capacity covered by IDOP with the total flexible capacity in sites.	The total flexible capacity available in buildings is estimated using data from a recent DNV study (2022), which assessed the potential benefits of demand-side flexibility (DSF) across the EU by 2030. The study highlights the main DSF technologies applicable to buildings, which include: • Residential electric heating, primarily using heat pumps (106 GW) • Smart charging infrastructure (65 GW) • Behind-the-meter battery energy storage systems (BESS) (22 GW) • District heating solutions (14 GW) The ratio will be determined based on the subset of these technologies that are supported by the IDOP and demonstrated in the project pilots (D3.1, D3.2, D6.1 and D6.2).
KPI7	Number of wholesale and flexibility markets supported	8	Different markets from the same operator (e.g. Fingrid, Nord Pool) are counted separately.	A count of energy wholesale and flexibility markets supported by the AEMS Package of the IDOP. The supported market is tested and demonstrated in the project pilots (D4.1, D4.2, D6.1 and D6.2).
KPI8	Increase in profits from DSFM with multi-market operation	10%	The profit increase estimates are based on results obtained with multi-market simulations. Market price fluctuation is estimated to increase the profits in the future.	The expected revenue from offering flexibility potential compared to the case where flexibility potential is offered in FCR-N market as baseline. The comparison will be done with other flexibility markets, too.
KPI9	Total volume of buildings managed by IDOP-based CEMS	200 km3	The total volume (area multiplied by average room height) of all pilot buildings. Volume is used instead of customer count to properly account for different types of consumers (ranging from households to large building and industrial sites).	The sum of pilot building volumes is calculated based on building specific data collected from the pilots (D6.1 and D6.2).
KPI10	Total amount of flexible capacity available for RES balancing	1,4 MWh	The capacity includes maximum up and down flexible energy from all pilot buildings.	The maximum up and down flexibility per pilot is tested and demonstrated in the project pilots. Then a sum is first calculated separate for up and down flexibility, which are then added together to find the final number.
KPI11	Annual GHG emission reductions with IDOP	15%	Results obtained with self-consumption maximisation, energy efficiency, and global RES balancing are compared to the situation without any DSFM solutions.	Quantitative analysis based on the results obtained in the project pilots (D6.1 and D6.2).

KPI12	Annual RES curtailment avoided with IDOP	20%	The share of local RES production that does not need to be curtailed because of IDOP-based CEMS.	Quantitative analysis based on the results obtained in the project pilots (D6.1 and D6.2).
KPI13	Reduced development, deployment, and integration efforts	70%	Indicates the effort and cost reductions obtained with the IDOP. Evaluated by comparing the amount of work required for new CEMS deployments in phase 2 against the efforts required for implementing the source code, interfaces, and resource representations that can be re-used across deployments.	The evaluation will be based on the 1st and 2nd phase pilots (D6.1 and D6.2). Following data will be collected from pilot partners to estimate the reduced development, deployment and integration efforts: • Share of IDOP based software (lines of code ratio) in the pilots (i.e., software that can be replicated across pilots). • Estimate of the reduced efforts for development, deployment and integration facilitated by the IDOP.
KPI14	Number of data sources available via IDOP data spaces	1k	The total number of different data entries (e.g. measurement points) that can be accessed via IDOP data spaces.	The data points entries are calculated from the IDOP data spaces. Each measurement point, etc. is counted as an individual entry.
KPI15	Return on Investment in DSFM business models	10%	Based on a discounted cash flow analysis for IDOP users. Future numbers assume an increase in market prices and price fluctuations. The possible price decrease caused by DSFM is not accounted in the numbers.	The ROI analysis will be performed with the Data-driven Tool for Investment Analysis (D5.1 and D5.2). Quantifiable data from pilots regarding investment and profit will be used where available, otherwise data from publicly available studies will be used.
KPI16	Annual energy cost reductions for consumers with CEMS	20%	The results are compared to a situation without any DSFM system.	Quantitative analysis based on the results obtained in the project pilots (D6.1 and D6.2). With the usage of the investment analysis tool a sensitivity analysis of the cost reductions for different climate zones, price profiles, technology combinations can be obtained.
KPI17	Number of EMS service companies utilising the IDOP	7	The count of EMS service companies provides CEMS and AEMS services.	The count of companies with IDOP based CEMS and AEMS in the project pilots.
KPI18	Number of aggregators utilising the IDOP	4	The count of aggregators using the IDOP.	The count of aggregators using the IDOP based AEMS in the project pilots (D6.1 and D6.2)
KPI19	TRL for IDOP and IDOP-based CEMS/AEMS.	8	The complete IDOP based CEMS and AEMS have been qualified in operational environment	Testing and validation of the CEMS and AEMS in the project pilots. Assessment of the TRL according the TRL scale defined for EU projects (D6.1 and D6.2).

7 Conclusion

This document has presented the initial validation framework and plans for the IDOP platform developed in the INDEPENDENT project. The validation framework covers four core dimensions—technical, end-user, business, and KPI-based validation—designed to comprehensively evaluate the performance and impact of IDOP-based CEMS and AEMS solutions.

The work conducted under T2.4 establishes the foundation for structured validation activities in WP6. It aligns with the requirements and architectural principles defined in earlier tasks (T2.1–T2.3) and ensures that IDOP-based systems will be assessed for usability, performance, compliance, and market-readiness. The pilot-specific validation plans address diverse deployment contexts in Germany, Finland, Sweden, and Slovenia, reflecting real-world operational scenarios and enabling meaningful feedback from all stakeholders.

By integrating standard-compliant testing criteria, secure data handling principles, and user-centric validation methodologies, the framework ensures that the IDOP will meet the needs of consumers, aggregators, and system operators. The work also contributes to ensuring interoperability, security, and sustainability of demand-side flexibility management solutions across Europe.

In the second phase of the project, the validation framework will be further refined based on the lessons learned from the initial pilots. These refinements will be detailed in subsequent deliverables and used to guide the final system qualification and market uptake activities.

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