Extended dEPCs applications toolkit

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Executive Summary

This report is the first version of the Extended dEPCs Applications Toolkit. D4.3 v1 delivers a detailed description of the D^2EPC toolbox that provides a series of invaluable services to the end-user. The respective modules correspond to the "Energy Performance Benchmarking" and the "Energy Performance Verification and Credibility" and are thoroughly discussed within the deliverable.

D4.3 initially presents a conceptual overview of the application's toolkit to be integrated into the D^2EPC architecture along with the literature research which preceded the design of components. Then, the report dives into the sub-modules that constitute the two main components of the toolkit, providing insights into their overall operation and functionalities to be delivered to the end-users and other stakeholders.

Starting from the Energy Performance Benchmarking, the module comprises two separate sub-modules, the Classification and Benchmarking Tool. The Classification Tool is equipped with the appropriate modern data mining algorithms able to extract information from operational and temporal building characteristics. Its main focus is to generate distinct classes for the categorisation of the buildings under study. On the other hand, the Benchmarking Tool steps on the generated classes and materialises the benchmarking service. This service contributes to the evaluation of the building performance by establishing a set of performance criteria – built upon the comparison of buildings- to be satisfied by future EPC users.

The large number of installed devices and the huge volumes of generated data raise the need for specific applications to check the operation of IoT equipment and the quality of extracted data. For this reason, the D^2EPC Applications Toolkit includes the Energy Performance Verification & Credibility module which is equipped with the appropriate software to undertake the device monitoring and data quality assessment. The Network Monitoring Tool keeps track of the operational status of deployed devices and delivers a network representation to the end-user via a Credibility UI. Meanwhile, the Data Quality Tool performs tailored checks on the collected data to ensure their adequacy prior to their utilisation from other project components.

Beyond the components' description, the report includes the development status of the modules and presents some validation results, part of the works conducted as of M26 of the project. Lastly, the deliverable wraps up the insights provided and concludes with what will be included in the second and final version, D4.7.

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List of Acronyms and Abbreviations

Term	Description
DQ	Data Quality
CSV	Comma Separated Value
DWD	Deutscher Wetterdienst
EPC	Energy Performance Certificate
EPB	Energy Performance Benchmarking
EPG	Energy Performance GAP

EPVC	Energy Performance Verification and Credibility
GDPR	General Data Protection Regulation
GEG	Gebäudeenergiegesetz
HVAC	Heating, Ventilation and Air-Conditioning
IT	Information Technology
ISO	International Organisation for Standardisation
IoT	Internet of Things
KPI	Key Performance Indicator
PHP	Hypertext Preprocessor
SVG	Scalable Vector Graphics
UI	User Interface

1 Introduction

1.1 Scope and objectives of the deliverable

The main focus of the deliverable is to provide an overview of the D^2EPC Extended dEPCs Applications Toolkit and report the works conducted as of M26 of D^2EPC. More specifically, D4.3 describes the operation and properties of two separate tools constituting the Applications Toolkit. The "Energy Performance Benchmarking" is responsible for the categorisation of buildings on various traits and the "Energy Performance Verification and Credibility" undertakes the monitoring of the installed IoT Devices in the project's pilots and performs tailored checks to the extracted datasets to ensure the overall data quality.

The report aims to provide insights into the research performed towards the designing of the relevant components, the definition of their integrated functionalities and the overall development status up to this stage of the project.

1.2 Structure of the deliverable

The content of D4.3 is structured into 5 chapters to provide a holistic view of the Extended dEPCs Applications Toolkit. A brief description of the sections and their respective content is presented below:

- **Chapter 2 - Insights on the Extended dEPCs Applications Toolkit**: This chapter includes a detailed description of the modules residing in the Applications Toolkit. It begins with a general view of the toolkit and the literature research that preceded the implementation of the tools. It further dives into the functionalities of the sub-modules that will materialise the desired services
- **Chapter 3 - Extended dEPCs Applications Toolkit - Design and Implementation**: This chapter delivers the development status of the respective components up to this stage of the project. In the next version (D.7) it will be enriched with technical details such as the technology stack used (tools, libraries, licenses), functional and non-functional specifications, interfacing documentation etc.
- **Chapter 4 - Extended dEPCs Applications Toolkit Validatio**n: This chapter includes the works conducted towards the validation of the incorporated components as of M26 of D^2EPC
- **Chapter 5 – Conclusions**: This chapter wraps up the included information and provides insights on the second version of the deliverable expected in M36.

1.3 Relation to Other Tasks and Deliverables

D^2EPC work structure is broken down into eight building blocks in total, the Work Packages (WP), which are further segmented into tasks that undertake specific pieces of work. Task 4.3 is part of D^2EPC's fourth WP which will implement the project's digital platform as well as the enabled applications. The components that will be delivered within the task have been initially described in the project's architecture under WP1 and specifically T1.4. Both modules of the Applications Toolkit (EPB and EPVC) are highly engaged in data acquisition and provision. As a result, T4.3 is closely related to the activities of T2.5 (in which the project's Common Repository is designed and delivered), T3.1 (i.e., the task responsible for the definition of the Information Management Layer) and T3.3 (which delivers the D^2EPC Digital Twin component) for the static and dynamic data acquisition and streaming of the assessed information. Other interactions of the toolkit's modules concern the project's calculation engine (T4.1) which takes as input the collected data from the pilots to calculate various quantities (e.g., performance indicators) and the alerting system (T4.2) which aims to inform the user about the building's energy performance or warn the user for various inconvencies (e.g., data quality) . Finally, provided that the integrated services will be delivered to the end user via a web application, T4.3 is highly related to the works of T4.4 which undertakes the design and development of the main D^2EPC web platform .

2 Insights on the Extended dEPCs Applications Toolkit

2.1 Overview of the Applications Toolkit

D^2EPC aims to deliver a holistic platform that comprises a plethora of services and applications that provide insights to end-user in regards to the building's operation and performance. The "Extended dEPCs Applications" corresponds to a toolkit that includes the appropriate software components which activate two distinct functionalities of the D^2EPC framework:

- The categorization and, hence, the comparison between buildings of similar characteristics delivered by the Building Energy Performance Benchmarking (EPB) module
- The validation of the dynamic data elements entered as input for the issuance of the dynamic EPC undertaken by the Energy Performance Verification and Credibility (EPVC) module

In Figure 1, a conceptual diagram of the components that constitute the D^2EPC system is presented

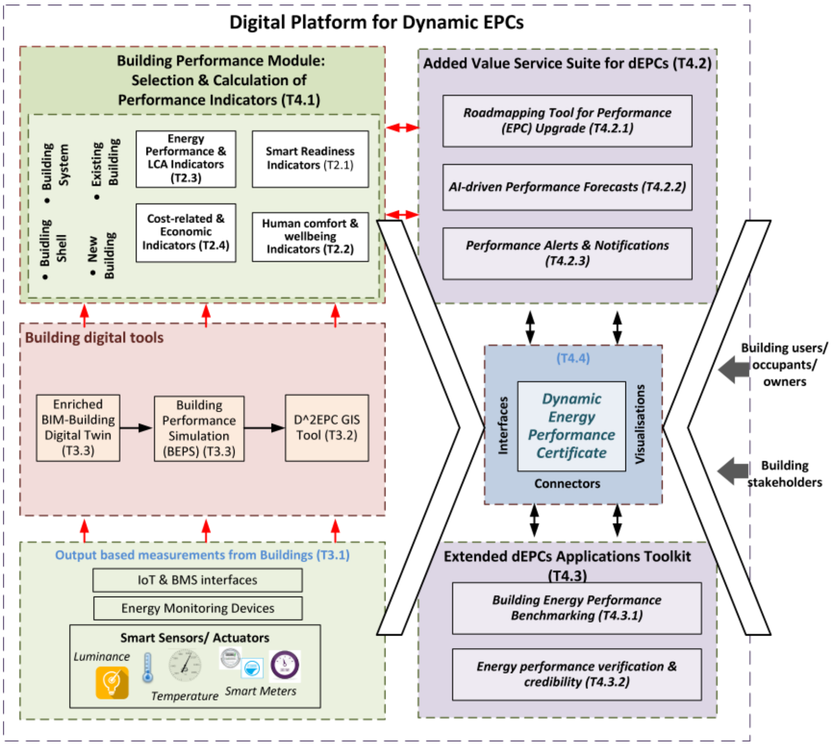

Figure 1. The Extended dEPC Applications Toolkit within D^2EPC [1]

2.2 Literature Research

The design process of the modules residing in the Extended dEPCs Applications Toolkit has been based on wide desk of research performed on data quality and network monitoring tools, as well asclassification and benchmarking processes. The results of the research are presented in the next sub-sections.

2.2.1 Research in Energy Performance Benchmarking

2.2.1.1 Current Scene in Building Benchmarking

Benchmarking is the enduring comparison of processes, to close the gap to the best-performing entity systematically [2]. So the task is to define "best performing" and quantify a value to be compared to. One possibility is to work with quantiles and compare the existing values with the 1% or 10% quantile. However, it can also be decided to compare the energy demand of a building complying with the latest building code and to the average [3].

There is criticism about the efficiency of asset-based EPC, pointing to prebound and rebound effects. It was found that 'there is very little difference in actual average consumption for households across the EPC spectrum' [4]. Based on the results in [4], the Energy Performance Gap (EPG) - i.e., the deviation between the predicted energy consumption during the design stage of a building and the measured consumption during the actual operation- was inversely correlated with energy efficiency. More specifically, higher energy use (or higher EPG) was associated with energy-efficient buildings while inefficient buildings presented lower energy use (lower EPG). The main factor that causes these discrepancies has been identified as the occupant's behaviour which plays a determining role in the building's actual consumption.

To eliminate this type of influence in the building classification, the operational rating should be considered, which involves actual building measurements. However, the tenants' behaviour is not always homogeneous, provided that a multitude of factors (e.g., thermal comfort, insufficient building insulation etc.) might trigger increased energy usage. For this reason, input from more than one normalized metric should be considered (e.g., as per the SRI framework, Human Comfort etc.)

There are two options for EPC rating. One uses absolute values and the other uses those of reference buildings for defining EPC classes. Thus, there is embedded benchmarking in both approaches, while in the second one, more relevance is given and D^2EPC is centered around. Furthermore, it is possible to have a twofold approach [5, 6, 7] as shown in Figure 2.

1. Compare to the energy demand of a building complying with the latest standards
2. Compare to the average of the existing stock.

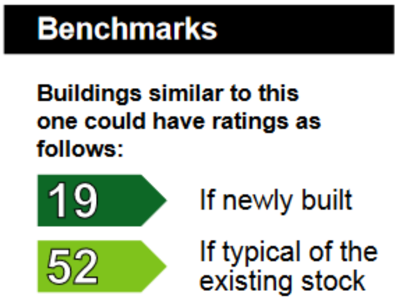

Figure 2 Benchmark as in UK's EPC [3]

2.2.1.2 Research in Benchmarking Approaches

In contrast to conventional statistical or simulation models, data mining techniques are combined with building data characteristics to address the fundamental issues with building energy benchmarking. Sensitivity analysis is taken as a feature selection problem and building grouping is achieved via clustering. Numerous data mining techniques were implemented and conducted in four stages: data cleaning and statistical analysis, sensitivity analysis, building energy classification and model performance evaluation. To determine which building and energy system factors have the greatest impact on energy use, the feature selection algorithm RF-RFE is used and identification of comparable buildings is made using the k-prototypes clustering algorithm.

Another approach is presented in [5], where data mining techniques are used to create an energy performance benchmark for office buildings. The K-prototypes method is employed to classify buildings and a wrapper model based on regression analysis for feature selection. The key concept is to group the structures containing mixed-type data (both categorical and numerical) and construct benchmarks within each group based on the relative importance of each structure resulting in eight different kinds of energy benchmarks for office buildings, one for each cluster and validated using Adjusted R-squared.

In [6] a benchmarking approach is chosen that takes the least amount of input data. A 10-100 scale was added as a rating system directly proportional to energy efficiency. The benchmarking results are organized in a table called “benchmarking table”. As a higher cut-off, they utilized an EPC value of 500 kWh/(m^2a), which corresponds to class H for all the building clusters taken into consideration. Any EPC that was higher than this one was removed from the calculations for the fit distribution because it was deemed to be an out-of-scale outlier. For fitting distributions and construction of the benchmarking tables R programming language was used, which is not demanding in computational resources and is simple to implement in spreadsheet-like tools as well.

Finally, in [7] a systematic development process of whole-building energy models as performance benchmarks for retrofit projects is presented. Regression methods of energy benchmarking used rely on statistical models developed by using an existing data set (from utility data and on-site measurements), to find potential links between a dependent variable (e.g., utility bill) and some independent variables (e.g., weather data, occupancy patterns, operational schedules). The second goal of this approach is to characterize dominant factors or significant determinants of energy use (via sensitivity analysis). The use of this model explained the correlations between climate-adjusted energy use intensities and a few explanatory building characteristics such as building age, occupancy patterns and schedules, HVAC (heating, ventilation, air conditioning) type, and lighting equipment and controls.

2.2.2 Research in Network Monitoring Tools

Generally, the term network monitoring corresponds to a system that includes the appropriate software (and hardware) components that allow for tracking a variety of aspects related to the network and its operation. Such aspects can be the traffic, utilisation of bandwidth, or the status of several devices or sub-systems that constitute the overall network [8]. A network monitoring tool enables the timely detection of connection failures/disruptions, device malfunctions, or any other type of issue that widely occurs in data flow and might lead to system delays or even shutdowns.

In today’s IT systems, the utilization of a network monitoring tool offers a variety of benefits, guaranteeing a smooth, accurate and faultless information exchange among software components [9]. More specifically:

- A monitoring tool enables the network administration to forestall the probable outages that may happen in a high-complexity network. It provides the necessary visibility for the early locating of an outage, prior to the generation of any bottlenecks to the system.
- In cases when the system is down, network monitoring significantly facilitates problem-solving as it provides invaluable information all the way to the bottom of the issue. Live network maps and performance metrics are utilized to save as much time as possible for successful network crisis management.
- A well-organised network monitoring yields notable added-value for the IT personnel and the enterprise as a whole. Immediate access to the source of the issue saves significant amounts of troubleshooting and, as a result, this staff time is freed up for the completion of day-to-day

tasks and projects or further business development. Ultimately, this time-saving is translated to a speedy return-of-investment of the purchased tool.

- In the age of information, an increasing number of devices (e.g., IoT) are being deployed to all types of commercial, industrial and residential buildings. Moreover, modern services require internet-based communication to ensure remote access. Consequently, the IT environments are growing in size and the networks are gradually becoming more complex. Reliable monitoring tools are considered mandatory, as the systems are rendered susceptible to performance fluctuations from increased complexity and internet dependency.
- The network monitoring tools can also act as a stepstone for the first level of system security as they provide insight into its normal operation. In cases when all devices are up and running and no spikes in traffic levels are recorded, a baseline behavior can be inferred for the standard performance of the network. Any deviation from the baseline operation could be an indication of a security threat.
- The majority of network monitoring tools grant access to historical data (e.g., log files). Those can heavily contribute to the assessment of the installed equipment regarding its performance. As an example, trends analysis can be performed in order to ensure the current infrastructure meets the business needs or, alternatively, updates should be introduced in the system.

In IoT systems that include massive information flow among a large number of deployed devices and cloud infrastructure, the integration of a network monitoring concept is extremely valuable. An IoT system comprises various appliances utilized in both industries or residences. These appliances can be metering, sensing or actuating instruments that do not differ in essence from a conventional computer. To get maximum value out of them, they need to operate seamlessly at peak performance for the vast majority of the time. Based on the IoT system's nature, it is quite unrealistic to allocate human resources for constant checking on the operation of the numerous devices. An automated monitoring tool can undertake this procedure and alert the involved users when a malfunction or communication disruption occurs within the network. From then on, certified personnel can act upon the issue via remote access.

Nowadays, there is a plethora of tools tailored to monitor IoT networks. Based on the findings of [10] tools such as Domotz[1], splunk[2], Datadog IoT Monitoring[3], senseye[4], skyspark, [5]TeamViewer IoT[6], AWS IoT Device Management are highly recommended due to the user-friendliness and functionalities they offer. However, these services are not open-source and expect a paid membership to activate (apart from a short free trial period).

2.2.3 Research in Data Quality

The term data quality has numerous definitions. In general, quality data are considered those that can be utilised for various intended uses (operation, decisions, planning) provided that they correctly represent the real world in regards to the physical quantity they measure.

[1] https://www.domotz.com/?utm_source=ctech&utm_medium=review&utm_campaign=iot-device-monitoring

[2] https://www.splunk.com/en_us/data-insider/iot-monitoring.html?301=/en_us/iot.html

[3] https://www.datadoghq.com/dg/monitor/iot/

[4] https://www.senseye.io/

[5] https://skyfoundry.com/

[6] https://www.teamviewer.com/en/iot/

According to ISO 8000-8 [11], data quality is classified into three fundamental categories. The **syntactic** quality, the **semantic** quality and the **pragmatic** quality. The first category concerns the level of data conformity to the specified syntax. The second one describes how well data are matched to the content they represent. Lastly, the third category refers to the extent to which the recorded data are fitting, relevant and valuable for the objective they were initially recorded for. In Figure 3[7], the three previously mentioned categories are presented in tabular form, along with the main goal, properties and measures associated with each category.

Semiotic Level	Goal	Properties	Measures
Syntactic Data Quality	Consistency	Syntax, rules, symbols	e.g. % of inconsistencies in data
Semantic Data Quality	Comprehensiveness and accuracy	Completeness, meaningfulness, correctness, unambiguous	e.g.% of errors in data sample
Pragmatic Data Quality	Usability and usefulness	Timeliness, conciseness, accessibility, reputability, understood	e.g. time of update, user surveys, influence on decision-making and outcomes

Figure 3. Fundamental categories of data quality

ISO 25012 [12] delivers a general data quality model applicable to any information system which stores data in a structured way. The standard introduces several dimensions describing the overall quality of a dataset segmented into two main classes, inherent and system-dependent data quality. Inherent data quality concerns the intrinsic potential of data to meet specified requirements and is expressed via the said dimensions. More specifically:

- **Accuracy** which concerns whether the data values recorded for an object or a metric are correct
- **Completeness** which addresses the level of comprehensiveness of a dataset.
- **Consistency** which examines whether the same data kept at different places within a system are identical.
- **Credibility** (or Validity) which covers the level of trustfulness of a dataset
- **Timeliness** which corresponds to the speed of data dissemination

Figure 4 sums up the aforementioned dimensions and presents indicative examples per case.

[7] http://wiki.doing-projects.org/index.php/Data_Quality_Management

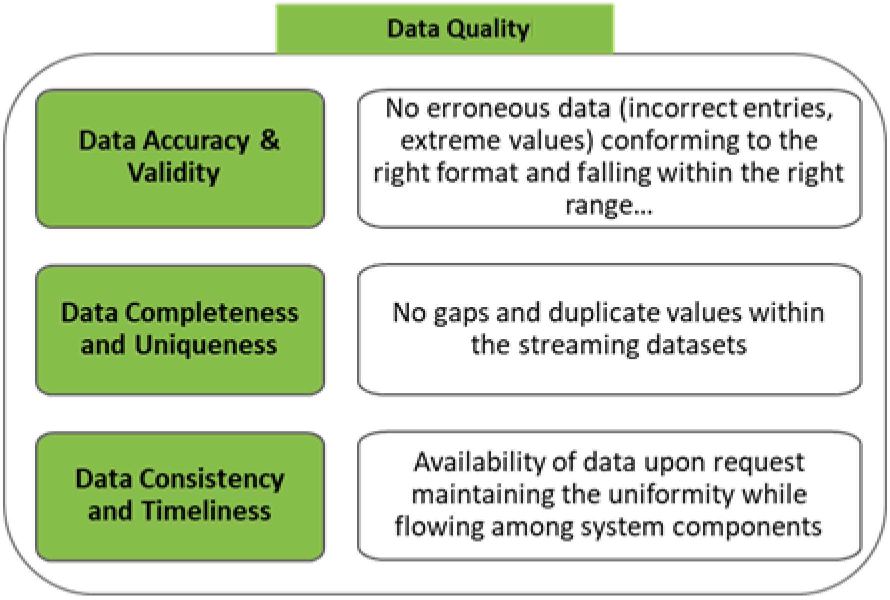

Figure 4. Inherent Data Quality Dimensions

The other data quality category mentioned in ISO 25012 is system-dependent. It is related to the level of achieved quality through a computer system under certain conditions. The respective dimensions are:

- **Availability** which is related to sufficient storage for the extracted data and accessibility by authorized users.
- **Portability** which is the ability of data to be recorded, updated or removed from one system to another
- **Recoverability** which regards a system's ability to restore data that have been lost, accidentally deleted, corrupted or made inaccessible

In the present day, there are numerous propriety and open-source data quality tools available. The main purpose of such tools is to contribute to the overall data management of an enterprise by delivering specific functionalities. Some significant functionalities are mentioned below:

- Perform checks in the data flows to identify and remove errors, typos or redundancies in an automated way
- Apply cleansing algorithms for the detection and elimination of any extreme values present in the datasets (i.e., outliers)
- Maintain logfiles that include details on identified errors (and the corresponding timestamps) within the streaming datasets
- Calculate specialized performance indicator and allow for the monitoring of the systems' progression in regards to the quality of the recorded data
- Provide visualizations to the end-user towards facilitating the data management process

2.2.3.1 Data Quality in IoT

Regarding the Internet of Things, the IoT systems are typically prone to low-quality data due to various causes. Indicatively, the multiple data sources, vast data volume, data type variations (structured, unstructured, high-dimensional etc.) and the growing scalability of IoT systems significantly increase the probability of recording bad-quality data.

In [13], a three-layered structure is utilised to showcase the DQ problems and challenges in IoT. In a high-level representation, a conventional IoT system comprises the device layer, the processing layer and the application layer. The device layer includes the metering, sensing and actuating IoT devices deployed in the physical world (buildings). The network layer is responsible for the acquisition of the IoT data with the utilisation of several specialised protocols, allowing for interoperable communication. Finally, the application layer contains several applications that undertake the processing, analysis, storage and streaming of the collected datasets to other software components that deliver services to the end-users. Based on the feedback of many researchers dealing with IoT data quality, bad data problems can be generated in every abovementioned layer. Faulty installations, incorrect placements, vandalisms (device layer), constraints in network resources, connectivity issues (network layer) and data processing (application layer) can be sources of invalid, incomplete or inconsistent data.

The most common data errors occurring in sensing/metering devices correspond to anomalies, missing values, constant values, stuck-at-zeros, noise and drifts. Typical anomalies are the extreme values within a dataset (outliers) that normally stem from temporary device malfunctions. Meanwhile, constant values and stuck-at-zeros are commonly correlated with malfunctioning or disconnected devices. Missing and noise values can be generated by unstable wireless networks, power failures or environmental interference (blockages, walls, weather etc.). Lastly, the drifts are readings that deviate from the true value over time due to the degradation of sensing material which is an irreversible chemical reaction.

Figure 5 presents a series of affecting factors, indicative examples and error types occurring in each layer of an IoT structure.

Layer	Affecting Factors	Examples	Error Types
Perception layer	• Sensors • Environment • Security • Privacy • Network	• Battery problems • Precision limitation • Mechanical failures • Bad weather • Device upgrades • Unstable network • Non-encrypted	• Missing value [66] • Incorrect value
Network layer	• Network • Environment • Security • Privacy	• Unstable network • Bad weather • Security attacks	• Missing value • Incorrect value
Application layer	• Streaming processing • Security • Privacy	• Manually errors • Obsolete schema definition • Streaming operators	• Wrong schema definition • Misplaced value • Broken join relationship • Misplaced column values • Missing record

Figure 5. Data Quality Threats per layer

2.2.3.2 Data Quality in EPC Issuance

As dictated by metrology [14] (i.e., the science that studies measurement), a meaningful measurement needs to be extracted based on common standards that deliver the approved methodology to be followed for different setups. In Europe, the measuring instruments directive MID defines the regulative framework. Within the directive 2004/22/EG for metering energy flows MI-002, M-003 and MI-004 are relevant.

For the issuance of an operational EPC, beyond the monitoring of the data flows and credibility of measured physical entities, there is a need for validating the data in terms of EPC input. Provided that a multitude of different metering devices are engaged in the EPC calculations, the acquired data are prone to generating meaningless or erroneous results.

The errors from metering setups can be segmented into avoidable, systematic and random. Avoidable errors are those related to the time stamp of the measurement, encoding analog information, interpreting strings with floating point data or any other error generally occurring when transmitting data electronically. Systematic errors are the result of an improperly calibrated apparatus that introduces the same one directional bias into all of the measurements. Lastly, random errors are difficult to detect and lay in the working principle of the meter, possibly exposed to random environmental influences.

The D^2EPC-relevant metering setups are the heat, gas and electricity meters utilised for consumption measuring and billing. Regarding heat meters, the calculation of the resulting energy involves temperature and mass flow measurements. The respective measurement errors might originate from a detached or wrongly-positioned sensor, signal digitization or calibration. For the gas meter, only the volume flow is measured without any measurement-based corrections for temperature or pressure. Furthermore, another influencing factor is the gas quality which is also affecting the correctness of the result if given as energy. Lastly, for the electric meters it is important having enough measurements per small intervals, if current and voltage are out of phase.

Generally speaking, the following problems may occur when meter data is taken on a monthly basis:

- The meter may have low power (smart gas meter, heat meter), so the measurements are inaccurate
- The communication channel might have problems
- The meter might have been exchanged (and the old value before exchange and values of the new meter before installation has not been recorded properly)

2.3 D^2EPC Energy Performance Benchmarking Module

Within T4.3.1, a classification mechanism is delivered to benchmark the buildings under study based on configuration data and KPI results. This mechanism steps on data-mining techniques to enable the categorization of buildings taking into account metrics linked to the building's operation and human-centric features. The main purpose of the module is to act as a basis towards informing future dynamic EPC users whether they meet the set performance criteria or not and which paths should be followed for performance improvements.

2.3.1 Building Energy Performance Benchmarking within D^2EPC Architecture

The Building Energy Performance Benchmarking (EPB) module comprises the necessary sub-components that realise the building's classification and enable its comparison with other buildings in regards to specified metrics. The first sub-component corresponds to the Classification Tool, which includes the algorithms responsible for data mining based on various traits regarding both infrastructure and temporal characteristics. The second sub-component residing in the EPB is the benchmarking tool which steps on the defined classes (from the classification tool) to evaluate the performance of different buildings based on determined reference values.

EPB communicates with the appropriate components within D^2EPC to extract the necessary information and deliver the calculated results. More specifically, it interfaces with the Digital Twin to retrieve the building information as well as the project's common Repository to obtain KPIs, weightings and reference values. Finally, the component provides the benchmarking results to the D^2EPC Web Platform while any updated reference values are stored in the project's Calculation Engine. Figure 6 presents a functional diagram that includes the entirety of the BEPB's interactions.

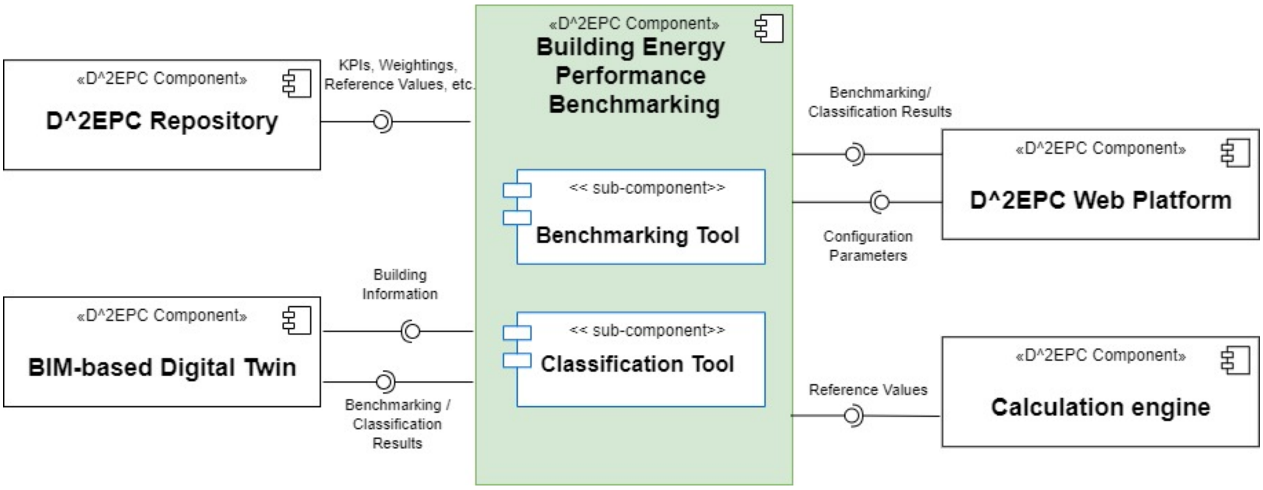

Figure 6 Building Energy Performance Benchmarking Functional Diagram [1]

2.4 D^2EPC Energy Performance Verification & Credibility Module

D^2EPC project aims at delivering a new-age performance certificate focusing not only on the building's expended energy but also on other aspects related to its sustainability, indoor ambient conditions, smartness and overall operation. To achieve this, a vast amount of information needs to be collected, analysed and circulated among a multitude of software components. Therefore, every piece of data requires to be gathered and distributed, guaranteeing their syntactic, semantic and pragmatic quality provided that credible information is mandatory for EPCs. The issuance of an energy performance certificate includes contracting; thus, high-quality data empowers the mutual trust between involved parties.

The overall information flowing from the project's demonstration cases to the system's modules can be segmented into two main types of elements. The static elements represent the building's configuration (location, usage, size, typology, materials etc.) and the dynamic elements correspond to the data recorded by the deployed sensing and metering devices (i.e., energy and environmental metrics).

Within T4.3.2, a component is delivered to undertake the verification process for the entirety of dynamic data captured by the IoT infrastructure in the D^2EPC pilots and guarantee the reliability of the data collection. The Energy Performance Verification and Credibility (EPVC) module is designed to constantly monitor the status of deployed devices and check specific data quality features in an automatic and continuous manner.

EPVC is a composite component that comprises two separate sub-components, the Network Monitoring Tool and the Data Quality Tool. The former is responsible for receiving and analysing the operational status of the IoT devices installed locally at the pilot sites. The latter is responsible for verifying the qualitative and quantitative reliability of the collected data defining their suitability to be used by other project components. Lastly, another sub-module, the Verification & Credibility UI, will be delivered to notify the end-user in the D^2EPC platform. Equipment malfunctions and communication disruptions at the installed IoT devices as well as identified problems in the collected data, will be presented via alerts.

2.4.1 D^2EPC Network Monitoring Tool

According to the research mentioned in 2.2.2 as well as the project requirements described in D1.7, a list of desirable characteristics (Figure 7) has been compiled indicating where the focus for the implementation of the D^2EPC Network Monitoring Tool is gathered. The most important functionalities to be an integrated concern the alerting mechanism, the representation of the devices residing in the network and the scalability of the tool.

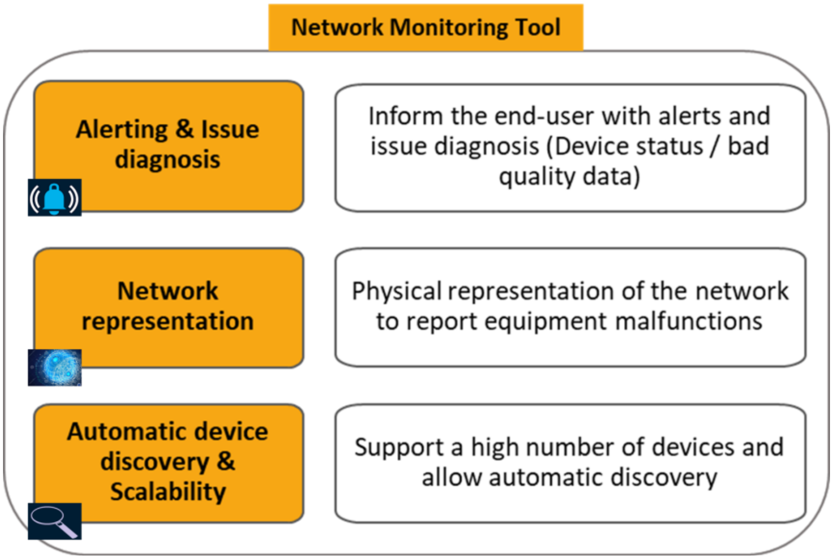

Figure 7. D^2EPC Network Monitoring Tool desired functionalities

Hypertech has already developed and integrated into its solution a web-based monitoring tool delivering a representation of the deployed devices and the IoT gateways to the user. The purpose of this tool is to provide the necessary information to the pilot partners (access is only provided to authorized persons) in regards to the issues that might occur in the deployed IoT devices. The tool is frequently updated and presents the status of the entire IoT equipment per prosumer (i.e., pilot site). Therefore, the personnel in charge per pilot is able to monitor the installed equipment, identify any connection losses and swiftly act towards restoring the communication per device. It's worth noting that Hypertech's monitoring tool only reports information about the status of the devices and not the quality of the collected data. The respective functionality is integrated in the Data Quality sub-component of the EPVC, described in the next sub-section.

In Figure 8, the main dashboard of the monitoring tool is provided. Starting from the left, a list of the available prosumers (within Hypertech's solution) is presented, along with the overall status of the corresponding network and the number of devices that remain active. In the upper middle and right part of the dashboard, the percentages of active IoT gateways and devices in total are offered via pie charts. Finally, an interactive map is also delivered to the user indicating the location per prosumer (in a GDPR-compliant manner).

Each user can further dive into details related to the status of the network of interest by choosing a distinct prosumer id. Figure 9 presents the prosumer-specific dashboard, unveiling the functionalities of the tool. In the upper left, the user can be informed about the IoT gateway status as well as the percentage of active devices deployed in the respective pilot. Below, a status history notifies the user about the latest status updates in the network and the (indicative) time they occurred. Lastly, the dashboard offers a detailed list of the deployed devices per zone and provides information regarding their status and latest update.

In general, three different cases can be identified:

i. The IoT gateway and the deployed IoT devices are indicated with the green color. In this case, everything is up and running
ii. The IoT gateway is indicated with the red color. In this case, the communication is completely lost with the deployed IoT devices in the pilot and immediate actions need to be taken in order to restore the connection
iii. The IoT gateway is indicated with green color while some IoT devices are indicated with red color. In this case, a separate issue per the OFFLINE device needs to be identified and distinct actions should be considered.

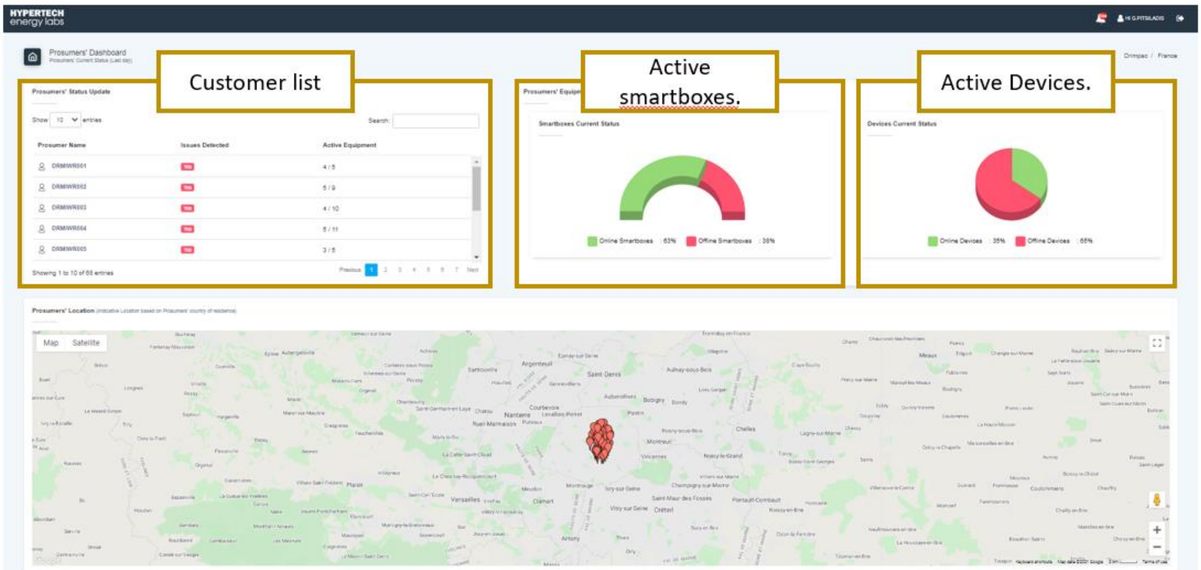

Figure 8. D^2EPC monitoring tool main dashboard

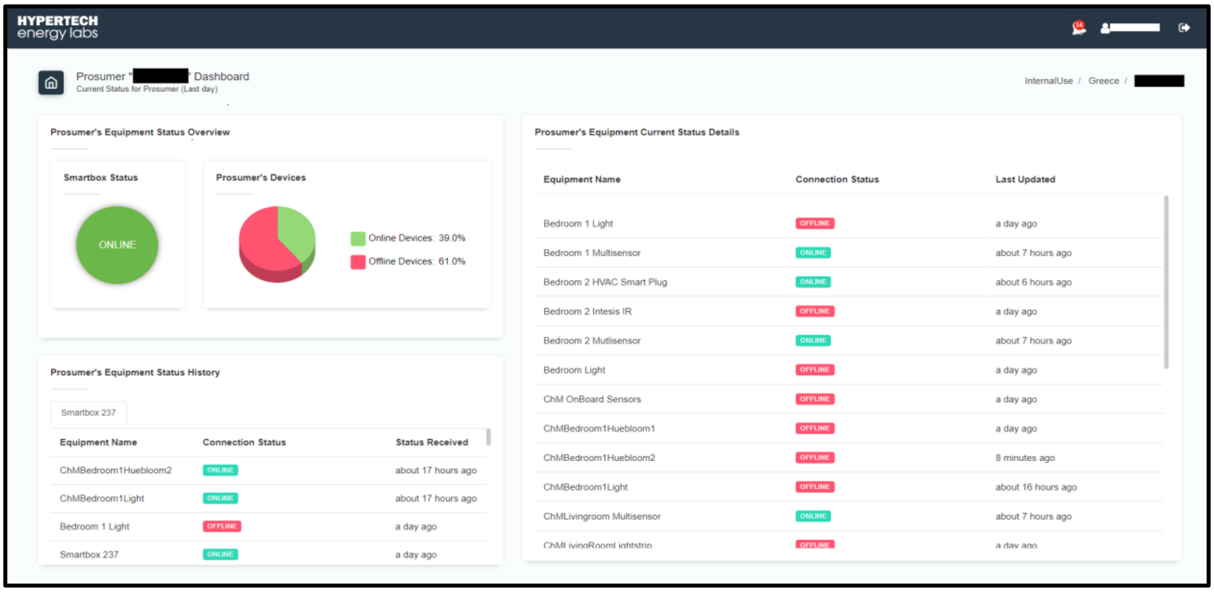

Figure 9. Prosumer/pilot site dashboard

2.4.2 D^2EPC Data Quality Tool

Based on the findings of WP2 and WG2, D^2EPC's work package 2 includes the works conducted towards the definition of the project's key performance indicators. Meanwhile, Working Group 2 has been assembled to deliver the framework for the building's operational rating. The outcome of WP2 and WG2 has led to a set of of dynamic data requirements expected to be satisfied for the overall project rollout. The main purpose is to obtain the appropriate information for the calculation of specific performance indicators related to the building's operation and indoor conditions. To satisfy the abovementioned requirements, IoT equipment has been deployed in the project's demonstration cases to deliver various measurements of energy consumption and ambient conditions metrics.

The large number of installed devices increases significantly the overall system's complexity. Each piece of deployed equipment needs to be registered along with a series of attributes regarding the corresponding building, space and device type (static configuration). Furthermore, the measurements from IoT devices (usually more than one type per device) are recorded in a time series format in order to maintain the sequence of events (dynamic data). Therefore, a robust IoT system should undertake the streaming of the combined static and dynamic elements.

D^2EPC's Information Management Layer (IML) component steps on the well-established Hypertech's solution, which has been designed to satisfy the IoT system requirements towards a secure, speedy and scalable information flow. IML is composed of both software and hardware components. In brief, the three main IML parts correspond to the i) the Wireless Sensor Network (WSN), which includes the deployed IoT sensors and meters in the pilot buildings, ii) the IoT Gateway, which is a raspberry-based computing device that collects the data captured by the WSN and iii) the IML Cloud which gathers and processes the acquired information from the IoT Gateways and further streams it to other system components. Concerning the D^2EPC case, the majority of demonstration cases are already equipped with rich IoT infrastructure covering a large portion of the D^2EPC requirements. Consequently, the IML Cloud is adjusted to interface with the respective web platforms that collect pilot data, without the usage of IoT Gateways.

IML is based on a concrete data model specially designed to ensure the syntactic, semantic and pragmatic quality of data. Thus, it manages to extract and distribute the time series datasets in a consistent, comprehensive and timely manner. However, communication disruptions (e.g., power outages, internet disconnections) or other malfunctions are highly likely to occur. The overall quality of the collected data is heavily susceptible to any type of operation disturbances. Data gaps or extreme values render a dataset inadequate to be used as input into calculation methodologies. For this reason, Hypertech's IML solution is equipped with state-of-the-art algorithms able to detect and treat discontinuities and inaccuracies. In ANNEX C of D3.4 [15], the integrated algorithms are presented in detail in regards to the utilised cleansing and imputation techniques.

Under the works of D^2EPC, the IML component is enriched with a brand-new Data Quality Tool which extends the data quality assessment. Beyond the cleansing techniques, additional validation is applied to the streaming datasets to deliver even more reliable data for the issuance of the dynamic EPC.

The tool is designed on the basis of specific applied checks (adapted to the nature of the project's metrics) which evaluate various features relevant to the type, shape and range of the collected data. More specifically:

- **is_shape**: Based on the type of communication (Restfull or event-based) with each of the pilot sights, a certain shape of the incoming dataset (index, number of columns, number of rows) is expected per data source (i.e., sensors/meters). This check evaluates whether the shape coincides with the anticipated one.
- **only_positive_values**: As dictated by the nature of the D^2EPC-relevant metrics (energy, power, temperature, humidity, illuminance, air quality), no negative values should be delivered by the IoT measuring devices. A negative value indicates a device malfunction or faulty installation that needs to be addressed as soon as it is observed.
- **is_monotonic**: Apart from the positivity of the acquired data values, there are metrics that describe cumulative quantities (e.g., the cumulative energy consumption). In this case, the values are expected to grow sequentially meaning that the previous measurement should always be smaller than the current one.
- **Is_occupied_space**: In cases when access to occupancy data of a space is granted, several measurements can be further evaluated based on the metric type. Indicatively, the power consumption of an unoccupied space should be maintained at baseload levels provided that no person is present to trigger any energy-consuming actions. If there is no access to occupancy data, the building's occupancy will be inferred -where feasible- by the respective operation schedule based on the building's typology (commercial pilots)
- **Is_outside_range**: Although the integrated cleansing algorithms in the IML manage to eliminate the majority of the inaccuracies detected within the data, some values -escaping detection- can still be considered as erroneous. For example, the relative humidity has a range of values between 0% and 100%. A very high (or low) measurement of relative humidity within this range might not be treated as an outlier. Nevertheless, such humid (or dry) indoor conditions are quite unrealistic to occur in real-life scenarios. To tackle this, a baseline value per metric is generated based on previously accepted "healthy" data[8]. From then on, each time a dataset is evaluated in the Data Quality Tool, the received values are compared to the respective baseline values towards inferring their validity.

As described in the previous section, Hypertech's solution includes a Network Monitoring Tool that utilises the operation status of each device and delivers a physical representation of the corresponding network to the end-user. However, within D^2EPC, the datasets extracted from the already-existing IoT equipment in the pilots (via interfacing) do not include the operation status of the respective devices as an attribute. In order to derive an indication of the device status, some extra checks are integrated in the Data Quality Tool presented below:

[8] For the validation tests up to M26 of the project, the baseline was generated based on the 24-hourly mean profile of 30 days including accepted historic data. More baseline methodologies will be tested on actual pilot data after the finalisation of the information exchange within the project.

- **is_stuck_device**: This function analyses a chunk of data and calculates the number of consecutive values. If the values are not altered for a specific amount of time, then the sensor/meter is considered stuck
- **is_dead_device**: As analogous to the previous function, is_dead_device calculates the number of consecutive missing values reported from a device and infers its status based on a predefined time interval.

The aforementioned checks provide insight into the device status and can further communicate it to the network monitoring in order to warn the end user whether any of his/her devices is OFFLINE based purely on the feedback derived by measurements.

2.4.3 D^2EPC Data Verification KPIs

The data verification process which takes place in the EPVC Data Quality Tool provides the necessary information towards the calculation of specific Key Performance Indicators. These KPIs enable the monitoring of the IoT Networks progression and the assessment of the overall data quality with the passage of time. In Table 1, the definitions and calculation processes of the indicators that have been considered for integration in the D^2EPC data verification framework are presented in tabular form.

Table 1. D^2EPC Data Verification KPIs

Indicator	Definition	How to calculate
Percentage of Empty Values	Empty values indicate information is missing from a data set.	Count the number of data gaps within a data set and divide it by the total number of timestamps in the period of interest
Deviation from the baseline value	Data values are compared with the respective baseline values defined from validated past data	A baseline is generated based on previous trusted data. Then the percentage of deviation between the actual and baseline value is calculated
Amount of Dark Data	How much information is unusable due to data quality problems?	Look at how much of your data has data quality problems.

2.4.4 Data Verification in D^2EPC System Architecture

For the implementation of the previously mentioned subcomponents, EPVC interfaces with the appropriate data sources as well as other D^2EPC modules responsible for the data storage and alerting mechanism. Firstly, it communicates with the Information Management Layer, which gathers all data extracted from the D^2EPC pilots. After a series of checks performed on the datasets, EPVC streams the processed information to the D^2EPC BIM-based Digital Twin (DT), which corresponds to a virtual representation of the project's demonstration cases. If the data quality is not acceptable, an alert is generated and sent to the Performance Alerts and Notification module which is responsible for connecting and pushing notifications to the D^2EPC platform. In parallel, EPVC forwards the credibility alerts and other related information to the Credibility UI to be presented to the end-user.

Inside DT [16], another data validation component resides, the Input Data Validator. Its main purpose is to confirm the correctness of static elements of data about to be stored in the project's repositories. Those elements are inextricably linked with user input which is a common factor for error generation in a database. The Validator performs tailored checks on the data types and detects any missing element required as input for the calculations of either the asset or the operational-based EPC ratings. The module ultimately delivers a report containing all the fields that are ineligible to pass the validation and prompts the user to provide any missing piece of information directly through the project's web platform. Finally, regarding the dynamic data elements, the Input Data Validator ensures that every single measurement acquired from the IML (after the EPVC checks) is mapped to a unique provided ID that corresponds to a specific sensor or meter installed in one of the D^2EPC pilots.

In Figure 10, a functional diagram is presented, highlighting the interactions between the EPVC and other D^2EPC components as described in the project's architecture [1].

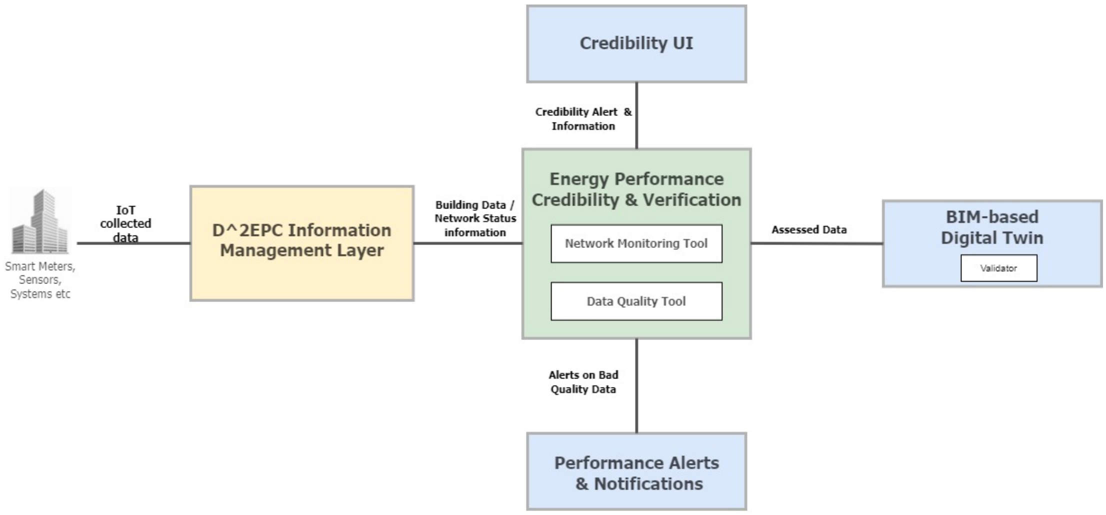

Figure 10. Energy Performance Verification & Credibility Functional Diagram.

Apart from the data verification procedures taking place in the EPVC and DT components, further verifications have been set up by Senercon towards ensuring the harmonisation of the new age EPC. Based on the issues discussed in section 2.2.3.2., the data extracted from energy meters are occasionally deemed inappropriate for operational rating calculations. To tackle this, SEC has been investigating a methodology to detect and eliminate problematic energy measurements on a monthly basis with the usage of degree days correction. Early results have been generated based on heat meter data from demonstration case 5 and are presented in chapter 4, including the components validation. It is worth noting that this type of verification will be integrated into the project's web platform.

3 Extended dEPCs Applications Toolkit - Design and Implementation

3.1 Building Energy Performance Benchmarking - Development Status

In this task, a classification mechanism for buildings will be developed, which in combination with the benchmarking tool will facilitate monitoring the overall energy performance of buildings under study and compare it not only with the performance of other buildings of the same type and specifications but also with a reference building's energy performance of the respective building category. The results produced will refer to normalized metrics as per the SRI framework and facilitate users' decisions on any course of action in order to bring improvements to buildings and maintain or improve occupants' comfort, health and well-being while achieving essential goals concerning energy consumption.

To classify buildings, a proper dataset will be constructed in order to test the most suitable clustering algorithms. The dataset will consist of two parts. One part should contain building metadata, including primary space use labels and the other part data related to heating, cooling, electricity, lighting, and other appropriate domains of the SRI framework.

To continue with, clustering results will be analyzed, and a general report will be composed after post-processing for each one of the clusters. The next step will be to match a building under study with one of the produced clusters and compare its specifications to the cluster's general report in order to deduce useful analytics related to normalized metrics as per the SRI framework. A number of visualization methods will be deployed in order to present comparative results in various forms and to ensure that the user receives insightful combined information in an intuitive way.

Finally, the building under study will be compared to a reference building of the same primary space use category and provide the persons of interest with a report demonstrating the distance from an ideal overall energy performance. More details about the technology stack, functional and non-functional specifications will be provided in the next version of this deliverable, after the first development stages are concluded.

3.2 Energy Performance Verification and Credibility - Development Status

As previously mentioned, the EPVC component: i) communicates directly with the D^2EPC Information Management Layer to retrieve the collected datasets from the pilot IoT infrastructure, ii) performs tailored checks on the streaming data and iii) forwards the assessed elements to the project's components responsible for data storage and analysis.

As of month 26 of D^2EPC, a prototype of the Data Quality Tool has already been implemented and tested on pilot data (indicative results delivered in chapter 4). The tool is developed in the python language exclusively using open-source libraries. As soon as the overall information provision between the pilots and the D^2EPC modules is initialised, the Data Quality Tool will be integrated in the system architecture of the project.

The network monitoring functionalities of EPVC will be provided to the end-user (or any other stakeholder) through the usage of a Credibility User Interface accessed by the D^2EPC Web Platform.

The web-based monitoring tool -described in 2.4.1- has been designed on the basis of Hypertech's end-to-end solution as a plug-and-play service to be delivered to the end-users. In D^2EPC, however, the majority of the project's demonstration cases is already equipped with IoT equipment. The acquired data are communicated to the IML component through defined interfaces. These D^2EPC-specific interfaces with the pilot IoT infrastructure impose modifications on the network monitoring tool, which will be adjusted to match the project's needs.

Beyond the device status (ONLINE/OFFLINE), the Credibility UI will present various information in regards to the overall quality of the streaming datasets (e.g., performance indicators). Furthermore, based on the D^2EPC's alerting system, the user will be informed in cases when there are issues in the collected data (in predefined time intervals) and be able to retrieve additional information concerning the credibility of the flagged data upon request.

4 Extended dEPCs Applications Toolkit Validation

4.1 Validation of the Performance Benchmarking

In order to investigate the benchmarking options, SEC designed a research prototype as a PHP script realizing a parametrized SVG-based frontend. SECs implementation extracted data from its own EPC database, so it can show the typical class for existing stock (only two classes, single family and multi-family homes). For further detailing into subsegments new statistics shall be produced and for future releases, new data field may be introduced. The research prototype shown in Figure 11 presents a histogram on a vertical axis.

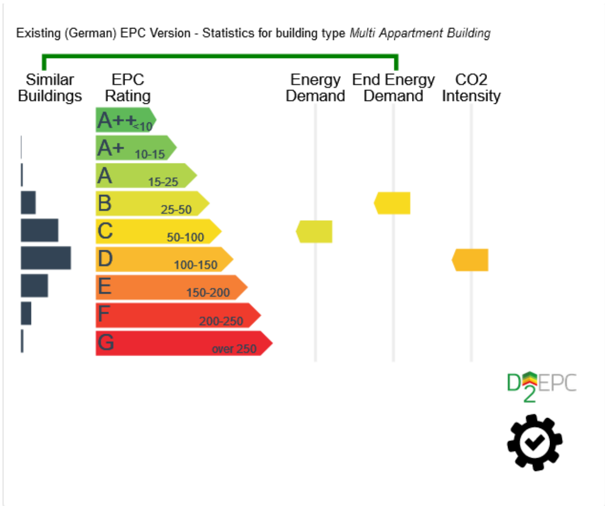

Figure 11 benchmarking example for on-line presentation

The SEC tool allows showing of the histogram for each of the categories. The green bar points to the category. The digital implementation also provides UI interaction to the user (i.e., motion) . The best case after the renovation was sliding in the prototype to show the aim that could be achieved. Additionally, the renovation roadmap will give concrete information on how to proceed. In some countries, for the renovation of buildings, strict standards for thermal quality apply, which are different to the values for newly built houses [17] if a larger renovation takes place. This might be different for the regions. This would not allow for optimization measures to increase the benefit-to-cost ratio. The German GEG additionally requires such efficient renovation steps if the owner of a building changes (comprising heat converter exchange, pipe insulation and insulation towards the roof) [18].

4.2 Validation of the Data Verification Processes

4.2.1 Validation of the Data Quality Tool

As of month 26 of the project, a prototype of Hypertech’s Data Quality Tool has been implemented and tested on data input originating from pilot case 1, i.e., CERTH’s smarthouse (nZEB). The applied tests simulated the actual data provision that will be realised between the pilot and Hyp’s IML component under the works of D^2EPC. More specifically, data acquired by CERTH's Restful API have been segmented into consecutive chunks of energy/power consumption and ambient conditions measurements captured by the nZEB's metering and sensing infrastructure. Subsequently, the data quality checks have been successively performed on the incoming data. It is worth noting that a long-term quality assessment has been carried out -on historical data dating back almost a year- in order to collect sufficient information towards the calculation of the data verification KPIs. Results for 335 days of data acquired from nZEB are presented in Table 2.

Table 2. Verification KPI results from nZEB

Data Verification KPI	nZEB
Deviation from the Baseline Value	0%
Percentage of Empty Values	50%
Amount of Dark Data	51%

4.2.2 Metering Data Validation for EPC Issuance

As mentioned in 2.4.4, a verification process for metering data was set up by SEC, correlating the measurements with the degree days provided by DWD. This method was introduced by Johannes Hengstenberg [19] and is capable of handling also buildings with central domestic hot water production.

The SEC approach used Degree Days from the location of the building acquired via DWD data from the next weather station [20]. This data from 2019 to the end of the last month has not been quality checked.

Figure 12a shows the two steps of the tool. In the first step, the correlation is shown to the assessor and he/she can see which months are lying outside the correlation area. In the second step, he/she can then unselect those months so they are not taken into consideration when calculating the EPC rating.

For heat meter data from Pilot 5, two monthly readings are clearly problematic. In this case months significantly below the regression line are marked as outliers and should be discarded by the assessor (Figure 12b).

Correlation kWh-DD

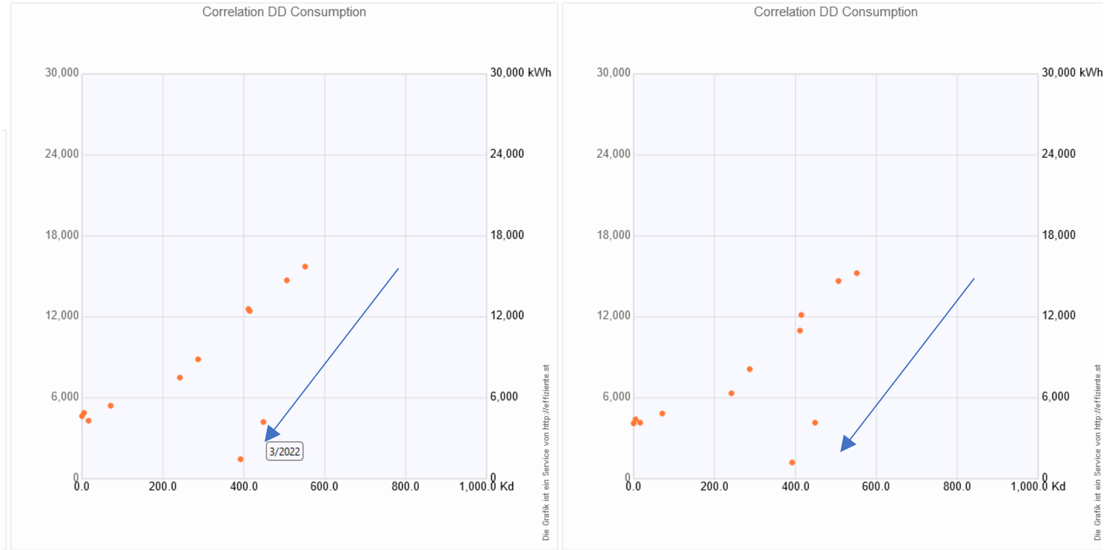

Figure 12a Energy Correlations from meter data acquisition vs. Degree Days

Exclude Months

Exclude	Date	Natural gas	Electric power	Electric power	Solar thermal	Heating and Domestic Hot Water	Heating and Domestic Hot Water	Occupany %	Degreedays	Degreedays Factor	ID Weather Station
☑	4/2021	8,221.06	0.18	2,187.41	1,516.78	1,495.91	1,251.70	90	392.10	2.10	430
☐	5/2021	7,395.47	7.78	1,882.67	1,888.95	7,546.45	6,339.55	90	242.90	2.13	403
☐	6/2021	4,318.67	24.00	242.74	2,734.04	4,905.12	4,444.08	90	5.10	0.18	403
☐	7/2021	4,800.52	73.16	0.66	2,392.67	4,661.44	4,116.46	90	0.00	0.00	403
☐	8/2021	5,556.89	128.04	2.92	1,852.07	4,337.06	4,188.12	90	16.20	0.68	403
☐	9/2021	7,221.33	83.64	118.16	1,341.21	5,463.16	4,886.00	90	72.40	0.95	403
☐	10/2021	13,656.22	10.15	33.90	1,296.45	8,869.87	8,151.20	90	288.00	0.96	403
☐	11/2021	21,003.88	17.69	17.99	95.60	12,585.09	11,005.49	90	411.60	0.87	403
☐	12/2021	27,893.41	19.61	43.44	0.00	15,738.34	15,260.63	90	552.00	1.13	403
☐	1/2022	23,223.43	2,621.45	36.53	94.22	14,720.25	14,665.82	90	507.00	0.86	403
☐	2/2022	14,299.56	8,162.54	60.44	332.07	12,471.65	12,168.78	90	414.70	0.73	403
☑	3/2022	5,026.50	2,504.22	20.06	493.97	4,246.51	4,168.01	90	449.50	0.96	403

Figure 13b Excluded months after correlation

The arrows show measurements lying way below the expected curve approximation, indicating that the measurements might not be taken for the full month. If the amount of data pointsa is not sufficient after excluding several months, an EPC cannot be computed. The allowed deviation from the minimum correlation can be assumed and the process automated, but the final decision should be with the assessor. SEC tested the operational EPC prototype with the following data:

- CSV download from the energy monitoring portal for Pilot 5 stating energy metered in each month
- Online Service of DWD for degree days

5 Conclusions

The first version of D4.3 provides insights on the works conducted -up to M26- towards the design and implementation of the modules residing in the Extended dEPCs Applications Toolkit. Starting from the literature review, the document highlights the current status of benchmarking approaches and further focuses on the functionalities of modern network monitoring tools as well as the data quality assessment as performed in the present day.

Regarding the Energy Performance Benchmarking module, the report presents the main operation and properties of the included Classification and Benchmarking Tools, as described in the project's architecture. Initially, special reference is made to the data input of the clustering algorithms, which will consist of building metadata (i.e., primary space use) as well as attributes built upon the SRI domains. The produced clusters act as a basis for the building categorisation. More specifically, each of the D^2EPC demonstration cases is expected to be ascribed to a cluster to enable its comparison with buildings of similar specifications. Furthermore, the building under study will be compared to a reference building -with the same primary space use- and a report will be generated demonstrating the distance from an ideal overall energy performance.

Concerning the Energy Performance Verification and Credibility module, the two tools materialising the desired services are the Network Monitoring and Data Quality Tools. The Network Monitoring Tool steps on Hypertech's solution, which has already developed a scalable and secure web application that provides a physical representation of the deployed IoT devices along with their operation status. Meanwhile, the Data Quality Tool steps on open-source tools and modules to perform tailored checks on energy metering and ambient conditions data. A set of key performance indicators is further incorporated into the EPVC to enable the monitoring of the system's progression towards the overall quality of provisioned data.

In the second version of the deliverable D4.7, following the maturity of the implementation of interacting components, the finalised versions of the modules constituting the Extended dEPCs Applications Toolkit will be documented. In the EPB case, the selected data input, clustering algorithms and benchmarking processes will be thoroughly described. Moreover, indicative examples of comparative results will be presented in the validation section based on the utilised visualisation methods. In the EPVC case, any developments or modifications imposed on HYP's monitoring tool to match the project's specifications and needs will be delivered. In addition, the outcome provided to the user via the Credibility UI based on the operational status of the deployed IoT devices and the data quality assessment will be included.

Finally, the second report will be enriched (chapter 3) with i) sequence diagrams highlighting the components' interactions and information flows ii) the overall technology stack used (tools, libraries, licenses) and iii) functional and non-functional specifications and other interfacing documentations.

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