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Big data for buildings

Building Information aGGregation, harmonization and analytics platform

Project Nº 957047

D6.3- Final evaluation of the BIGG pilots results on use cases

Responsible:	Oriol Escursell Jové (ICAEN)
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Executive Summary

The BIGG project aims at demonstrating the application of big data technologies and data analytic techniques for the complete buildings life cycle of more than 4000 buildings in 6 large-scale pilot test beds. The pilot test beds defined at the start of the project a series of challenges related to buildings and data management to overcome and improve on which have guided the technological developments of BIGG.

The project has developed the infrastructure to maintain and operate the 6 pilots, from the reference architecture to the AI based analytical tools necessary. The 6 pilots test beds were defined to cover a wide range of building data challenges including both public and private needs, which could benefit from shared developments and improvements such as a reference architecture and a common Data model, keeping in sight the differences and particular needs of each different case. Therefore, the solutions required to cover them span from harmonisation and mapping of the data to the advanced analytical solutions that calculate accurate baselines, buildings benchmarking, flexibility potential in DR events, among others. The 6 pilots are also referred as Business Cases (BC) and have been further divided into 15 Use Cases (UC) to tackle the different challenges proposed into their individual components. For example, managing a large building portfolio and its energy efficiency improvement actions, such as in BC1, required different data collection approaches (for the buildings and the improvements actions separately), mapping and changes to the Data model, which promoted to split this overall task into two different use cases.

The BIGG project was dived into 8 work packages to accomplish the defined tasks, four of them focusing on the technical development, with the pilots being the core of the WP6. The work presented in this document is the conclusion of the projects' pilots M36, including the challenges encountered by each pilot. During the first half of the project, the work focused on setting up the different pilots (also known as Business Cases) and preparing the necessary infrastructure to measure and monitor them, as well as, defining the methodology to evaluate their progress. During the second half, the pilots have focused on implementing and testing the technical solutions provided by the technical work packages to constantly provide feedback and improve each solution.

The report starts with an introduction of the pilots work package, an overview of the progress of the cross-cutting technical components and the methodology for the evaluation of the current report.

The description of the Buisiness Cases is briefly shown in section II along with the main results of each Business Case. The section presents each of the 6 Business Cases, summarising the extended descriptions provided in D6.2. The section main purpose is to present the final results of the pilots divided among the 6 Business Cases using the KPIs methodology developed. The analysis section explains the current state of each pilot, at the detail level of the individual use case, using the developed KPIs. The section also describes the challenges faced by each pilot (if there are any) in the form of limits detected and modifications of the initial data sets, either by adding new sources of information to expand the current ones or removing data sets deemed not useful or accessible due to the evolution of the pilots.

Finally, conclusions, lessons learned and future actions are included based on each partners' interests and the results obtained.

Contributors Table

DOCUMENT SECTION	AUTHOR(S)	REVIEWER(S)
All sections	Oriol Escursell (ICAEN)	Nerea Gomez (ECTP) and Laura Balan (Inetum)
Section II	Oriol Escursell (ICAEN), Jordi Carbonell (CIMNE), Eloi Gabaldon (CIMNE), CORDIA; Romain Hollanders (Energis), Riccardo Devivo (Energis); Katerina Karagianni (CORDIA), Tonia Xepapadaki (CORDIA), Nikos Mitrofanis (CORDIA), Vangelis Mestousis (CORDIA); Stratos Keranidis (DOMX), Polychronis Symeonidis (DOMX), Ellie Efstathiou (DOMX), Giannis Kazdaridis (DOMX); Athanasios Papakonstantinou (HERON), Marion Paraschi (HERON).	Nerea Gomez (ECTP) and Laura Balan (Inetum)
Section III	Oriol Escursell (ICAEN), Jordi Carbonell (CIMNE), Eloi Gabaldon (CIMNE), CORDIA; Romain Hollanders (Energis), Riccardo Devivo (Energis); Katerina Karagianni (CORDIA), Tonia Xepapadaki (CORDIA), Nikos Mitrofanis (CORDIA), Vangelis Mestousis (CORDIA); Stratos Keranidis (DOMX), Polychronis Symeonidis (DOMX), Ellie Efstathiou (DOMX), Giannis Kazdaridis (DOMX); Athanasios Papakonstantinou (HERON), Marion Paraschi (HERON).	Nerea Gomez (ECTP) and Laura Balan (Inetum)

Table of Contents

Table of Figures

List of tables

Table of Acronyms and Definitions

Acronym	Definition
AI	Artificial Intelligence
AHUs	Air Handling Units
API	Application Programming Interface
BC	Business Case
BIM	Building Information Modelling
BMS	Building Monitoring System
BPC	Building Performance Certificate
BSO	Building Stock Observatory
CDD	Cooling Degree Day
CLI	Command-Line Interface
CMMS	Computerized Maintenance Management System
CVRMSE	Coefficient of the Variation of the Root Mean Square Error
DEEP	De-Risking Energy Efficiency Platform
DR	Demand Response
DSO	Distribution System Operator. Acts as a neutral market facilitator for flexibility services
ECM	Energy Conservation Measure
EEFIG	Energy Efficiency Financial Institution Group
EEM	Energy Efficiency Measure
EIU	Energy Intensity Use (kWh/m2)
EMS	Energy Management Software
EnPC	Energy Performance Contract
EPC/BPC	Energy Performance Certificate/Building Performance Certificate
ESCO	Energy Service Co. knowledgeable in EPC contracts.
EUBSO	European Union Building Stock Observatory

FCU	Fan Coil Unit
GCP	Ground Control Points
GDPR	General Data Protection Regulation
GPG	Patrimonial management tool of Generalitat de Catalunya (original name: Gestió del Patrimoni de la Generalitat de Catalunya)
HDD	Heating Degree Day
HVAC	Heating Ventilation and Air Conditioning
ICT	Information and Communication Technology
INSPIRE	Infrastructure for Spatial information Europe
IPMVP	International Performance Measurement & Verification Protocol.
IPTO	Independent Power Transmission Operator
ISP	Integrated Scheduling Programming
IXON	Remote service & IoT solution for industrial machines. An end-to-end solution with remote access, data logging, dashboards, alarms…
KPIs	Key Performance Indicator
LCA	Life Cycle Assessment
MBE	Mean Bias Error
ML	Machine Learning
MLP	Multilayer Perceptron
MQ	Message queuing
NMBE	Normalized Mean Bias Error
NPV	Net Present Value
PA	Public Authority
SIME	Energy accounting tool used for centralized purchasing in Public Catalan Administration
RAF	Reference Architecture Framework
RES	Renewable Energy Systems
REST	Representational State Transfer

RL	Reinforcement Learning
RNN	Recurrent Neural Network
ROI	Return of investment
TSO	Transmission System Operator
UC	Use Case
UML	Unified Modelling Language
UTM	Universal Transverse Mercator, coordinate system that divides the world into 60 north-south zones, each 6 degrees of longitude wide.

I. INTRODUCTION

I.1. Purpose and organization of the document

This report describes the results achieved in the 6 BIGG pilots until the end of the project. Highlighting two key aspects of each business case:

Firstly, a summary of the scope and main objectives of each pilot, as well as the most relevant results in each one, also mentioning the challenges that were overcome. **Secondly**, the conclusions of the work based on the results and how they contributed to facing the challenges encountered.

The report is organized as follows:

Section I: explains the structure of the report, scope of the BIGG project and the audience to which it is directed. As well as the methodology used in the evaluation of results.

Section II: contains the summary of each business case, the KPIs selected to measure its performance, the results achieved, and the limitations presented in some cases.

Section III: contains the conclusions of the BIGG project, lessons learned and future work.

I.2. Scope and audience

The BIGG project aims at demonstrating the application of big data technologies and data analytic techniques for the buildings life-cycle of more than 4000 buildings in 6 different large-scale pilot test-beds, that we have called them Business cases (BCs) and they have been sub-divided into 15 more specific Use Cases (UCs).The 6 Business Cases focus on data about buildings and energy, diverging on the type of data they use and the goals for each of them. The common filed of work but differentiated approach contributes to all the technical development by providing needs that will be made compatible just in case they are merged in the future, being the Data model the most relevant example of that since it is common and grow out of the pieces of each UC.

This deliverable is the final document of Work Package 6, which objectives are the following:

- Demonstrate the applicability of the designed BIGG solutions to support diverse real-world business scenarios in terms of the defined KPIs across pilots.
- Demonstrate how the solutions address the challenges and needs defined by each pilot.

Figure 1 shows how work package 6 (WP6) is in connection to the work packages of the project, to put in place all pilots:

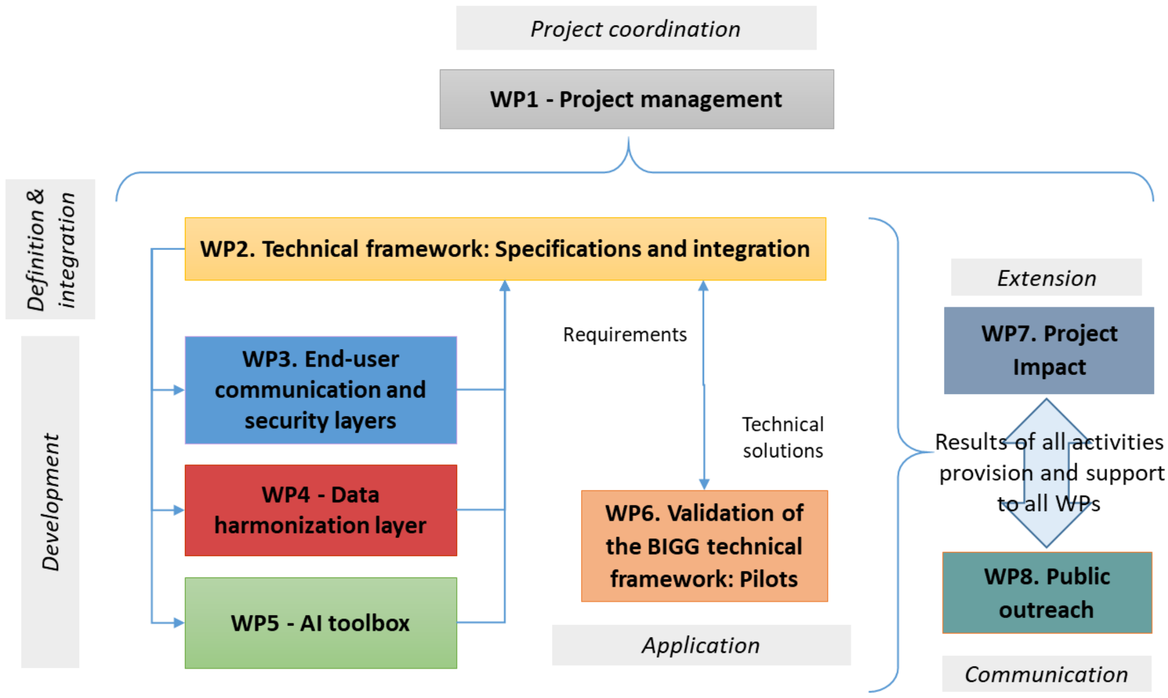


Figure 1: Scenario of relation between WP6 and other WPs of BIGG project

At the beginning of the project the pilot owners, within the context of WP6, described the 6 different Business cases and the available datasets, this description was then used by WP2 to elaborate the technical requirements of the project and coordinate with WP3, 4 and 5 to develop all the necessary tools to fulfil the needs of each Business case. The developed technical solutions were returned to WP6 in an iterative process to improve and refine them in a constant feedback loop between the pilots and (WP2), the technical WP.

The technical development objectives are defined based on the goals of the six different business cases summarised in section II of the current deliverable (and that is related to what is defined in section III of deliverable D6.2)[1]. Each business case has two or more use cases (UCs) that aim to cover all the aspects necessary to fulfil the business case main goals.

As mentioned above the BIGG project divided the technical development among 4 work packages to develop the solutions needed to fulfil the 6 Business cases of the project. The technical WP worked towards the continuous development of their solutions, which have been continuously tested by the pilots (as shown in Figure 1). The technical development of BIGG has been described in the WP2-5 deliverables, specifically the public deliverables **D2.3** “Final technical specifications and description of the integrated BIGG solution”; **D.3.2** “Description of the end-user communication and security layers”; **D4.2** ”Description of the final harmonization layer”; **D4.3** “Public BIGG Data”; and **D5.2** “The BIGG Artificial Intelligence (AI) toolbox for building data”. A brief summary of the progress and development so far is presented below regarding these public deliverables with the aim to describe the progress towards the Business cases.[2]

Work package 2 developed the BIGG Architecture which required to confront the envisioned architecture options by the different business realities of the different consortiums’ partners. One of the key findings of BIGG is that, in order to fulfil all requirements from pilots, the BIGG

[1] https://www.bigg-project.eu/wp-content/uploads/2022/09/BIGG_D6.2.pdf

[2] https://www.bigg-project.eu/deliverables/

architecture should not be exclusively a cloud-based system. The proposed solution must be modular and flexible in terms of BIGG components deployment choices. Actually, BIGG components must be deployable locally on partners infrastructures where BIGG components can be close to the place where data-to-be-exploited resides. Therefore, the BIGG technical specifications are a “pick and choose” system describing components that end-users may take and deploy individually. Architectural guidelines describe state-of-the-art ways to organize these components’ interactions.

The modularity and versatility requirements of the BIGG components, due to the multiple business cases, lead to structuring the different components code in several layers:

- (1) A CLI stand-alone tool consuming and/or producing data files and configured by options;
- (2) A Web service exposing a REST (Representational State Transfer) API;
- (3) An event stream messaging system compatible node: In the context of big data management use cases, event stream messaging systems are more relevant to be used than message queuing (MQ) systems.

In the BIGG project, the Kafka event stream messaging system has been used for the Reference Architecture Framework. Compatible components must thus be publishers (aka “producers”) and/or subscribers (aka “consumers”) that can connect to the Kafka message bus. The components codes and deployment artifacts need to be centralized in a repository shared among users. Every user is then able to pull the components versions that fits the best his local architecture and update the components for future shared improvements. Further descriptions of the BIGG Architecture can be found in D2.3.

Work package 3 is developing three different aspects of the project, the communication layer, the graphical user interfaces and the security layer development. Out of the three tasks the most relevant towards this report is the communication layer development, in which, WP3 has developed the ingestors needed by BIGG. However, the work of WP3 is closely linked to the WP4 harmonisation and BIGG data model for buildings. The data model developed by WP4 has been used by WP3 to ingest and harmonise the data from external source into the BIGG format. The data ingested through the communication layer (Task 3.1) passes through the harmonization process, the harmonized data then goes through the AI Toolbox (WP5, which is the actual user of the data) and is stored or displayed to the user (Task 3.2). All of these steps have happened in a secure way (Task 3.3). Storing data before or after harmonization can optionally be done depending on the use case.

In the following Figure 2 there is a schematic of all the components of BIGG and the external sources, divided by the WP responsible of developing each part. The communication layer has developed the necessary components to **ingest** and **expose** all types of building data. Regarding the state-of-the-art Reference Architecture Framework (RAF) which has been designed in WP2 (see D2.3), the communication layer components are laying in the northbound and in a southbound of the architecture as presented in the following simplified schema:

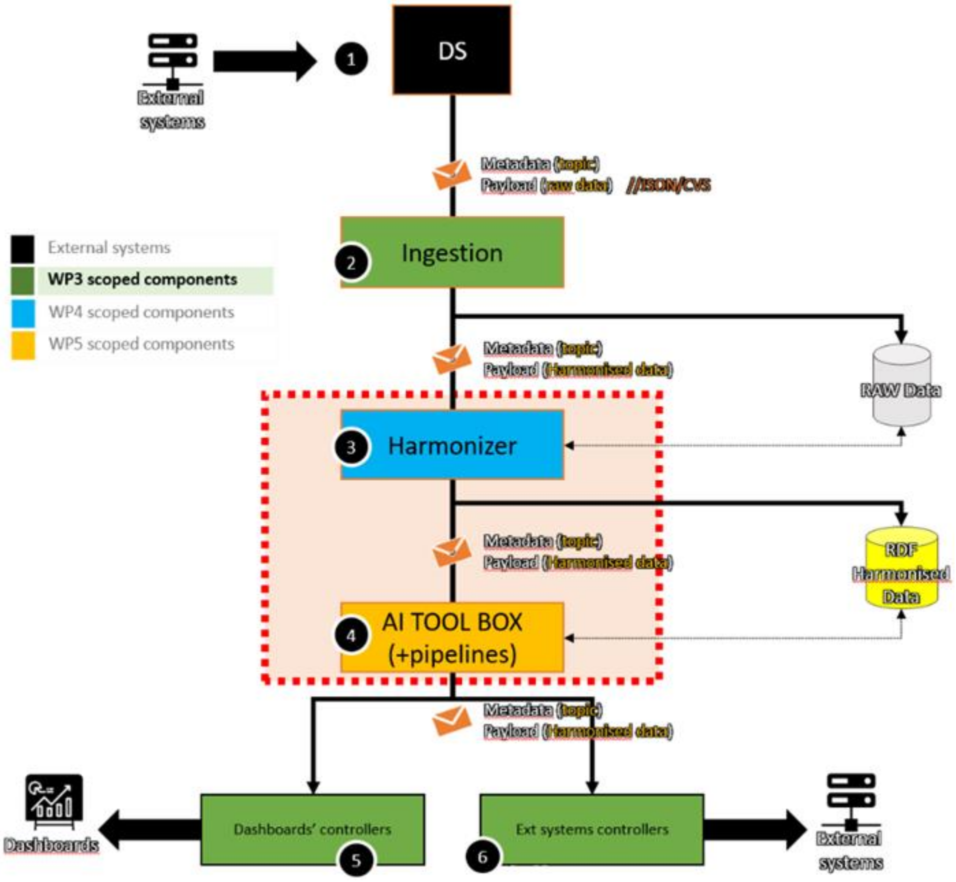


Figure 2: Simplified communication layer architecture. Source: D3.2 "Description of the end-user communication and security layers"

The work of WP4 has focused on the development of the BIGG Standard Data Model 4 Buildings in the core of the harmonisation process that provides the **semantics** and **structure** of the data and enables their adequate allocation in databases and use in analytics services. The work started with the analysis of the data requirements over the BIGG Use Cases and the available datasets from the pilots, which lead to the identification of data concepts and relations between them (read D4.2 and D4.3 for further details). In parallel, a preliminary analysis of existing ontologies identified models' correspondences with the BIGG data concepts that could be reused. On the base of these analyses, the initial BIGG data model was created in iterative steps of revisions, addition, and reorganisation of the data. The BIGG Standard Data Model 4 Buildings is comprised by detailed definition of classes, attributes, data types, relations, and a UML class diagram. The data model was used as a common reference for mapping of the available data sources in order to enable the elaboration and testing of the first and second version (V1 and V2) of the pilot solutions and the AI Analytics Toolbox.

The **AI toolbox** developed in work package 5 can be found in the GitHub of the BIGG project[3] where all the tools are explained and defined. The AI toolbox has focused its developments on solving the specific requirements of the BIGG business cases. Therefore, the development followed a bottom-up approach where the needs were defined based on each of the BC with a special focus on providing answers to the challenges presented by the BC. Each Function Block identified during the BC needs problem definition phase was then described with three main parameters: the inputs, the function and the outputs. The preliminary toolbox is composed of this list of Function Blocks. Although the preliminary toolbox development was

[3] https://github.com/biggproject

based on addressing specifically the challenges of BIGG, the final product allows the use of the Function Blocks for different use cases beyond the test pilot beds. Some examples of the AI toolbox tools used by the pilots are explained in section II.

The results of the technical work packages of the BIGG project combined are then displayed through each of the business cases defined, from large building portfolio management, to ESCO (Energy Service Company) project implementation. In those terms, and with respect to the audience, the results of this deliverable are relevant to all project partners, policy makers working on the field of buildings and energy efficiency, ESCO companies, building owners (small and large) that aim to improve the energy efficiency of their building stock and the public in general that is interested in following the latest trends in building, Big Data and energy efficiency.

The WP8 Communication and Dissemination has thoroughly exposed the work of WP6 as part of the outreach actions of the BIGG project. The main pilots and their outcomes are explained in the project newsletters[4], the first white paper[5] covers the general aims of each pilot and their technical solutions proposed; and in the video series of the whole project covering each of the business cases (youtube)[6].

I.3. Methodology for evaluation

The evaluation of the pilot progress has been used to analyse overall progress of the pilots and to monitor evolution of the pilots, which facilitated taking corrective actions with the aim of reaching the set objectives during BIGG. All the pilots of BIGG have three distinct phases, starting with the data acquisition actions, followed by the data processing steps and closed up with the users' interaction with the solutions and its systems. In order to measure the progress of each pilot key performance indicators (KPIs) were defined for each of them. First the data acquisition KPIs that analyse all the actions connected to gathering the data into the platform, which facilitate monitoring the rate of key project information gathering. The actions range from uploading building data, energy consumption data, and the set-up of any links between different data sets of information (associating building and energy consumption data). The second group are the data processing KPIs that measure all aspects of the data transformations, harmonisation and analysis using the developed AI tools. The actions include data quality checks (for example, outlier detection), data upload checks (to detect data losses for new data), analysis such as baseline calculation, savings calculation or benchmarking performed. This group analyse how the BIGG developed solutions perform to tackle the challenges presented and their stability and robustness. The third group are the KPIs that measure user interaction with the platform, some examples such as total number of users registered or share of active users compared to the total users.

The evaluation section ends with a summary of the work carried out in each BC aiming to define 2 key aspects of the project results to be taken into account after BIGG:

[4] BIGG newsletters https://www.bigg-project.eu/bigg-project-pilots-business-cases-and-use-cases/; and https://www.bigg-project.eu/bigg-project-pilots-business-cases-and-use-cases-in-greece/

[5] White Paper I: https://www.bigg-project.eu/validation-of-the-bigg-data-analytics-toolbox-over-the-bigg-data-reference-architecture-in-6-business-cases-in-spain-and-greece/

[6] https://www.youtube.com/@BIGGProject/videos

- The detected limits to each BC
- Reasoning behind the inclusion/exclusion of certain data if there have been changes during the duration of BIGG

II. RESULTS OF THE BIGG PILOTS

This section defines the pilots' results of the BIGG project when it ended (November 2023). The pilot projects were at the same time the drivers of the technical development (WP2-5) and the testers of those developments. Therefore, the technical development was designed to tackle the diversity of pilot cases of BIGG (also known as BC - Business Cases) ensuring a wide applicability of the obtained results.

The technical development of the project has already produced a Reference Architecture Framework (RAF) in WP2, some ingestors for the data and the definition of security to take into account in WP3, a BIGG data model that allows the data harmonisation for all the BCs in WP4, and a wide array of analytical and data processing tools for the AI toolbox in WP5.

The pilots of BIGG had three distinct phases, starting with the data acquisition actions, followed by the data processing steps and closed up with the users' interaction with the platform and its systems. They started one after the other, but some did run in parallel until the end of the project, since the project is based on life data in most cases the pilots have been uploading and analysing data continuously. In order to measure the progress of each BC Key Performance Indicators (KPIs) were defined for each of them.

The summary section analyses for each BC the aspects of the project referring to i) Limits detected to each BC and ii) Reasons for including or excluding data (associated to the progress of each BC). The analysis only covers the aspects that are relevant to each BC, if there are any.

II.1. Business Case 1: Benchmarking and Energy Efficiency tracking in Public Building – ICAEN

The goal of Business Case 1 is to improve and facilitate large building portfolio energy management by offering considerable advances in data gathering, building data's management and analytical services for improving energy efficiency in public buildings. It can be achieved by providing:

- An **open** big **data** infrastructure for storing all building data in one place and monitoring the performance of the whole building stock of the organisation through an easily accessible web application.
- Advanced energy **benchmarking** by using the BIGG data analytics and storage capabilities, and tailored reports for different stakeholders in the organisations (policy decision makers, energy managers, maintenance staff, financial officers).
- **Continuous data gathering** from different sources (energy consumption, investments in energy efficiency measures, user provided information) for evaluation of applied Energy Efficiency Measures (EEM) both in terms of energy and financial performance.

The following two use cases descriptions are focused on the improvement of the energy efficiency on a major part of Catalonia's public buildings, by monitoring their consumptions and energy efficiency actions. Currently the Catalan government and its dependant public entities manage more than 4000 buildings and implement yearly hundreds of energy efficiency measures.

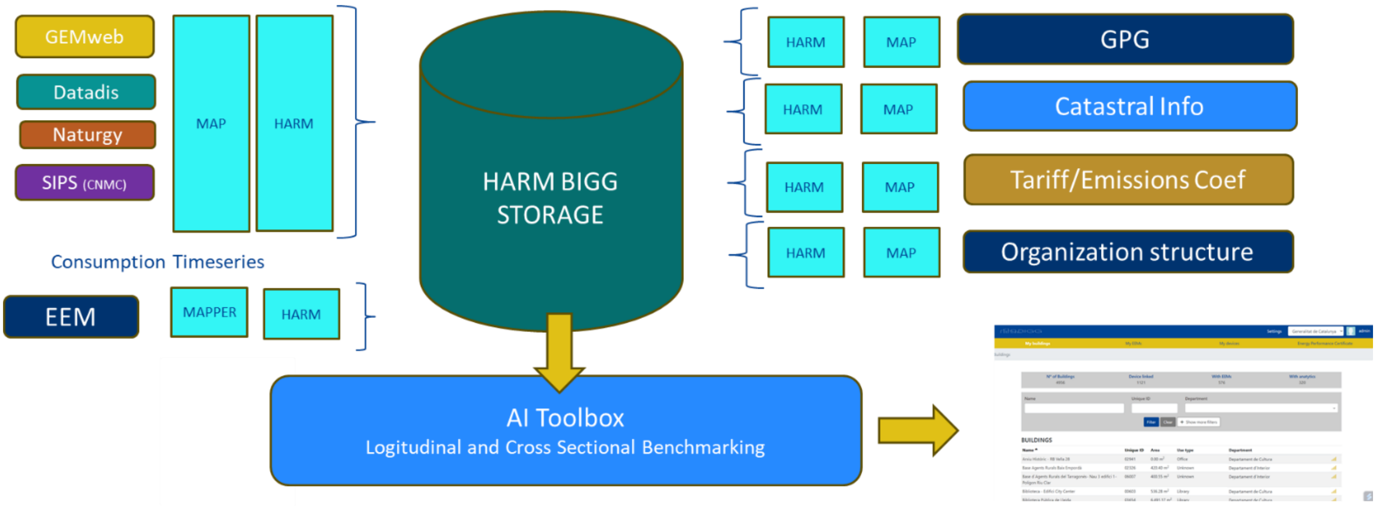


Figure 3: BC1 Input Data processing diagram

The results of BC1 are divided among UC1: "Benchmark and Monitoring of Energy Consumption" and UC2: "Energy Efficiency Measures (EEM): Registration & Evaluation". The purpose of each use case is to develop tools and systems to enable advanced building benchmarking and monitoring both of building's performance and energy efficiency trends, focusing on the same buildings from different perspectives.

II.2. Use Case 1: Benchmark and Monitoring of Energy Consumption

II.2.1.a. Context

Use case 1 focuses on developing tools and systems that enable advanced building benchmarking and monitoring both of building's performance and energy efficiency trends. The main objective of this use case is to give public authorities and energy managers the necessary tools to improve control and manage the energy performance of a large park of buildings with automated methods.

The KPIs defined for UC1 analyse sequentially the data acquisition, data processing and user interaction. The data acquisition KPI analyses the available data sources for the analytical tools. The data processing KPI evaluates both the data quality and the results obtained from the BIGG developed analytical tools. The user interaction KPI measures the scope of the users engaged and their rate of interaction with the solution provided.

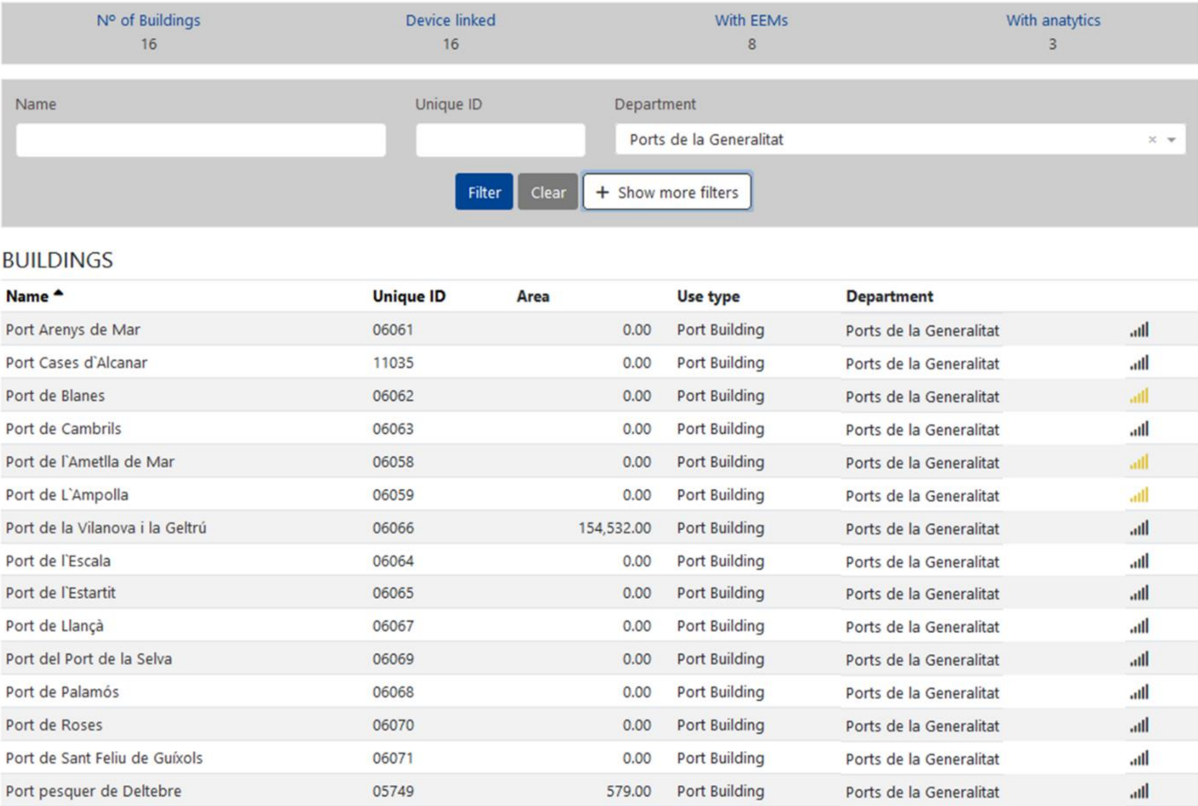
Table 1 – Use Case 1: Data acquisition KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Current Value (M36)	% of achievement M36
Number of Public Buildings (with data)- [UC1-NPB]	Public Buildings with their data associated to Platform: GPG data (building properties), building location (weather data)	3000	4956	165,2%

Number of electricity consumption with a building-[UC1-NEC]	Amount of consumption points linked to the buildings where they are used	6000	2327	38%
Number of gas consumption with a building-[UC1-NGC]	Amount of consumption points linked to the buildings where they are used	500	503	100%
Availability of monthly electricity energy data (electricity)-[UC1-MED]	Public Buildings with their monthly electricity data (recorded) associated to Platform	>80%	85%	100%
Av. of hourly consumption data (electricity)-[UC1-HED]	Public Buildings with their hourly electricity data associated to Platform	>80%	85%	100%
Av. of Monthly gas energy data (GN)-[UC1-MGD]	Public Buildings with their monthly gas data associated to Platform	>80%	83%	100%

II.2.1.b. Solution and Results

The data acquisition of BC1-UC1 (Figure 3) is a constantly ongoing process of sorting out all the available information and ensuring the linking of the different sources and their respective data sets, while keeping up to date a living building portfolio that is in constant change. The advancements on the data acquisition were linked to the associations between datasets, in part due to the work of the technical work packages in which the BIGG data model has been defined and the data sources mapped to the ontology (WP4).



Nº of Buildings	Device linked	With EEMs	With anatytics
16	16	8	3

Name | Unique ID | Department: Ports de la Generalitat

Filter | Clear | + Show more filters

BUILDINGS

Name	Unique ID	Area	Use type	Department
Port Arenys de Mar	06061	0.00	Port Building	Ports de la Generalitat
Port Cases d'Alcanar	11035	0.00	Port Building	Ports de la Generalitat
Port de Blanes	06062	0.00	Port Building	Ports de la Generalitat
Port de Cambrils	06063	0.00	Port Building	Ports de la Generalitat
Port de l'Ametlla de Mar	06058	0.00	Port Building	Ports de la Generalitat
Port de L'Ampolla	06059	0.00	Port Building	Ports de la Generalitat
Port de la Vilanova i la Geltrú	06066	154,532.00	Port Building	Ports de la Generalitat
Port de l'Escala	06064	0.00	Port Building	Ports de la Generalitat
Port de l'Estartit	06065	0.00	Port Building	Ports de la Generalitat
Port de Llançà	06067	0.00	Port Building	Ports de la Generalitat
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Port de Roses	06070	0.00	Port Building	Ports de la Generalitat
Port de Sant Feliu de Guíxols	06071	0.00	Port Building	Ports de la Generalitat
Port pesquer de Deltebre	05749	579.00	Port Building	Ports de la Generalitat

Figure 4: Building data repository

The data required for BC1 is the combination of the main sources of building information using common internal identifiers to feed the analytical tools. The first KPI focuses on the number of public buildings [UC1-NPB] with the building characteristics data usable for the project. It means that from the project target of reaching 3000 buildings of the Generalitat de Catalunya, data is available for more than 4000 of them. The buildings have to fulfil the criteria of having the building information obtained from the internal patrimonial system (GPG database) and the building location (link to weather stations) associated using internal identifiers. Meaning that the information is all available and that it has been possible to link each piece of information to a building.

The energy consumption data of the buildings has been divided among electricity and gas, however, not all buildings do have both of them, some only have electricity or nothing, and some buildings do have multiple connections to electricity and gas. Of the ambitious target of 6000 consumption points of indicator "Number of electricity consumption with a building-[UC1-NEC]" 2327 (the 38%) are associated to buildings. The achieved result proves the challenge of collecting the information and associating the energy consumption to a large building portfolio. Even though the results have not reached the ambitious target for the association to buildings the consumption data for 6016 buildings has been collected from multiple sources, 5656 from Datadis[7] and the rest from our energy accounting system.

The gas consumption indicator (Number of gas consumption with a building-[UC1-NGC]) showed greater advances with 503 consumption points out of the target of 500 (100%) already linked to their respective buildings. These indicators required the association of information sources finding key values that allow to combine different datasets (from different sources) to a building. This line of work rests on the data harmonisation of WP4.

[7] https://datadis.es/home

Indicators UC1-MED and UC1-HED analyse the share of buildings with information (first indicator) that have monthly and hourly electricity energy data available. Currently, both indicators are already performing great having reached the target of having more than 80% of building with data.

The final indicator measuring data acquisition is the Availability of monthly gas data-[UC1-MGD] that measures monthly gas data for the public buildings. It has already reached the target of having more than 80% of the building with the gas data by the end of the project (November 2023).

Table 2 – Use case 1: Data processing KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Current Value (M36)	% of achievem ent M36
Number of Electricity data with enough quality-[UC1-MEQ]	Dataset integrity check for electricity data	>95%	757	50%
Number of hourly Electricity data with enough quality-[UC1-HEQ]	Dataset integrity check for hourly electricity data	>95%	750	50%
Number of Monthly gas data with enough quality-[UC1-MGQ]	Dataset integrity check for monthly gas data	>95%	219	53%
Number of buildings with a baseline-[UC1-NBB]	Public Buildings with their baseline consumption calculated by the platform	>80%	620	82%
Number of Buildings with longitudinal benchmarking-[UC1-NBH]		>80%	620	82%

The data processing of BC1-UC1 includes all the different data transformation and analysis steps that use BIGG related tools, from the harmonisation to the AI toolbox. One example of tools developed to check the data integrity are the ones designed to detect outliers, from impossible values (previously defined, in the case of energy consumption, it should be a positive value and not exceeding the total capacity permitted) to calendar outliers (based on local working days and holidays). Data integrity also analyses the presence of data within the datasets to ensure that the device relaying the information is properly working. The data integrity checks will be carried out for electricity data for both the hourly [UC1-HEQ] and monthly [UC1-MEQ] data, as well as the monthly gas data [UC1-MGQ].

The data upload time for both electricity at hourly [UC1-HEU] and monthly [UC1-MEU] intervals and gas monthly data [UC1-MGU] are key to ensure the timely management of large building portfolios. One of the BC1 objectives is to provide energy managers the necessary tools to improve control and manage the energy performance of a large park of buildings with automated methods, which needs the data readily available to perform analysis and control of the performance. All the data quality steps, integrity (>95%) and upload time (>80%), have set high targets to ensure that all the data that is found within the system is reliable, and that the acquisition step does not add any extra uncertainty to the data, and the following analysis. The results show that the data quality does not reach the set targets for any of the tested values, which forced us to discard both electricity and gas data before the analytical tools were applied. The main reason data does not pass the quality checks is due to a decreasing reliability from our data providers (Datadis and Nedgia).

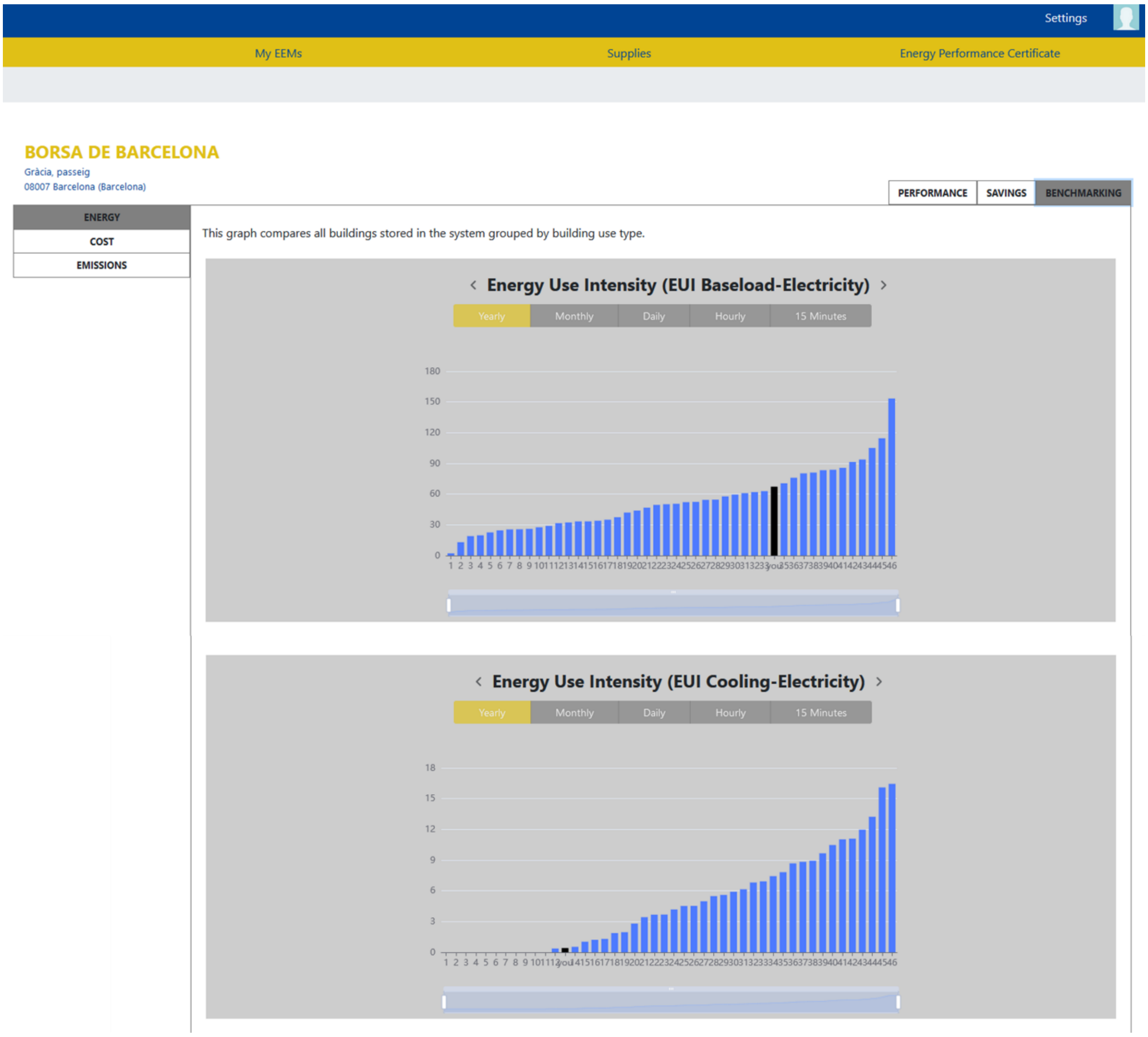


Figure 5: Building benchmarking functionality

The main analysis section focuses on calculating baselines for all the buildings that will later be used to estimate energy savings or building performance (over and under-consumptions). Associated to the baseline calculation, the building can be compared (benchmarking) against its past-self (longitudinal benchmarking) or against peer buildings, as shown in Figure 5 (cross-sectional benchmarking). The two indicators that measure the progress in the analysis section focus on calculating the baseline for all buildings [UC1-NBB] and performing the longitudinal benchmarking of the buildings [UC1-NBH]. Both baseline calculations and building benchmarking were applied to the set of buildings with enough quality data and were obtained by 82% of the total cases analysed, overcoming the set target of 80%. The tools used for performing the analysis and their pipe (Aplication A1) have been developed and are presented in the AI toolbox (WP5).

Table 3 – Use case 1: User interaction KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Current Value (M36)	% of achievement M36
Users registered-[UC1-UR]	Total number of users registered	130	106	82%
Active users-[UC1-AU]	Share of active users (that at least log in once in 6 months)	20%	79	75%

The user interactions have been measured to detect the reach of the users incorporated and the usefulness of the solution for them. The user interaction is measured at BC level since both UC1 and UC2 share a common system. The first indicator measures the total number of users registered [UC1-UR] that have access to the platform and the BIGG tools, the users registered are expected to be mainly energy and building managers with a small share of policy makers. During the project 106 users have registered into BC1 platform, which represent entities and departments responsible for 99.6% of the total energy cost of the Generalitat de Catalunya.

The second indicator measures the share of users that are active of the total users [UC1-AU], which measures the platform interactions as a proxy of the platform usefulness to them. The combined functionalities of BC1 have ensured a constant user engagement since they had a continuous need to register new EEM implemented coupled with the chance to observe their building evolution.

II.3. Use Case 2: Energy Efficiency Measures, EEM: Registration and Evaluation

II.3.1.a. Context

Use case 2 completes the energy performance analysis of UC1 by including the Energy Efficiency Measures (EEM) registration and evaluation with the goal to track the achievement of the EU sustainability targets.

The work of use case 2 focuses on the energy efficiency measures (EEM) registration and evaluation to build a repository of their essential information based on their typology, characteristics, difficulty of implementation, required investment, etc., and evaluation on impact assessment of measures on achieved energy savings. The main objective of this use case is to make a structured data base to store EEM and evaluate their impact on achieved energy savings from energy consumption data. The EEM must be associated to a building (UC1) to be able to associate them to energy savings obtained. The KPIs of UC2 analyse the data acquisition and data processing sides of the UC, the user interactions are presented along with UC1 since they use the same system.

Table 4 - Use case 2: Data acquisition KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Nº of improvement actions collected-[UC2-IAC]	Amount of improvements in general in a given building or facility.	2200	1808	82%
Share of actions without finish date-[UC2-WFD]	When logging data the finish date of the action is missing, or it is not complete	<50%	0%	0%
Share of actions without the value of EEM effect over whole building-[UC2-WSD]	When logging data the affected share over the total building is missing, or it is not complete	<50%	0%	0%
Share of actions without typology of action-[UC2-WTD]	When logging data the typology of the action is missing, or lacking in specific details	<50%	0%	0%
Share of actions without investment cost-[UC2-WID]	When logging data the investment cost is missing	<25%	38	2%

II.3.1.b. Solution and Results

The main project result for UC2 is the launch of the EEM registration functionality of the BIGG platform which improved EEM data collection, minimising data loses, and facilitating the data recording, reducing errors (see Figure 6). The change from an excel based table to the current template has simplified recording the information (reducing errors and data loses), reaching the energy managers and extracting the information (avoiding the need of data cleaning).

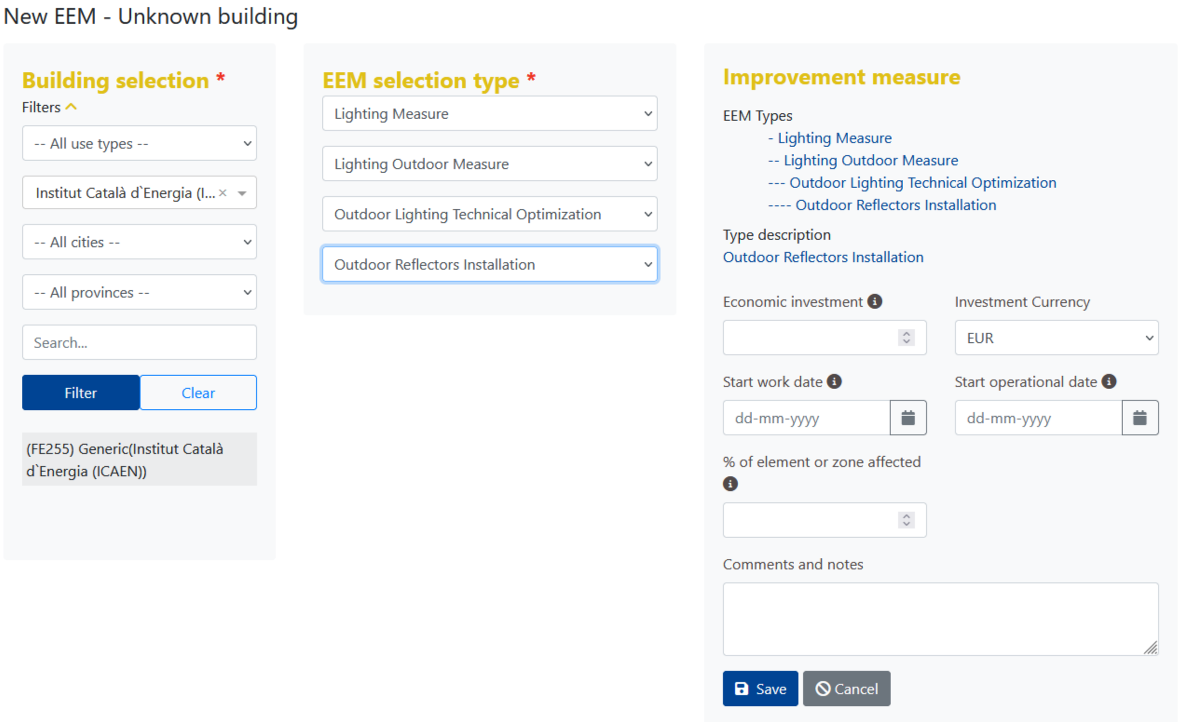


Figure 6: EEM registration form. Source: BC1 BIGG platform.

As explained in UC1, the data acquisition for BC1 is a continuously ongoing process of both sorting the information and linking the different sources as new ones appear. The first KPI focuses on the number of improvement actions collected [UC2-IAC] which are recorded for a building or facility. Currently, there are 1808 EEM registered for the years 2021-2022 (82% to the target) compared to the 471 (data of year 2020) that were recorded with the Excel based system (doubling the amount of data collected per year). Another improvement of the platform is that each EEM implemented can be associated directly with the building in which it is implemented unlike the Excel based template that required an extra step to associate actions with savings.

The use of the platform has ensured that all the essential information got recorded, from finish date to categories and cost for all the EEM registered. The finish date [UC2-WFD] provides an indication of when to start measuring the expected “savings” associated to the EEM implemented due to it being completed, assuming that the impact can be analysed from the same moment. For example, improving heating over summer will not be detected as savings until the next heating season.

The affectation of the EEM over the whole building [UC2-WSD] provides knowledge of the share of the old installation affected by the improvement action, and therefore an idea of the effect it will have regarding savings, as well as a measuring of the savings potential.

The typology of action [UC2-WTD] allows to categorise the EEM based on their typology which is essential to understand the effect each action will have.

The investment cost of an EEM [UC2-WID] is essential information needed to perform any economic calculation in combination with the savings obtained from the EEM and the energy cost at the time. The knowledge of the investment cost and the economic value of the savings can be used to calculate the return of investment (ROI), the net present value (NPV) and a wider array of economic indicators.

Table 5 - Use case 2: Data processing KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Share of savings evaluated-[UC2-NSE]	Share of savings evaluated = Savings evaluated/Savings registered	15%	82	13%
Share of EEM which ROI, Pay-back time and IRR can be calculated based on investment-[UC2-NFC]	Share of financial indicators = Financial indicators can be evaluated/Savings registered	15%	82	13%

The UC2 data processing evaluates the two essential elements for energy efficiency measures, which are the evaluation of savings [UC2-NSE] and the calculations of economic indicators [UC2-NFC]. The main objective of UC2 is to try to evaluate the savings obtained from the registered EEMs, so the KPI evaluated savings quota [UC2-NSE] was established with the aim of reaching the 15% savings estimate. The modelling and analytics for this use case has been developed in WP5 of the project and both the AI tools and the pipeline (A2 Application) are available in the project's Github (https://github.com/biggproject).

The challenge in calculating savings comes not only from the analytics developed in the AI toolbox (WP5), but from the data itself, as BC1 uses a single smart meter per building that includes all energy consumption at the location. The use of a single point of energy data means that any EEM that achieves small savings compared to the whole building consumption will not be statically significant enough to be beyond the error/confidence margins established, and therefore the savings will not be measurable for that particular EEM. The results show that for the buildings with quality, data only for 13% of them the savings can be calculated, mainly due to the minimal effect of the EEM implemented compared to the overall consumption, which did not grant enough confidence to calculate them statistically. The calculation of the financial indicators follows the same logic as the savings evaluation, because the calculation of the economic returns of investment depends on having the savings obtained in financial terms (saved €/m^2 instead of kWh/m^2).

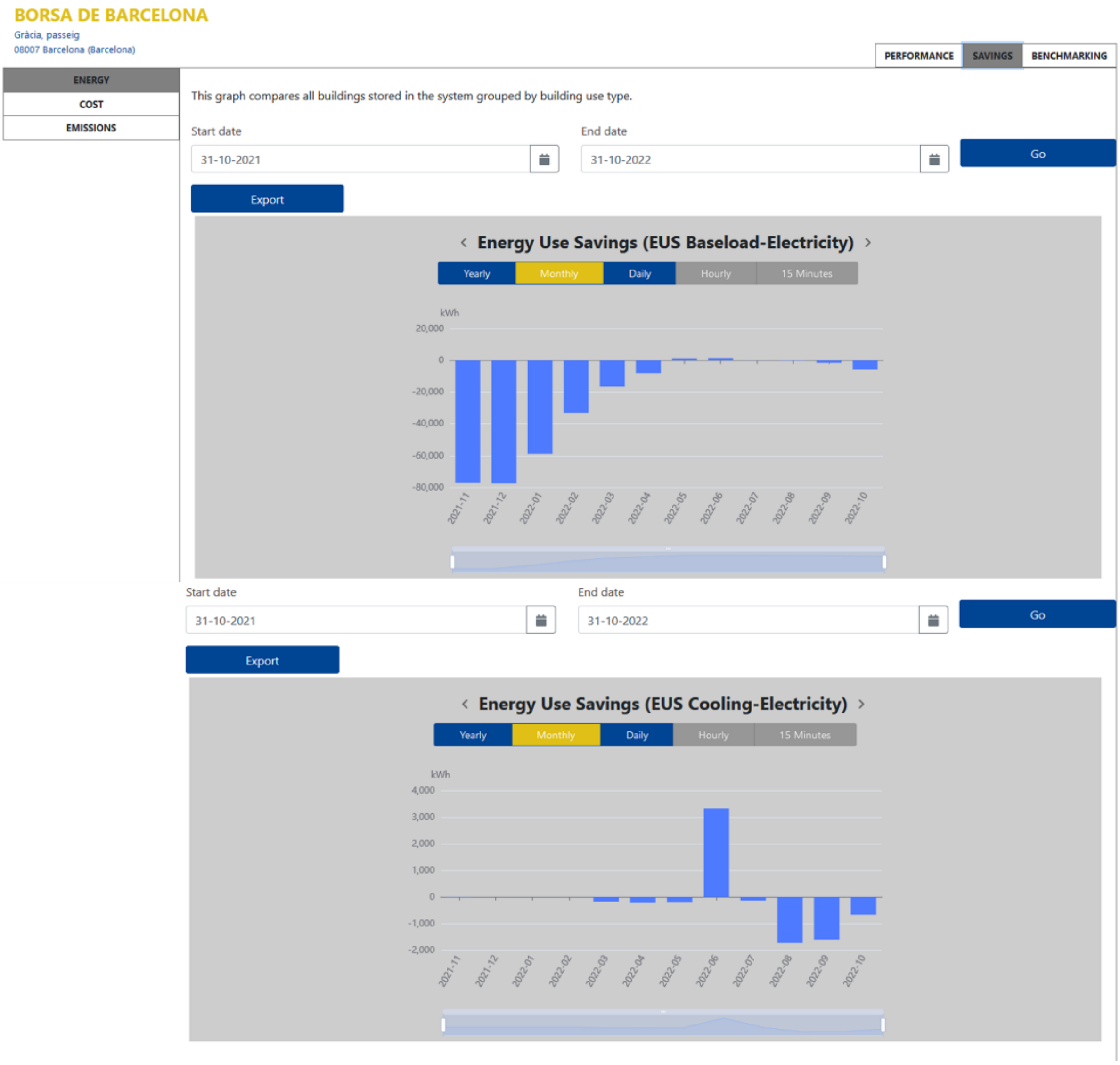


Figure 7: Energy savings calculations

II.3.1.c. Summary of BC1

The goal of BC1 is to provided public authorities and energy managers the necessary tools to improve control and manage the energy performance of a large park of buildings with automated methods. This task required to gather all the relevant building and energy data in a system to perform the BIGG developed advanced analytics [D5.3 for further information], with the aim to establish baselines, detect savings, monitor building performance and ultimately track building degradation. Towards these goals, UC1 has progressed and achieved results as expected in almost all tasks: data acquisition, data processing and user interaction.

The data acquisition task was the hardest in terms of the overall volume of information to obtain, over 4000 buildings managed, spread over 14 government departments and over a 100 different public entities and bodies. The building information was retrieved from several sources such as the internal patrimonial database (GPG), cadastral information, and open data for the organisation structure.

The data gathering has been a success in terms of the overall reach, the information has been obtained, structured and fed to the analytical part with enough data to perform the analysis required. Both building information and energy efficiency actions implemented have been a success in terms of data collection, reaching the set targets and establishing a strong initial database for the Catalan government. At the end of the project over 4000 buildings have their data logged into the system, and 1800 EEM were registered over the 2021-2022 period since the platform became operative, more than doubling the rate of EEM collection before BIGG. Regarding the energy consumption data, it has been retrieved for both for electricity and gas for close to 7000 consumption points, but only 2800 have been associated to their respective buildings, 2300 for the electricity data (below the initial ambitious target) and 500 for gas (reaching the target).The data collection also highlighted the limitations of the current data sources, which in the case of the internal patrimonial system has already led to improvements of the database.

The data acquisition indicators show that the current situation of the UC1 regarding data still has work to do in order to reach all the set targets. Even though some indicators are below 50% the overall progress of the project is not impeded, because there is plenty of data to start the deployment of the analytical tools developed in WP5. It is also worth mentioning that the users are being recruited for each department of the Catalan government and they will be in charge of speeding the association of the different data sources, by providing BIGG with the key elements in common for each database and by using the platform to improve their building energy governance.

The data processing results show that the WP5 developed solutions provide added value to the needs of energy managers. Currently, building performance and building benchmarking can be carried out, displaying the evolution of the building in terms of energy performance and comparing it to its peers, respectively. The building performance functionalities, as well as the savings measurements already provide energy managers with an overview of the evolution of each building and energy efficiency measures implemented. The building benchmarking functionalities facilitate the decision-making process of energy managers by reducing the whole building stock to those few that are in more need of an intervention.

The user engagement of the BC1 solutions has been a success, it has managed to get user's representing over 95% of the Generalitat de Catalunya overall energy cost (based on year 2021), with 106 users registered, and with a highly active user base. The added functionalities developed such as energy efficiency measures registration provided a constant source of interaction with the platform.

II.3.1.c.1. Limits detected to BC1

The pilot buildings data was affected by the COVID-19 pandemic, altering the data values compared to a pre o post covid situation. Baseline calculation have been affected by the working patterns induced by the covid pandemic, the most relevant of them the generalisation of working from home for all the workforce of at least two days a week. This change implies new patterns of building occupation, with more people assigned to a single building but with a concurrent lower occupation than before covid, therefore, there should be a lower need for support systems such as HVAC. The challenge resided in having enough pre-covid data for most of the buildings to understand if the "work from home" schemes do have a statistical impact on the energy consumption of the buildings. Savings estimation/calculation have also been impacted by the "effected" baselines since the reduction in energy consumption could be associated to the EEM implemented or to a reduction in work force within the office.

Another aspect of working from home is the fact that the same space can host more occupants since they are not all there concurrently, meaning that the organisations do require less overall space (meaning less buildings for large organisations), which in turn reduced the overall energy consumption of an organisation. This effect can be englobed within the normal dynamics of any organisation with large building portfolios that change to adapt to needs of space and economic needs overtime. For the Catalan government there has been a trend to move from several small buildings to fewer larger buildings, coupled with the building renovation moving from old to new buildings.

The European Union aims to drastically reduce its $CO_{2eq.}$ emissions by 2030 and achieve climate neutrality by 2050 (European Green Deal) [3,4], in line with these targets all public institutions are bound to reduce their impacts and emissions. To reach these targets the emissions have to be accounted for, which is one of the strengths of BIGG.

II.4. Business Case 2: Energy Certification (EPC) in Residential and Tertiary Buildings – ICAEN

The objective of Business case 2 is to extend the usefulness of Energy Performance Certificates (EPC or BPC). The BIGG project's contribution to advancing the use of Energy Performance Certificate (EPC) information will be a significant improvement over its current state:

- Providing an open big data infrastructure for storing EPC data, while offering a clear mapping of the data, in a harmonized way.
- The simple fact of having the data stored, mapped, harmonized, and verified will favour the possible use of these data, not only a punctual moment in the life of the building as is the current case, but that they can be used and updated throughout the life cycle of the buildings.

The results of BC2 are focused on the use of energy certifications and on laying the foundations for future applications and modifications of the certificates. With these objectives, BC2 aims, firstly (UC3), to integrate the data with the INSPIRE format to standardize it (easier communication with other systems) and, secondly (UC4), to start exploring future avenues for certificates, such as level(s) indicators. Due to the nature of BC2, most of the work done has focused on the data processing steps, including data harmonization and proposed data mapping for Level(s).

The following figure shows schematically the process followed by the data processing for this business case.

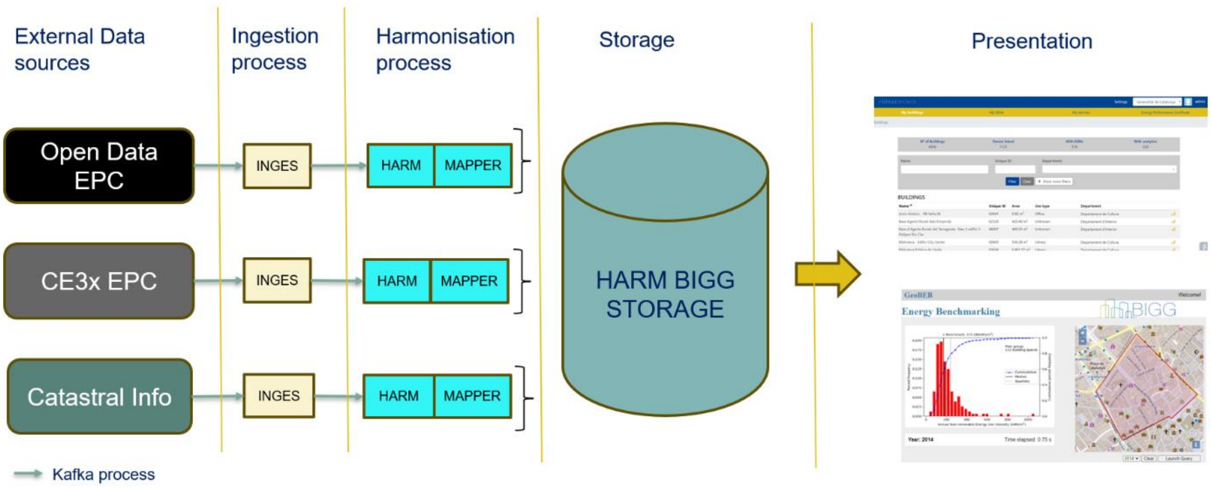


Figure 8. Schematic of the data processing for business case 2

As shown in the figure the certificate data comes mainly from two main sources:

- Opendata portal of the Government of Catalonia. Where there is a summary of the data (70 fields) of all the energy certificates of buildings that have been registered in the territory (~1.4 millions).
- Result of the certification tools themselves (Ce3X). This is a standardized XML with all the data, both inputs and results, of each individual certification.

For both resources, ingestors, mappers, and harmonisers have been created to acquire and process the data. The ingestors, mappers, and harmonisers are published with free access on the project's Github. In the first case, the ingestor is the implementation of an API client, and in the second case a parser of individual XML files. The harmonised data are finally saved in the Bigg Data Model format so that they are available for further use.

Table, 6 - BC2: Data acquisition KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Value (M36)	% of achievement M36
Number of energy performance certificates-[BC2-NC]	Amount of certificates which data has been uploaded	1,000,000	1.397.314	140%

The KPI target number of certificates [BC2-NC] to include 1,000,000 certificates was achieved in M18 with a current total number of certificates of 1,397,314, which represents 140% of the target.1 The data obtained from the building certificates include information related to the key parameters of an energy certification (non-renewable energy consumption, associated CO_2 eq. emissions, etc.), without revealing any personal information. The collection of this data will be a continuous process, as over time new information fields will be released in the certificates, such as information on the construction of the building, materials, etc., which will have to be entered into the system with specific mappings to the new fields of the original resources.

II.5. Use Case 3: Integration of INSPIRE spatial data with Energy Performance Certification

II.5.1.a. Solution and Results

The main target of UC3 is to adapt the current certificates to the INSPIRE standard,[8] adapting all the certificates fields and defining the harmonisation where possible. The main task for UC3 has been defining the harmonisation of the BPC (WP4) and ensuring that the end product complies with the INSPIRE standard.

The BCPs in Spain are already available in INSPIRE format, so all that has had to be done is to import and map the data to the BIGG model. The link between both resources has been made in a simple way as both the BCP and the cadastral data contain the cadastral reference.

[8] https://inspire.ec.europa.eu

The linking of these data has proved to be very useful for the spatial exploration of the BCP data. It solves in an agile and flexible way questions such as those presented in the figure below.

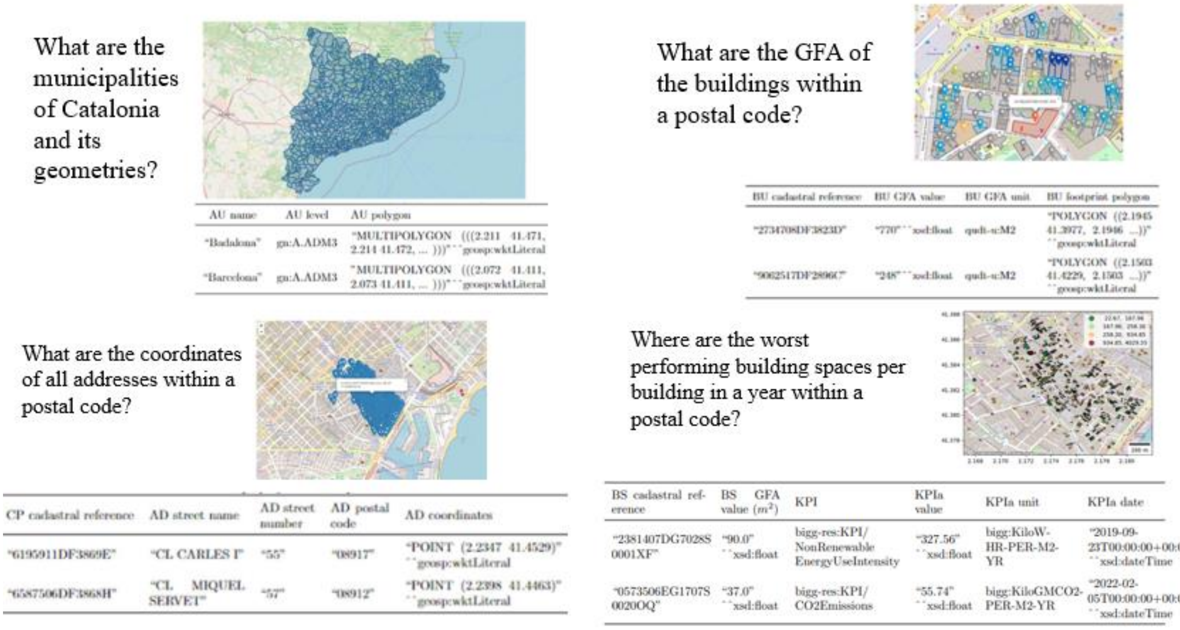


Figure 9. Example of geospatial scanning of building energy certificates.

For the demonstration of the possible real application of this use case, an application has been developed. This application allows the geospatial exploration of energy efficiency certificates in the territory of Catalonia.

The following figure shows how we can select an area in which we want to explore the certificates, selecting a polygon on the map, and the application generates a comparative benchmarking for example of the energy consumed per square meter of the certificates. The application presents the frequency distribution of the selected sample together with the average value of the KPI in the area.

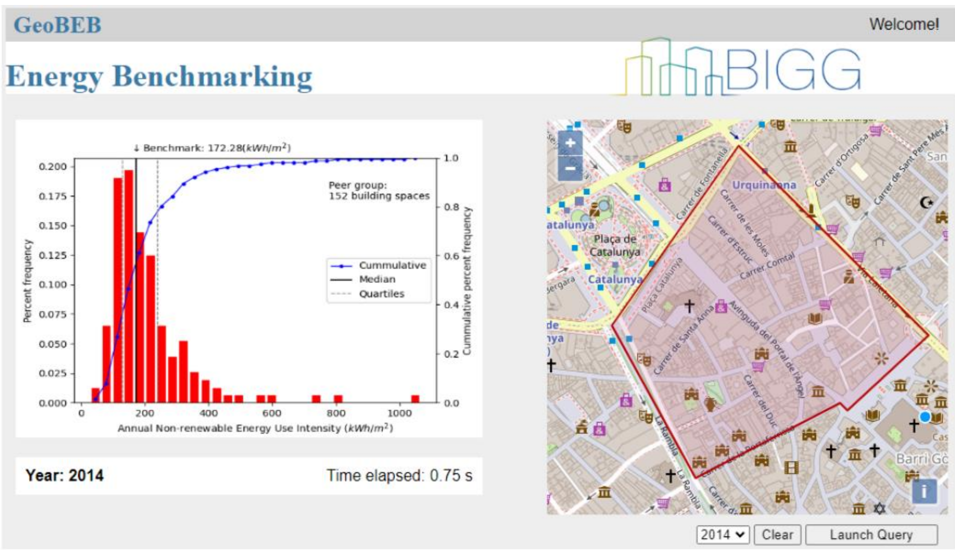


Figure 10. Demonstration example of the real application of the use case developments. Geographical selection of EPCs and benchmarking of KPIs [kWh/m2] of the selected buildings.

The KPI Share of BPC files with cadastral information [UC3-CAD] measures the number of certificates that have the cadastral reference associated to the BPC file.

The cadastral database (already in the INSPIRE standard) provides several pieces of information for each building, such as building coordinates (UTM format), building surfaces and building energy rating. The information provided can be used for cross-checks with other information sources or as a common reference between different databases, as the cadastral reference is widely used as a reference for buildings. Therefore, ensuring that the majority of the ground control points (GCPs) have the cadastral reference [UC3-CAD] will facilitate future applications of the certificates for private citizens, policy makers and the European Commission itself.

Table 7 - Use case 3: Data processing KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Value (M36)	% of achievement M36
Share of BPC files with cadastral information-[UC3-CAD]	Share of BPC = BPC files with cadastral information/All BPC files	>95%	1.397.314	100%
Share of BPC data Standardised in INSPIRE format-[UC3-STD]	Share of BPC in INSPIRE = BPC standardised in INSPIRE/all BPC data	>85%	1.397.314	100%

The progression towards standardisation of BPC towards INSPIRE is measured by the KPI Share of BPC data standardised in INPIRE format [UC3-STD]. The aim is to maximise the use of GCP as a source of information for other projects, therefore they should be aligned with the INSPIRE spatial data standard, and this can be achieved by harmonising the current GCP data in the above-mentioned standard [UC3-STD].

II.6. Use Case 4: Adoption of sustainability indicators of EU framework Level(s) in building Certification

II.6.1.a. Context

The alignment of building certification with Level(s) will link the building use phase of the building certificates with the full lifecycle of Level(s). The work of UC4 aims to define a path towards Level(s) based on the current energy performance certificates information. In order to reach this target, the information within the energy certificates was mapped to the Level(s)'s requirements.[9] The goal of the mapping is to establish the necessary information to breach the gap between EPC and Level(s), therefore, the KPIs aim to understand the 6 different indicators of Level(s) and their requirements. The work for UC4 has been carried out to understand the data requirements to map the above-mentioned indicators with the EPC.

Table 8 - Use case 4: Data processing KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Value (M36)	% of achievement M36
Share of indicators mapped for: Greenhouse gas emissions along a buildings' life cycle-[UC4-EL1]	Greenhouse gas emissions along a buildings' life cycle	50%	50%	100%
Share of indicators mapped for: Resource efficient and circular material life cycles-[UC4-EL2]	Resource efficient and circular material life cycles	25%	25%	100%
Share of indicators mapped for: Efficient use of water resources-[UC4-EL3]	Efficient use of water resources	100%	100%	100%
Share of indicators mapped for: Optimised life cycle cost and value-[UC4-EL6]	Optimised life cycle cost and value	50%	50%	100%
EPCs indicators aligned with European Levels framework - Level(s)-[UC4-ELF]	EPC indicators aligned to Level(s)	1	1	100%

The process of associating the current information within the EPC certificates to the different indicators of Level(s) is the mapping step, which has shown to have varying success rate. The mapping is done based on the BIGG data model and ontology explained in WP4 [WP4 deliverable reference here] The main reason for the variable success rates are limited by the current information within the EPC, which currently focuses on the use phase, including energy, emissions and building properties associated to energy loses and solar gains, but excludes construction phase data, comfortability information of use phase and climate adaptation. The mapping has been divided among the 6 macro-objectives of level(s), even though objectives 4 and 5 are beyond the information available within the EPC.[2]

II.6.1.b. Solution and Results

The first Level(s)' macro-objective (see Table 9), is Greenhouse gas emissions along a building life cycle [UC4-EL1], it is divided among two indicators, one for the use stage energy

[9] https://ec.europa.eu/environment/topics/circular-economy/levels_en

performance (indicator 1.1) during the building occupation (kWh/m2/year) and another analysing the whole life cycle building global warming potential (kg CO2 eq./m2/year) (indicator 1.2). Indicator 1.1 “Use stage energy performance” can be obtained from the simulation results of producing an EPC. The indicator requires information about the use stage energy performance, which is also required to produce the energy performance certificate of a building. The EPC will have the energy consumption of the use stage divided by heating, cooling, illumination and even ventilation (depending on the building typology some may not be required). The EPC also includes the information about renewable energies production which combined provides an estimation of the energy performance of the building. Indicator 1.2 “Life cycle Global Warming Potential” can be partially calculated from the EPC information. The EPC information includes the building materials that encompass it (walls, windows and bridges) and the use stage energy related emissions. It does not include all the emissions associated to the extraction, building and decommissioning phases. For the use phase also includes energy related emissions but it does not cover any other vector or building maintenance requirement. Indicator 1.2 can be partially calculated requiring external LCA (Life Cylce Analysis) software to complete.

The second Level(s)’ macro-objective (see Table 9) is the Resource efficient and circular material life cycle [UC4-EL2] which analyses 4 different indicators, two of them can be partially mapped to the current EPC information. Indicators 2.1 “Bill of quantities, materials and lifespans” and Indicator 2.2 “Construction & demolition waste and materials” can be partially calculated from the EPC information. The EPC information includes the building materials that encompass it (walls, windows and bridges), however, depending on the certification software used the materials information accurateness varies. It does not include lifespans of materials (required by indicator 2.1) nor it does include materials post-processing information (demolition, waste and recycling) (required by indicator 2.2), both of which would require a specialised construction database to provide them. Indicator 2.3 “Design for adaptability and renovation” it is not covered by the EPC data, and Indicator 2.4 “Design for deconstruction, reuse and recycling” depends on the results of indicators 2.1 and 2.2.

Table 9: Level(s)’ macro-objectives 1 and 2, with indicators and capability to be calculated with EPC data.

Macro-objective	Indicator	Can it be calculated from EPC data?
1: Greenhouse gas and air pollutant emissions along a building’s life cycle	1.1 Use stage energy performance	Yes
	1.2 Life cycle Global Warming Potential	Partially, building materials information and energy use data are available. Missing life cycle data
2. Resource efficient and circular material life cycles	2.1 Bill of quantities, materials and lifespans	Partially, building materials information is available, but it does not include lifespans
	2.2 Construction & demolition waste and materials	Partially, building materials information is available, but requires post-processing

	2.3 Design for adaptability and renovation	No
	2.4 Design for deconstruction, reuse and recycling	If 2.1 and 2.2 have been calculated

The third Level(s)' macro-objective (see Table 10) is the Efficient use of water resources [UC4-EL3] which analyses the use stage water consumption, information that the EPC just holds in the form of the daily hot water consumption. Indicator 3.1 "Use stage water consumption" requires three sources of information to be calculated. The first one is building occupation to calculate overall consumption values, second is the water uses by typology (such as cooking, hot water, cleaning, gardening, etc) that each building has. The last source is the river basin to allocate the building and correct the water availability and demand based on the climatic conditions. The combined information provides the overall water needs of the building per occupant per year. This indicator cannot be calculated with the information of the building certificate since it does not include overall occupation and main water uses beyond hot water usage, both of which currently can only be manually collected for most of the buildings. Overall water consumption could be "easily" digitalised (as an external source of information) however, that is not what the indicator uses as a reference for the water consumption.

The sixth Level(s)' macro-objective (see Table 10) is the Optimised life cycle cost and value [UC4-EL6] which analyses 2 different indicators "Life cycle costs" and "Value creation and risk exposure". Indicator 6.1 "Life cycle costs" has partial information referring to the cost of the use phase only. EPCs include energy cost and energy efficiency improvements proposed budget, but do not include any cost associated with the construction and disposal of the building. The rest of the information would require external sources to be completed such as specialised construction database for the construction and demolition costs. Indicator 6.2 "Value creation and risk exposure" does not have any information.

Table 10: Level(s)' macro-objectives 3 and 4, with indicators and capability to be calculated with EPC data.

Macro-objective	Indicator	Can it be calculated from EPC data?
3. Efficient use of water resources	3.1 Use stage water consumption	No, Missing total water use and occupation
6. Optimised life cycle cost and value	6.1 Life cycle costs	Partial cost of use phase. It includes energy cost and energy efficiency improvements proposed budget.
	6.2 Value creation and risk exposure	No

There are two macro-objectives of Level(s) that are not currently analysed, which are the fourth and fifth macro-objectives (see Table 11), Healthy and comfortable spaces and Adaptation and resilience to climate change, respectively. They are not covered at the moment due to a lack of development of both indicators by Level(s) and because there have been no matches found among the current EPC towards these indicators, which made them redundant to study at the moment. The only indicator that may be calculable is Indicator 4.2 Time outside of thermal comfort range, using the most detailed certification software and a building thermal model.

Table 11: Level(s)' macro-objectives 4 and 5, with indicators and capability to be calculated with EPC data.

Macro-objective	Indicator	Can it be calculated from EPC data?
4. Healthy and comfortable spaces	4.1 Indoor air quality	No, it requires real sensors data
	4.2 Time outside of thermal comfort range	No, it requires real sensors data or a building model
	4.3 Lighting and visual comfort	No, it requires real sensors data or a building model
	4.4 Acoustics and protection against noise	No, it requires real sensors data or a building model
5. Adaptation and resilience to climate change	5.1 Protection of occupier health and thermal comfort	No
	5.2 Increased risk of extreme weather events	No
	5.3 Increased risk of flood events	No

The overall goal has been to map as many Level(s) indicators as possible to the energy performance certificates (EPC). The alignment to Level(s) has marked which indicators can be calculated, and which ones may be calculated with extra sources of information if desired. The extra sources not present into the EPC, have to be extracted and harmonised following the BIGG model to the point that all calculations required within the Level(s) indicator can be performed. The limited information that can be provided from the EPC, and the extra amount of manual work required for most of the indicators, make Level(s) at the current state not a desirable system to implement, in comparison to the results of BC1 and BC2-UC3.

II.6.1.c. Summary of BC2

The main objective of BC2 is to advance the utilisation of the energy performance certificates information. The BC2 work focused on harmonising the information of the EPC and start exploring new indicators such as Level(s).

The uploading of EPC certificates has already reached the target set for M36, providing large amounts of data for testing the harmonisations tools being developed in WP4. The progress of the work in BC2 is closely linked to the harmonisation tools developed in WP4 for UC3, as well as the work in UC4.

The work done in UC3 has achieved the expected result, linking building energy certificate data with INSPIRE spatial data. This has been possible thanks to the capability of the Bigg building data model to host BPC data and cadastral data of buildings and parcels in INSPIRE harmonized format.

It has been demonstrated that the linking of these data favours and simplifies the spatial exploration of the certificates, being able to establish in an agile and robust way the search of certificates geographically. On one hand, this favours the visual verification of the data of the individual certificates in reference to their location; and on the other hand, it can give valuable information of the registered certificates, being able for example to know what are the energy characteristics of the buildings, how many buildings have registered certificates or where are the buildings better or worse energetically in a particular geometric area.

The work in UC4 has analysed all the indicators of Level(s), to match as many indicators as possible of Level(s) to pieces of information found in the current EPC with the aim to define the missing information for the full calculation of one of the Level(s) indicators. Out of the 16 indicators, 6 have some information to calculate them, at least partially, requiring little extra information from external data sources.

The results show that out of the energy related data (which is the focus of the EPC) most of it is usable to calculate indicators of Level(s) (6 indicators in total). The only indicator related to energy that cannot be calculated is indicator 4.2 “Time outside of thermal comfort range”. It does require modelling or real sensor data to be calculated which goes beyond any certification process. The indicators that lack information also lack an energy related to them. These results show that modifying the EPC legislation to include further information would probably damage its core functionality without approaching any real benefit, keeping in mind other initiatives, such as the building passport, that are more suited to include the extra necessary information since they take a holistic approach to the building compared to the EPC (energy focus).

II.7. Business Case 3: Building Life-Cycle: From Planning to Renovation – ICAT

The main objective of this business case is to facilitate interoperability between the different tools (and their datasets) that can be used throughout the building lifecycle. This interoperability should ensure the exchange of data between systems and applications, facilitating the reuse of data between them, reducing the cost of configuring them and bringing more value and new advanced data processing services for buildings.

Data interoperability in this BC is approached in a broad way. Both different systems can be found within an individual building (UC5) and the interoperability between the BIGG platform and platforms external to the project (UC6 and 7).

The actors involved in the construction phase of the building, on site and in the maintenance phase (during building operation) also develop and use different tools and generate a large amount of data. However, the combination with more dynamic information in the operation phase, such as data from IoT sources, or the exchange of the dynamic data with the building maintenance tools will increase its usefulness throughout the whole building life cycle.

BIGG will advance beyond the state of the art in:

- Combining static and dynamic data from building HVAC systems, comfort and occupancy information, BIM Modelling by harmonising the data through transformations to BIGG's internal Standard 4 Building Data Model.
- Achieving interoperability of different types of data hosted in BIGG format.

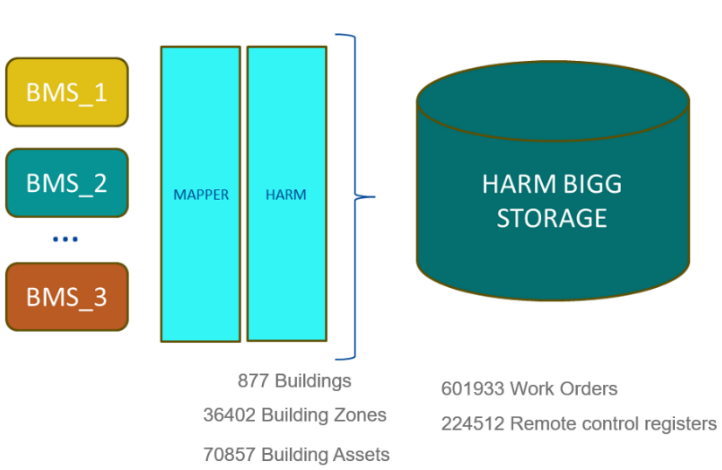


Figure 11. Schematic of the data processing for business case 3

The results of this BC presented in this section allow us to demonstrate in UC5 the data interoperability between systems within the building (BIM, CMMS, BMS, etc..), in UC6 the interoperability of data of Energy Efficiency Measures stored in BIGG format with EFFIG-DEEP platform, and finally in UC7 the interoperability of BPC - with EU BSO (European Building Stock Observatory).

II.8. Use Case 5: Interoperability between BIM, BMS, CMMS and building simulation engines

II.8.1.a. Context and KPIs

Use case 5 focuses on collecting, harmonizing and linking data from different systems that may be found in a commercial or tertiary building. These systems can be Computerized Maintenance Management Systems (CMMS), remote Building Management Systems (BMS) or building modelling systems such as BIM models.

The data used in this use case have been provided by Infraestructuras.cat (ICAT), responsible for the management of more than 800 buildings of the Generalitat de Catalunya.

The linking and possible joint exploitation of the data provided by these systems is a handicap, even more so when managing a large building stock, because it is not only necessary to integrate data from different systems, but also because these systems are not homogeneous across the entire building stock. Finding different BMS vendors with different data structures and different configurations in each building.

The general objective of this use case is the creation of a data repository that allows storing and linking the large amount of data that can be provided by the systems described above. This linkage is achieved thanks to the harmonization of the data in the BIGG Data Model.

In this use case, the necessary ingestors have been developed to be able to collect data from the available sources. In the case of the CMMS, an API client has been developed for the software used by ICAT, in this case Manttest. In the case of remote BMS, we have encountered the handicap of the heterogeneity of the systems installed in the buildings. To solve this problem, a BACnet log output has been enabled in all systems, and a gateway (IXON) has been installed in each building, which ensures connectivity with these outputs through a VPN channel.

The data provided by the maintenance systems are mainly the following:

- Building zones. (in Bigg Data Model as s4bldg: BuildingSpace)
- Registered assets. (in Bigg Data Model as s4bldg: PhysicalObjet)
- Work orders for each zone or asset. (in Bigg Data Model as geosp or gn: Feature)

These data have been harmonised in the BIGG model and related to the building entity thanks to the following main classes (marked in red in the following figure).

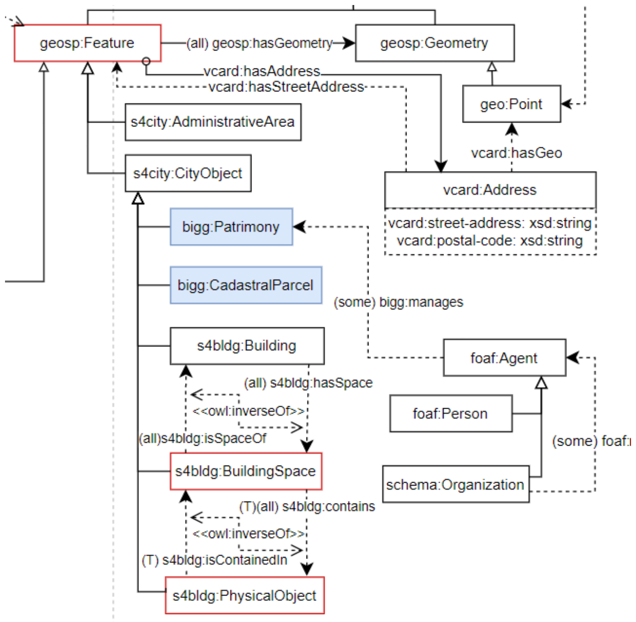


Figure 12. Examples of BIGG ontology fields related to building elements, assets and areas (in red)

The data provided by remote building management systems are mainly time series of systems linked to areas or assets of the building.

- Descriptive of systems (ssn or s4agri:Deployment and snn or s4syst:System, bigg:EnergyMeter, etc.).
- Time series of the different records (Saref:Property, saref:FeaturesIdInterest, saref:Measurements)
    - Energy consumption
    - Temperatures and humidity
    - Equipment status
    - Etc.

These data have been harmonised in the BIGG model and related to the building entity thanks to the following main classes (marked in green in the figure below).

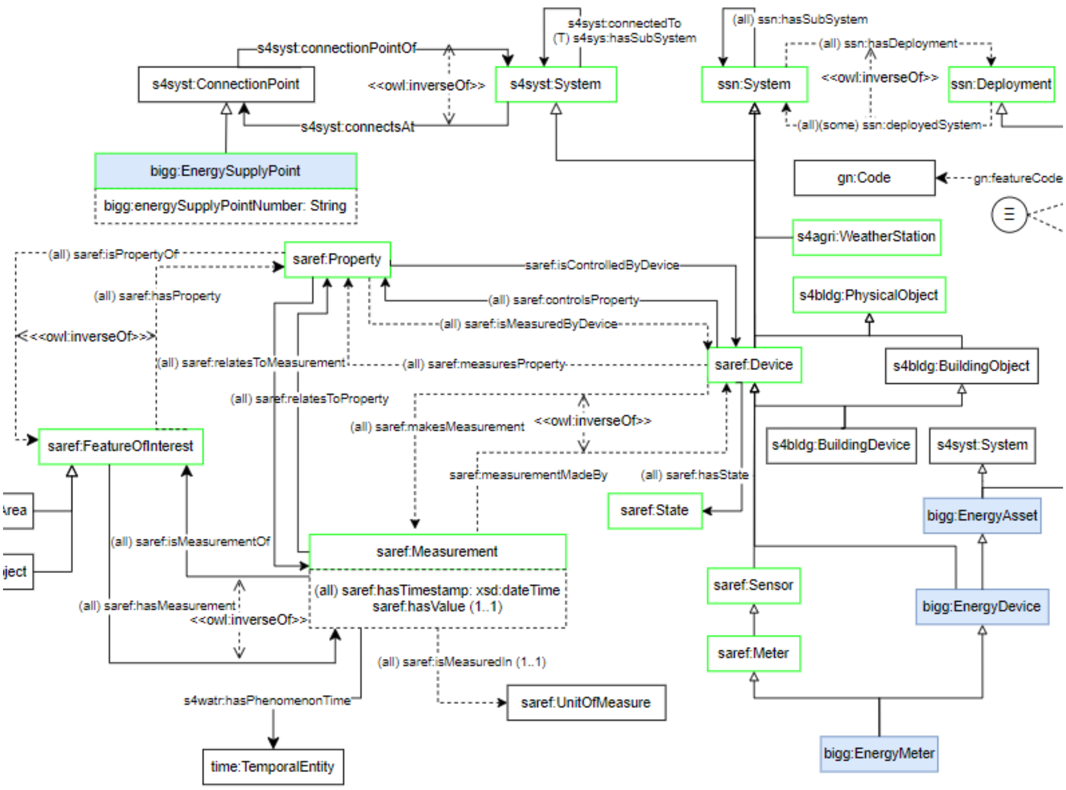


Figure 13. Sample fields from the BIGG ontology related to system fields and system records (in green)

The data provided by the building models are similar to the data provided by CMMS and BMS. These data have been harmonised in the BIGG model and related to the building entity thanks to the same classes marked in the previous systems.

The UC5 KPIs sequentially analyse data acquisition and results (linked data). The first KPIs analyse the availability of the data committed in the project proposal together with the developments to ensure the data acquisition process (ingestors). The second KPIs analyse the interoperability of data from different sources.

Table 12 - Use case 5: Data acquisition KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Current Value (M36)	% of achievement M36
Basic building data -[UC5-NBD]	Number of buildings with basic data (id, name, area, location) imported into the system (raw data).	272	877	322%
CMMS Building data -[UC5-MM]	Number of CMMS data from different buildings imported into the system (raw data)	272	680	250%

Remote control (BMS) Buildings data -[UC5-BMS]	Number of BMS data from different buildings imported into the system (raw data)	40	36	90%
BIM models data-[UC5-BIM]	Number of BIM models data from different buildings imported into the system (raw data)	25	1	4%

BC3-UC5 data acquisition is an ongoing process of sorting through all available information and linking the different sources and their respective datasets. (Part of the work done in WP4-Harmonization).

The first KPI focuses on the number of public buildings [UC5-NPB] with usable data for the project. It means that out of the 272 that were initially planned to be available in the project, thanks to the work done on data acquisition from Infraestructures.cat, the project has recorded 877 buildings, 322% more than planned.

The second indicator "CMMS Building Data - [UC5-MM]", gives information about the amount of data from CMMS of the different buildings. The target value of this KPI is 272, at this moment the system has recorded CMMS data from 680 buildings. Infraestructuras.cat has been working with CMMS system providers in the development of communication APIs for their systems, which has allowed to exceed the initial target by 250%.

The third KPI "Number of BMS data from different buildings imported into the system (raw data)" provides information on the amount of BMS data from different buildings. Of the 40 buildings targeted by this KPI, data from 36 buildings from BMS systems are currently recorded. Infraestructures.cat and CIMNE have been working on the process of collecting data from different BMS providers. This work has consisted of the physical installation of a communications gateway in each building (IXON) and the adaptation of the output data from the BMS systems to a homogeneous protocol, in this case BACnet. This allows communication with each BMS via a secure VPN channel.

The last acquisition KPI is the "Number of BIM model data of different buildings imported into the system (raw data)", this KPIs gives information of the number of BIM models of different buildings registered in the BIGG system. The project target for this KPI is 25 and the actual value is 1, which is 4% of the expected value. This small value is because the data provider (in this case Infraestructures.cat) does not have more building models. So even if the system is prepared for the uploading of these data, it is not possible to provide the 25 that were put in the project proposal.

Table 13 - Use case 5: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Current value (M36)	% of achievement M36
CMMS data linked to Buildings -[UC5-MML]	Percentage of CMMS data recorded in the system that has been linked to the building entity.	>90%	680	100%

BMS data linked to Buildings-[UC5-MSL]	Percentage of BMS data recorded in the system that has been linked to the building entity.	>90%	36	100%
BIM data linked to Buildings-[UC5-IML]	Percentage of BIM model data recorded in the system that has been linked to the building entity.	>90%	1	100%

As mentioned above, the main objective of this Use Case is to demonstrate the interoperability between the systems of a building, so the KPIs that verify this interoperability will reflect that the data of the different systems have been able to link with the building entity, and thus with each other. So, the KPIs results are percentage of CMMS data linked to building, BMS linked to building and BIM models data linked to building. The expected target for these KPIs is above 90%.

The percentage of achievement of the link between elements is 100%. This means that in cases where we have the building element and this building has a CMMS, BMS or BIM system (if these have records), by harmonising the BIGG project, we manage to link them.

The figure below shows an example of the implementation of the interoperability between building systems. The implementation is done in a NEO4J database of the CIMNE infrastructure. We can see how the different elements are related. Entity building in orange - from the ICAT Buildings resource, its zones o spaces in red - coming from the ICAT CMMS, BMS, and BIM systems, and elements or assets in blue - from the ICAT CMMS, BMS and BIM.

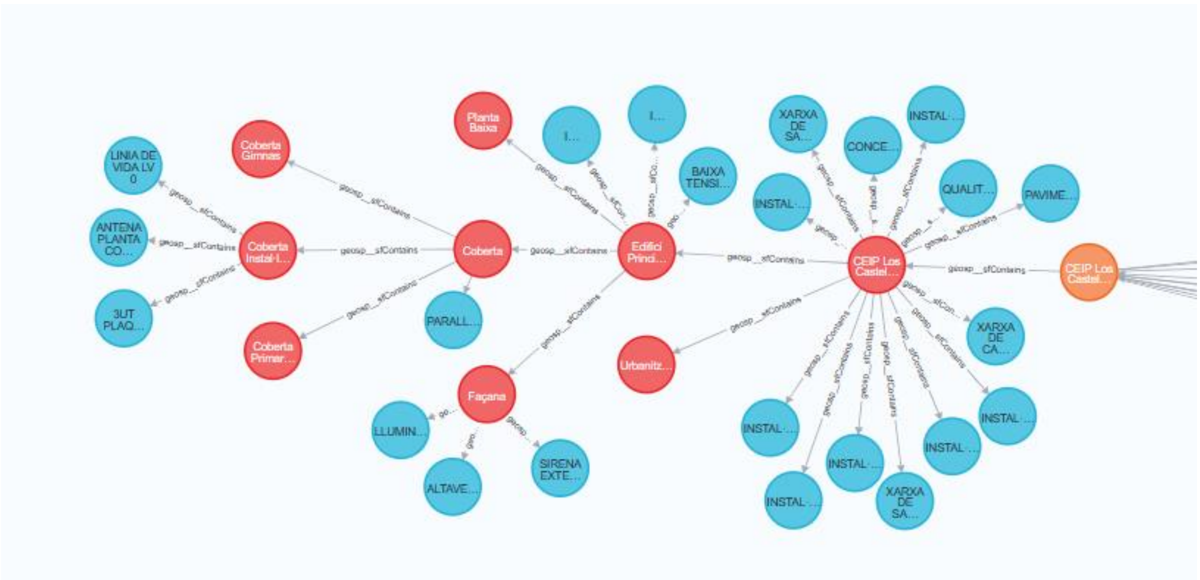


Figure 14. Example of the implementation of the different building subsystem data in the Neo4J database for the fields Building (orange), Building zone (red) and Assets of each zone (blue).

As an example of implementation in a user interface of this interoperability between systems, it is shown in the following figure. It can be seen how the user can explore the zones of the building, the elements within these zones and the ornamental elements.

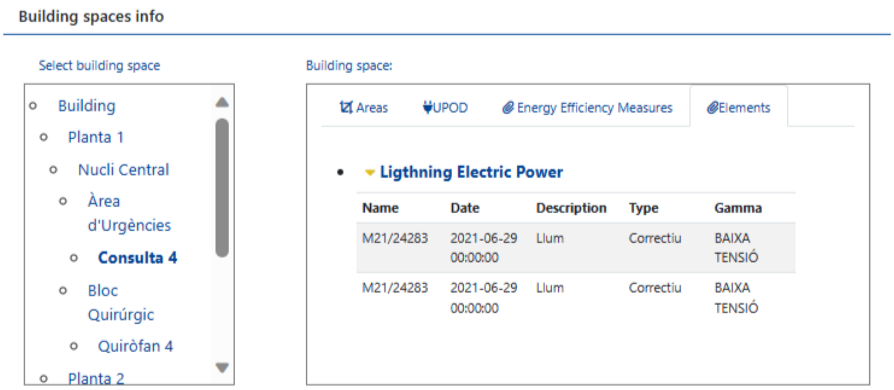


Figure 15: Image of the BIGG application with the location of the DEEP export button in the list of Energy Efficiency Measures.

II.9. Use Case 6: Interoperability of BIGG with EEFIG-DEEP

II.9.1.a. Context

As mentioned above, the main objective of this Use Case is to demonstrate the interoperability of the data related to the Energy Efficiency Measures registered in BIGG and the DEEP platform.

The EEM data used in this Use Case are the same as in Use Case 2, so the KPIs related to data acquisition and processing are the same for both UCs. Thus, these are not going to be repeated in this section.

Only the result KPIs are unique for this use case. Specifically, this Use Case has only 1 result KPIs, [UC6-EXP] which indicates the percentage of the EEMs recorded in the system that are ready, i.e. in the right format, to be exchanged with DEEP.

Table 14 - Use case 6: Results KPI

Name of KPI and acronym [ID]	Description or Formula	Target	Current value (M36)	% of achievement M36
EEM/ projects ready to shear with DEEP - [UC6-EXP]	Percentage of EEMs registered in the BIGG platform ready to be exported to DEEP platform	>50%	1808	100%

As illustrated in the table above, the KPI indicating the interoperability between the BIGG platform and the DEEP platform has reached its target of 100%.

Thus, it is shown how the 1808 energy efficiency measures registered in the BIGG platform have been harmonised and are ready to be exchanged with the DEEP platform, in the Excel format required by the DEEP platform.

The following Figure 16 shows the energy efficiency measures registered in the BIGG platform together with the export button in DEEP format.

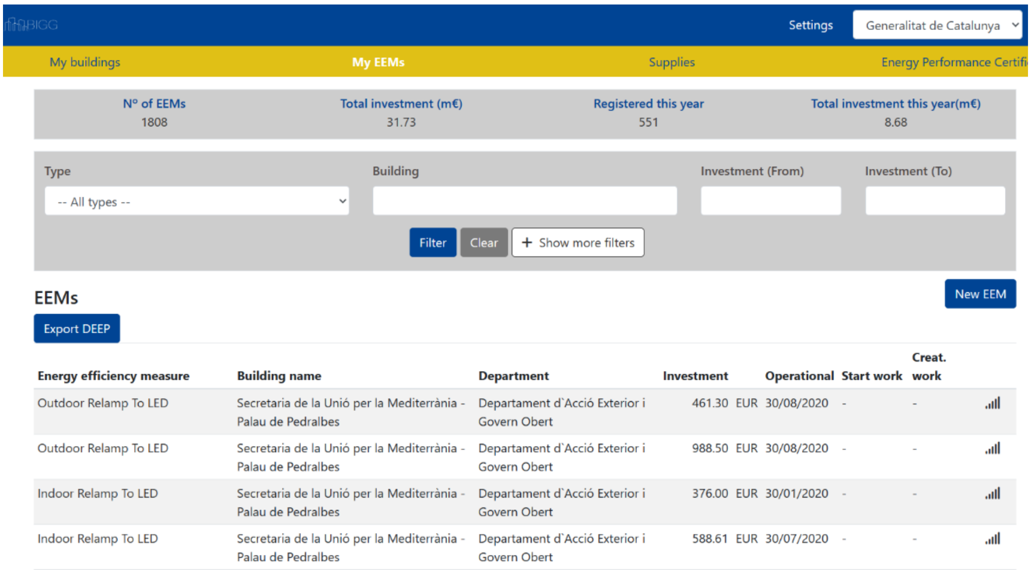
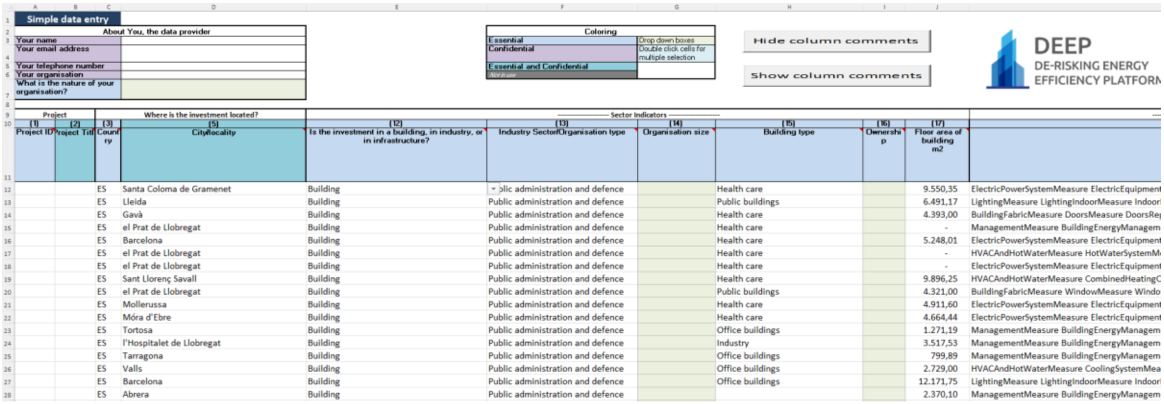


Figure 16. Image of the BIGG application with the location of the DEEP export button in the list of Energy Efficiency Measures.

Figure 17 is an example the Excel that is exported in the format required by the DEEP platform.



Project (1) Project ID	(2) Project Titl	Where is the investment located? (3) Country	(5) City/locality	Sector Indicators (12) Is the investment in a building, in industry, or in infrastructure?	(13) Industry Sector/Organisation type	(14) Organisation size	(15) Building type	(16) Ownership	(17) Floor area of building m2	
		ES	Santa Coloma de Gramenet	Building	blic administration and defence		Health care		9.550,35	ElectricPowerSystemMeasure ElectricEquipment
		ES	Lleida	Building	Public administration and defence		Public buildings		6.491,17	LightingMeasure LightingIndoorMeasure Indoor
		ES	Gavà	Building	Public administration and defence		Health care		4.393,00	BuildingFabricMeasure DoorsMeasure DoorsRe
		ES	el Prat de Llobregat	Building	Public administration and defence		Health care		-	ManagementMeasure BuildingEnergyManagem
		ES	Barcelona	Building	Public administration and defence		Health care		5.248,01	ElectricPowerSystemMeasure ElectricEquipment
		ES	el Prat de Llobregat	Building	Public administration and defence		Health care		-	HVACAndHotWaterMeasure HotWaterSystemM
		ES	el Prat de Llobregat	Building	Public administration and defence		Health care		-	ElectricPowerSystemMeasure ElectricEquipment
		ES	Sant Llorenç Savall	Building	Public administration and defence		Health care		9.896,25	HVACAndHotWaterMeasure CombinedHeatingC
		ES	el Prat de Llobregat	Building	Public administration and defence		Public buildings		4.321,00	BuildingFabricMeasure WindowMeasure Windo
		ES	Mollerussa	Building	Public administration and defence		Health care		4.911,60	ElectricPowerSystemMeasure ElectricEquipment
		ES	Móra d'Ebre	Building	Public administration and defence		Health care		4.664,44	ElectricPowerSystemMeasure ElectricEquipment
		ES	Tortosa	Building	Public administration and defence		Office buildings		1.271,19	ManagementMeasure BuildingEnergyManagem
		ES	l'Hospitalet de Llobregat	Building	Public administration and defence		Industry		3.517,53	ManagementMeasure BuildingEnergyManagem
		ES	Tarragona	Building	Public administration and defence		Office buildings		799,89	ManagementMeasure BuildingEnergyManagem
		ES	Valls	Building	Public administration and defence		Office buildings		2.729,00	HVACAndHotWaterMeasure CoolingSystemMea
		ES	Barcelona	Building	Public administration and defence		Office buildings		12.171,75	LightingMeasure LightingIndoorMeasure Indoor
		ES	Abrera	Building	Public administration and defence				2.370,10	ManagementMeasure BuildingEnergyManagem

Figure 17. Example of a file, in DEEP format, exported from BIGG application

II.10. Use Case 7: Interoperability between EU Building Stock Observatory (EUBSO) and national/regional Energy Performance Certification through BIGG

II.10.1.a. Context

Use case 7 is intended to demonstrate the ease of CPB data exchange with widely deployed external systems, in this case the EUBSO. As in use case 6, this use case uses data acquired and processed by other use cases. Specifically, the building energy certification data used in UC3 and UC4, from business case 2.

In this case, the only outcome KPI available is [UC7-EXP], which expresses the percentage of registered GCPs that are ready to be sent to EUBSO or other national GCP centres. The target for this KPI is more than 80%.

Table 15 - Use case 7: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	Current value (M36)	Current value (M36)
EPC ready to shear with EUBSO - [UC7-EXP]	Data ready to be exchange with EUBSO or National hubs	>80%	1.4M	100%

As can be seen in the table above, the objective of this use case has been 100% achieved. To achieve this objective, an ingestor of the data available in the EPC Hub of Catalonia has been created and a mapper and harmoniser have been prepared to transform the data available in the Hub (1.4 million EPCs) into the format of the BIGG data model.

As an example, Figure 18 illustrates the granular fields required for EUBSO.

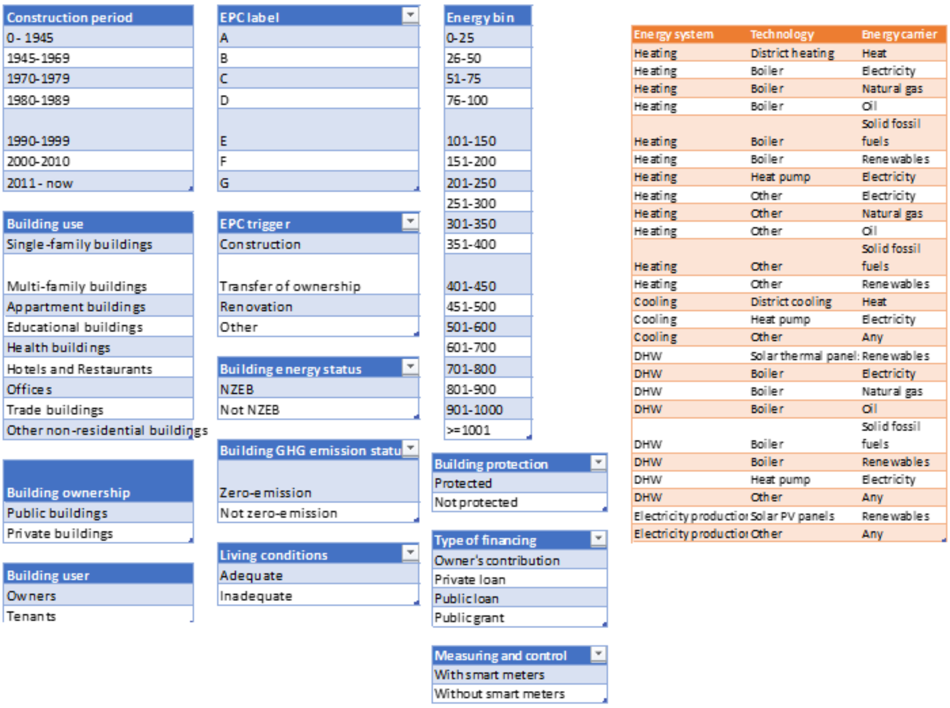


Figure 18. Sample granular fields of interest/required for EUBSO

The Figure 19 shows how these fields have been mapped to the BIGG data model.

LocationInfo

Origin	Harmonization
adre_a	addressStreetName
numero	addressStreetNumber
codi_postal	addressPostalCode
longitud	addressLongitude
latitud	addressLatitude
nom_provincia	hasAddressProvince
poblacio	hasAddressCity

CadastralInfo

Origin	Harmonization
referencia_cadastral	landCadastralReference
metres_cadastre	landArea

Building

Origin	Harmonization
any_construccio	buildingConstructionYear

EnergyPerformanceCertificate

Origin	Harmonization
num_cas	energyPerformanceCertificateReferenceNumber
qualificaci_de_consum_d	energyPerformanceCertificateClass
qualificacio_d_emissions	C02EmissionsClass
emissions_de_co2	annualC02Emissions
cost_anual_aproximat_d_energia	annualEnergyCost
consum_d_energia_final	annualFinalEnergyConsumption
eina_de_certificacio	energyPerformanceCertificateCertificationTool
emissions_refrigeraci	annualCoolingCO2Emissions
qualificaci_emissions_1	coolingCO2EmissionsClass
emissions_calefacci	annualHeatingCO2Emissions
qualificaci_emissions	heatingCO2EmissionsClass
emissions_acs	annualHotWaterCO2Emissions
qualificaci_emissions_acs	hotWaterCO2EmissionsClass
emissions_enllumenament	annualLightingCO2Emissions
qualificaci_emissions_2	lightingCO2EmissionsClass
qualificaci_energia_acs	hotWaterPrimaryEnergyClass
qualificaci_energia_1	lightingPrimaryEnergyClass
qualificaci_energia_calefacci_1	heatingEnergyDemandClass
motiu_de_la_certificacio	energyPerformanceCertificateCertificationMotivation
motiu_de_la_certificacio	energyPerformanceCertificateCertificationMotivation

EnergyPerformanceCertificateAdditionalInfo

Origin	Harmonization
vehicle_electric	electricVehicleChargerPresence
solar_termica	solarThermalSystemPresence
solar_fotovoltaica	solarPVSystemPresence
sistema_biomassa	biomassSystemPresence
xarxa_districte	districtHeatingOrCoolingConnection
energia_geotermica	geothermalSystemPresence
valor_finestres	averageWindowsTransmittance
valor_aillaments	averageFacadeTransmittance

Figure 19. Example of EPC mapping fields with origin and harmonised field to be imported to EUBSO.

II.10.1.b. Summary of BC3

With the results presented above we can conclude that the use of the BIGG project developments generated breakthrough towards interoperability of building data, on the one hand, between systems within a building (UC5) and, on the other hand, between BIGG and external standard repositories (UC6 and UC7).

The work done in BC3 has focused on data acquisition (especially in UC5) and harmonisation, where heterogeneous data have been collected from different systems. The collected data have been harmonised in order to store them in a single system and link them together.

In all cases, data loading and harmonisation have achieved the objectives. The work done in this BC3 has been closely linked to the harmonisation tools developed in WP3 and WP4.

The developed components are available and published in the project's github, so they can be used by the general public. It is expected that they will be of great use in advancing building data interoperability.

II.10.1.b.1. Limits detected in BC3

The main limitation detected in BC3 is the acquisition and communication of data from existing private systems. This usually requires some work, however minimal, on the part of the provider (enabling some API or communication process, changing/adapting communication protocols or modifying the semantics of the variables, etc...).

On the other hand, in the project proposal it was considered that more than 25 BIM models of buildings would be available, but in the end, it was not possible to have so many, as ICAT did not have them for the Catalan government buildings. However, the necessary developments have been made to integrate them into the BIGG data model.

II.11. Business Case 4: Energy Performance Contract based savings in commercial buildings – Cordia

The goal of Business Case 4 (BC4) is to streamline, for all the involved actors, the management of Energy Performance Contracts (EnPCs) once the corresponding Energy Efficiency Measures (EEMs) have been put in place. This includes the collection and follow up of the data from the key building assets, including their energy consumption data, evaluating and following the achieved savings, integrating the contractual data and in particular the cost related data, and finally providing the right tools to enable a proper follow up by all involved actors. These include the Energy Service Company (ESCO) that manages the project and sometimes finances it, the end customer owning the impacted building or renovated entity and any other third-party actors such as auditors or investors.

By streamlining this process, our goal is to enable scaling up the number of EnPC projects that an ESCO can put in place. It assumes facilitating the following tasks:

- The collection of all the contract related data, that is, all the information about the building or other key assets (the perimeter of an EnPC can be restricted to a certain perimeter of a building) including their energy consumption data, both historical and live, the information about the EEMs (nature of the EEM, impacted perimeter, expected savings per energy, etc.) and the contractual information, especially the one that has an impact on the cost calculations of the parties (contract periods, savings targets, savings distribution mechanisms, etc.) Such data can be provided in many different forms and therefore it is key to harmonize it and uniformize its treatment. This is the object of Use Case 8.
- The evaluation of the savings which must be made by comparing the live consumption measured after the project start date (typically when the EEMs are implemented) with a consumption baseline model representing the consumption behaviour of the building prior to the project implementation. Such a baseline model can be either imposed (e.g. because the EnPC contract was already signed with a certain baseline model beforehand) or needs to be discovered based on a representative past period. In the first case, the integration of custom made baseline models must be facilitated. In the latter, a proper machine learning based regression model must be identified following the procedure described by the IPMVP protocol. Managing such baseline models is the object of Use Case 9.
- The regular follow up of the savings, the contractual milestones (such as savings targets) and the financial impacts on the parties. This assumes all parties must be able to access the data and KPIs relevant to their role in the project and receive regular reports about the project achievements which requires the implementation of a solution in an Energy Management Software (EMS). Enabling such a solution, including the proper calculation of the required KPIs, usable at the scale of a possibly large number of EnPC contacts, is the object of Use Case 10.

II.12. Use Case 8: Assets management to store, view, update all relevant assets such as buildings, contracts, invoices, meters, sub-meters, sensors, equipment.

II.12.1.a. Context

Use Case 8 is focused on data collection and digitization. The main goal of the use case is to collect existing information that describes the actors, the assets and the contractual terms and details of an Energy Performance contract. As such the KPIs were defined quantitatively by the information that was gathered, digitized, stored and made accessible for use in the other use cases related to BC4.

The KPIs cover most of the aspects of an Energy Performance Contract to be digitized. It includes the contract details, building details, description of the building assets that are impacted by the EEM project, the nature of the EEM and of the data streams that must be collected.

Note that the KPIs below account mainly for the EnPCs belonging to the portfolio of members of the consortium of the BIGG project (namely CORDIA and HELEXIA) but it has also been deployed beyond that scope in the portfolio of other customers of ENERGIS. These extra EnPCs are taken into account in the total of the following KPIs: [UC8-KPIs006], [UC8-KPIs009], [UC8-KPIs010].

Table 16 - Use case 8: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Portion of EPC contracts related information digitized on BIGG data format-[UC8-KPIs001]	Portion of the information describing an Energy performance contract digitized and harmonized through the BIGG platform	100%	100%	100%
Number of EEM digitized on BIGG data format-[UC8-KPIs002]	Number of EEM for which the critical information has been collected, analysed and digitized	5	5	100%
Number of buildings digitized on BIGG data format-[UC8-KPIs003]	Number of buildings for which the critical information has been collected, analysed and digitized	2	2	100%
Number of buildings entities digitized on BIGG data model-[UC8-KPIs004]	Number of buildings entities for which the critical information has been collected, analysed and digitized	91	85	93%

Number of energy bills digitized-[UC8-KPIs005]	Number of Energy Bills for which the critical information has been collected, analysed and digitized	(not enough data)	(not enough data)	(not enough data)
Number of Time series data collected-[UC8-KPIs006]	Number of time series for which the critical parameters have been collected, analysed and digitized	409	500+	100%
Average Time series Data completeness [UC8-KPIs009]	Measurement of the data completeness (% of data available). Is being measured in % of the last 12 consecutive months	90	95	100%
Data completeness pre-ECM implementation (for at least 12 months) [UC8-KPIs010]	Measurement of the data completeness (% of data available). Is being measured in % of the total baseline period which must be minimum 12 months long	95	98	100%

II.12.1.b. Solution and Results

As mentioned in the introduction, the various information that must be collected about the buildings, their assets and the EnPC contract data may come in various forms and formats which are not always uniform nor using the same vocabulary. This is why the first step that needs to be applied is the harmonization of the data using the BIGG data model (developed in WP4).

In this context, the BIGG data model serves as a canvas describing all the possible objects and their properties that can be encountered when managing buildings in a broad way, and in particular when managing EnPCs[10]. It serves as a common way for any data owner to structure and format their data.

Harmonizing the project related data is achieved by creating a mapping between the data managed by the ESCO (about the buildings, the contracts, etc.) and the BIGG data model. Thanks to this mapping, the data is encoded in a database using the BIGG data model format. From there, it becomes easy for an external system query this database to recover the data in the uniform, predictable format provided by the BIGG data model.

[10] More details about the BIGG data model can be found in the deliverable D4.2.

Concretely, in BC4, the CORDIA Connect platform was hosting the ESCO data and the Energis.Cloud EMS platform was used as the external system[11]. The data was ultimately recovered and organised according to the structure of Energis.Cloud, as illustrated in Figure 20.

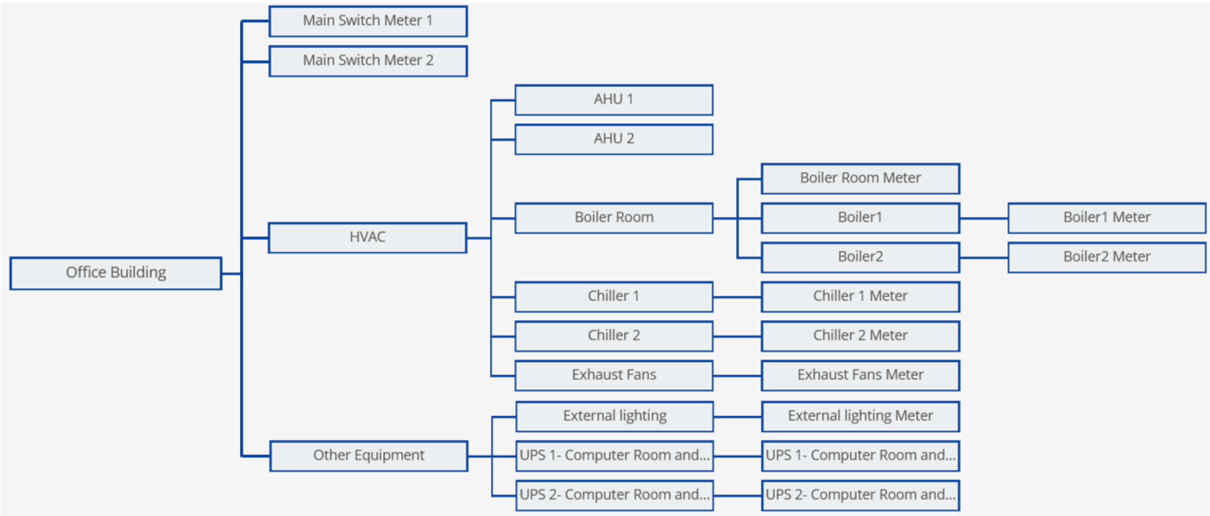


Figure 20. Example of a building and its assets encoded in the Energis.Cloud platform.

In terms of the objectives of Use Case 8, the two energy performance contracts from the partners of the project have been digitized entirely. Information regarding the buildings, the contracts, the equipment impacted, the target savings, the baseline definition are mapped over the BIGG data model.

II.13. Use Case 9: Actual savings tracking realized by the Energy Conservation Measures (ECMs) undertaken by the ESCO and monitors on a daily/weekly/monthly basis

II.13.1.a. Context

Use Case 9 is defined as the logical extension of Use Case 8. While Use Case 8 focuses on collecting and analysing the existing data about EnPC contracts, Use Case 9 is designed around the creation of data models to be used as baseline, that is, as a proxi for the past

[11] In reality, for timing reasons, the ESCO data was first encoded in Energis.Cloud, then from Energis.Cloud to the BIGG data model and then back from the BIGG data model to Energis.Cloud. These last two steps have thus been performed as a proof of concept of the mechanism.

behaviour of the building, in order to be compared with the actual consumption post-retrofit/renovation to evaluate the savings of the project.

As a result, the KPIs created have been identified to measure the pace at which models could be created and monitor the accuracy of the created models. The pace was of central attention to ensure the scalability of the approach to a large number of EnPCs. Indeed, model identification is typically the type of activity that is strongly customized to the individual projects, requiring hours of work to be properly put in place. In this project, the goal was precisely to push the scalability to the next level, preventing individual treatment for each model.

The KPIs are defined in the table below. The objectives were set in terms of the buildings belonging to the portfolio of members of the consortium of the BIGG project (namely CORDIA and HELEXIA) but it has also been deployed beyond that scope in the portfolio of other customers of ENERGIS. The achieved value takes into account these additional buildings.

Table 17 - Use case 9: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Number of building consumption model created-[UC9-KPIs001]	Data streams for which historical data was collected and for which a data model pipeline was created and ran to get a consumption data model. This KPIs will be monitored through the ML Flow platform which is the platform used to monitor the execution of AI pipelines.	1	143	100%
EPC management dashboard created to follow an EPC results-[UC9-KPIs002]	Dashboards created on an existing platform or a BIGG specific User Interface to monitor the progress of the EPC performances	1	18	100%
Average Mean biais error (Normalized) of building consumption model across models-[UC9-KPIs003]	NMBE = 1/AVG(m_i) * SUM(m_i - s_i) / n with m_i and s_i being the model and actual values of timestep i and n being the total number of timesteps on which the SUM and AVG operations are performed[12]	[-5 : 5]	0	100%
Average CVRMSE of building consumption	CVRMSE = 1/AVG(m_i) * sqrt(SUM((m_i - s_i)^2) / n) with m_i and s_i being the model and actual	[0 : 5]	4	100%

[12] Model evaluation criterion described by the IPMVP protocol which specifies the conditions to enable the usage of a model for Measurement & Verification purpose. See [Ruiz, Germán Ramos, and Carlos Fernández Bandera. "Validation of calibrated energy models: Common errors." *Energies* 10.10 (2017): 1587] for a proper definition of these criteria in the context of UC9.

model across models -[UC9-KPIs004]	values of timestep i and n being the total number of timesteps on which the SUM and AVG operations are performed [1]			
Average R^2 of building consumption models across models-[UC9-KPIs005]	R^2 = ((n * SUM(m_i * s_i) - SUM(m_i) * SUM(s_i)) / sqrt((n * SUM(m_i^2) - SUM(m_i)^2) * (n * SUM(s_i^2) - SUM(s_i)^2)))^2 with m_i and s_i being the model and actual values of timestep i and n being the total number of timesteps on which the SUM and AVG operations are performed 1	[0.9 : 1]	0.95	100%
Qty of model under the IPMVP Threshold for Mean bias error (normalized)-[UC9-KPIs006]	NMBE = 1/AVG(m_i) * SUM(m_i - s_i) / n with m_i and s_i being the model and actual values of timestep i and n being the total number of timesteps on which the SUM and AVG operations are performed [1] Percentage of the models which show data quality indicators above the IPMVP threshold, Should be [-5 : 5]	95%	97%	100%
Qty of model under the IPMVP Threshold for Average CVRMSE -[UC9-KPIs007]	CVRMSE = 1/AVG(m_i) * sqrt(SUM((m_i - s_i)^2) / n) with m_i and s_i being the model and actual values of timestep i and n being the total number of timesteps on which the SUM and AVG operations are performed [1] Percentage of the models which show data quality indicators above the IPMVP threshold, Should be <20	95%	94%	99%
Qty of model under the IPMVP Threshold for Average R^2-[UC9-KPIs008]	R^2 = ((n * SUM(m_i * s_i) - SUM(m_i) * SUM(s_i)) / sqrt((n * SUM(m_i^2) - SUM(m_i)^2) * (n * SUM(s_i^2) - SUM(s_i)^2)))^2 with m_i and s_i being the model and actual values of timestep i and n being the total number of timesteps on which the SUM and AVG operations are performed [1] Percentage of the models which show data quality indicators above the IPMVP threshold, Should be >.75	95%	96%	100%
Basic Operations needed on the platform to generate 100 models (measured	Given that there is enough data to generate 100 models. Number of basic operations to identify 100 models.	30	1	100%

in click per 100 model for 100 model)-[UC9-KPIs009]				

Regarding this last KPI [UC9-KPIs009], the current value is omitting an initial setup of the solution which is embedded in the scope of Use Case 8. Once this initial setup is available, a large number of models can be identified using a single python command.

II.13.1.b. Solution and Results

The evaluation of the savings which must be made by comparing the live consumption measured after the project start date (typically when the EEMs are implemented) with a consumption baseline model representing the consumption behaviour of the building prior to the project implementation. Such a baseline model can be either imposed (e.g. because the EnPC contract was already signed with a certain baseline model beforehand) or needs to be discovered based on a representative past period. In the first case, the integration of custom made baseline models must be facilitated. In the latter, a proper machine learning based regression model must be identified following the procedure described by the IPMVP protocol.

With the project, we encountered two distinct situations:

1. The EnPC of the considered building already exists or a specific baseline model was agreed between the parties independently.
2. The EnPC is a new contract that requires the identification of a baseline model.

In the first case, it was critical to flexibly integrate the agreed model into the solution. This was made possible thanks to the Energis.Cloud system which allows to freely define baseline models thanks to a built in formula syntax, illustrated in Figure 21. As long as the said models are picking from the same input variables, standardisation, and thus scalability is possible.

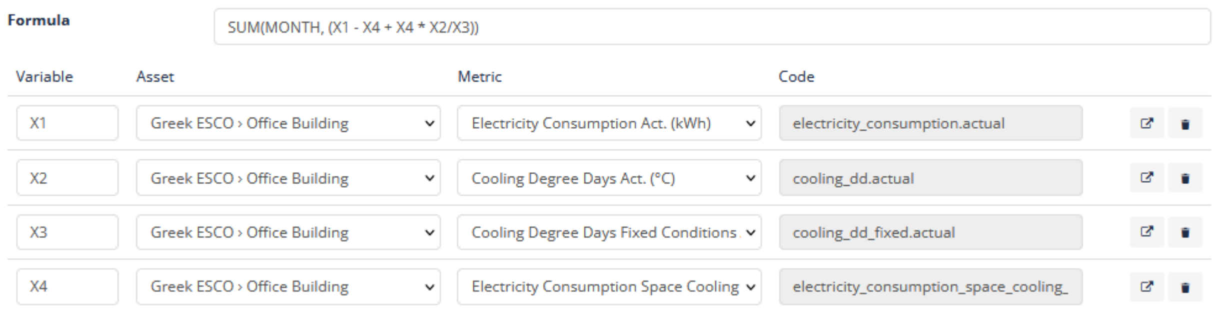


Figure 21. An example model formula for an EnPC contract from the CORDIA portfolio.

In the second case, we are using the AI Toolbox developed in the WP5[13] to identify a baseline model. The toolbox provides ready to use pipelines with all the required layers of data cleaning, data alignment, outlier detection, cross validation mechanisms and IPMVP model evaluation, among others. Moreover, it comes with a tailored set of KPIs suited for the modelling of tertiary buildings consumption such as weekly patterns, weather based KPIs like degree days, occupancy detection, standard holidays, etc. It is particularly well suited for a usage with harmonized data as ensured by the Use Case 8 using the BIGG data model because it can then rely on the presence of standardized input data. This model identification pipeline is

[13] More details about the BIGG AI Toolbox for buildings can be found in the deliverable D5.2.

described with full details in the Deliverable D5.2 (Application A3) as well as on the project's GitHub[14].

The model identification has been applied on a number of different data sets. In particular, it has been applied to an office building from the portfolio of CORDIA in which it is possible to to compare 3 different models:

1. The model that was imported from the pre-existing EnPC contract of the building, generated from a linear regression in Excel;
2. The model that was generated by the previously existing regression modelling tool from Energis.Cloud;
3. And the model generated by the AI toolbox.

The 3 models were evaluated using the IPMVP criteria CVRMSE (the normalised sum of squared errors; the lower the score, the better), NMBE and MBE (normalised and non-normalised bias; the closer to 0, the better) and R^2 (correlation; the closer to 1, the better). On the Figure 22 we show the result of the comparison where we can clearly see the model generated from the BIGG AI Toolbox surpassing the 2 others. This example is not an isolated case and the good performance in the modelling was observed in essentially all the situations where we tested the tool, provided good quality data was available.

[14] https://github.com/biggproject/A3-EPC-baseline-identification

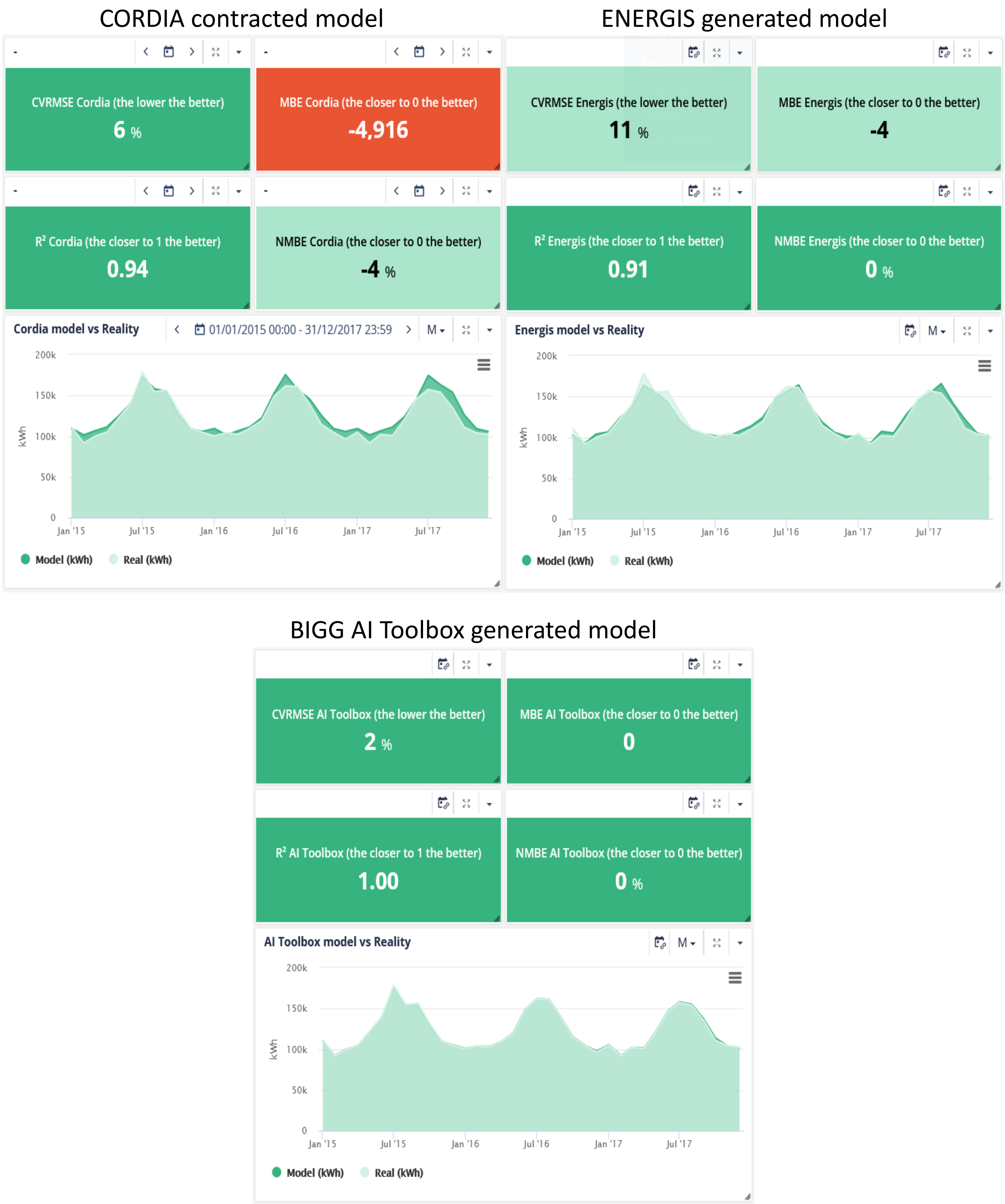


Figure 22. The model generated from the BIGG AI Toolbox provided significantly more accurate results than the 2 other models. Visually, the model curve is practically superposed to the actual data.

Ultimately, the benefits from using the AI toolbox to generate the regression models required as a baseline in EnPC contracts can be summarized as follows:

- High accuracy, guaranteeing trust with between the ESCO and the other parties as well as improving the ability of the ESCO to detect possible irregular usage of the building by its occupants;
- High predictive power, and thus high ability to remain true in time, thanks to the built in Cross-validation mechanism used to build the models and which ensures that the model is evaluated based on data that it has not used to be trained;

- High scalability when used in conjunction of harmonized data such as the one provided from Use Case 8;
- High flexibility as the BIGG AI Toolbox allows to freely select the categories of models that should be used, e.g., avoiding models that are not human interpretable.

II.14. Use Case 10: Energy Performance Contract Management to manage the EPC life-cycle and perform actions (eg. Reporting) according to contractual milestones

II.14.1.a. Context

Use case 10 focuses on the EnPC management itself providing a set of supporting tools to facilitate the management process through automatization of several aspects of EnPCs such as savings calculations, comparison with targets, cost impacts calculation for the different actors, reporting of the results. The use case anchors in the observation that managing an EnPC is generally done in an ad hoc way, redoing the work entirely for every new contract, even though the essence of EnPC management is similar from one contract to the next. The KPIs were chosen to describe how the BIGG platform helped to generate EnPC indicators and periodic reports, and how these indicators were used in the context of existing Energy performance contracts.

Today the time allocated with managing an EnPC comes as a limiting factor. Reporting is still being handled manually or with a strong involvement of the manager where standardization and harmonization could be a real game changer, allowing the EnPC manager to only verify the results of the last reporting period.

The goal of this use case is thus to leverage the two previous use cases and allow Energy Service Companies to optimize the time associated with an EnPC management and increase the profitability of the contract. This would eventually lead to more profits made, an increase of the number of EnPCs being contacted and eventually to a cost of EnPC decreasing allowing more customers to implement them.

As members of the consortium and EnPC managers, both CORDIA and HELEXIA see a strong interest in this use case that could be implemented and generate value very quickly in their own activities.

Table 18 - Use case 10: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36

Ability to recreate results from existing reporting-[UC10-KPIs001]	Ability to create a report through the BIGG platform with the help of an external system that outputs the same indicators than the existing EnPC report. KPIs measured in percentage of similarity compared to the existing report.	100%	100%	100%
EnPC periodic reports created by BIGG Platform with the help of an external system -[UC10-KPIs001]	% of quarterly reports over last 12 months	100%	100%	100%

II.14.1.b. Solution and Results

A complete solution for the management of EnPCs was built using the Energis.Cloud platform. It relies on several components.

First, the structure of an EnPC contract is composed from a global project scope - which is the right level for financial and general contractual data - and below it, multiple sub-scopes – accounting for the different utilities and perimeters on which savings are expected to be made. Thanks to this structure, a specific savings target or baseline model can be set for each sub-scope individually. Then, using the computation power of the Energis.Cloud platform, the results of the different sub-scopes are automatically aggregated at the level of the main scope.

With the way Energis.Cloud is structured, it is also possible to add an arbitrary number of non-routine adjustments to a sub-scope where each non-routine adjustment will modify the baseline model or the actual consumption according to a custom adjustment rule, valid over a custom specified period. Since multiple non-routine adjustment can be created it is possible to stack the adjustment on top of each other.

This structure is illustrated in Figure 23.

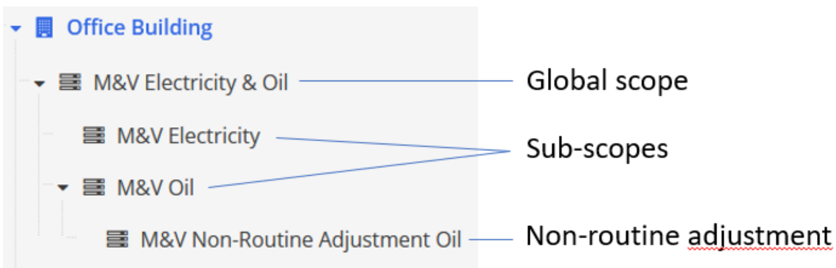


Figure 23. Decomposition of an EnPC contact into its main scope, accounting for the general financial and contract data, and its sub-scopes

This structure is the key to then enable scalable automatic computations of the different required KPIs including savings, deviations from target, monthly subscriptions, bonuses and maluses in case of over- and under-performance, etc., as well as providing dashboards and reports for the follow up of the EnPC. As an illustration, Figure 24 shows how it is possible to track the savings and compare them to the specified targets.

Figure 24. On the top chart, the actual consumption of the site is compared to the baseline (the green line) and to the project target (the red line). The contract's bonus/malus mechanism is highlighted using colours (green, blue, red) based on the achieved performance (bonus, normal, malus).

Thanks to the way Energis.Cloud is configured, it is also possible to analyse a single sub-scope at a time, as illustrated in Figure 25.

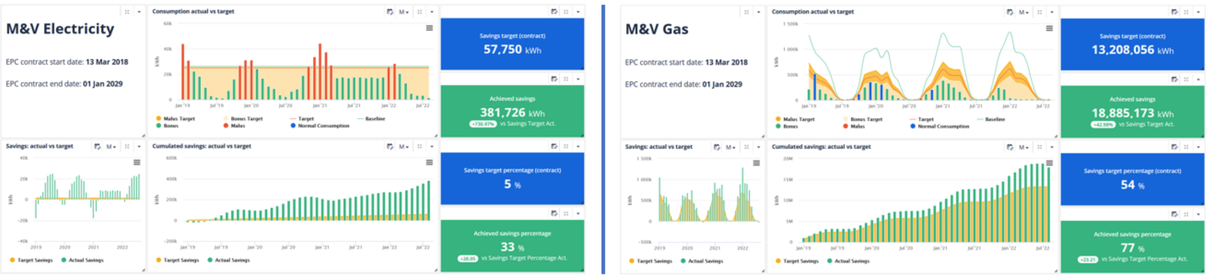


Figure 25. Using the solution, it is also possible to analyse a single sub-scope at a time in a single click.

When it comes to financial analysis, it was analysed through the different EnPC contracts that have been encountered in the project that the following structures can be used:

1. Before the project starts, the ESCO estimates the minimum savings to be expected by the EnPC project and guarantees these savings. Then, the extra savings are redistributed according to a redistribution key (e.g., 50% each for the first years of the contract, decreasing over time in favour of the end customer).
2. Before the project starts, the ESCO makes the most accurate savings estimation possible which determines a target. A bonus/malus mechanism is then agreed upon based on how far from the target the measured savings reached every year. Within a "normality range", no bonus/malus is owed, while outside this range, a redistribution mechanism of the over- or under-performance is agreed upon.

While this second case is more complex, it is often encountered in practice and requires determining the different parameters (what is the normality range, what is the redistribution key in case of over-consumption and under-consumption, is there a limit to these mechanisms, etc.). In addition, it is required to know the base monthly fee that the customer will pay each month as well as the periodicity of bonus/malus payment. For this purpose, 16 parameters have been identified that all together define the contract structure. Moreover, to facilitate the collection of the values for these parameters, sometimes perceived technical by the project managers, it has been derived a simple questionnaire which determines the key parameters in at most 5 questions.

The two situations are illustrated respectively in Figure 27 and Figure 26.

Perspective of the ESCO Perspective of the end customer

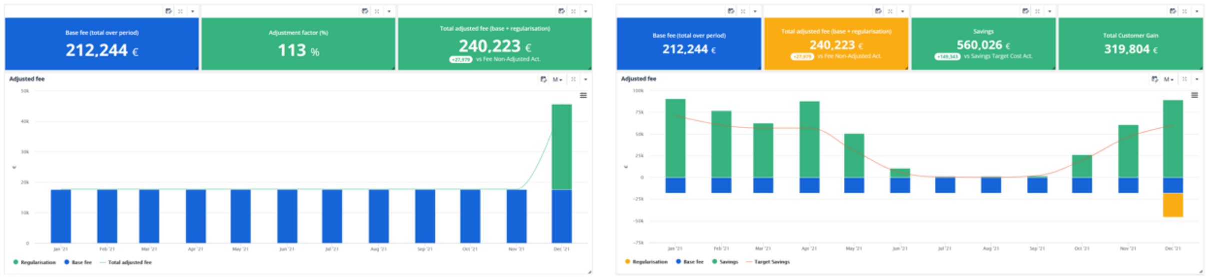


Figure 26. On the left, the view on what the ESCO will perceive as benefits from the project, including a bonus in this case at the end of the 12-month period. On the right, the perspective of the end customer with its costs and its benefits originating from the achieved consumption savings.

Perspective of the ESCO Perspective of the end customer

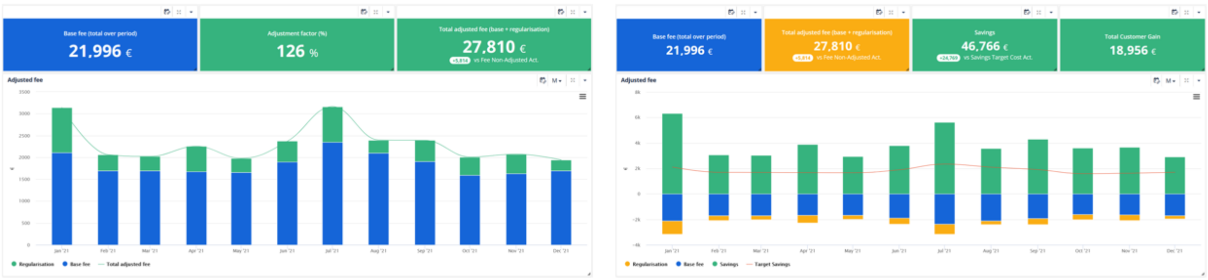


Figure 27. The same view as Figure 26 in the case where the ESCO estimated the target based on the minimum savings to be achieved. In this case, bonuses will generally be owed every month.

Finally, the reporting of the achieved savings is organised on the Energis.Cloud platform and sent on regular base to the relevant actors, as illustrated in Figure 28.

Figure 28. A typical generic report generated by the solution to report the savings of the latest period.

II.15. Summary of BC4

The main objective of BC4 is to provide the ability to easily implement, monitor and control an EnPCs of commercial buildings, to give the necessary feedback for any deviations from the savings goals and lastly to assess and recommend any corrective actions that should be made. In order to do so, all the relevant data (energy, environmental and contractual) is collected, harmonized and encoded into the external system Energis.Cloud with the adequate structure thanks to the work done in Use Case 8 and based on the BIGG data model developed in WP4. The identification and/or incorporation of the required baseline models is ensured thanks to the developments made in Use Case 9, relying upon the BIGG AI Toolbox developed in the context of WP5. Finally, all these elements are packaged in a global solution that includes the calculation of all the required KPIs as well as the needed dashboarding and reporting capabilities.

II.15.1.a. Achievements of BC4 implementation

Overall, BC4 has been a success beyond our expectations.

In the context of Use Case 8, it was possible to integrate all the data from the partners of the project. In a first phase, this data was integrated directly into the Energis.Cloud platform and was successfully harmonized according to the BIGG data model at a later stage.

In Use Case 9, we were able to generate accurate models and to automate the generation of these models to large numbers of buildings, enabling scaling our solutions up.

In the context of Use Case 10, a complete solution was built, achieving all the objectives of the project in a satisfying way.

The solution created is now mature and reached a level allowing for a large scale deployment. And this deployment has already started, in particular for the customer base of ENERGIS.

Moreover, the tools that were developed in the context of BC4 were generic enough to be applied in different contexts, allowing the creation of brand new solutions with a low additional effort.

A first notable example is the application of the same savings logic to the results of BC5 which allowed us to follow and validate the impact of the control solutions put in place, illustrated in Figure 30.

Finally, the pipelines developed in the context of Use Case 9 were adapted to build a smart alerting system with Energis.Cloud. This solution is creating a model similar to the ones created for the baselines, which is then used to be continuously compared against the actual consumption. Whenever a significant deviation is detected (significance being defined by the standard deviation of the deviations), an alert is raised by the Energis.Cloud system and sent directly to the right users. The solution is complemented with adequate dashboards that enable a close follow up. The strength of this solution stands in the accuracy of the generated models which creates a high degree of confidence from the users, but also to its ability to be deployed at a large scale.

II.15.1.b. Limits detected to BC4

The data gathered during the time period since the beginning of BIGG project development, will seem to be altered in comparison to the historical data of the relevant buildings. The reason to that is the COVID19 pandemic, as it caused significant changes to the working environment and hourly profiles, and in turn, important differentiations occurred to the equipment operations, the energy consumption and the indoor environmental conditions of those buildings.

Specifically, in most cases due to pandemic, the facility operators had to mandatorily operate the Air Handling Units (AHU) constantly, in order for the air to always be freshened. This resulted in the creation of new, revised baseline consumptions, both for the total and the HVAC consumption, due to the constant operation of the AHU fans. In addition to that, the “work from home” instructions resulted in a different and more unique profile in the indoor environmental conditions.

All of the above resulted in more difficulties concerning the creation of the models and made it even more challenging.

The progress made on the data modelling aspect raised the question of contractualization of a model. EnPC models used nowadays are usually linear or polynomial and these are not necessarily the models that show the best results in terms of data analysis. But one of the key conclusions of this work was that a data model to be contractualized would need not only to be accurate but also to be understood and computable by the final customer. This point raised the issue of potential disqualification of data models due to their complexity and the impossibility to clearly describe them in a written contract. Alternatively, ad hoc solutions will have to be developed to enable the transparent and trustworthy usage of models, in agreement with the requirements of an EnPC.

II.15.1.c. Reasons for including or excluding data

The conditions due to COVID 19 resulted in revisions of baselines of energy consumption calculations.

As a whole, the BC4 was severely impacted by the covid situation with a building occupancy that was significantly lowered for a long period of time. Not only occupancy was impacted but

HVAC operating conditions were also adapted to reflect the extraordinary air treatment needed to ensure a better air quality.

From a data management perspective, this was a very interesting case to be considered as a non-routine event. Non-routine events are a common theme in the management of EnPCs. Usually, non-routine events are related to extraordinary events that have an impact that to be considered singularly. Obviously covid magnitude was beyond anything that is commonly encountered in an EnPCs but from a data management perspective, it could be considered as a non-routine adjustment and delt with accordingly.

II.15.1.d. Recommendations and requirement for improved tools and analytics

Given the dramatic perspectives that global warming is presenting, it may be surprising to see so few buildings being renovated using the mechanism of an EnPC. According to our experience, the complexity that such contracts present and the high risk of conflict between the different actors that may follow are some of the main breaks dragging its large-scale deployment down. The solution developed in BC4 allowed to make a big jump forward in reducing both burdens. Indeed, thanks to the solution it becomes possible to put in place the follow up of an EnPC in hours, not weeks. Likewise, the follow up itself can be performed in a few minutes per month, not hours. As for the reduction of conflicts, the solution provides high accuracy models integrated to a system that performs all the necessary calculations with a high degree of reliability. This prevents human errors, allows detecting the misuse of a building by its occupants early on and makes the whole follow up process transparent and objective, hence drastically reducing the space for debate between the parties.

Therefore, it is recommended to give a new push to the deployment of EnPCs using modern solutions such as the one developed in BC4.

II.16. Business Case 5: Buildings for occupants: Comfort Case – Cordia

Building Management Systems (hereafter BMS) are optimizing comfort and, to a limited extent, energy consumption based on an internal feedback loop, a programmed occupancy schedule and the expected comfort level in the different building parts. They use a single objective function based only on the comfort conditions of the building; consumption, cost and green energy usage as well as weather conditions are not taken into consideration in this optimization.

In Business Case 5 (BC5), it was designed a control scheme using a multi-objective function in which cost and usage of green energy are optimized upon, in addition to comfort and energy consumption. The optimization does not only use inputs about the current environmental conditions, such as current occupancy, temperature and humidity, but also about the forecasted situation of the building. Therefore, it is able to reach better results than regular BMS controllers, in particular regarding the energy optimisation. In the Use Cases 11, 12 and 13, weather, occupancy and price[15] forecasts were successively added as input to the

[15] Regarding the price data, we ultimately could not experiment with a building featuring variable prices and thus could not exploit this information for the optimisation. See Section II.20.1.b. for more details on the reasons behind this limitation.

controller, aiming to exploit the new information to the maximum extent possible. However, it is important to note that ultimately the 3 use cases have been merged together into a single BC5 solution. In the following sub-sections, the specificities brought by each new forecast input are described. The overall results will be presented in the Section 0about the summary of BC5.

To demonstrate the approach, the output of the control scheme was used to overrule BMS actions and send instructions via IoT actuators in the pilot building, an office building located in Athens within the portfolio of CORDIA. Several trials have been performed to test the controller's performance: 2 in Winter and 1 in Summer. For each trial, the results have been recorded and analysed. However, only the last Winter scenario was actually successful as the 2 others suffered from multiple technical issues and human interference, as described in the Section II.20.1.b. The savings results generated by the controller for this last Winter scenario were evaluated using the solution from Business Case 4, considering it as an Energy Efficiency Measure installed in the building.

II.17. Use Case 11: Optimization using weather forecast

II.17.1.a. Context

Use Case 11 considers weather forecasts like predicted outside temperature, predicted solar irradiation, etc., as input to the optimisation scheme.

The objective of this use case is to design and develop a control algorithm that takes into account variables such as outdoor temperature and solar irradiance, current and forecasted, to optimize energy usage of the site while maintaining the comfort within an acceptable range. For example, the irradiation played a crucial role in the optimization of the comfort conditions of the pilot building. During the winter scenario, the irradiation forecast was used as a decision variable in the ruleset to reduce the pre-heating window needed by the building to keep a good level of comfort.

The process to put in place the BC5 solution can be described as follows: the facility management company performs a survey of the on-site equipment (HVAC, chiller, AHUs, …), provides an inventory list of all the available actuators and sensors and clear instructions to properly interface with them, collects information from occupants to identify comfort issues in the site, building or in zones of the building. When required, extra sensors must be installed on site.

The facility manager then designs and implements a ruleset to optimize comfort and energy usage. Based on this ruleset, the BC5 solution allows to build the controller which is then used to take actions on the controllable devices.

The facility manager ultimately disposes of a dashboard for comfort and energy monitoring of the different buildings and zones. The occupants of the building have a local dashboard to see the decision logic of the optimisation algorithms provided by the BC5 solution and to follow the comfort related KPIs.

The KPIs associated with this use case are evaluating sequentially the collection of weather data forecasts, the actions triggered on the building control system and the results that these actions had on the building performances and the comfort of building occupants.

As mentioned earlier, the performance KPIs [UC11-KPIs003], [UC11-KPIs004], [UC11-KPIs005], [UC11-KPIs006] and [UC11-KPIs007] are here reported based on the global BC5 solution grouping the inputs of the use cases 11, 12 and 13.

Table 19 - Use case 11: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Weather forecasts data time series collected on the BIGG platform-[UC11-KPIs001]	Based on three potential data time series (temperature, RH, Irradiance)	6	3	50%
Number of Actuators enabled in control capabilities-[UC11-KPIs002]	Number of actuators for which control rules are applied	19	5	26%
Average temperature comfort ratio witnessed on the building zones where actions are taken-[UC11-KPIs003]	% of time during which the internal room temperature is within the comfort interval (between minimum and maximum threshold) during occupancy hours, averaged over all controlled areas	90%	96%	100%
Average relative humidity comfort ratio witnessed on the building zones where actions are taken-[UC11-KPIs004]	% of time during which the internal room relative humidity is within the comfort interval (between minimum and maximum threshold) during occupancy hours, averaged over all controlled areas	90%	54%	60%
Average CO2 comfort ratio witnessed on the building zones where actions are taken-[UC11-KPIs005]	% of time during which the internal room CO2 level is within the comfort interval (below maximum threshold) during occupancy hours, averaged over all controlled areas	90%	100%	100%
Average overall comfort ratio witnessed on the building zones where actions are taken-[UC11-KPIs006]	Average of [UC11-KPIs003], [UC11-KPIs004] and [UC11-KPIs005]	90%	83%	92%
Energy efficiency gain (energy consumption reduction during controlled hours) -[UC11-KPIs007]	% difference between the actual consumption during controlled hours and the baseline consumption during the same hours. The baseline is determined as a regression model based on UC9 methodology.	-5%	-15%	100%

II.17.1.b. Solution and Results

Measuring the quantity of data collected is important to understand how available this data actually is and hence how replicable the process is.

The KPI [UC11-KPIs002] describes the capacity to implement a control sequence on the concerned asset. Use cases 11, 12 and 13 rely on the capacity of the designed controller to take action upon the on-site operations.

KPIs [UC11-KPIs003] to [UC11-KPIs006] were defined to follow the trends of comfort during the phases where rules are triggered and make sure that the rules' effect eventually improve comfort or maintain it in an acceptable range. A dedicated dashboard was built to follow up the comfort conditions, as illustrated on Figure 29 for the period of the last, successful Winter Scenario trial.

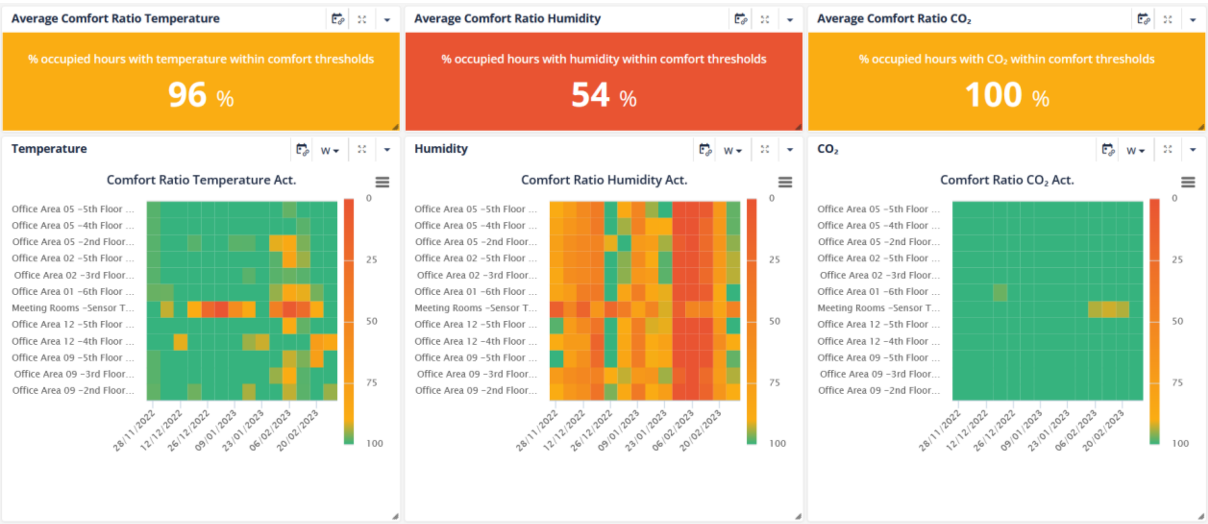


Figure 29. The comfort results during a successful Winter Scenario trial. The poor comfort values for the relative humidity comfort ratio should be regarded in perspective to the same indicator for equivalent periods in which the regular BMS controller was in control of the comfort conditions and in which the values were below 40%.

KPI [UC11-KPIs007] was defined to track the energy impact of the control scheme. It was evaluated on the data from the last Winter Scenario trial using a solution adapted from Business Case 4. In this solution, a regression model was identified based on the past consumption over a period equivalent to the trial period (from December to February, skipping COVID years). This model was then used to evaluate the savings generated from the controller, as illustrated in Figure 30.

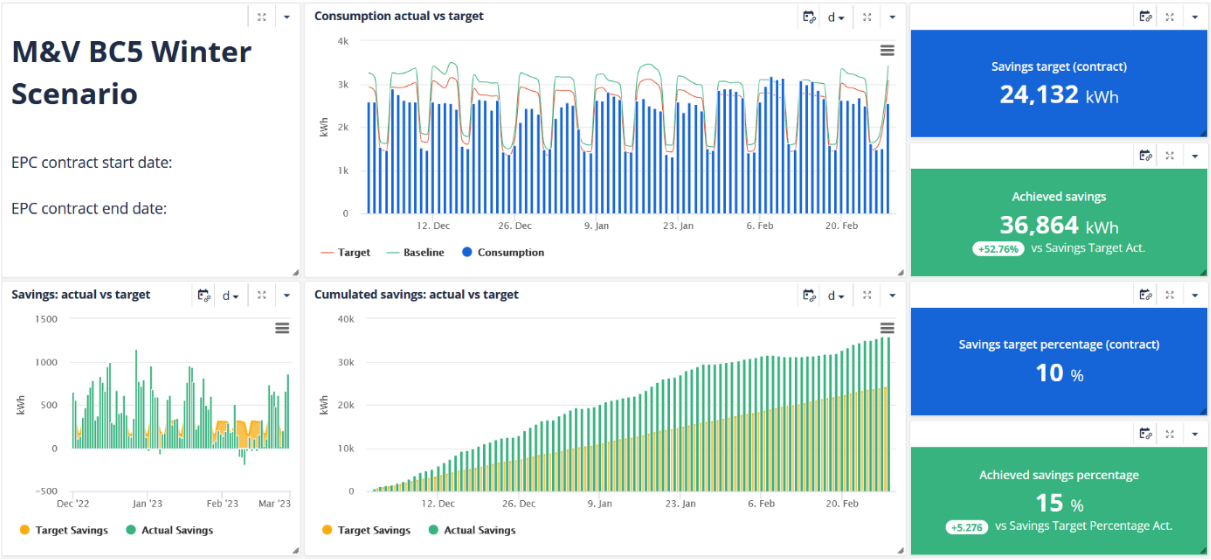


Figure 30. Application of the BC4 savings following approach to the real time control application of BC5.

It is important to note the poor performance reached on some KPIs compared to the initial expectations. This is mainly due to fact that the controller of BC5 could only be installed in a single building instead of the multiple buildings originally planned for. As described in Section II.20.1.b. , it was not an easy task to convince candidate buildings to experiment with their comfort conditions. Regarding the achieved comfort levels, they need to be regarded positively as the comfort levels in the tested building were actually improved with the controller compared to the situation without controller. Finally, the results in terms of achieved savings were beyond our expectations, which is a good sign towards future applications of the solution.

II.18. Use Case 12: Optimization using occupancy forecast

II.18.1.a. Solution and Results

Use case 12 is very similar to use case 11, the most significant difference being that the building occupancy is used in addition to the weather forecasts as a variable of adjustment.

From a workflow perspective, the two use cases are very similar. From a data perspective however, the two use cases are showing a major difference in the sense that weather forecasting service exists as a public service and the associated data is available. Building occupancy on the other hand does not exist and needs to be analysed through sensors data and a building occupancy model needs to be created to make predictions. This was achieved using the BIGG AI Toolbox developed in the context of WP5[16].

The BIGG AI toolbox provides ready to use pipelines with all the required layers of data cleaning, data alignment, outlier detection, cross validation mechanisms and IPMVP model evaluation, among others. Moreover, it comes with a tailored set of KPIs suited for the modelling of buildings occupancy such as weekly consumption patterns, time functions, standard holidays, etc. This model identification pipeline is described with full details in the Deliverable D5.2 (Application A4) as well as on the project's GitHub17.

[16] More details about the BIGG AI Toolbox for buildings can be found in the deliverable D5.2.

[17] https://github.com/biggproject/A4-Occupancy-pattern-detection

The following KPIs evaluate the collection of occupancy data, the identification of occupancy models and the actions triggered on the building control system. Again, see Use Case 11 for results about the performance of the controller.

Table 20 - Use case 12: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achieveme nt M36
Occupancy history data time series collected via the BIGG service-[UC12-KPIs001]	Number of occupancy timeseries data collected	2	14	100%
Occupancy model created based on historical data-[UC12-KPIs002]	Number of occupancy models identified	2	1	50%
Number of Actuators enabled in control capabilities using occupancy-[UC12-KPIs003]	Number of actuators for which control rules are applied using occupancy data and model	19	5	26%

KPI [UC12-KPIs001] is measuring the quantity of data collected and is important for the same reason explained for Use Case 11. Occupancy data streams are usually more difficult to collect because they imply the installation of sensors. BMS only include occupancy sensors in recent installations but are not so common on older systems. KPI [UC12-KPIs002] is important to describe the BIGG capability to use occupancy data streams to generate models. Unlike other data streams, occupancy data is very prone to irregularity and occupancy sensors are often reporting on a non-regular basis but rather on an event-based sequence which presents a specific challenge in terms of data management and data analysis.

The same comment about the importance of being able to take control on the on-site equipment also applies to this use case.

As for Use Case 11, due to the limitations described in Section II.20.1.b. , occupancy data could only be collected for one building. The data collection started early in the project and, as a result, was sufficient to enable the creation of an occupancy model.

Two main rules have been implemented in the context of use case 12:

- Thermal inertia rules

To use thermal inertia of the building, the building occupancy once known is used as an input to know at what exact time the building will turn unoccupied. A control sequence was implemented to command the HVAC system to turn in night mode as soon as possible without affecting the occupant comfort.

- Pre-cooling/Pre-heating rules

Pre-cooling during summer and pre-heating during winter must be taken into consideration in the optimization algorithm to ensure an adequate level of comfort when the occupants arrive at the office in the morning. The heating and cooling loads must indeed be shifted according to the thermal inertia of the building. Knowing the expected occupancy of the building and the future weather conditions of the area allows to shift heating and cooling loads with a higher accuracy and to improve the energy efficiency without reducing the level of comfort.

During the first half of the project, a significant effort was put on setting the control system up on the pilot building. Beside the technical challenge associated with the implementation of the equipment allowing to take control, a significant effort was needed on the communication process between the ESCO and the on-site O&M team. As anticipated, taking control over the HVAC equipment and managing the communication with the O&M team to ensure that remote control would not jeopardize the on-going operation was a major hurdle and turned out to be the major limit to overcome.

II.19. Use Case 13: Optimization using price forecast

II.19.1.a. Context

Use case 13 was designed as a logical continuation of the two previous use cases. Use case 11 to optimize comfort and energy consumption based on outside conditions, use case 12 adding the possibility to account for the unoccupancy of the building. Then use case 13 to add the energy cost as an additional factor of optimization.

The KPIs were defined following the same logic as the use cases 11 and 12. The first two KPIs describe how available the pricing information is and where it impacted the result of the optimisation. The last KPI reflects the success rate of control optimization over the existing control sequences on site in terms of the generated cost savings. Again, see Use Case 11 for results about the performance of the controller.

Table 21 - Use case 13: Results KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Pricing forecasts data time series collected on the BIGG platform-[UC13-KPIs001]	Number of pricing forecast timeseries data collected	1	0	0%
Number of Actuators enabled in control capabilities-[UC13-KPIs002]	Number of actuators for which control rules are applied using pricing data	19	0	0%

As for Use Cases 11 and 12, due to the limitations described in Section II.20.1.b. , data could only be collected for one building which was in addition featuring a constant price model, hence leaving no room for any type of cost optimisation. Due to this reason, it was not possible to integrate the effect of price in the optimisation scheme for the building.

Nevertheless, the control scheme should be regarded at the level of the whole Business Case where the developed mechanisms to define custom rulesets offer a high degree of flexibility and in particular, include the ability to integrate cost related criteria for the optimisation.

II.20. Summary of BC5

Business Case 5 goal is to optimize the occupant comfort and the energy efficiency of a building. To achieve this, a multi-objective function that takes into consideration the consumption, costs, occupancy and weather data, was applied. Weather and occupancy forecasts were also considered for a more dynamic and efficient operation of the equipment. This was achieved in some cases, by providing relevant recommendations for the optimum equipment operation and in some case by overruling the current control system.

II.20.1.a. Achievements of BC5

For the implementation of BC5, none of the two existing platforms used in BC4 could be leveraged for control sequence implementation. The Energis.Cloud platform presents strong capabilities in terms of data management and data analysis but were not designed to take actions directly on the HVAC equipment.

As a result, a dedicated framework was used leveraging the platform for data collection, data aggregation and data transfer but a separate dashboard was created on the open-source tool Grafana to manage the display of actuators and rule implementations. This dashboard is illustrated in Figure 31.

Figure 31. The controller cockpit used to track the applied ruleset at any given time and to track the effect of the control actions in real time.

The control aspect being one of the most challenging points of this business case, it was chosen to use a versatile edge device provided by ENERGIS: the Raspicy. This data logging device is used by ENERGIS and HELEXIA on other projects and allows both to collect, store and manage data but also to be used as a relay to the BMS and the implementation of control rulesets.

II.20.1.b. Limits detected to BC5

Similarly to BC4, significant constraints were identified during the development of the Business Case 5. As a result of COVID-19 pandemic, according to the instructions of the Ministry of Health, the AHU system in office buildings always had to keep operating to constantly freshen the air. So, this resulted in difficulties accessing and controlling the relevant systems and additionally was giving a hard time to focus in the comfort and the energy consumption optimization. Discussions took place about the AHU operation, aiming at the optimization of the occupant comfort and the energy efficiency of the system, alongside the health measures that kept being applied. Not only did these limitations hinder the potential of the controller, limiting its range of action, it also had a severe impact on the first 2 trials that were planned on the building. The main issues were first of all, the 7 days / 24 hours AHU operation with no air recirculation (as it is mentioned and described above) and the reduced occupancy of the building.

Beside the COVID-19 impact, the second significant challenge of this business case was the consortium capacity to take control over the equipment on site. This is a common limit to the use of on-line platforms and more generally to the use of data models on control logic optimization. In this case, it has been strengthened by the fact that the CORDIA team was no longer in charge of the O&M contract on site. CORDIA remains committed on the energy efficiency of the building but is dependent on a third party to take action upon the on-site equipment. This specific organization led to difficulties in the communication process and constituted a significant hurdle in the efficiency of the rule's implementation.

Given all the challenges faced with the pilot building due to the CORDIA team not being in charge anymore of the operations and maintenance of the building, the process to deploy the BC5 solution on another facility, namely CORDIA HQ, started. In the CORDIA building, all the necessary equipment was installed and was connected with CORDIA Connect Platform However, this last case did not go further than the data collection phase because of the technical limitations on the controllable equipment, i.e. there was no possibility to take actions on boilers and chillers but only on AHUs.

Furthermore, the project’s needs included the installation of new metering equipmenton site. The pandemic restrictions that were relevant to transportation and also to the site visiting permissions along with all the bureaucracy that comes with it, resulted in huge delays and difficulties for the completion of the necessary works. Finally, the only buildings to which we had access did not feature any sort of variable pricing structure in their energy contract, therefore they did not offer the possibility to optimise their cost. This led to our inability to complete the work for Use Case 13.

These points explain the lack of data for some of the KPIs defined above. Most KPIs were defined to reflect the impact of the rule implementation but the instances where control could be implemented for a long period of time were ultimately very limited.

II.20.1.c. Reasons for including or excluding data

Some changes on the plans of the local technical management team and the new property managers of one of our clients affected several of our pilot sites and our ability to control their equipment. So, it created the need to add another building in the agenda of the pilot sites and more specifically, the CORDIA’s HQ building. This meant that all the necessary data that are described in the relevant D6.3 sections had to be gathered for this additional building together with the metering and control equipment data and control inputs.

II.20.1.d. Recommendations and requirement for improved tools and analytics

As a conclusion, it is acknowledged that Business Case 5 has not been a smooth ride. Nevertheless, a number of essential lessons can be drawn from this experience:

- It is extremely challenging to install new control solutions in buildings that are already equipped with a BMS system. People on site are reluctant to change and will only accept to cooperate if we can demonstrate to them that the proposed solution is without risk, reliable and cheap to install. In that sense, it seems unlikely that we would be able to deploy our solution at a large scale in the short term.

- As of today, being confident that energy savings can be achieved seemed to be of secondary importance. However, there is a chance that this criterion would turn a game changer with energy becoming a major concern (due to its cost or to possible regulations to come that would force building owners to decrease their energy consumption below certain thresholds).
- The achieved energy savings were significant, even more than we thought they would be.

These learnings hint that strong regulations to make energy more and more of a concern will help the relevant actors to move forward in their engagement to reduce their energy usage, possibly making relevant a solution such as the one attempted in BC5.

II.21. Business Case 6: Flexibility potential of Residential consumers on electricity and natural gas - Heron-DomX

The objective of BC6 is to demonstrate and exploit the flexibility potential of residential buildings across the two main energy vectors of electricity and natural gas. The following analysis details the two considered use cases. UC14 focuses on electricity consumers that are offered recommendations to participate in an implicit DR service. UC15 focuses on the participation of natural gas consumers to: (a) improve the energy efficiency of legacy boilers through load reduction and (b) contribute to real-time gas balancing services.

II.22. Use Case 14: On demand-response for Electricity

II.22.1.a. Context

UC14 KPIs aim at quantifying the performance of the data acquisition, data analysis and user interaction procedures. UC14 service is based on HERON's Smart Monitoring platform which initially supported smart meters, relay for boiler control and a motion/movement sensor. The platform was expanded as part of BIGG effort to accommodate smart plugs so that the use of consuming residential appliances can be validated, therefore verifying the acceptance of BIGG flexibility services by pilot participants. Utilising BIGG RAF components, Inetum has developed a recommendation service with HERON responsible for conveying them via SMS to the Pilot participants.

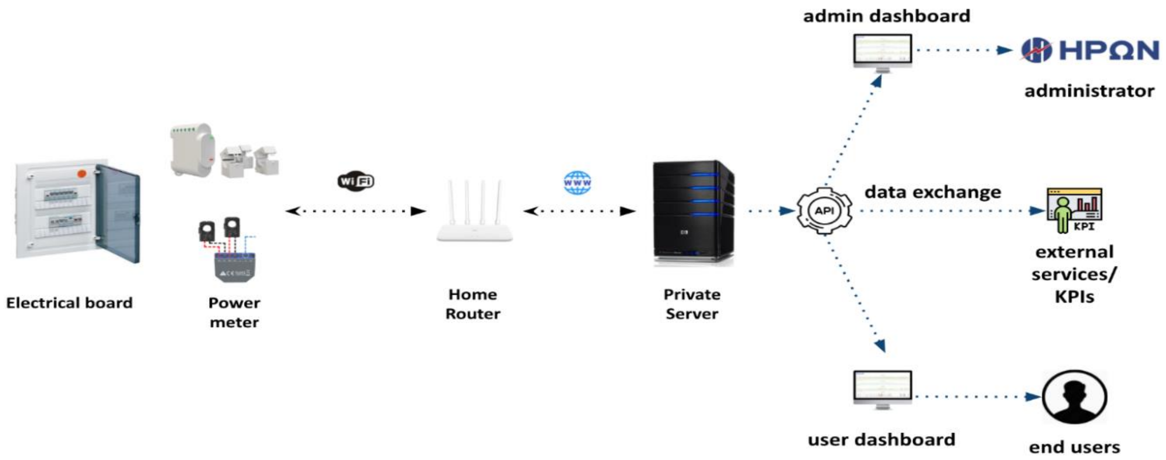


Figure 32: Supported usage scenarios for HERON's Smart monitoring platform.

In this context, HERON’s platform provides 30 second measurements (power, energy, voltage, power factor) for the smart meters, power and energy for the smart plugs and area luminosity and movement for the motion sensors. The service is supported by an integrated platform (databases and APIs) that accommodates its smart metering and smart home monitoring activities and dashboards as a means of guiding customers towards more efficient and environmentally aware consumption. HERON Smart Monitoring consists of two building blocks:

1. Real-time Energy Metering and Actuation Platform (REMAP): the technical infrastructure upon which the metering equipment operates,
2. Dashboards and visualisations in support of services developed to engage consumers and reduce.

Using this infrastructure, Inetum utilised BIGG toolkit to develop an Implicit DR Service based on HERON’s sustainability driven Green Tariff (Figure 33). The proposed Green Tariff relies on the calculation of the percentage of system load satisfied by both Intermittent and dispatchable (such as Hydro) renewable energy drawn from Load and RES generation forecast from the Integrated Scheduling Programming (ISP) provided by IPTO, the Greek TSO. ISP is a fairly common market process, carried out by TSOs that use central dispatch systems. The process aims at covering the forecasted generation/demand imbalances and procuring the required reserves. In Greece, ISP is executed at three scheduled times for each dispatch day also defining the timeline of the service.

The RES+Hydro percentages are calculated and hourly intervals are ranked from lowest to highest percentages. In reference to Day Ahead Market tariffs, active in countries with DSO issued smart meters, peak hours are considered as the hours with the lowest Green energy share. In doing so, HERON’s customers are expected to shift their electricity consumption to hours whereby the system is dominated by renewable energy.

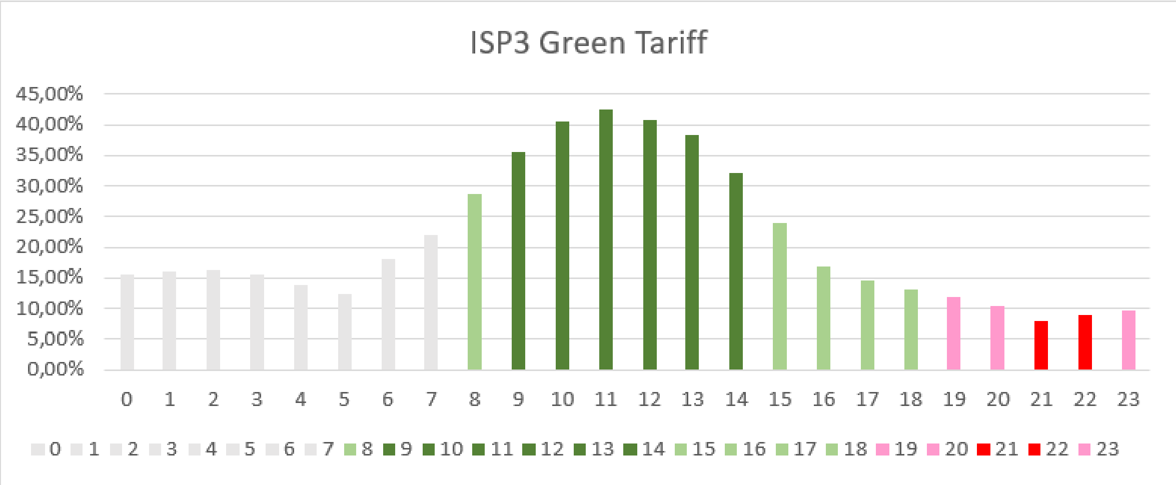


Figure 33: UC14 Green Tariff

The group of Data processing and acquisition KPIs [UC14 001-005] aim to evaluate the technical infrastructure of the pilot, most notably the installation of smart meters and flexibility assets.

Table 22 - Use case 14: Data processing and acquisition KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Number of potential pilot participants accepting terms and conditions and GDPR [UC14-KPIs001]	Count (invited participants)	100	140	140%
Number of monitored households [UC14-KPIs002]	Count (households with installed smart meter)	100	75	75%
Number of installed flexible assets: relay for electric boiler [UC14-KPIs003]	Count (households with installed electric relay)	10	3	30%
Number of installed monitored assets: smart plugs on white goods [UC14-KPIs004]	Count (households with installed smart plugs on white goods)	20	17	85%
Number of monitored households with smart meter being online over 80% of time [UC14-KPIs005]	Count (households that satisfy requirement) /Count (households with installed smart meter)	80%	78,67%	98,33%

Data analysis KPIs [UC14 006-014] and user interaction KPIs [UC14 015-016] have been setup to quantify the performance of BIGG services. Based on the re-alignment of the Use Case towards Implicit DR and the flexibility of appliances, some KPIs had to be redefined. For example, it would have been straightforward to define UC14-KPIs007 and UC14-KPIs008 for the initial Explicit DR, due to the clear operation of the water boiler which peaks at an easily identifiable plateau regarding its Power. However, with white good appliances the consumption patterns are not easily identifiable given the differences in models, specifications, programmes that consumers use, weight of loads for dishwashers and washing machines. For this reason, 5 consumers registered their main consumption habits for 5 days during September 2023 in a logbook, which was then compared with the data from the smart plugs. It was identified that a sufficient KPI to evaluate whether a pilot participant followed a DR advice was if their total hourly consumption was less than 65% of the average daily. Based on the logbook and the smart plug data, this rule applied to ca. 95% of the subset of the mostly online users (as defined in UC14-KPIs005).

To this end, KPIs that are no longer relevant have been replaced by their appropriate modifcations when comparing with deliverable DF6.2. Specifically, UC14-KPIs012a has been introduced to evaluate whether consumers follow the recommendations, based on data from their smart plugs. Following, the aforementioned logging process which identified 65% as the appropriate parameter for smart meter consumers, consumption less than 100 Wh for an hour for which a recommendation is given, was deemed appropriate as the validation rule.

Table 23 - Use case 14: Data analysis KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Baseline electricity consumption (kWh - within a specific time period, e.g. daily, monthly) [UC14-KPIs006]	Calculate electricity consumption (kWh) for a given interval (t) under the baseline mode of operation for Baseline period	NA	307.86 Wh	NA
Total energy consumption over a specific time period, e.g. daily, monthly [UC14-KPIs009]	SUM (electricity consumption for given interval) kWh for Recommendation period	NA	467.04 Wh	NA
Number of scheduled DR requests within a specific time period, e.g. daily, monthly [UC14-KPIs011]	Count (communicated DR requests i.e. recommendations, within a month)	2 for each of 60 users per month	3077 per month 96 avg per day	80%

Number of activated DR requests within a specific time period, e.g. daily, monthly [UC14-KPIs012]	Count (activated DR requests i.e. recommendations, within a month)	0.5 for each of 60 user per month	1380 per month 43 avg per day	143.3%
Number of activated DR request for appliances in smart plug e.g. daily, monthly [UC14-KPIs012a]	Count (smart plug energy < 100 Wh, within a month)/ Count installed plugs	50% on avg for each plug	94% on avg for each plug, With 35% of the plugs at 100%	188%

Table 24 - Use case 14: User interaction KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
No. of registered users with a unique account created [UC14-KPIs015]	Count (Number of registered users)	100	140	140%
No. of registered users with a unique account created that are actively using the system [UC14-KPIs016]	Count (Number of active users)	60	75	125%

II.22.1.b. Solutions and results

In UC14, the integration of the BIGG systems and services has been successfully completed, with the adoption of the BIGG Data Model 4 Buildings, which has been used to store and harmonize residential electricity consumption and electricity market data. Based on the achieved data harmonization, data acquisition and analysis were implemented for the various considered data sources, enabling the implementation of Implicit DR Recommendations.

Specifically, UC14 recommendations are based on the Green Tariff methodology provided by HERON and integrated by Inetum into the AI Model.

Based on the Greek TSO data required for the calculation of the tariff, BIGG Harmonizer and aspects of AI Toolbox are utilized to forecast 24 hours of residential consumption. A ML algorithm developed by Inetum estimates residential consumption for the following 24 hours by combining a Recurrent Neural Network (RNN) encoder and a Multilayer Perceptron (MLP) (Figure 34).

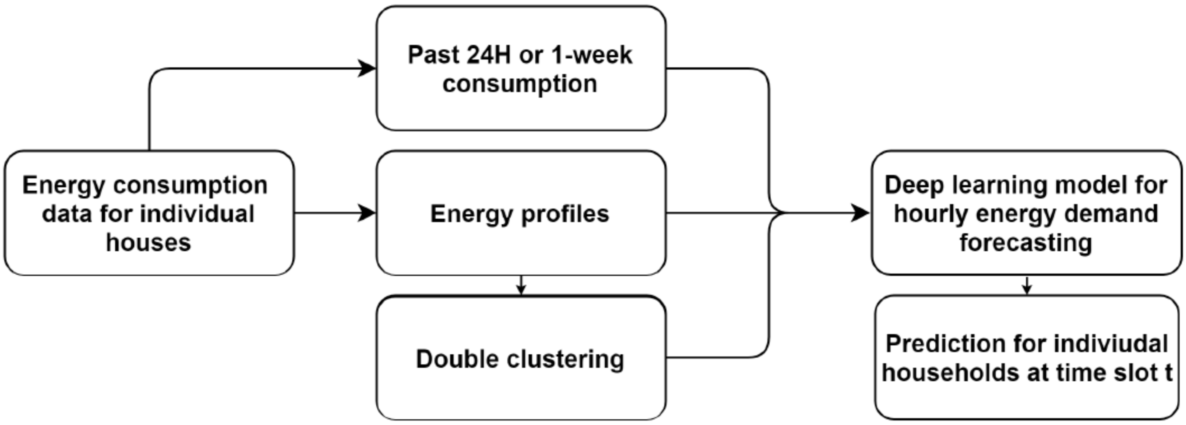


Figure 34: Structure of ML Algorithm for UC14.

The modelling approach is called, augmented modelling and it is designed to take advantage of household energy profiles to learn the differences between the consumption patterns and characteristics of individual consumers based on a double clustering procedure to group households with similar energy profiles, leading to an encoding for each energy profile based on its distance from each cluster's centroid. Augmented modelling, involves the utilization of the last predicted hour as input for subsequent predictions presents notable advantages. The process is computationally efficient, expediting predictions without the need to rerun the entire model for each step. Furthermore, its flexibility allows for easy adjustment of the forecasting horizon, accommodating specific requirements. The observation is that 70-75% of devices exhibit forecasted values consistent with historical data which emphasize its practicality. However, challenges arise as forecasts can swiftly become divergent or flatline, compromising long-term accuracy. The reliance on the last prediction also complicates model evaluation, rendering traditional metrics like MAPE less applicable. Additionally, issues such as flatlining suggest a potential limitation in the model's adaptability to evolving data patterns. The examples presented here has three such cases for demonstration. Addressing these concerns may necessitate periodic retraining and the incorporation of strategies to enhance model resilience and adaptability in the future.

An output of the algorithm is shown in Figure 35.

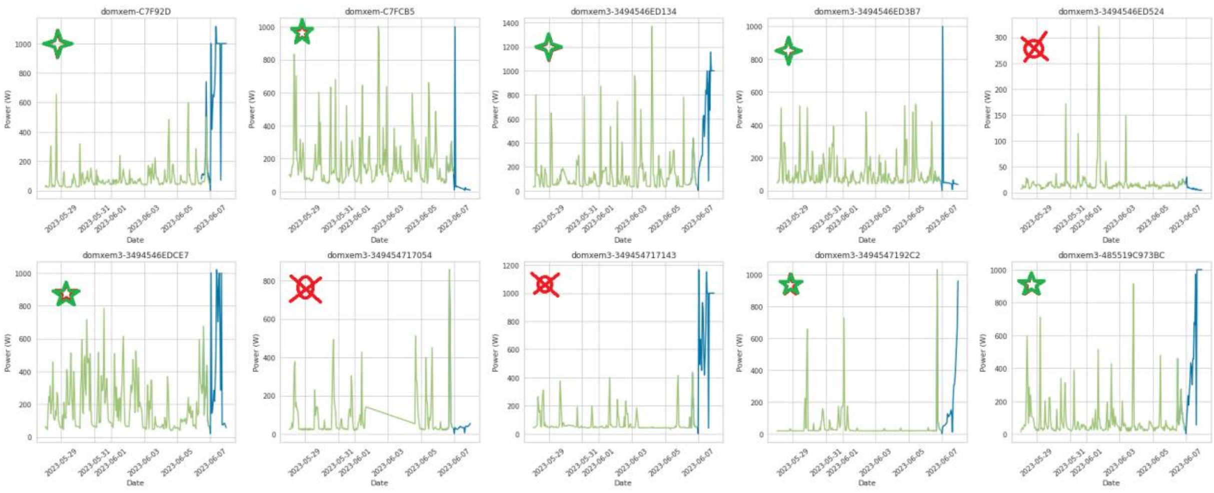


Figure 35: Forecasts for UC14 electricity consumers.

The above forecasts, conclude to a set of recommendations based on the tariff (Figure 36) which are communicated by HERON via an SMS service every day at 17.10 EET (Figure 37). From the recommendation block, HERON identifies 2 hours at which are preferably adjacent and if possible outside 02:00 – 06:00 in dates where there are more than two recommendations.

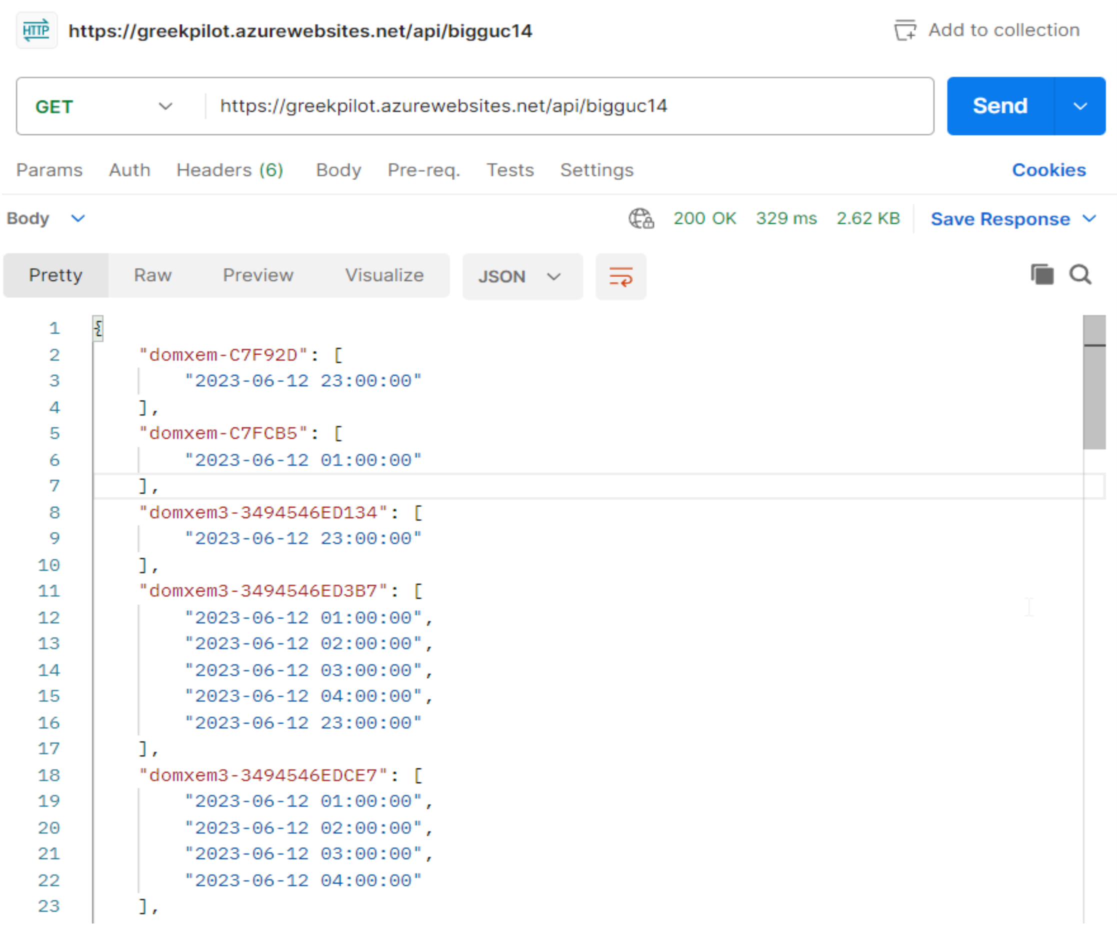


Figure 36: Visualisation of UC14 Recommendations

Figure 37: An SMS to a Pilot participant.

As an additional method of engagement to keep users engaged and active, HERON has provided a dashboard which demonstrates all aspects of the participants' consumption, also showing smart plug and water boiler specific measurements.

Figure 38: General Smart meter data.

Figure 39: Water Boiler specific consumption.

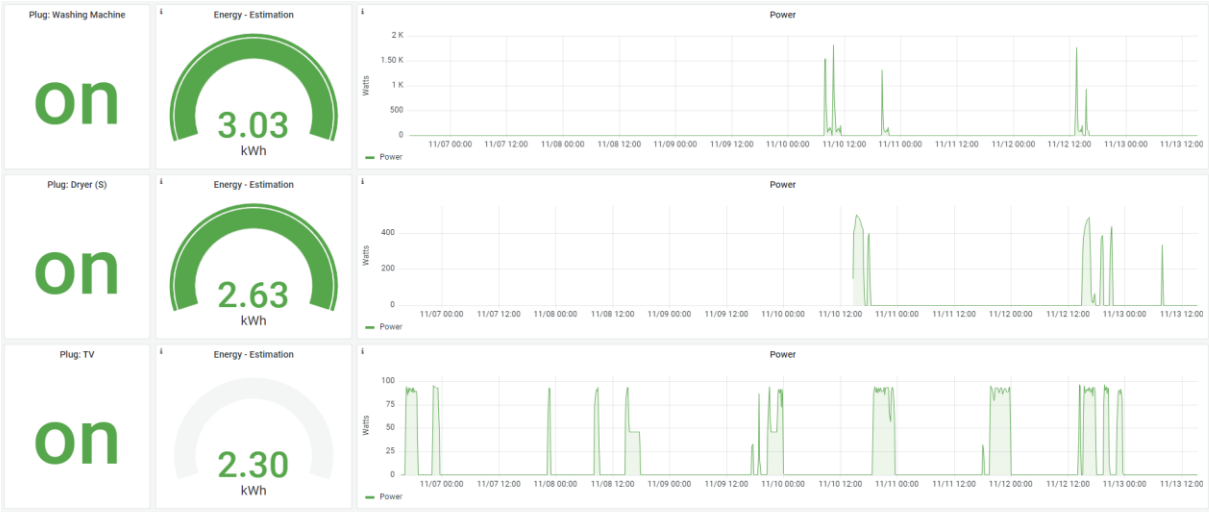


Figure 40: Smart plug consumption.

To validate UC14 service, a baseline period has been selected (1/10/2023-7/11/2023) in which recommendations were generated but not communicated, followed by an active period (8/11/2023-12/12/2023) in which recommendations have been sent to pilot participants through SMS. Baseline [UC14-KPIs006] and recommendation period [UC14-KPIs009] hourly average consumptions for each day are given in Figure 41.The discrepancy among Baseline and Recommendation periods can be possibly attributed to daylight savings at 29/10 with users increasing their average consumption as days become shorter and relatively colder.

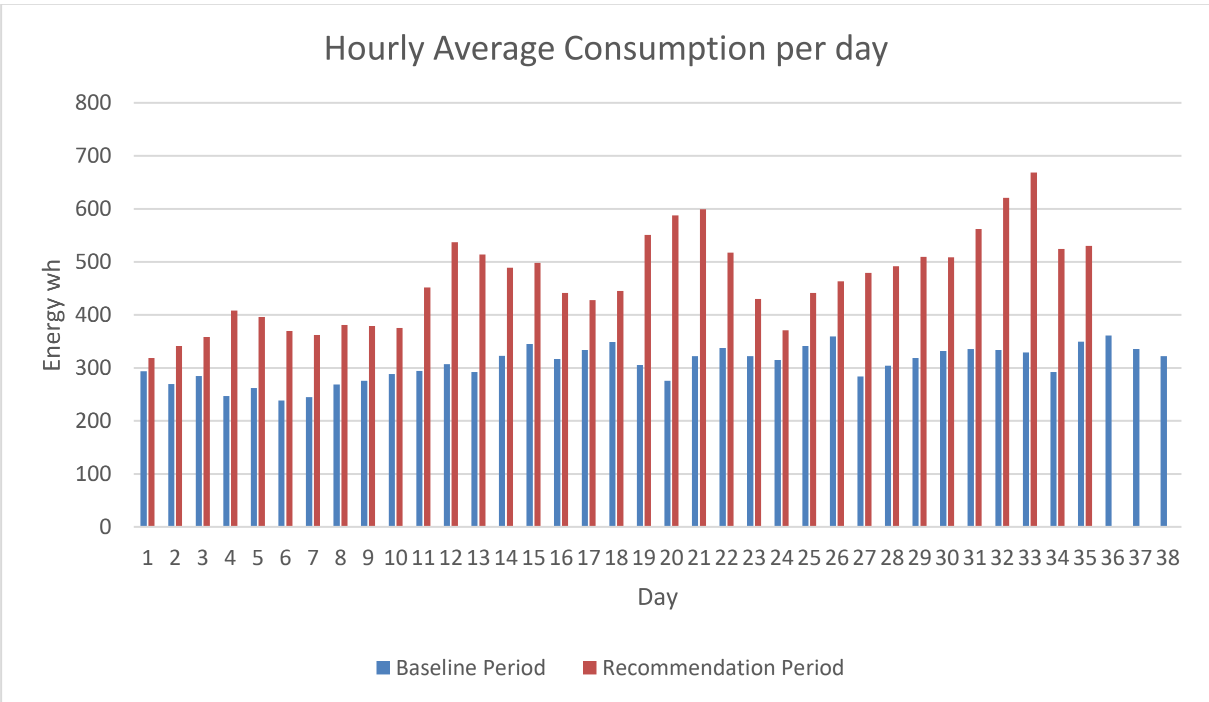


Figure 41: Hourly average consumption for given baseline and recommendation periods.

Overall, as also demonstrated in UC14-KPIs012 and UC14-KPIs012a and direct communication with pilot participants, there was not initial interest in the opening week of the recommendation service, but it gradually picked up generating results that exceeded expectations as defined with KPIs012. Figure 42 proves this argument by counting for each day the hourly recommendations that were sent and for these intervals assessing whether they were followed if the energy consumption for that hour is less than 65% of the daily average.

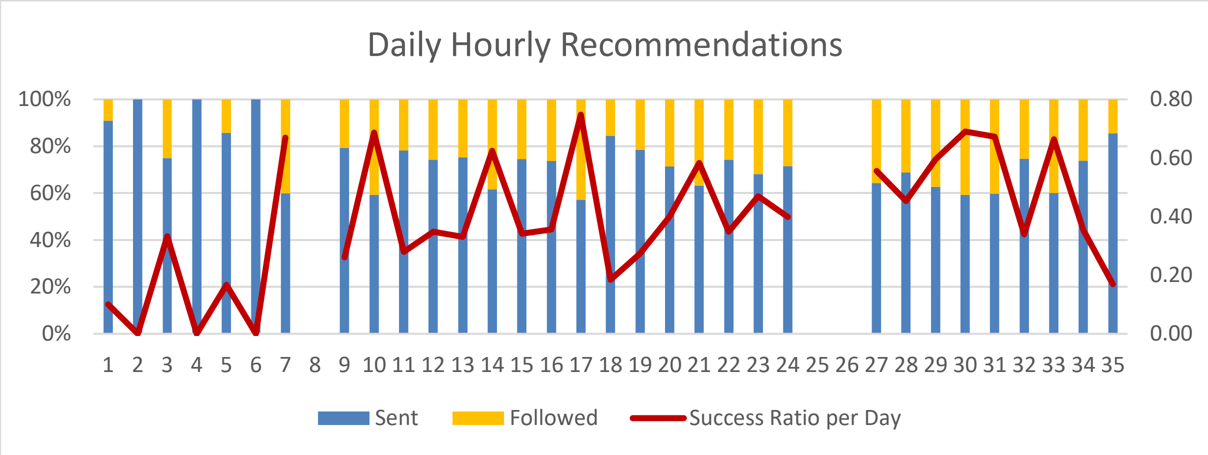
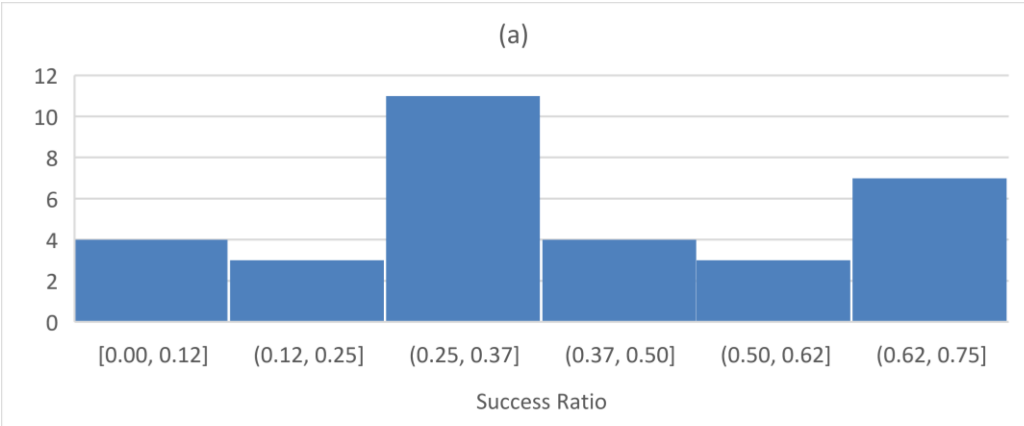


Figure 42: Success Ratio for hourly recommendation durind the Recommendation period.

These findings are further reinforced by histograms (a) and (b) of Figure 43 which summarise the Success Ratio of the hourly recommendations (up to 2 daily received per consumer). Chart (a) shows how many hourly recommendations are sent and followed per day for all participants, while chart (b) shows how many recommendations are sent and followed per participant for the Recommendation period.



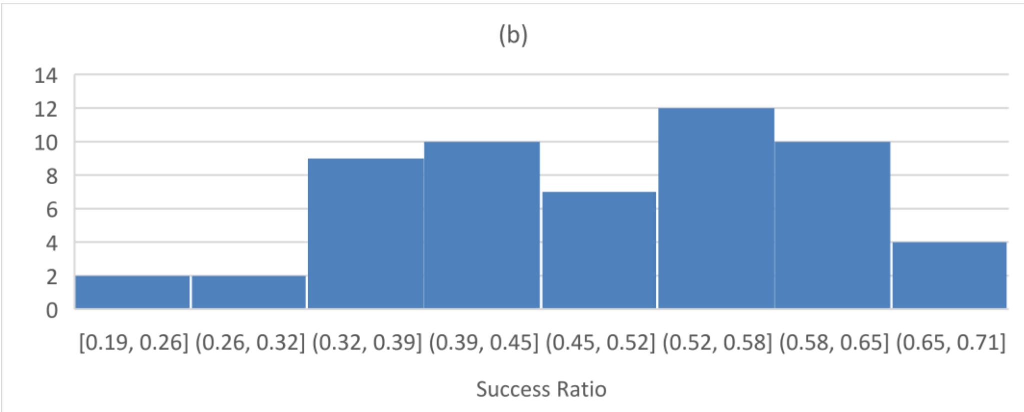


Figure 43: Histograms for Hourly Success Ratio.

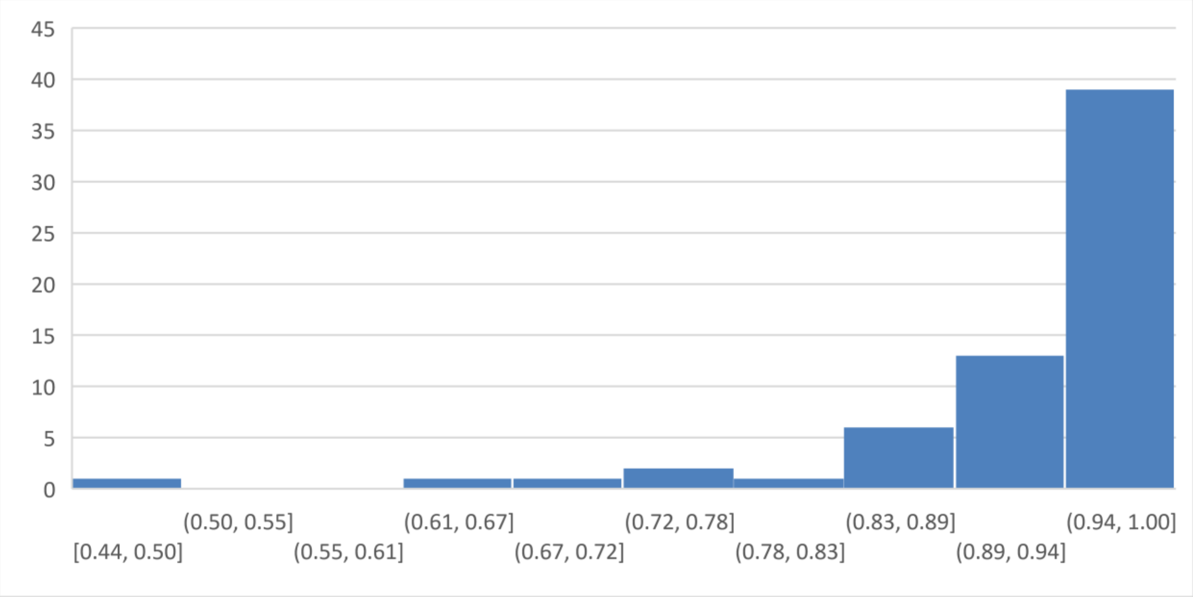


Figure 44: Histogram of Success Ratio for smart plug energy consumption.

This positive reaction is even stronger among consumers with smart plugs, who demonstrated overwhelmingly, that they willing to avoid using the heavy appliances (mainly Dishwashers and Washing Machines) during the recommendation periods (Figure 44).

These results imply that the public is interested in such services, even if the focus is on sustainability, without direct monetary gains. However, to keep them engaged and maximise these environmental gains, participants need to be appropriately motivated and engaged.

II.23. Use Case 15: Demand-response for Natural Gas

II.23.1.a. Context

UC15 focuses on the upgrade of natural gas boilers through the cost-effective and universal smart heating solution of DOMX to: (a) improve their energy efficiency through load reduction and (b) deliver real-time balancing services to the natural gas supplier. The DOMX heating controller enables the optimal management of gas boilers, by adapting their operation to the building characteristics (envelope, boiler), climate variations (indoor, outdoor) and user schedules-preferences, while circumventing the need to install dedicated metering equipment for consumption monitoring. The DOMX smartphone application enables gas consumers to understand how energy is consumed and to remotely manage their heating system. Ultimately the offered energy efficiency service is able to deliver up to 30% of savings for space heating when attached with legacy natural gas boilers, without affecting the occupants' thermal comfort. A plurality of energy (boiler load, efficiency improvement, savings, etc.) and non-energy (temperature variations, climate comfort, etc.) parameters can be collected in real-time. Key energy stakeholders (suppliers, facility managers, governmental bodies, etc.) get access to the data collected in real-time by their assets, belonging to consumers of their portfolios over secure APIs, for enabling real-time monitoring and management at scale (Figure 45).

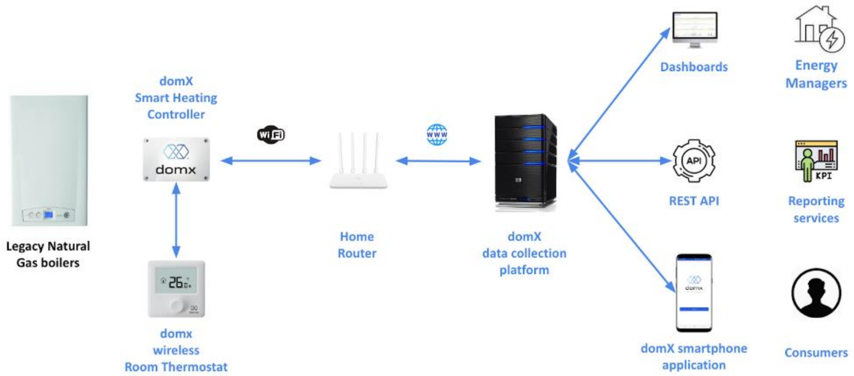


Figure 45: Representation of the data flows within the DOMX system components

In UC15, the BIGG Data Model 4 Buildings has been used to store and harmonize smart heating, building, weather and natural gas market data. On top of the various considered data sources and the corresponding harmonized data, two services have been implemented to deliver Energy efficiency and Demand-Response (DR) services for natural gas consumers and the respective energy supplier. In Figure 46, the integration of the BIGG architecture, as implemented for UC15 is presented. More specifically, green colour is used to depict the custom implementation of the Ingestor and API components for UC15, while blue colour is used to depict the Harmonizer and AI toolbox components that have been directly integrated from BIGG.

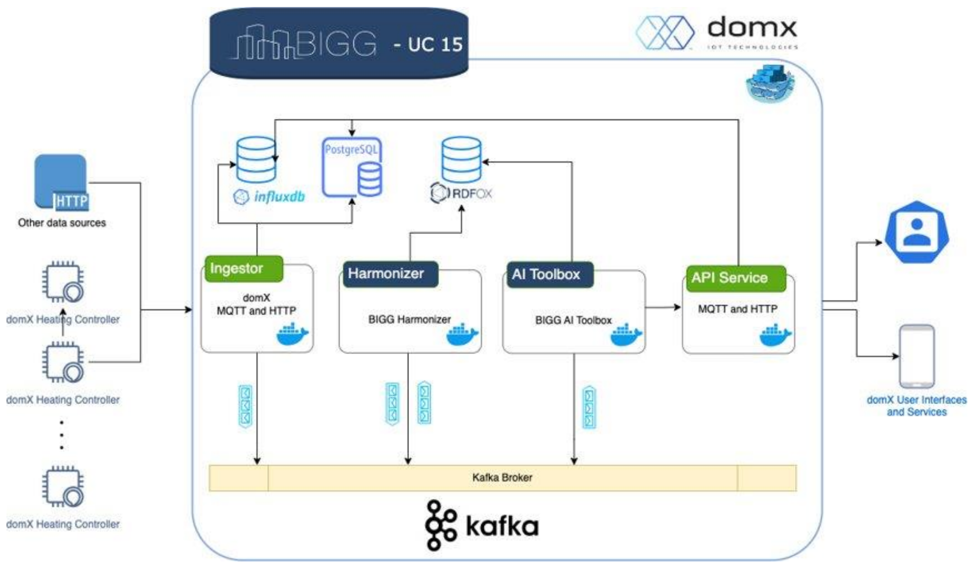


Figure 46: Integration of BIGG components with the DOMX system components in UC15

In Table 25, we list the UC15 KPIs that have been used for quantifying the performance of the data acquisition procedure. Overall, we observe that most KPI targets have been achieved, with certain KPI values even exceeding the target value, e.g. number of monitored households. On the contrary, a small subset of KPI targets were not achieved at all, as in the case of EPC available data (0 out of 50), which fact is analysed in detail in the limits that have been detected in BC6.

Table 25 - Use case 15: Data acquisition KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Number of monitored households [UC15-KPIs001]	Count (households with installed heating controller)	100	108	108%
Number of monitored households with heating controller being online over 90% of time [UC15-KPIs002]	Count (households that satisfy requirement) /Count (households with installed heating controller)	80	102	127.5%
Number of buildings with available EPCs [UC15-KPIs003]	Count (Number of buildings with available EPCs)	50	0	0
Households with AVG Monthly gas consumption data (legacy DSO meter) [UC15-KPIs004]	Count (Households with AVG Monthly gas consumption data)	>50	20	40%
Households with AVG Daily gas consumption data (smart DSO meter) [UC15-KPIs005]	Count (Households with AVG Daily gas consumption data)	>10	3	30%

Regarding the data analysis KPIs, which are detailed in Table 26, it can be clearly observed that the target KPIs related with the energy efficiency service have been achieved in most cases. Specifically for the energy efficiency service, it is noticed that the achieved energy savings and thermal comfort managed to exceed the initial targets. In addition. The DR service related KPIs reached their initial target with 8 participating households and 80 activated DR requests within a month of trials.

Table 26 - Use case 15: Data analysis

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
Baseline Gas consumption for space	Calculate gas consumption for space heating (kWh) for a	100	80	80%

heating (kWh - within a specific time period, e.g. daily, monthly) [UC15-KPIs006]	given interval (t) under the baseline mode of operation			
Adaptive Gas consumption for space heating (kWh - within a specific time period, e.g. daily, monthly) [UC15-KPIs007]	Calculate gas consumption for space heating (kWh) for a given interval (t) under the weather adaptive mode of operation	100	80	80%
Gas consumption reduction %" [UC15-KPIs008]	Calculate gas consumption reduction for the same household under days with similar heating requirements between the baseline and weather adaptive modes of operation	>20%	30%	150%
Average temperature comfort ratio witnessed on the buildings where measures are employed [UC15-KPIs009]	% of time during which the internal room temperature is within the user specified target temperature and comfort band (between minimum and maximum threshold)	>80%	94%	117.5%
Total energy consumption savings evaluated within a specific time period, e.g. daily, monthly [UC15-KPIs010]	Amount of energy consumption savings (in kWh) over a given period of time	NA	8.92 kWh daily	NA
Number of DR participating households [UC15-KPIs011]	Count (households participating in the given DR request)	8	8	100%
Number of scheduled DR requests within a specific time period, e.g. daily, monthly [UC15-KPIs012]	Count (scheduled DR requests)	(not enough data)	80	NA
Number of activated DR requests within a specific time period, e.g. daily, monthly [UC15-KPIs013]	Count (activated DR requests)	(not enough data)	80	NA

Demand Flexibility Potential: The total amount of energy consumption that end users could potentially accept to reduce/shift within a specific time period, e.g. daily, monthly [UC15-KPIs014]	Calculate the difference between the baseline gas consumption for space heating (kWh) for a given interval (t) and the consumption under the DR mode	(not enough data)	(not enough data)	NA

The user interaction KPIs of UC15 are detailed in Table 27, considering the total number of registered end users [UC15-KPIs015] that have installed the DOMX heating controller and the share of users that are actively using the system [UC15-KPIs016], as evaluated on top of their interactions through the smartphone application, as a proxy of the platform usefulness to them.

Table 27 - Use case 15: User interaction KPIs

Name of KPI and acronym [ID]	Description or Formula	Target	current Value (M36)	% of achievement M36
No. of registered users with a unique account created [UC15-KPIs015]	Count (Number of registered users)	100	155	155%
No. of registered users with a unique account created that are actively using the system [UC15-KPIs016]	Count (Number of active users)	60	77	128%

II.23.1.b. Solution and Results

In UC15, the integration of the BIGG systems and services has been successfully completed, with the adoption of the BIGG Data Model 4 Buildings that has been used to store and harmonize smart heating, building, weather and natural gas market data. Based on the achieved data harmonization, data acquisition and analysis were implemented for the various considered data sources, enabling the implementation of two energy services for delivering energy efficiency and DR services for natural gas consumers and the respective energy supplier. On top of the unified adopted data architecture, two different user interfaces have been implemented, for assisting the energy supplier to quantify the performance of their consumer portfolio when applying the two services, while the DOMX smartphone application has been used in both cases by the end consumers. In the next two sections, we briefly present details about the developed tools and executed trials for the two energy services that have been implemented through UC15.

II.23.1.b.1. Energy efficiency service

The inability of traditional heating systems to match the heating needs of the building under consideration with the prevailing outdoor and indoor conditions, the habits and preferences of the users and the performance of each building/heating system combination, directly affects the achieved performance and energy efficiency of the heating system, thus resulting in excess energy consumption and costs as well as in reduced thermal comfort. A typical configuration for natural gas boilers in Greece considers the application of the boiler outlet temperature of 65 °C.

Contrary to the **baseline** mode, the DOMX controller implements a sophisticated algorithm to control the boiler activation patterns and to adapt the actual temperature of the boiler's outlet temperature, directly affecting the boiler's load of operation. The followed approach considers as input the user specified target temperature, the varying indoor temperature, the prevailing outdoor conditions, along with the given building's response to heating requests, towards dynamically adapting the boiler's operation to deliver the exact amount of heat required to properly heat the building under consideration, while respecting the user's comfort limits. For the rest of this document, this energy efficient mode of operation is referred as adaptive. Figure 47 represents the evolution of various parameters for the same household under a 24h period, between the adaptive and baseline modes respectively. In both cases, the outdoor and indoor conditions, along with the heating schedule that is specified by the user are identical. In the baseline mode, the estimated consumption corresponds to **40.31 kWh**, while in the adaptive mode, the estimated consumption corresponds to **28.19 kWh**, resulting in consumption reduction of **29.7%**.

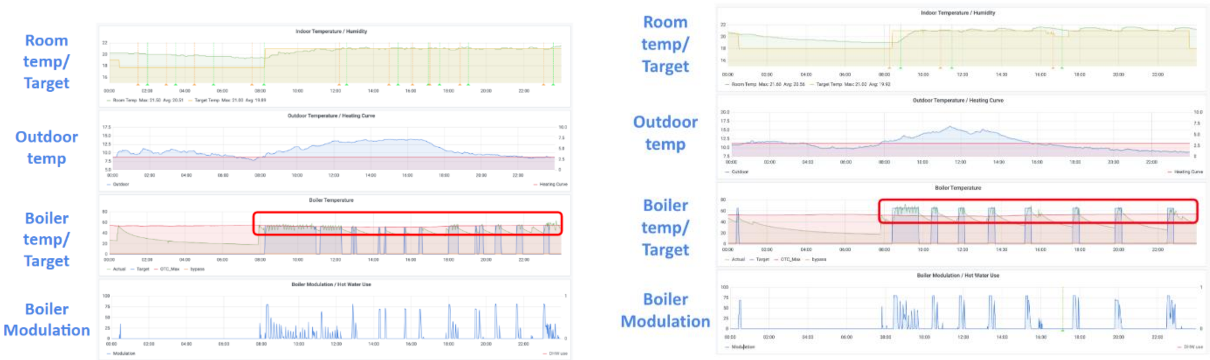


Figure 47: Evolution of various parameters for the same household in Adaptive mode and Baseline modes

Portfolio level demand monitoring and management is enabled for the energy supplier, through a custom dashboard that visualizes a plurality of energy (boiler consumption, savings, etc.) and non-energy (temperature variations, user preferences, etc.) data sources. The heterogeneous data types are collected in real-time and enable the analysis of heating demand and visualization of historical data through a common user interface. While the end users get informed about the attained energy savings through the smartphone application, the energy supplier is informed about portfolio level performance through the dashboard.

Figure 48: Energy supplier's dashboard visualizing various KPIs for the target consumer portfolio

Figure 48 presents a screenshot of the energy supplier's dashboard, showing the target KPIs as quantified for the consumer portfolio consisting of 5 homes, based on data that have been collected over the winter season between October 2021 to April 2022. In the top section, an overview of the quantified KPIs is presented, namely, the number of eligible devices in the portfolio, the total portfolio consumption (kWh), the total energy savings achieved (kWh), the energy efficiency improvement (%) over the baseline, the number of baseline days available for training and fine-tuning of the predictive models, the total emissions reduction achieved (kg CO_2), the total end-user cost reduction (€) and the total supplier's return of investment amount (€). In the middle section, the actual portfolio daily consumption is visualized with blue bars, the quantified portfolio daily energy savings is visualized with green stacked bars and the actual portfolio baseline consumption is visualized whenever present with yellow bars.

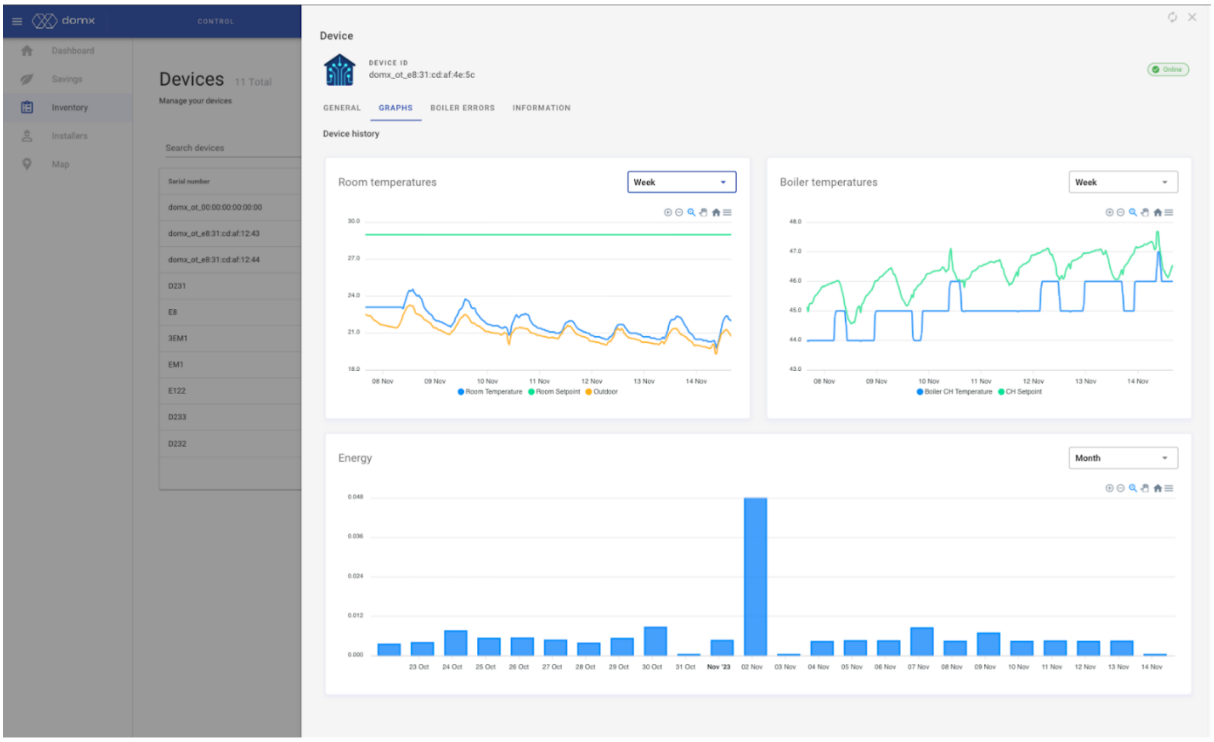


Figure 49: Energy supplier's dashboard visualizing the evolution of various monitored parameters (target, room, outdoor temperatures, consumption) for a specific household during winter 2021-2022

Figure 49 illustrates a screenshot of the energy supplier's dashboard, visualizing the evolution of various parameters for a specific household during winter 2021-2022. In the top left line chart, various temperatures are visualized including the target, room, and outdoor temperatures levels, while in the top right line chart the boiler outlet and target temperature levels are illustrated. In addition, the bottom bar chart visualizes the hourly consumption of the given consumption point.

II.23.1.b.2. Demand flexibility service

The application of DR services for natural gas consumers primarily lags behind due to the lack of DSO (Distribution System Operator) deployed smart-metering infrastructure. In addition, guaranteeing comfort limits for end consumers requires the collection of their preferences in real-time and access to smart heating data, as generated by their heating system. In UC15, the integration of smart heating data from the DOMX heating controller and the DOMX smartphone application provided access to the required data, while the BIGG developed tools enabled the collection and analysis of the heterogeneous collected data. More specifically for the needs of the DR service, an integrated system has been developed by imec and DOMX teams to implement the complex process of data collection, flexibility potential evaluation and the subsequent dispatching of boiler commands. An overview of the overall system architecture is presented below:

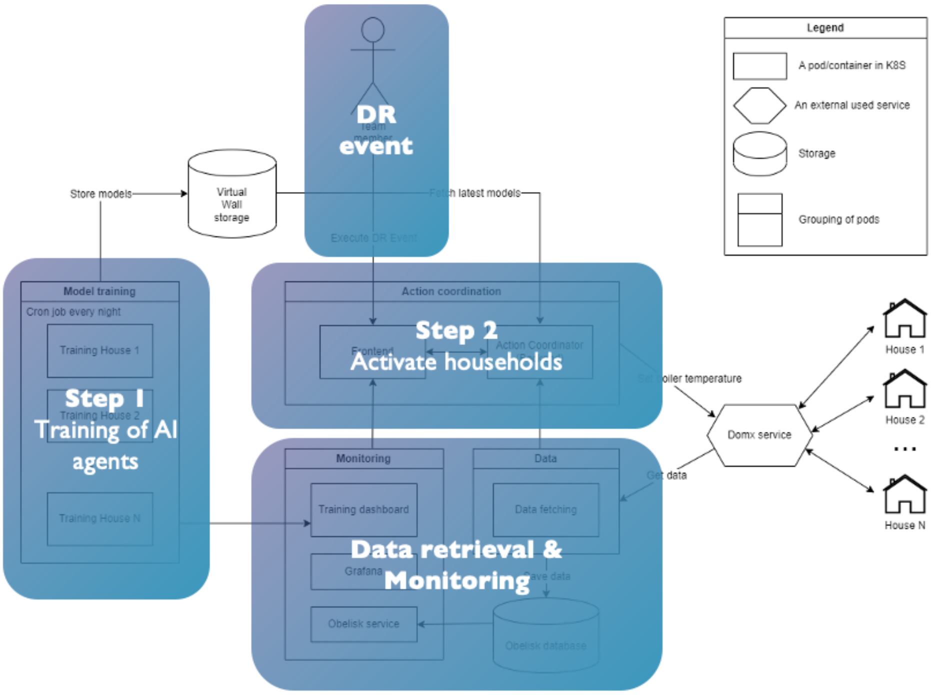


Figure 50: Architecture of the different components integrated for the DR service of UC15

The system consists of five separate components that communicate with each other via REST APIs or a file-based exchange. The **data retrieval and monitoring component** (middle bottom) builds on the DOMX API and periodically retrieves the data from the households and stores it in a central secure database. The **training component** (for reinforcement learning agents) (left of the diagram) uses the data as input to train an agent for each household. The trained models are then exported to a network drive so that they can be used by the action coordinator. The **action coordinator** (middle top) is responsible for setting the internal boiler temperature, with which the gas consumption can be controlled. During DR events, the action coordinator ensures that the last trained reinforcement agent is used to send an appropriate action to each participating boiler. Finally, there is an online **monitoring platform** that visualizes DR events and boiler data.

Based on the above architecture, certain processes can be identified. Some processes happen periodically, such as retrieving measurement data and training a reinforcement learning algorithm. Other processes are executed when a DR event is triggered. The strategy can be summarized as follows:

<u>Periodically (e.g. every hour or every day):</u>

- Retrieving (real-time) measurement data required for training a reinforcement learning agent, or for monitoring during DR events. During business-as-usual, when there is no ongoing DR-event, the last measured data points get retrieved every 5 minutes. During a DR-event, a higher frequency of the data is desired, and the data points get retrieved every 30 seconds.
- Training a reinforcement learning agent (policy evaluation). An agent is trained separately for each household. This agent can provide a prediction of the accumulative energy consumption for the next 24 hours at any time of the day, given the activity of the boiler and a set of properties, including internal boiler temperatures, the thermostat temperature and indoor/outside temperature. In the pilot, the (re)training of the agent happened every night.

<u>During DR events:</u>

- The reinforcement learning agent is used to predict the expected gas consumption. In addition, the target consumption that is calculated is aimed for the DR event.
- The boilers are ranked on the highest expected gas savings, which is calculated by the RL agent, while comfort constraints are considered. The comfort limits in the pilot are set at a maximum (negative and positive) deviation of 1 degree Celsius from the thermostat temperature.
- Continuous sending of commands to the boilers according to their ranking, so that the actual consumption approaches the target consumption as closely as possible. A proportional integral (PI) controller is used to control a discrete value that determines the number of participating boilers and the magnitude of the actions.
- Monitoring the observed boiler values on an online platform. This platform also shows an indication of how much flexibility is being 'used' at any moment of time during a DR event, by measuring how many households are activated. An example of a downwards DR event shown on this monitoring platform is shown below:

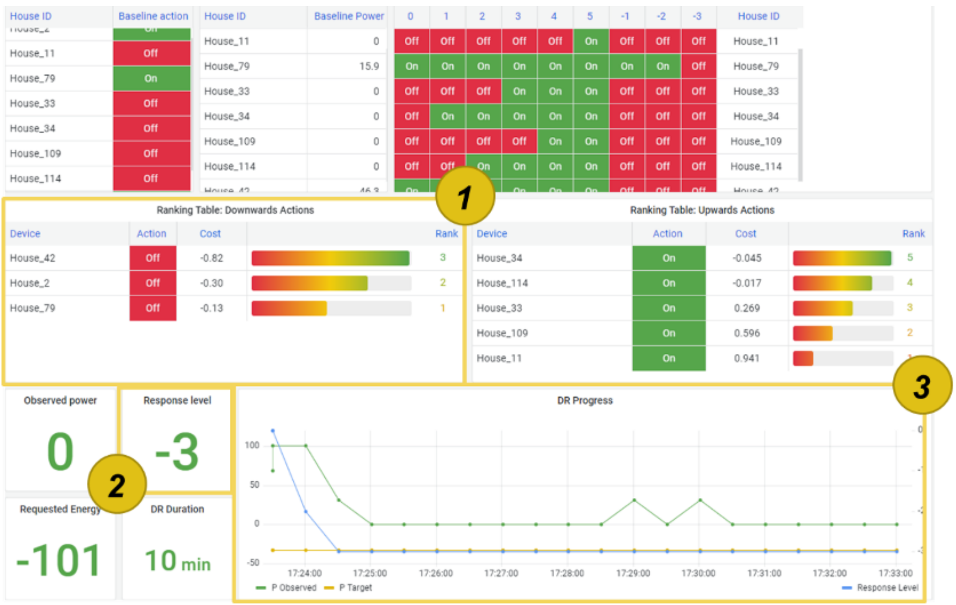


Figure 51: Monitoring and Control Dashboard for the DR service of UC15

A few parts of this visualisation are highlighted: (1) shows which households are the first ones to 'turn off' during a DR event. (2) show the current response level, is discrete value that denotes extend of power enlargement or reduction. A negative level 3, as shown here, mean in this case that three boilers that were on before the DR event, are now turned off. (3) shows an aggregate portfolio power over time, which is used to track the progress of the DR event.

During the pilot, 80 DR events of 10 minutes duration were executed over a period of 5 weeks, enabling explicit control over the natural gas boilers of 8 participating households. Figure 48 illustrates the aggregate portfolio power during a downward DR event, where the grey area denotes the period of the DR event.

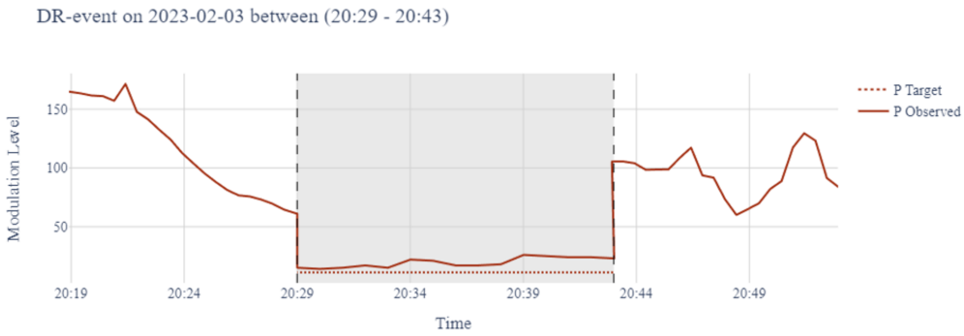


Figure 52: Aggregate portfolio power during a downward DR event

Although a downward trend was already visible before the DR event started, since the start of the DR event, consumption has dropped nearly to zero. The remaining consumption is because of a certain boiler that could no longer offer flexibility due to comfort constraints and is therefore forced to heat.

To validate finer steering, square-waved control signals have also been tested. This is a series of four separate 10-minute DR events (total time is 40 minutes): one high target (with a modulation level of 150), followed by one zero target, followed by two more high-low events. The control interval has been reduced from 60 to 30 seconds to achieve more precise steering. This type of experiment was performed ten times, with the results aggregated into the following confidence interval graph:

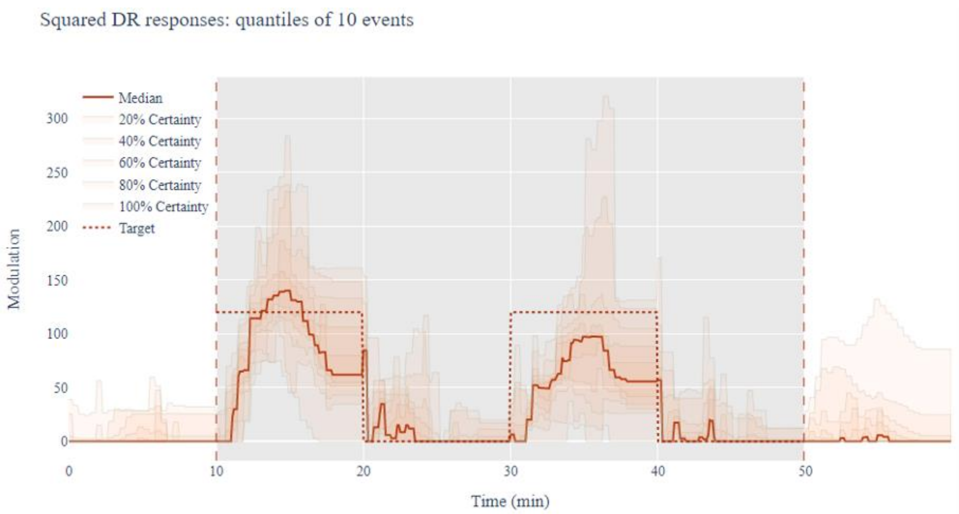


Figure 53: Illustration of aggregate portfolio power across 10 times repeated DR event

The visualization shows a clear trend during each of the four stages of the square-waved control signal test. Although the median is always around the target, it is not possible to achieve precise control for small portfolio sizes.

Integration with the Electricity vector

In an effort to take a step further than applying the developed solutions only to natural gas consumers, DOMX has recently developed a variant of their main product that can support the optimal management of electrical heat pumps as well. The developed solution has been integrated with multiple HP vendors, including Midea, LG, Hitachi and others. Three pilot installations have been completed within BIGG, for testing the integration with HPs of different vendors, enabling also the possibility to experiment with cooling scenarios and the delivery of Energy Efficiency and DR services beyond the short heating season in Greece. The engaged pilot users are using the DOMX smartphone application to remotely monitor and control their HVAC system. In addition, HVAC installation and maintenance companies can use the DOMX control dashboard to efficiently manage the HVAC systems of their customers, both during the commissioning and maintenance phases. Finally, the collected energy consumption and HVAC usage data can also be fed to the Energy supplier's dashboard that has been developed through BIGG, in order to enable the delivery of Energy Efficiency and Flexibility Services for electricity consumers as well.

Figure 54: Integration with heat pumps of different vendors at Greek pilot households

II.23.1.c. Summary of BC6

BC6 promotes Demand Response solutions in the electricity and natural gas domains. Although a unified Business Case with several common characteristics (as shown in in the respective KPIs lists) they do have different objectives. Given the current and mid-term regulatory framework in Greece and the lack of DSO deployed smart-metering infrastructure, the focus of the electricity Use Case (UC14) is to make electricity consumption "greener" by shifting it towards time interval dominated by RES generation. On the contrary, although for Natural Gas DSO smart-metering is equally limited, Natural Gas Use Case (UC15) can achieve monetary savings by reducing overall consumption under given comfort levels.

II.23.1.c.1. Limits detected in BC6

Several constraints were identified during the development of BC6. Below, the various detected issues grouped under three main categories are mentioned:

Device installation issues as a result of the COVID-19 pandemic. There was a lack of interest of engaged users to have an installer visiting their home for the installation of both electricity smart meters and DOMX heating controllers. This posed significant delays in fixing an installation appointment. In addition, unexpected disconnection issues were also faced for users with installed monitoring equipment, mainly arising due to users changing their router's WiFi credentials. Similar issues were faced also with users moving to a new household and not timely informing DOMX and HERON, in order to properly manage the device uninstallation and reinstallation process. Finally, in the context of UC15, compatibility issues were detected, as several engaged users had older boiler types that support only ON/OFF based control. The adaptation by HERON and DOMX: both are implementing a continuous recruitment and user support process, constantly expanding the pool of pilot participants. In order to extend the device support to more boiler types, DOMX developed a new heating controller version that can provide the basic functionalities of remote management for ON/OFF based natural gas boilers, thus being able to extend the range of eligible pilot households.

Encountered legal constraints in a complex GDPR process. The handling of real-time electricity consumption data is a complex process which involved significant effort and coordination between HERON's DPO and legal and R&D teams. Despite the effort, there have been several loopholes identified once the user registration process was open to even a controlled group of potential pilot participants. The most important one was a common characteristic among Greek families, whereby the bill payer / owner of the supply and the household dweller are not the same person. Consent forms had to be re-written and users that had accepted former versions had to be contacted so that they can sign new documents.

Limitation of assets for direct electricity Demand Response. Initial surveying of the pool of prospective pilot participants for UC14 showed that a significant percentage either did not own a water boiler to be heated by electricity, or that they were not willing to let the asset be controlled remotely. This could limit the scope of the project as flexibility potential of 5 water boilers could be negligible. UC14 was modified accordingly to expand the technical infrastructure by including smart plugs to monitor heavy loads. Specifically, washing machines have been selected given that their use could be shifted within the day, and due to access for physical intervention. Furthermore, direct control has been replaced by an under development real-time advice/ suggestion interface.

The collection of EPCs from the Hellenic Ministry of the Environment and Energy changed from the proposal to the implementation of BIGG. During the proposal preparation phase, the Hellenic Ministry of the Environment and Energy committed to facilitate offline access to the EPC data of the buildings participating in the Greek pilot activities. However, as soon as the project started, the contact person at the Ministry informed us that EPC data can only be shared with public bodies for statistical and research purposes, and the building owners, but not with research project partners. As in the BC6 use cases, most of the end consumers are renting their apartments, the BC6 partners (DOMX, HERON) are not in the position to reach the building owners directly. In order to overcome the identified issue, a survey was developed for end users to collect the core characteristics of pilot households (size, location, year of construction, # of occupants, etc.).

The impact of the energy efficiency mechanism may be superimposed by other factors, especially the extreme rise in energy prices. Based on preliminary analysis carried out by DOMX, several pilot users of UC15 actively changed their energy behaviour (target temperature, reduced heating duration) over this last winter. This fact further complexes the impact analysis of the energy efficiency and DR mechanisms. In order to tackle this limitation, DOMX decided to consider the target temperature and heating duration, as two additional factors to be considered by the clustering algorithm that is employed for identifying heating days with similar characteristics, between the baseline and intervention periods.

III. CONCLUSIONS

The BIGG project has successfully reached most of their initial objectives, the building data has been retrieved, processed and used to analyse the behaviour of the buildings as individual units and as part of portfolios. The technical solutions developed are able to cope with the challenges provided by the BIGG pilots and have been designed to be used by a wider range of applications beyond the test beds. Some of the project results include an improved system to create, manage and analyse an EnPC project, or a portfolio of them; they also include large building portfolio management; and DR of both electricity and natural gas to shift consumer demand towards more favourable moments either by share of green energy or cost.

The main shared challenge of the project came at the data gathering step which became more complicated (each pilot had a different issue) due to the Covid-19 pandemic, which acted as a catalyst for impediments. The effects that Covid-19 had on the pilots cover a wide range of situations including Changes to the occupation patterns with new occupation patterns emerged forcing to ”quarantine” pre-covid data because it was not as relevant anymore, etc. A more extensive example is the case of new rules of ventilation that were applied in response to Covid, in which energy efficiency was dropped in favour of constant ventilation of new fresh air, requiring an increase of energy consumption to keep comfortable and healthier interior spaces. In other cases, it led to limitations of access both to systems to prevent modifying the constant ventilation, and to buildings to install new measuring devices. All of pilots managed to adapt to these emergent challenges and they have been incorporated into the new ways buildings' operation.

Business case 1: "Benchmarking and Energy Efficiency tracking in Public Building" has successfully developed tools to improve control and manage the energy performance of a large park of buildings with automated methods in the form a common web-based platform. The results include automated data gathering of key information (building data, energy consumption, weather forecast), which is then mapped and harmonised to later be used by the analytical solutions to seamlessly produce the energy performance and benchmarking analytics. The integration of the data into a single platform coupled with the ease of collecting data by the user's has ensured a high degree of participation and data verification by the end users.

Currently data is collected for over 4000 buildings, spread among 14 government departments and over 100 public entities. The main data sources are the internal patrimonial database (GPG), cadastral information, open data for organisational purposes, weather conditions and energy consumption. Data gathering has been a success with data for the 4000 buildings being collected, close to 7000 consumption points (mostly electricity, with around 500 gas points). It is also worth noting the 1800 EEM registered over the 2021-2022 period since the platform became operative, doubling the rate of EEM collection before BIGG. The collected data is then used to continuously obtain the most up to date information about the building portfolio with two main types of information focusing on the evolution of each building on its own (energy performance analysis) and comparing the building against its peers (building benchmarking). Both analytics have improved the capability of energy managers to focus on the buildings that required attention, specifically building benchmarking allows to detect which are the buildings that have a higher potential for actions, greatly reducing the time necessary to act on them and also highlighting potential future actions pathways and needs.

The project has provided valuable lessons towards its own implementation. The main one is that buildings are dynamic, due to the Covid pandemic and the changes it brought, building occupation and behaviour will never be the same as before the pandemic. The pandemic has promoted a shift in the way buildings are used, mainly by “encouraging” the “work from home”, which reduced first the building occupation and then, allowed to host the same number of people with a lower building count, since most of them are working remotely and not concurrently.

In summary, the BIGG developed solution and services provide an automated tool for data gathering and analysis that facilitates decision making by highlighting the most relevant buildings among a large portfolio based on different criteria, for example, potential targets for EEM implementation within the large building portfolio.

The aim of the **Business case 2 “Energy Certification (EPC) in Residential and Tertiary Buildings”** is to expand the utilisation of the energy certificates information and their wealth of building and energy data. The two paths analysed are the standardisation of the certificates information into the INSPIRE format, and the exploration of the Level(s) indicators towards defining the path between the current energy performance certificates and Level(s). Towards those aims, the first step was uploading energy certificates exciding the 1,000,000 targeted, which then were used to successfully test the harmonisation tools of WP4. The EPC harmonisation using the WP4 tools allowed to adapt the current energy performance certificates into the INSPIRE format, which facilitates that their data can be used in further applications. An example of a further applications are the Level(s) indicators analysed in UC4. The results show that out of the energy related data (which is the focus of the EPC) most of it is usable to calculate indicators of Level(s) (6 indicators in total), with some additional information that needs to be obtained from external databases. The only indicator related to energy that cannot be calculated is indicator 4.2 Time outside of thermal comfort range. These results show that legislative modifications to bridge the gap between the current EPC and Level(s) would probably damage its core functionality without approaching any real benefit. The current data is in the INSPIRE format, which simplifies sharing it with other initiatives that can take a closer approach to Level(s), such as the building passport.

Business case 3 "Building life cycle: From planning to renovation

The work of business case 3 "Building life cycle: From planning to renovation" has managed to collect and harmonize data from different systems and make them interoperable. These works are very close to the developments of WP3 and 4 of the BIGG project.

Specifically for Use Case 5, all the main fields of the individual building systems (BMS, CMMS and BIM) have been analysed and found for about 877 buildings of the Catalan government. This analysis has been the contribution of the BC in developing the BIGG data model for WP4. The specific works developed in this use case have been the ingestors of the original data sources (BMS, CMMS, and BIM) and the mappers and harmonizers to transform these data into the BIGG model. All of them have been published in the project Github. It is worth highlighting the large amount of data processed with more than 30,000 building zones, 70,000 elements or assets, 600,000 work orders, and more than 200,000 devices registering every 15 min.

For Use Case 6, the same ingested and harmonized data has been used as in Use Case 2, about 2000 Energy Efficiency Measures applied in the Catalan government buildings. These have been formatted and an exchange file has been prepared in the format required by the DEEP platform. The solution used the same user interface in Use Case 2, the button for exporting EEM to DEEP has been implemented.

For Use Case 7, the same ingested and harmonized data used in Business Case 2, 1.4 million of building energy performance certificates, has been used. These have been formatted and stored in the BIGG data model for future exchanges with EUBSO.

Business case 4 "Energy Performance Contract (EPC) based savings in commercial buildings" successfully carried out the creation of an end-to-end solution to manage and follow up the savings generated from EnPC projects. The solution is addressed both to ESCOs or third-party investors wishing to keep a global view on their EnPC contracts and to end customers wishing to visualise the result of their actions and the resulting financial gains. What makes it unique is its ability to:

- Cope with any encountered structure of EnPC definition: with or without bonus/malus mechanism, with monthly/quarterly/yearly savings evaluations, with or without custom identified baseline model, with possibly multiple targets per sub-scope, etc.;
- Seamlessly collect all the required data: the contractual information, the historical consumption data required for the IPMVP baseline model identification and the real-time consumption data required for the continuous follow up;
- Work at the scale and gain huge amounts of time from qualified engineers: setting up a new EnPC contract follow up steps from a weeks to hours, the regular follow up and reporting steps from a few hours a year per contract to a few minutes for a whole portfolio.

Additionally, many other advantages can be expected from using this solution such as reducing the risk of errors, increasing the amount of standardisation in the follow up, reducing the dependency to Excel or providing engaging visuals to communicate about the results, all of these coming off the shelve.

The solution was successfully tested on 3 pilot projects in 2 different countries, all presenting fairly different characteristics from each other. It was also applied to evaluate the savings generated from the solution of BC5 and is already being applied more widely to the customers of HELEXIA and ENERGIS.

As a final note, the developed solution was the premise to create even more model based solutions such as a smart alerting system able to accurately detect consumption issues while drastically reducing the number of false positives.

Business case 5 "Buildings for occupants: Comfort Case" enabled the design of a novel multi-objective controller, able to optimize the energy usage and cost of a building, including green energy production, while maintaining comfortable conditions at the same time. This controller integrated inputs that are generally unexploited by conventional Building Management Systems (BMS) controllers such as the forecasted weather conditions or occupancy.

The controller was installed and tested in a large office building in Athens achieving an average of 15% savings on the energy consumption while improving the comfort conditions at the same time. Unfortunately, due to the Covid conditions and the reluctance of occupants to bypass BMS controllers, it was not possible to test the controller on other pilot buildings.

Business case 6: **"Flexibility potential of Residential consumers on electricity and natural gas"** has successfully developed tools to evaluate the flexibility potential, deliver fine-grained control of power-hungry appliances (electrical/ natural gas boilers) at end consumer premises and ultimately manage the demand of large consumer portfolios at scale, through the application of automated and scalable algorithms and easy to use graphical interfaces.

In UC14, the integration of the BIGG systems and services has been successfully completed, with the adoption of the BIGG Data Model 4 Buildings, which has been used to store and harmonize residential electricity consumption and electricity market data. Based on the achieved data harmonization, data acquisition and analysis were implemented for the various considered data sources, enabling the implementation of Implicit DR Recommendations. The DR recommendations have been based on a Green tariff methodology that encourages participants to move their large consumption (dishwashers and washing machines) towards the "green hours" of the day based on the recommendations provided by Heron. The "green hours" proposed are based on the daily market forecast hourly and the renewable energies share at each of them. The limited group of pilot participants' has shown an increasing interest over time to follow the recommendations provided as the pilot progressed with no or little follow up at the first week to constant interaction by the end of the pilot. This was further tested by creating control recommendations that were not sent to the users to detect if their behavior had been altered by participating. The results showed that they only actively modified their daily behavior when prompted by Heron's recommendations and did not try to foresee the best times of the day by themselves.

Specifically, the adoption of the BIGG Data Model 4 Buildings in UC15 enabled DOMX to collect, harmonize, store and analyse information gathered from heterogeneous data sources in a unified way, including smart heating, building, weather and natural gas market data. The integrated system, effectively combined BIGG derived components with the DOMX architecture and enabled the collection of multiple energy and non-energy data from end consumer assets in real-time. On top of the unified adopted data architecture, two energy services for delivering energy efficiency and DR services have been implemented and delivered to the energy supplier through two different user interfaces for assisting the system's deployment. Extensive pilot trials have been executed over the winter periods of 2021-2022 and 2022-2023, ultimately engaging the consumers of more than 100 pilot households. The gathered results showcased up to 30% of energy savings for end consumers, along with the ability to adapt the demand for space heating while maintaining the thermal comfort of end consumers within their limits. DOMX also took a big step further than planned at the proposal phase, by integrating the developed solutions with electrical heat pumps and paving the way for delivering the developed tools to electricity consumers as well.