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RESPOND

DEMAND RESPONSE FOR ALL

Integrated Demand REsponse SOlution Towards Energy POsitive NeighbourhooDs

WP6 Validation and replication of project results

RESPOND validation methodology

D6.1 RESPOND validation methodology

The RESPOND Consortium 2019

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EXECUTIVE SUMMARY

Task 6.1: The aim of this task is to define RESPOND validation methodology able to provide an assessment of project results and related use cases from the perspective of energy/cost saving, carbon emission reduction and economic sustainability. The activities of this task will be based on the outputs of WP1 (delivering relevant KPIs). Concepts of IPMVP protocol for performance measurement and verification (ISO/DIS 17741), with ongoing EU initiatives such as eeMeasure ICT PSP methodology for energy saving measurement will be highly respected in this regard. Furthermore, this task will define a set of criteria applicable in Task 6.2 to test the whole RESPOND system and its components. In particular, it will define the data to be collected or measured and design the means how to effectively collect it per component in order to reach the users' requirements defined in Task 3.1 and assure the user acceptance considering system performance, indoor (thermal) comfort, functionality, usability, security and safety. Benchmarking techniques will be devised to qualitative evaluate the technical achievement and the level of satisfaction. The output of this task will be a harmonized validation methodology able to clearly provide an assessment procedure for the application of RESPOND solution to other buildings and infrastructures.

Purpose:

The purpose of this document is to address all the Demand Response actions of RESPOND project and describe the validation methodology. The main inputs coming from previous WPs are described below:

- WP1: relevant KPIs and DR strategies from T1.1 [1], T1.2 [2] and T1.4 [3];
- WP3: DR strategies from user prospective and existing comfort practices and comfort requirements, mainly from T3.3 [4];
- WP4: demonstration scenarios definition from T4.3 [5].

This document provides a link between RESPOND objectives, Measurement and Verification fundamentals, use cases to be applied within the project pilots and project assessment through KPIs definition.

Business cases will be added on top of the use cases, following the definition and the approach, which it will be fully described in T6.4. A cost-benefit analysis will be performed within the mentioned task in order to provide coherent and sustainable business models, in order to guarantee the address of effective exploitation of the delivered project results.

Key findings and conclusion:

The most common issues for Performance Measurement & Verification assessment is the development of a baseline, which in RESPOND will be addressed with the adoption of the RESPOND demand forecast, monitoring and repository services. These services aim to provide the most accurate estimation of electrical and thermal energy demand at a dwelling and neighborhood levels via predictive models. The models provide a continuous calibrated baseline to obtain higher accuracy

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ABBREVIATIONS AND ACRONYMS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BPL	Baseline profile models
Capex	Capital Expenditures
CEN	European Committee for standardization
COP	Coefficient of performance
DHW	Domestic Hot Water
DR	Demand Response
ECM	Energy conservation measures
EeB	Energy efficient Buildings
EEM	Energy efficiency measurement
EU	European Union
FP7	Framework Programme 7
GDPR	General Data Protection Regulation
H2020	Horizon 2020
ICT-PSP	Information and Communication Technologies Policy Support Programme
IEQ	indoor environmental quality
IPMVP	International performance measurement and verification protocol
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LF	Load Factor
M&V	Measurement and Verification
NAESB	North American Energy Standards Board
NEMVP	North American Measurement and Verification Protocol

OPEX	Operational expenditures
PMV	Predicted Mean Vote
PPP	Public Private Partnership
TRL	Technology readiness level
U.S.	United States

1. INTRODUCTION

Measurement and Verification (M&V) methodologies can affect all the project evaluation. For this reason, a simple and accurate M&V methodology should be provided for an accurate and reliable assessment of project results.

Application of Key performance indicators (KPI) already validated in other ongoing EU Demand Response (DR) projects with technics found in documents as IPMVP protocol [6] and ISO 17741:2016 [7] will be used to analyze the project outcomes.

The RESPOND validation methodology will provide an assessment of the project results and related use cases from the perspective of energy cost/savings, carbon emission reduction and economic sustainability.

Different approaches as quantitative and qualitative analysis, will be able to provide a clear assessment procedure for the project results.

2. RESPOND OBJECTIVES

The main objective of this project is to study the suitability of DR programs in residential sector. The project objectives can be divided in general and specific, which are described on the following sections.

2.1 GENERAL OBJECTIVES

For the perspective of the RESPOND project, the general objectives will ensure the main drivers for realizing the designed Demand Response schemes (DR). This way, to exploit in the best way the use of the energy, RESPOND project will use **COOPERATIVE DEMAND MANAGEMENT TO MAXIMIZE THE USE OF COMMON ENERGY RESOURCES** and ensuring that 100% of common energy resources are being used, respecting comfort requirements of the buildings occupants.

ENGAGEMENT OF BUILDING OCCUPANTS is a fundamental aspect for successfully implementation of DR event. The goal for the RESPOND project is to get 80% of the customers involved in the manual actions and 90% of acceptance in the automated actions.

RESPOND project will deliver an **IMPROVED SYSTEM INTEGRATION AND INTEROPERABILITY**, based in high replicability, flexibility and scalability. The cloud-based system deployment will be at last in Technology readiness level (TRL) level 8 and should have 100% of interoperability with relevant standards. The RESPOND solution should be easily applied in different types of building infrastructures and can be integrated with different home automation systems.

Thinking about Energy-efficient Buildings (EeB), **STRATEGY TOWARDS EEB PUBLIC PRIVATE PARTNERSHIP (PPP)** will be applied. With 6 PPP established during the period of the project at 3 pilot sites, the objective is to serve as an example of partnerships delivering solutions.

Another fundamental objective of the RESPOND project, it is to guarantee an **EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL**. Expecting an economic cost saving of at least 20% under 9 DR use cases in 3 pilot sites.

2.2 SPECIFIC OBJECTIVES

RESPOND will provide **REAL-TIME OPTIMISATION OF ENERGY SUPPLY AND DEMAND SIDE**. A real time optimization for energy utility and demand side will be implemented as a mathematical optimization algorithm develop in FP7 EPIC-HUB project. The algorithm will be scalable and capable of optimization both for the building level and district level. With expected energy savings of 10%.

CLOSING THE DR LOOP WITH OPTIMISED CONTROL ACTIONS will be the action to deploy data and comfort analysis for the building energy parameters. Guaranteeing that the comfort level is appropriate, there will be few user actions contrary to the automated system activities, ensuring the customer acceptance of 90%.

For exploit all the potential of renewable systems, **USER HABITS ADAPTION TO RENEWABLE ENERGY GENERATION** will be implemented for both building and district level, ensuring the 100% of exploitation of renewable energy available.

RESPOND project will use **PREDICTIVE MAINTENANCE TO REDUCE OPERATIONAL COSTS**. With algorithms to determine the operational status of technical systems, the data will be analyzed and monitored in real time. Energy conservation opportunities will be identified and is expected to have savings of 20% in operational costs and 5% longer operational time.

For guarantee **USER COMFORT**, RESPOND will constantly monitor and analyze the comfort parameters, such as temperature and indoor air quality in building units. Using data that comes from the end user, the analysis will be both quantitative (based on prEN1525) and qualitative.

3. REVIEW ON EXISTING M&V METHODOLOGIES

M&V methods and processes are used to measure and verify, in a defined, disciplined and transparent way, the energy savings resulting from planned and defined changes to all or parts of the energy infrastructure of a specific facility or a group of specific facilities. [8]

Figure 1 shows M&V methodologies development over the years.

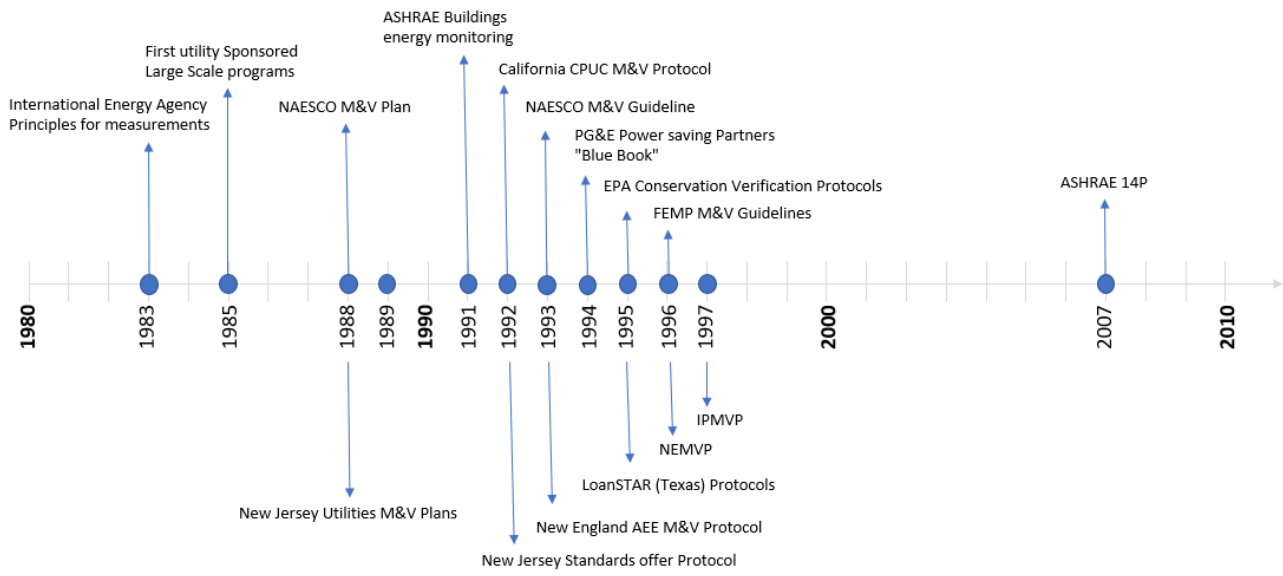

Figure 1 - Historical evolution of M&V Protocols [8]

In early 1994, financial advisors complained that existing protocols were creating a patchwork of inconsistent, sometimes unreliable efficiency installation and measurement practices, which prevents development of new forms of lower cost financing. In 1995, North Americans installed $5 billion in efficiency equipment in their buildings in order to save money and conserve energy and water. The installation covered only a small fraction of the existing cost-effective opportunities for energy savings investments. This way, the U.S. Department of Energy (DOE) began to collaborate with the industry in 1994 to develop a methodology to measure and verify efficiency investments. In 1996 the NEMVP, also defined as North American Measurement and Verification Protocol, was published.

As a result of strong and widespread interest outside of North America, in 1997 a revised version involving the participation of national organizations from twelve countries and individual experts from more than 20 nations was published and called IPMVP – International performance measurement and verification protocol [9]. The IPMVP was originally developed to help increase investment in energy and water efficiency, demand management and renewable energy projects around the world [10].

IPMVP is possibly the most used method of M&V. Although, there are other protocols that share part of the methodology.

In 2012, the European Committee for standardization (CEN) published the "EN 16212:2012 – Energy Efficiency and Savings Calculation, Top-down and Bottom-up Methods". The main objective was to conciliate monitoring methods with energy savings evaluation. It presents a general approach for the calculation of the energy savings in final energy consumption. The two proposed methods, top-down and bottom-up, were designed by European Directive 2006/32/EC on energy end-use efficiency and energy services. The top-down method proposes the estimation of savings and the top-up method is based on actions of end users.

The International Organization for Standardization (ISO) published three standards related to M&V guidance for EMS:

- "ISO 50001:2011 – Energy Management System";
- "ISO 50015:2014 – Energy management Systems – Measurement and verification of energy performance of organizations – General principals and guidance";
- "ISO 17741:2016 – General technical rules for measurement, calculation and verification of energy savings of projects".

In the ISO standards, energy savings are determined by comparing measured and calculated or simulated consumptions before and after the implementation of the Energy efficiency measurement (EEM) with adjustments in relevant variables. It is possible to see the influence of IPMVP in this international regulation.

In 2012, the American Society of heating, refrigerating and Air Conditioning engineers created a document of methodology for M&V focused on more technical aspect, called ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Guideline 14-2002.

3.1 IPMVP

IPMVP contain the following volumes:

Volume 01: Concepts and Options for Determining Energy and Water Savings

In this document the basic concepts are included and the methodology to be carried out is developed. It is, therefore, the most important volume since it includes most of the information needed to apply the IPMVP.

Volume 02: Concepts and practices for improved indoor environmental quality

The objective of this document is to educate building energy professionals about the most relevant aspects of IEQ - indoor environmental quality and provides guidance on IEQ M&V. [11] This document addresses the environmental aspects of indoor air that are related to the design, implementation and maintenance of EEM.

Volume 03:

Provides greater detail on M&V methods associated with new building construction, and with renewable energy systems added to existing facilities [10]. This volume is divided in two parts:

- Part I - Concepts and practices for determining savings in new construction
- Part II - Concepts and practices for determining energy savings in renewable energy technologies applications

IPMVP Core Concepts:

The IPMVP Core Concepts started to be published in 2014. This document defines the commonly used terminology and guiding principles for applying M&V. It describes the project framework in which M&V activities take place, the contents and requirements of adherent M&V Plans and saving reports and the attributes of fully adherent IPMVP projects. [10]

One of the first steps is to define the principles of M&V on which the IPMVP is based. This must be considered by any M&V plan based on this protocol.

Principle	Description
Accurate	The M&V report should be as precise as possible. Always considering the defined budget.
Broad	The savings report must consider all aspects of the project.
Conservative	When estimating numbers, the savings should be underestimated.
Coherent	The analysis must be consistent with different energy efficiency projects. Considering different variables, like energy management professionals, time period and energy supplies.
Relevant	The parameters of interest must be measured to determine the savings. The least important or predictable ones can be estimated.
Transparent	All the M&V activities must be documented.

Table 1 - Principles of M&V - IPMVP based [10]

Energy savings is impossible to be measured, since is the absence of energy consumption. The way to estimate the savings is to compare the consumptions in two periods, the reference one and after the implementation of the EEM, called reporting period. In the first period, the reference baseline is determined, representing the consumption curve. Otherwise, the reporting period is when the baseline curve will be estimated based on the reference baseline, taking into account significant variables, such as outside temperature, hours of operation and occupancy. The differences between the baseline curve and the actual measured consumption in the reporting period will define the savings achieved. The IPMVP framework, used to estimate energy savings is represented in Figure 2.

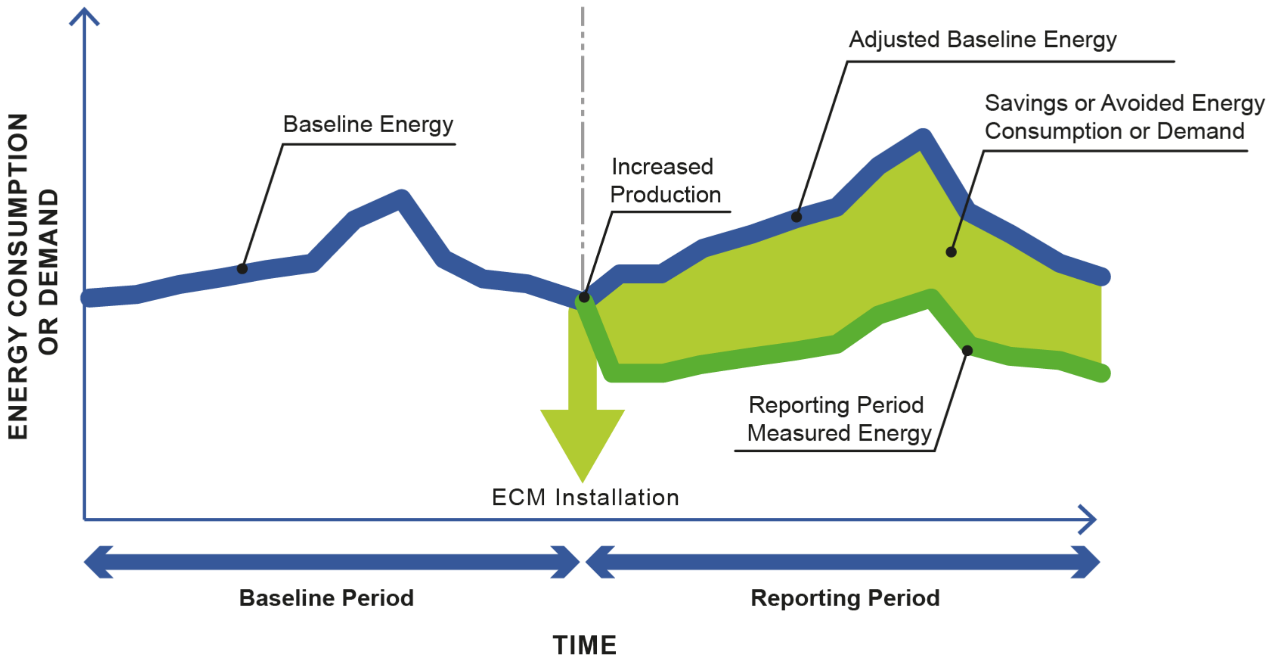

Figure 2 - IPMVP framework [10]

Depending on aspects of the project, to calculate the savings the IPMVP proposes four options[6]:

Option A: Partially Measured Retrofit Isolation

The savings are determined by partial field measurement of the energy used. In this option, is possible to stipulate some parameters if the errors are not significant to the result savings.

Option B: Retrofit Isolation

Using the field measurement, the savings are determined by the amount use of the energy. The energy is measured in every system that the Energy conservation measures (ECM) was applied. Although, the measurement can be carried out in a timely or continuous manner.

Option C: Whole Facility

In the option C, the savings are determined by measuring the energy use at the whole facility level. With data from utility meter and sub meters, the analysis is in the whole facility,

Option D: Calibrated Simulation

Savings are determined by the simulation of energy at the whole facility. This simulation must be calibrated with the information of the equipment.

Overall, option D (simulation of the energy use) is recommended in the following cases:

- Where it is not possible to provide data for a baseline period.

- Where multiple ECMs are implemented and you want to validate the efficiency of each one
- Where many future changes are expected within measurement boundary

3.2 M&V METHODOLOGIES USED FOR DR ASSESSMENT

M&V is the process of measurement to quantify and validate the provision of service according to the specification of a project. M&V applied to DR is typically used to determine the amount of energy or power that is delivered by a DR resource during the DR event and is the main input to guarantee a cost-effective assessment. To determine the correct amount of savings during the RESPOND event is necessary a good prediction of the demand and the demand delivered during the event. PMV applied in DR is used primarily for:

- **Eligibility:**

The capability of the resources needs to be established before the DR program begin. This can guarantee the eligibility of the participants, the services and products provided for the program.

- **Settlement:**

The determination of DR quantities achieved is a very important. Ensuring the impact estimation is valuable for assessing program effectiveness and for ongoing planning.

There are different DR program types. The common part for all of them is to determine the quantities of demand reduction achieved by the program. This reduction is calculated as the difference between what the consumers normally consume (baseline) and the actual measured consumption during the event. As the baseline cannot be measured directly, it must be estimated and calculated based on others measured data. Typically, measurements of DR programs involve comparing observed data with estimated ones that would have occurred without the DR event. The difference is the load reduction as showed in Figure 3.

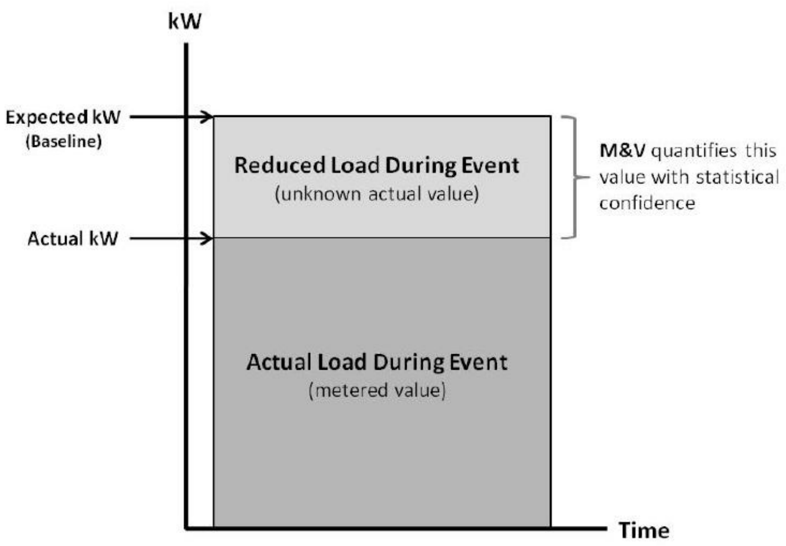

Figure 3 - M&V Load Reduction Value [12]

The performance evaluation used is the most important part for analyzing the success of a demand response program. In cases where the performance is measured relative to a baseline, the definition of the baseline and energy measurement are both essentials. Obtain a simple but accurate baseline is always a challenge, this way, according to NAESB recommendations, good baselines have four attributes:

Recommendation	Description
Accuracy	Make sure that the credit for the customer is given with accuracy, not more and no less than the fair value.
Integrity	The program should not encourage irregular consumption and, if it happens, this should not influence baseline calculations.
Simplicity	The performance data should be easily understandable by all the stakeholders.
Alignment	When choose the baseline methodology, the DR program should consider the expected goals.

Table 2 - Good baseline attributes according to NAESB

To balance all these attributes is complicated, but it is important that the baseline estimation should not reward or penalize natural variance caused by occupancy and weather conditions for example.

3.2.1 EEMEASURE METHODOLOGY

The eeMeasure Methodology is an extension of the IPMVP protocol for M&V with two different approaches. Both developed based in ICT PSP projects, these procedures have been applied to three H2020 projects and one FP7, such as NOBEL GRID, MOEEBIUS, ORBEET and Inertia, respectively. [13]

There are currently two ICT PSP methodologies: [14]

- Residential Methodology

This Methodology is applicable only to residences and generally assumes a monthly measurement period. The document introduces the IMPVP and discusses the four IPMVP Options and the use of statistical analysis. Measurement periods are suggested for different types of project and the evaluation of social and behavioral changes is considered.

- Non-Residential Methodology

The Non-Residential Methodology can be used for any property type (including residential) and can be used with any data frequency. This methodology is based on the IPMVP and ICT PSP project types related to the IPMVP Options. A process flow is defined to monitor appropriate variables and to create an accurate model. A description of the underlying mathematical statistics is also included.

The eeMeasure methodology before-after comparison of energy savings is estimated from the difference between the consumption after the event and the estimated consumption for that period.

- Baseline data: Projection of consumption before the intervention into the period after intervention.
- Reporting Period: Measurement of the period after the intervention

To estimate the avoided consumption is required the adoption of a model that varies under the influence of independent variables, such as outside temperature, occupancy and household size. The recommended approach is to develop regression models to reproduce the energy consumption based on values of the independent variables. Climatic changes are the main reason of variability in residential consumption profiles. For regression models an adequate accuracy of modelling of the variation in the dependent variable is necessary to accurately estimate the extended baseline in the reporting period. In the before-after comparison six steps are necessary:

Step	Description
Time Period - Baseline	Nominate a time period for the baseline which captures all variation of the variables and can reasonably be repeated in the future.
Variables	Gather data for the energy consumption and for all accessible independent variables.
Regression Analysis	Perform a regression analysis to establish the coefficients.
Time Period - Reporting	Nominate a time period for the reporting period which is long enough to capture all variation of independent variables.
Energy consumption	Gather data for the energy consumption and for all accessible independent variables.
Results	Apply the coefficients estimated in the baseline to the reporting period. Energy saving is the difference between estimated and measured consumption.

Table 3 - Six steps for before-after comparison according to eeMeasure [14]

3.2.2 UNCERTAINTY

Errors are the differences between observed and true energy use. The measurement of any physical quantity includes errors since no measurement instrument is 100% accurate. In a savings determination process, errors prevent the exact determination of savings. The uncertainty of a savings report can be managed by controlling random errors and data bias [13].

- Random errors are affected by the measurement equipment, the measurement techniques, and the design of the sampling procedure.
- Data bias is affected by the quality of measurement data, assumptions and analysis. Reducing errors usually increases M&V cost so the need for improved uncertainty should be justified by the value of the improved information.

To ensure that the resultant error is acceptable to the users of a savings report, the method for their quantification should be included in the M&V Plan. Characteristics of a savings determination process which should be carefully reviewed to manage accuracy or uncertainty are:

Characteristics	Description
Instrumentation	Measurement equipment errors are due to accuracy of sensors, calibration, inexact measurement, or improper meter selection installation or operation. The magnitude of such errors is largely given by manufacturer's specifications and managed by periodic re-calibration.
Modelling	The inability to find mathematical forms that fully account for all variations in energy use. Modelling errors can be due to inappropriate functional form, inclusion of irrelevant variables, or exclusion of relevant variables.
Sampling	Use of a sample of the full population of items or events to represent the entire population introduces error as a result of the variation in values within the population or biased sampling.
Interactive effects	That are not fully included in the savings computation methodology.

Table 4 - Characteristics of errors according to EVO10100 – 1:2018 [13]

In order to communicate savings in a statistically valid manner, savings need to be expressed along with their associated confidence and precision levels. Confidence refers to the probability that the estimated savings will fall within the precision range. Savings are deemed to be statistically valid if they are large relative to the statistical variations. Specifically, the savings need to be larger than twice the standard error of the baseline value. If the variance of the baseline data is excessive, the unexplained random behavior in energy use of the facility or system is high, and any single savings determination is unreliable. Where these criterions are not addressed possible solutions are [13]:

- more precise measurement equipment
- more independent variables in any mathematical model
- larger sample sizes
- an IPMVP Option that is less affected by unknown variables

3.2.3 BASELINE ACCORDING TO THE EEMEASURE METHODOLOGY

The eeMeasure methodology considers four different baseline methodologies for analyzing the achievements in a DR scenario. These methodologies are categorized from the simplest to the most accurate, according to Figure 4.

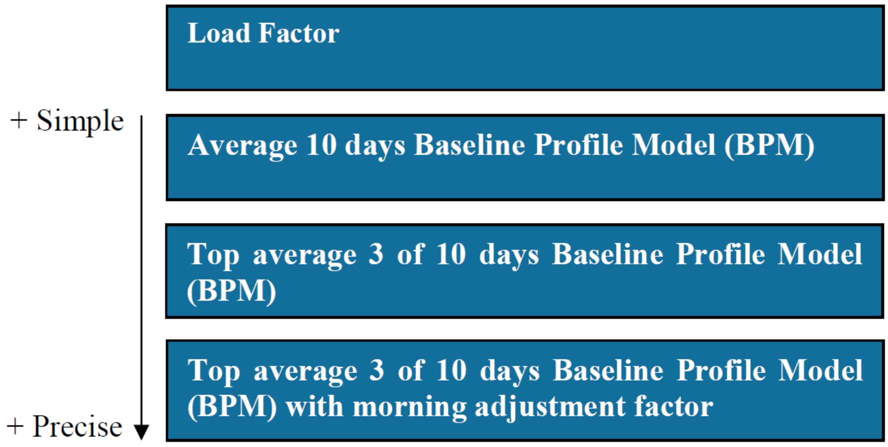

Figure 4 - DR baseline methodologies according to eeMeasure [13]

3.2.3.1 Load Factor

The load factor (LF) is defined as the value obtained by dividing the minimum power demand by the maximum power demand of a building [13]:

$$LF = \frac{(\min power\ demand)}{(\max power\ demand)}$$

Equation 1 - eeMeasure - Load Factor [15]

The closer the load factor is to the value 1, the less the demand curve peaks. If the building load curve peaks correspond to the electricity network peaks, movement towards 1 can represent useful peak shaving for the utility. [15]

3.2.3.2 Average 10 days Baseline

Baseline profile models (BPL) are used to estimate the shaving of peaks. To estimate non-intervention consumption at the peak event, it is generally accepted that a baseline period of 10 business days directly prior to the event reasonably represents consumption for normal operations. A 10-day baseline time frame is short enough to account for near-term trends and long enough to limit opportunities for manipulation. In this model the average represents the nonintervention reporting period (event day) estimate. The consumption over the 10 days is averaged as follows [15]:

$$\boldsymbol{b}: \frac{\boldsymbol{d1(t,h) + d2(t,h) + d3(t,h) + d4(t,h) + d5(t,h) + d6(t,h) + d7(t,h) + d8(t,h) + d9(t,h) + d10(t,h)}}{\boldsymbol{10}}$$

Equation 2 - eeMeasure - Average 10 days baseline [15]

$$DR_{consumption} = Demand_{event\ day} - Baseline_{average}$$

Equation 3 - eeMeasure - DR Consumption average 10 days [15]

3.2.3.3 TOP AVERAGE 3 OF 10 DAYS BASELINE

This model averages the 3 highest consumption figures from the previous 10 days, which must exclude other event days, holidays etc. The estimator for the non-intervention event day consumption is [13]:This model averages the 3 highest consumption figures from the previous 10 days, which must exclude other event days, holidays etc. The estimator for the non-intervention event day consumption is [13]:

$$\text{b: max }(1,3)\ \frac{(\sum \text{dn}(\text{t},\text{h}))}{3}$$

Equation 4 - eeMeasure - TOP average 3 of 10 days baseline [15]

$$DR_{consumption} = Demand_{event\ day} - Baseline_{average}$$

Equation 5 - eeMeasure - DR Consumption TOP average 3 of 10 [15]

3.2.3.4 TOP AVERAGE 3 OF 10 DAYS BASELINE WITH MORNING ADJUSTMENT FACTOR

In cases where demand is heavier on event days, this model captures day-of realities in a customer load profile through an adjustment based on day-of event conditions. The estimator for event day (reporting period) non-intervention consumption is [13]:

$$\boldsymbol{P}: \frac{\boldsymbol{d(t,h-1)-b(t,h-1)+d(t,h-2)-b(t,h-2)}}{\boldsymbol{2}}$$

Equation 6 - eeMeasure - Morning adjustment factor [15]

$$DR_{consumption} = Demand_{event\ day} - Baseline_{average} + adjustment\ factor$$

Equation 7 - eeMeasure - DR Consumption TOP average 3 of 10 with Adjustment Factor [15]

3.2.4 MACHINE LEARNING APPLIED TO DEFINE BASELINE IN RESIDENTIAL DR

Load forecasting for small scale residential buildings is a more complex process than the conventional forecasting methodologies [16]. This is because the load time-series for residential buildings with low aggregation are highly non-smooth and exhibit a volatile and chaotic behavior [17]. The accuracy of the forecasting methodologies are closely related to the size of the network and the level of aggregation [16][18]. The available literature suggests that conventional statistical methods may not work well when the number of residential buildings are small [18].

In [19], 5 baseline methodologies (Machine Learning, Polynomia extrapolation, Regression, Last 10 days California ISO, High 5 of 10 New York ISO) are compared for 66 DR participating residential customers of Australian energy company. The results showed that machine learning produces the smallest bias among the methods which means it has the least tendency to over or under predict the baseline.

4. RESPOND M&V METHODOLOGY

4.1.1 RESPOND M&V SERVICE

The RESPOND performance M&V will be based on international Measurement and Verification Protocols and other international ones, extensively described in section 3. The project will provide an approach using the RESPOND's measure-forecast-optimize-control iterative services as shown in Figure 5. The most common issues for Performance Measurement & Verification assessment is the development of a baseline, which in RESPOND has been addressed with the adoption of the RESPOND demand forecast, monitoring and repository services. These services aim to provide the most accurate estimation of electrical and thermal energy demand at a dwelling and neighborhood levels via predictive models. The models provide a continuous calibrated baseline to obtain higher accuracy.

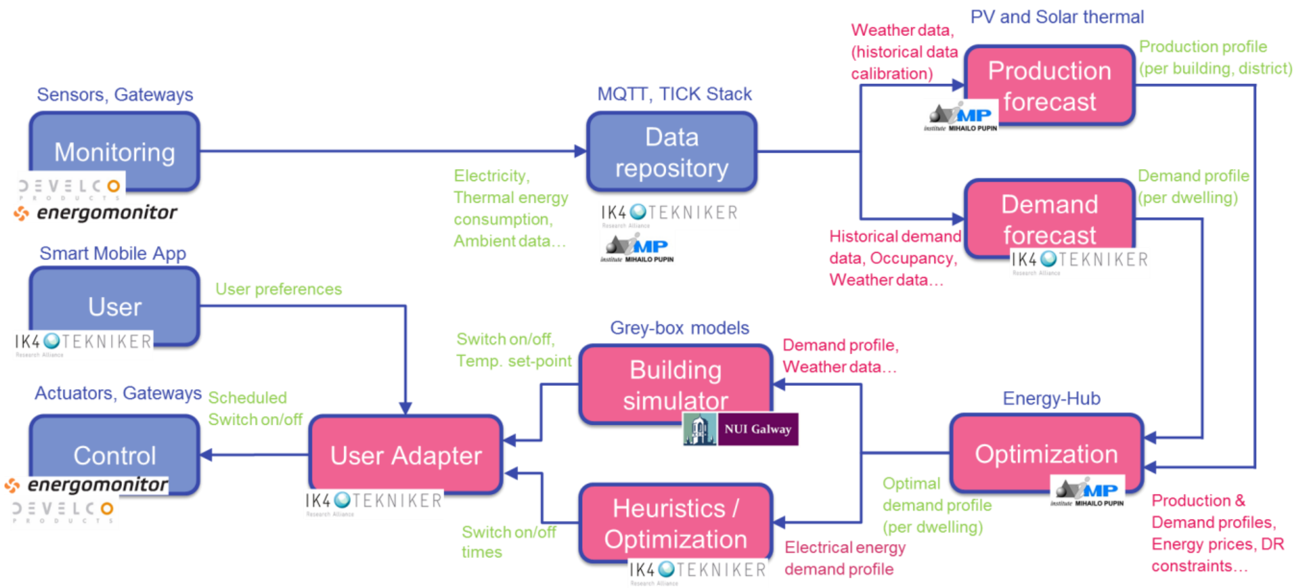

Figure 5 - RESPOND's measure-forecast-optimize-control iterative services

The RESPOND services involved in the M&V framework will be:

- Demand forecast → Baseline for electrical and thermal energy demand;
- Monitoring → Real electrical and thermal energy consumptions and production;
- Data repository → Weather data, monitoring data, forecasting data;

More details related to the machine learning application for RESPOND baseline generation will be provided on in D4.4 Demand forecasting service and D6.2 Validation analysis and reporting.

5. KPIS DESCRIPTION

The aim of this topic is to explain the Key Performance Indicators able to validate the methodology and provide the assessment of the results for the RESPOND project. In this context, the indicators were differentiated between quantitative and qualitative. In order to make a relevant evaluation of each pilot site, the KPI analysis will be done for each DR event, considering the applications for each case.

This section presents the objectives of each category of KPI and explains the indicators - correlating to the RESPOND objectives and which data is necessary to calculate them. The correlation between all KPIs and the data is described in Annex 1.

5.1 QUANTITATIVE DATA

Quantitative data are used to validate issues concerning the numeric analysis like Savings of energy, financial questions, carbon emission reduction and economic sustainability.

5.1.1 ENERGY KPIs

RESPOND project will impact the performance of the energy system. The real time algorithm optimization implemented, is capable to optimize the use of energy not only in the building level, but also the district level.

To analyze the energy performance, the project will consider the renewable energy produced and the differences between real energy consumption and the predicted one.

For this purpose, the objective of the energy analysis is measuring and monitoring the performance of the system.

5.1.1.1 RENEWABLE TOTAL ENERGY CONSUMPTION

The cooperative demand management is one of the drivers of the RESPOND project. This way, this KPI is for validate that the common renewable energy consumption resource is being exploited for all the buildings occupants.

KPI	Renewable total energy consumption
Description	This KPI is a metric to analyze the ratio of the total amount of renewable energy produced and the demand of consume in a building in a time period.
Inputs	- Renewable energy produced [kWh] - Demand of energy [kWh]
Outputs	- % of Renewable energy consumption in a building [%] - Total of renewable energy consumption [kWh]

Formulas	$$RE = \sum_{t} \min(REp, D)$$ *Equation 8 – KPI - Renewable total Energy consumption* $$\%RE = \frac{REp}{D} x100$$ *Equation 9 - KPI - % of Renewable energy consumption* RE: Renewable total Energy consumption [kWh] REp: Renewable energy produced [kWh] D: Demand of energy [kWh] t: Period of the measurement [minutes] $\%RE$: % of Renewable energy consumption [%]

Table 5 - KPI Renewable total energy consumption

5.1.1.2 ENERGY SAVINGS

To assess the energy efficiency performance required, the energy consumption will be analyzed during the DR Event. The difference between the data measured and the reference consumption data will be the indicator for project evaluation.

KPI	**Energy Savings**
Description	The KPI energy savings correspond to the variability of the energy consumption during a Demand Response event. This indicator is calculated for all the energies analyzed in this project (Electrical, Gas and Heat).
Inputs	- Demand of energy [kWh] - Baseline – Demand of energy [kWh]
Outputs	- $E_{Savings}$: Total Energy Savings [kWh]
Formulas	$$E_{Savings,tp} = \sum_{t} E_{BL} - E_{DR}$$ *Equation 10 - KPI - Energy Savings by energy type* $$E_{Savings} = \sum_{tp} E_{Savings,tp}$$ *Equation 11 - KPI - Total Energy Savings* $E_{Savings}$: Energy Savings [kWh] E_{DR}: Energy consumption during the DR Event [kWh] E_{BL}: Energy consumption baseline - without the DR Event [kWh] t: Period of the measurement [hour] tp: Energy type $E_{Savings,elec}$: Total Electrical Energy Savings $E_{Savings,gas}$: Total Gas Energy Savings $E_{Savings,heat}$: Total Heat Energy Savings

Table 6 - KPI Energy Savings

5.1.2 Carbon Emission Reduction

The environment conditions can be quantified on potential energy savings. The reduction of the carbon footprint is a challenge and every event that can do the difference in the pollutants is important to be measured.

5.1.2.1 Reduction of Greenhouse Gas Emissions

Reducing emissions of greenhouse gases like carbon dioxide is essential. Demand Response Events are moments when the concentration of gas is reduced and can be calculated for future study and specific analysis.

KPI	**Reduction of greenhouse gas emissions**
Description	This KPI corresponds to the variation of equivalent of CO_2 emissions in $kgCO_2$ during the DR event. The reduction of CO_2 emission is considering the three sources of energy in the project: Electrical, gas and heat.
Inputs	- Asset real energy demand during the DR event [kWh] - Asset baseline energy demand [kWh]
Outputs	- Variation of greenhouse gases emission [$kgCO_2$]
Formulas	$\Delta I_{CO_2} = \sum_{source}\left(D_{BL,source} - D_{DRsource}\right) * EF_{Source}$ *Equation 12 - KPI - Variation of greenhouse gases emission* ΔI_{CO_2}: Variation of greenhouse gases emission [kgCO2] $D_{DR,source}$: Asset real energy demand during the DR event [kWh] $D_{BLsource}$: Asset baseline energy demand [kWh] EF_{Source}: Emission factors of locally consumed fuel [kgCO2/kg]

Table 7 - KPI Reduction of greenhouse gas emissions

5.1.3 Demand Response KPIs

The main objective of the demand response category is to show the results of the actions during the DR events in the peak load.

5.1.3.1 Peak Load Reduction

The Demand Response main indicator will be the Peak load reduction. Proving that the peak load has been reduced is one important indicator for some use cases evaluation.

KPI	**Peak load reduction**
Description	This KPI correspond to the reduction of the demand during some DR events.
Inputs	- Demand of energy [kWh] - Baseline – Demand of energy [kWh]
Outputs	- Average peak power reduction [kW]

	- Percentage of the average peak power reduction [%]
Formulas	$$D_{PR} = \max(D_{BL}) - \max(D_{DR})$$ *Equation 13 - KPI - Average peak power reduction during the DR event* $$D_{\%} = 100\frac{D_{PR}}{\max(D_{BL})}$$ *Equation 14 - KPI - Percentage of the average peak power reduction* D_{PR}: Average peak power reduction during the DR event [kW] D_{BL}: Baseline energy demand [kWh] D_{DR}: Energy demand during the DR event [kWh] $D_{\%}$: Percentage of the average peak power reduction [%]

Table 8 – KPI Peak load reduction

5.1.3.2 RESCHEDULED DEMAND

Rescheduled demand has the objective to show the demand that is not used during the DR event but is used anyway in another period. This KPI is going to be used for analyzing the flexibility of the user in shifting demand to intervals where there is less demand for electricity.

KPI	**Rescheduled Demand**
Description	This KPI has the objective to verify if the demand that is not used during the DR event is used or not in another period during the same day of the event.
Inputs	- Demand of energy [kWh] - Baseline – Demand of energy [kWh]
Outputs	- Percentage of rescheduled demand [%]
Formulas	$$D_{Ex} = D_{out-event} - BL_{Out-event}$$ *Equation 15 – KPI - Excess of demand during the event day (without the event)* $$Savings = BL_{event} - D_{event}$$ *Equation 16 – KPI - Energy Savings during the DR event* $$RD = \frac{Savings - D_{ex}}{Savings} * 100$$ *Equation 17- KPI - Rescheduled demand* RD: Rescheduled demand DR event [%] $Savings$: Energy savings during the event [kWh] D_{Ex}: Excess of demand during the event day without the event [kWh] BL_{event}: Baseline energy demand during the event [kWh] $BL_{Out-event}$: Baseline energy demand out of event [kWh] D_{event}: Energy demand during the event [kWh] $D_{out-event}$: Energy demand during the event day but not in the event [kWh]

Table 9 - KPI - Rescheduled Demand

5.1.3.3 ANALYTICAL SERVICES ACCURACY

The objective of this indicator is to measure the accuracy between the forecasted energy generation and consumption and the Real data during the period.

KPI	**Analytical services accuracy**
Description	This KPI has the objective to verify if the predictions used for the baseline are accurate.
Inputs	- Real data during the period used for forecast [kWh] - Baseline created by the analytical service [kWh]
Outputs	- Percentage of accuracy [%]
Formulas	$Accuracy = \frac{R - BL}{R} * 100$ Equation 18 - KPI - Accuracy of the predictions $Accuracy$: % of the accuracy of the prediction [%] BL: Baseline during the period [kWh] R: Real data during the period [kWh]

Table 10 - KPI - Analytical services Accuracy

5.1.4 ECONOMIC KPIS

Economic gains correspond to the overall benefit in the national currency due to the DR implementation. Costs of installation and maintenance are measured in order to perform initial and future costs assessments and savings.

5.1.4.1 CAPITAL EXPENDITURES (CAPEX)

The Capital Expenditures of the RESPOND project is the sum of all investment required to purchase, manufacture and install for start the operation.

KPI	**Capex – Capital Expenditures**
Description	Sum of all upfront investments required for the RESPOND Project. The aim of CAPEX is to account all the incurred costs.
Inputs	- Cost of Materials [€] - Cost of Manufacturing [€] - Cost of installation and start operation (including systems) [€]
Outputs	- Total of the capital expenditures of the project
Formulas	$CAPEX = C_{mt} + C_{Mn} + C_i$ Equation 19 - KPI - Capital Expenditure $CAPEX$: Capital Expenditure [€] C_{mt}: Cost of Materials [€] C_{Mn}: Cost of Manufacturing [€] C_i: Cost of installation [€]

Table 11 - KPI Capex – Capital Expenditures

5.1.4.2 ECONOMIC SAVINGS DURING THE DR EVENT

This KPI corresponds to the economic gain during the DR Event. It is calculated by analyzing the difference between the average financial baseline costs of energy and the financial cost during the DR Event.

KPI	Economic savings during the DR Event
Description	The Economic savings KPI is analyzed according to the energy fees. The difference between the average baseline cost and the cost during the DR event will be the Output for the economic saving.
Inputs	- Average baseline energy cost during the period [€] - Energy expenses during the DR Event [€]
Outputs	- Rate of the energy cost in the period [%]
Formulas	$$\Delta EC = \frac{EC_{BL} - EC_{DR}}{EC_{BL}} x100$$ *Equation 20 - KPI - Economic savings during the DR Event* ΔEC: Economic savings during the DR Event [%] EC_{BL}: Average Baseline Energy cost [€] EC_{DR}: Energy expenses during the DR Event [€]

Table 12 - KPI Economic savings during the DR Event

5.1.4.3 ECONOMIC OPERATIONAL COST SAVINGS - OPEX VARIATION

The Operational expenditures variation is a KPI to analyze the savings of the project in terms of operations.

KPI	Economic operational cost savings - OPEX Difference
Description	This KPI analyze the difference in the OPEX before and after the implementation of the predictive maintenance algorithms.
Inputs	- OPEX before the predictive maintenance application [€] - OPEX after the predictive maintenance application [€]
Outputs	- Economic operation cost Savings [%]
Formula	$$\Delta EC_o = \frac{OPEX_{BL} - OPEX_{Actual}}{OPEX_{BL}} x100$$ *Equation 21 - KPI - Economic operation cost Savings* ΔEC_o: Economic operation cost Savings [%] $OPEX_{BL}$: OPEX before the predictive maintenance application [€] $OPEX_{Actual}$: OPEX after the predictive maintenance application [€]

Table 13 - KPI Economic operational cost savings - OPEX Difference

5.1.5 SECURITY KPIS

Security and Privacy are about control of the information, making sure that all data is available in most part of the time and in a safe place.

5.1.5.1 DATA SECURITY CONTROL

Data security is a KPI designed for guarantee the security of the data in the Respond Project. Making sure that all the predictive maintenance is being performed correctly and the vulnerability analysis is being done properly, is possible to understand the level of the system security.

KPI	Data security control
Description	This KPI objective is measuring if the vulnerability analysis has been done or not and if the issues found in the system are solved.
Inputs	- Vulnerability analysis has been done - Issue is solved
Outputs	- Qualitative measurement of Data Security Control
Formula	- If security vulnerability analysis has been done, and issues are resolved: 1 - Security vulnerability analysis has been done but issues are not resolved: 0.5 - No security vulnerability analysis has been done: 0

Table 14 - KPI Data security control

5.1.6 SYSTEM OPERATION KPIS

Ensure the system operation is always a challenge, this way KPIs in this area can guarantee constant improvement and the properly operation analyzing the performance of the RESPOND systems.

5.1.6.1 COEFFICIENT OF PERFORMANCE – COP

The coefficient of performance (COP) of a system (i.e. PV panels and Solar Thermal Collectors) should show its degradation in terms of performance under normal circumstances. Once the performance drops below a certain defined threshold, it is considered that a maintenance task should be performed in order to improve the COP close to 100%.

KPI	Coefficient of performance – COP
Description	The coefficient of performance of the system is the variation of performance of the system under normal circumstances.
Inputs	- Baseline Energy Production [kWh] - Real Energy Production [kWh]
Outputs	- Coefficient of Performance [%]
Formula	$$\%P_{up} = 100\,\frac{E_{pm}}{E_{BL}}$$ *Equation 22 - KPI - Variation of operational uptime* $\%P_{up}$: Coefficient of performance [%]

	E_{BL}: Baseline Energy Production [kWh] E_{pm}: Real Energy Production [kWh]

Table 15 - KPI Coefficient of performance – COP

5.1.6.2 COMMUNICATION PERFORMANCE

Communication performance is to guarantee that the data is being uploaded properly in the system.

KPI	Communication performance
Description	This KPI is for guarantee that all the data required for calculating the KPIs are in the database ready for being used.
Inputs	- Number of inputs of data that are in the system [units] - Number of inputs of data that should be in the system [units]
Outputs	- % of data already measured in the system [%]
Formulas	$$\%CP = 100\frac{N_{ds}}{N_{dt}}$$ Equation 23 - KPI - Percentage of all data in the RESPOND Database $\%CP$: Percentage of all data in the RESPOND Database [%] N_{ds}: Number of inputs of data in the database [units] N_{dt}: Number of inputs that should be in the database [units]

Table 16 - KPI Communication performance

5.1.7 USER KPIS

For analyzing the user opinion, qualitative evaluation measuring the social impact, user engagement, acceptance, and comfort level are some KPIs.

5.1.7.1 DR CAMPAIGNS PENETRATION

During the DR Event, there are some actions that the user should do. The campaign penetration is a KPI for measuring if the user is engaged during the event. The definition if the user is engaged is going to be based in the results, if the expected action was performed, this means that the user participated in the event.

KPI	DR campaigns penetration
Description	KPI for measuring the engagement of the user during the DR Event
Inputs	- Number of users doing the action during the DR Event [users] - Number of total users involved in the DR Event [users]
Outputs	- % of customers involved during the DR Event [%]
Formulas	$$\%C_i = 100\frac{U_a}{U_t}$$ Equation 24 - KPI - Percentage of customers involved during the DR Event

	$\%C_i$: Percentage of customers involved during the DR Event [%] U_a: Users doing an action during the DR Event [users] U_t: Total of users involved in the event [users]

Table 17 - KPI DR campaigns penetration

The assessment of the described KPI will be performed cross-correlating results from measured data, app notifications and questionnaire survey in T6.3.

5.1.7.2 NUMBER OF USER MANUAL ACTIONS

When some automated action is done during the DR event, the customer can still modify manually the system. If this happens, means that the customer didn't accepted the DR control automated action.

KPI	Number of user manual actions
Description	If a DR Event automated is happening and the user do some action for controlling manually, this means that the user had some issue with the automated action.
Inputs	- Number of customers that didn't change manually any parameter during the DR event [customers] - Total number of customers involved in the event [customers]
Outputs	- % of customer acceptance in the automated DR control action [%]
Formula	$$\%C_a = 100\frac{C_i}{C_t}$$ *Equation 25 - KPI - % of customer acceptance in the automated DR control action* C_a: % of customer acceptance in the automated DR control action [%] C_i: Number of customers that didn't change manually any parameter during the DR event [customers] C_t: Total number of customers involved [customers]

Table 18 - KPI Number of user manual actions on the automated DR control actions

5.1.8 INDOOR ENVIRONMENT KPIS

In terms of comfort, the RESPOND project will follow the prEN15251 and the user opinion.

5.1.8.1 INDOOR AIR QUALITY

The KPI Indoor Air Quality is for evaluation of the CO_2 concentrations in a time period. Indoor Air quality is going to be measured to analyze the comfort conditions in the place, but since there is no operation scenario based on ventilation control, the use will be purely for monitoring purposes during the DR event.

<table>
<tr><th>KPI</th><th>Indoor Air Quality - IAQ</th></tr>
<tr><td>Description</td><td>This KPI is for evaluating the Indoor Air Quality and analyze according to prEN15251.</td></tr>
<tr><td>Inputs</td><td>Level of CO_2 during the DR event [ppm]</td></tr>
<tr><td>Outputs</td><td>Validation if the indoor air quality is acceptable according to the dwelling category during the DR event.</td></tr>
<tr><td>Formula</td><td>Dwelling categories description:

I. High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.
II. Normal level of expectation and should be used for new buildings and renovations
III. An acceptable, moderate level of expectation and may be used for existing buildings
IV. Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year.

The CO_2 levels for each category should be analyzed according to this table:

<table>
<tr><th>Indoor Quality Category</th><th>Typical Range</th><th>Default Value</th></tr>
<tr><td>I</td><td><400</td><td>350</td></tr>
<tr><td>II</td><td>400-600</td><td>500</td></tr>
<tr><td>III</td><td>600-1000</td><td>800</td></tr>
<tr><td>IV</td><td>>1000</td><td>1200</td></tr>
</table></td></tr>
</table>

Table 19 - KPI Indoor Air Quality – IAQ

5.2 QUALITATIVE DATA

The qualitative data will be used to assure user acceptance and to analyze the data that can't be measured. Issues concerning user opinion such as indoor thermal comfort are going to be analyzed this way. Beyond the task 6.3 of Respond project is going to analyze the user experiences based on qualitative data, some comments are going to be included here to explain the main idea of the qualitative data analysis and address some topics.

The objective of qualitative data analysis is to measure level of some data related to user experience and provides recommendations for further improvements in the RESPOND system.

DR Campaigns penetrations (manual DR actions)

With the objective of 80% of users involved, the KPI has the objective to measure the engagement of the user during the DR events that involve active (manual) actions, such as households time-shifting energy consumption as a response to a notification about when it is best (cheapest) to consume energy.

The households' active participation level will be measured by combining quantitative and qualitative data (data triangulation). In qualitative data, the objective is to understand if the customer is involved in the actions, and what the reasons (motivations and incentives) are for their engagement (or lack of the same). In quantitative data, the analysis will be just if the result of the event happened and the percentage of people that did the action in the event time.

In practice, the measures will be done following these principles:

- Quantitative measure: For each manual DR action scenario trialed at the RESPOND pilot sites, data will be collected on the participants' actual actions via either: 1) analyzing data collected from smart plugs on appliances that the participants can time-shift consumption of (e.g. dishwashers and washing machines). Thus, it will be measured if these appliances are in use or not during the DR events and this will provide data for calculating the participation rate in actual actions during these events. Alternatively, in cases with missing data, 2) the households will have a logbook in which the participants will make recordings of their actions during events. These will be collected and analyzed.
- Qualitative measure: In combination with the above, all participants in RESPOND trials will be asked to fill in a survey (questionnaire) including a question on their level of engagement in manual DR actions. This will collect data on their general, self-reported participation rate (e.g. how often they respond to notifications of manual DR events).

The questionnaire survey and logbook will be carried out as part of the T6.3 Qualitative evaluation of user experiences and recommendations. The findings from the above empirical data will be compared to (benchmarked with) results from previous similar trials, including [20][21][22][23][24].

User acceptance (automated DR actions)

With the objective of 90% of user acceptance, this KPI analyses if the customers accepted the automated event that is occurring. A narrow definition of user acceptance is a situation in which the participants do not interrupt or cancel planned or ongoing automated DR action (e.g. automated peak-shaving of heating in the morning hours). A broader definition of user acceptance is whether the users experience the DR actions as convenient and would accept these in general. Both definitions of the user acceptance will be measured in T6.3 through a combination of a questionnaire survey and qualitative interviews (focus groups).

All participants in the RESPOND trials will be asked to complete a questionnaire survey with questions on their experience and actions in relation to the RESPOND trial. This will include a question on how often (frequency) they have cancelled or interrupted planned or ongoing automated DR events. Another question will be on their satisfaction with the automated DR events and willingness to accept this type of scheme in general.

The questionnaire survey data will be complemented by qualitative and in-depth knowledge on the participants' concrete experiences and assessments of the automated DR events collected through interviews (focus groups).

The findings from the above empirical data will be compared to (benchmarked with) results from previous similar trials, including [20][25].

Safety KPI

Data security and data privacy are important themes and previous studies have shown that lack of trust in especially data privacy can keep households from accepting smart energy solutions

[26][27]. For this reason, a KPI asking people how they feel about safety is designed. Topics such as trust in data security and data privacy, and property security will be addressed with open questions through the interviews (focus groups) for better understand the behavior and the feeling about the project data and objectives. This will be considered combined with two questions in the questionnaire survey that the RESPOND participants will have to complete (one question on data security, i.e. trust in that personal data are handled in a safe way, and one question on data privacy, i.e. the participants experience of sharing data with the RESPOND platform).

Thermal Comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by a subjective evaluation. Different quality levels of design criteria for the thermal environment is often based on the thermal comfort indices PMV-PPD (predicted mean vote - predicted percentage of dissatisfied) which link together air temperature, radiation, air velocity and humidity, levels of activity and thermal insulation of clothing. The thermal comfort indices PMV-PPD were developed by Fanger (1970) [28] on the basis of laboratory studies with human subjects assessing the thermal environment under controlled conditions in climate chambers. Therefore, the PMV-PPD indices may be suitable for application in controlled office environments but less suitable for homes where residents may have other individual preferences for temperature conditions, and the assessment of temperature may depend on other criteria than in an office environment. For example, they may make a trade-off in relation to economy and energy consumption, which can lead to a decision that allows some rooms to be cold during winter and warm during summer. Occupant's different preferences make it difficult to put it on one formula and it may prevent flexible solutions. Some people may find it acceptable to have different temperatures in rooms, while others are more willing to live with some discomfort if it means other benefits, like saving money (Knudsen, Mortensen and Kragh, 2015) [29].

Originally, it was proposed to assess the thermal comfort levels in the RESPOND dwellings by comparing measurements of temperature with quality levels as specified by CEN in EN 15251 [30]. However, as described above the preferred comfort levels in dwellings may be influenced by personal preferences, which supports that the situation in dwellings is less rigid than that of offices. Therefore, to get the most out of demand response, and thereby the highest energy saving/shift in energy use individual preference need to be exploited. RESPOND take into account user feedback and make it possible for occupants to individually decide how they will allow their indoor temperature to vary, within limits that do not damage the building. RESPOND will perform monitoring and analysis of temperature and relative humidity. To assess how the occupants perceive thermal comfort while performing DR control actions on heating by automatic control of thermostats, different techniques collecting qualitative data will be used. Qualitative data will be collected from the occupants, through interview, surveys and focus groups, and those data will be used for analyzing how successful the RESPOND actions are in satisfying the occupants.

6. RESPOND USE CASES

6.1.1 UC1 – ALL PILOTS – IMPACT OF THE RESPOND APP TO THE USER

The objective is to evaluate the impact to the user behavior, in terms of energy consumptions and indoor condition, having access to the monitoring data provided by the RESPOND app. This use case runs "by itself" in "the background".

For measuring the efficiency of this use case, the following KPIs will be used:

- Energy Savings
- Reduction of greenhouse gas emissions
- Communication performance
- Indoor air quality

The data needed for measuring all the KPIs are described in Table 20.

Data needed to calculate the KPIs	Unit
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Level of CO2	[ppm]

Table 20 - Data needed to calculate the use case 1

The correlation between the KPI and the data is described in Figure 6.

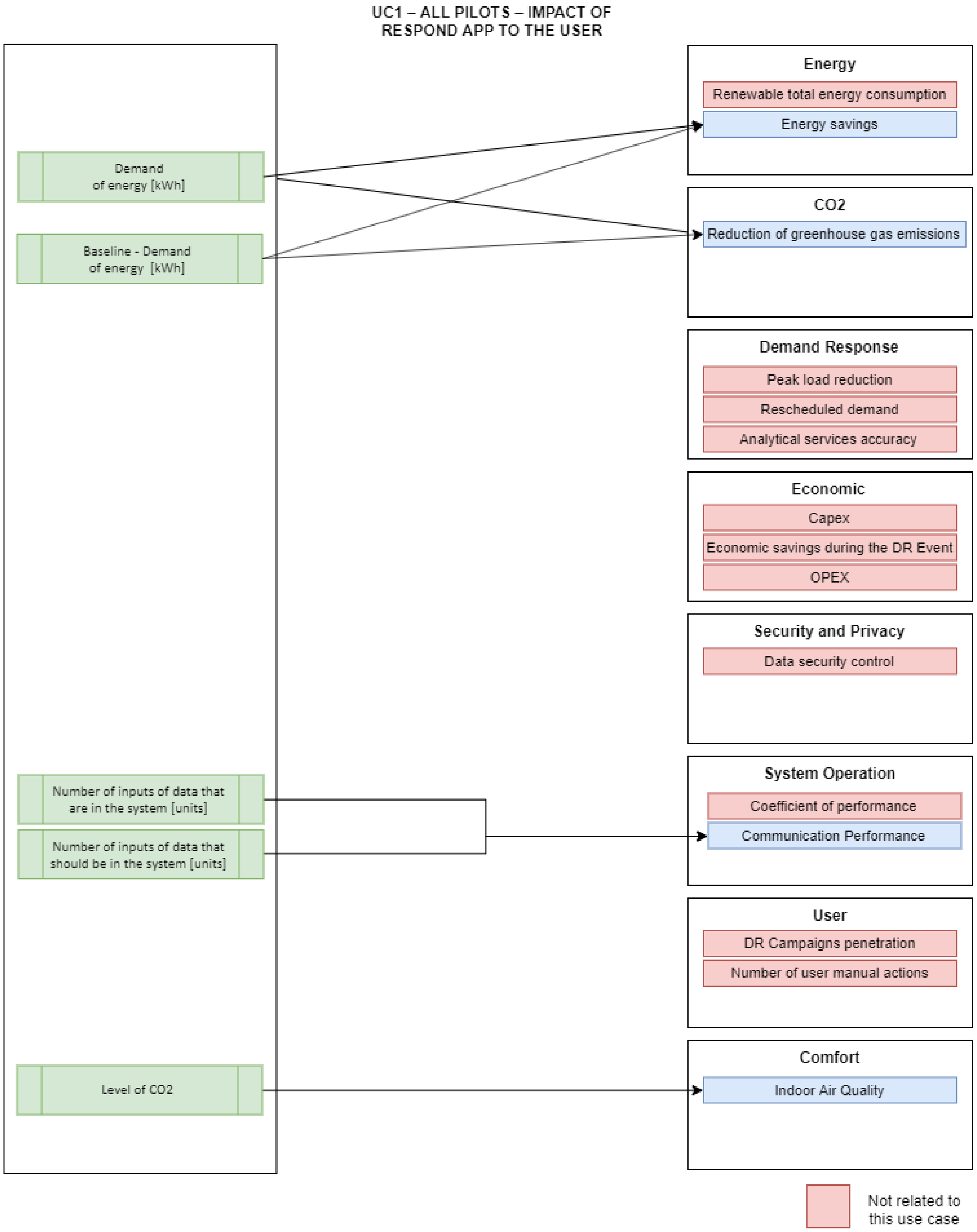

Figure 6 - Correlation between data required and KPIs - UC1

6.1.2 UC2 – Ireland - Maximize auto consumption control switches for appliances

This use case is applicable in periods with a predicted surplus generation of local renewable energy. The objective is to increase the use of energy in-house through load control switches for appliances, maximizing the use of the energy produced by PV panels, which in case it is not consumed, it is directly injected into the grid, without getting any payment from the energy provider.

When the users install the RESPOND app on their smartphone, they are asked whether they want to participate in the DR programme. This preference could be modified by the user anytime activating or deactivating the option. The residents that have accepted, get a notification via the app informing about the predicted surplus generation and recommending the residents to shift consumption to these hours if possible.

If residents participate, they will receive a notification via the mobile app informing the moment that there is a surplus generation of energy and the suggested actions.

If residents don't participate, they will not receive the notification informing the event.

This use case is highly dependent on PV production, which is intermitted and not always available. So, it is not possible to schedule the minimum amount of time that the scenario needs to be run per month.

For measuring the efficiency of this use case, the following KPIs will be used:

- Renewable total energy consumption
- Reduction of greenhouse gas emissions
- Rescheduled demand
- Analytical services accuracy
- Economic savings during the DR event
- Coefficient of performance
- Communication performance
- DR campaign penetration

The data needed for measuring all the KPIs are described in Table 21:

Data needed to calculate the KPIs	Unit
Renewable energy produced	[kWh]
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Number of users doing the action during the DR Event	[users]
Number of total users involved in the DR Event	[users]

Table 21 - Data needed to calculate the use case 2

The correlation between the KPI and the data is described in Figure 7.

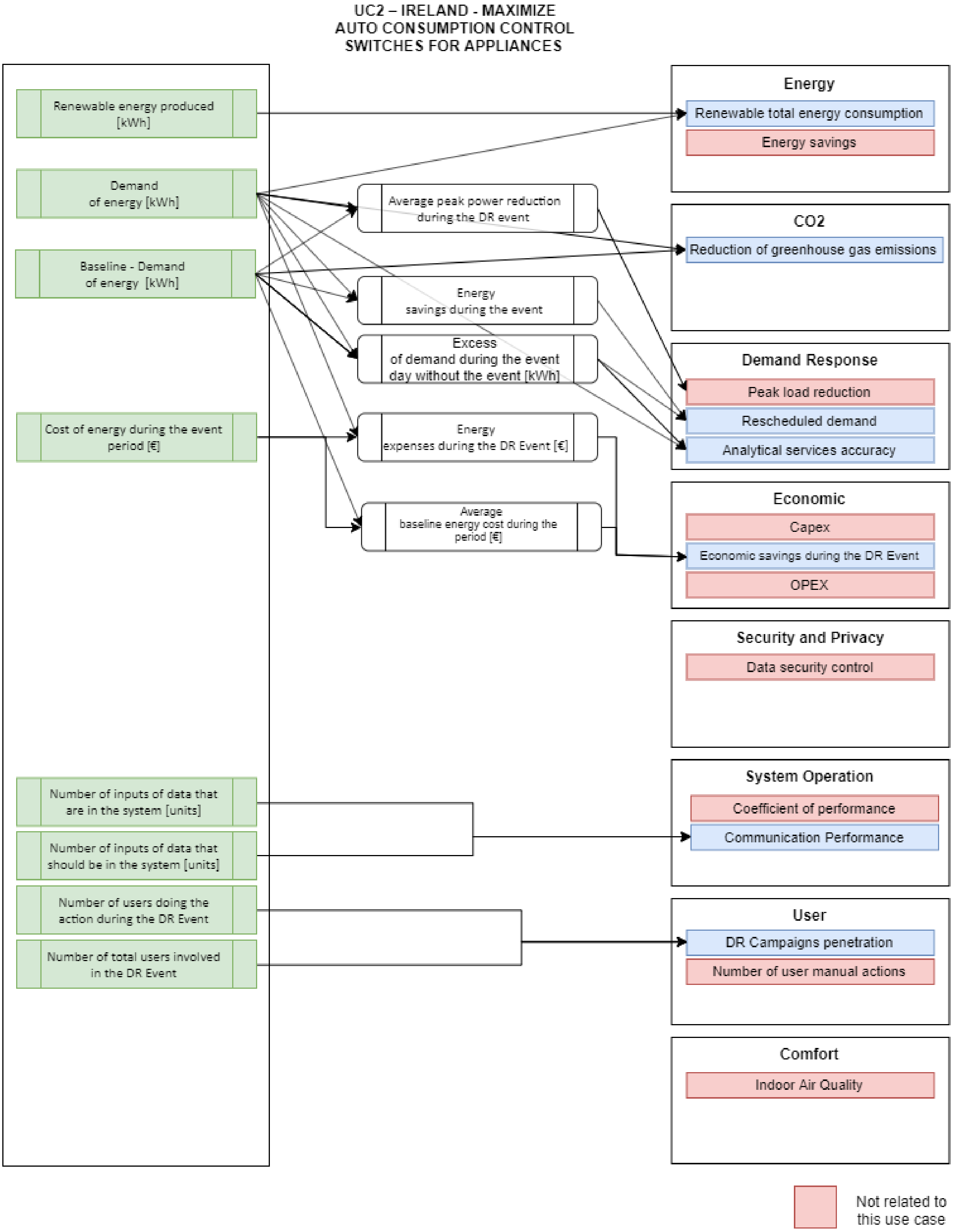

Figure 7 - Correlation between data required and KPIs – UC2

6.1.3 UC3 - Ireland - PV Panel – optimal profile of use for heat pumps

This use case is applicable in days with a predicted surplus generation of local renewable energy. This scenario is alternative to the previous one, in a way that instead of increasing the use of appliances, it will involve the definition and implementation of an optimal profile of use for the heat pump for the next day.

When the users install the RESPOND app on their smartphone, they are asked whether they want to participate in the DR programs. This preference could be modified by the user anytime activating or deactivating the option. If they accept, the residents get a notification via the app informing about the predicted surplus generation and asking the residents to participate in the event.

If residents participate, they will receive a message contained the optimized profile of use of the heat pump for the next day.

If residents don't participate, they will not receive any other message.

As the previous scenario, this use case is highly dependent on PV production, which is intermitted and not always available. So, it is not possible to schedule the minimum amount of time that the scenario needs to be run per month.

For measuring the efficiency of this use case, the following KPIs will be used:

- Renewable total energy consumption
- Reduction of greenhouse gas emissions
- Rescheduled demand
- Analytical services accuracy
- Economic savings during the DR event
- Communication performance
- DR campaign penetration

The data needed for measuring all the KPIs are described in Table 22:

Data needed to calculate the KPIs	Unit
Renewable energy produced	[kWh]
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Number of users doing the action during the DR Event	[users]
Number of total users involved in the DR Event	[users]

Table 22- Data needed to calculate the use case 3

The correlation between the KPI and the data is described in Figure 8.

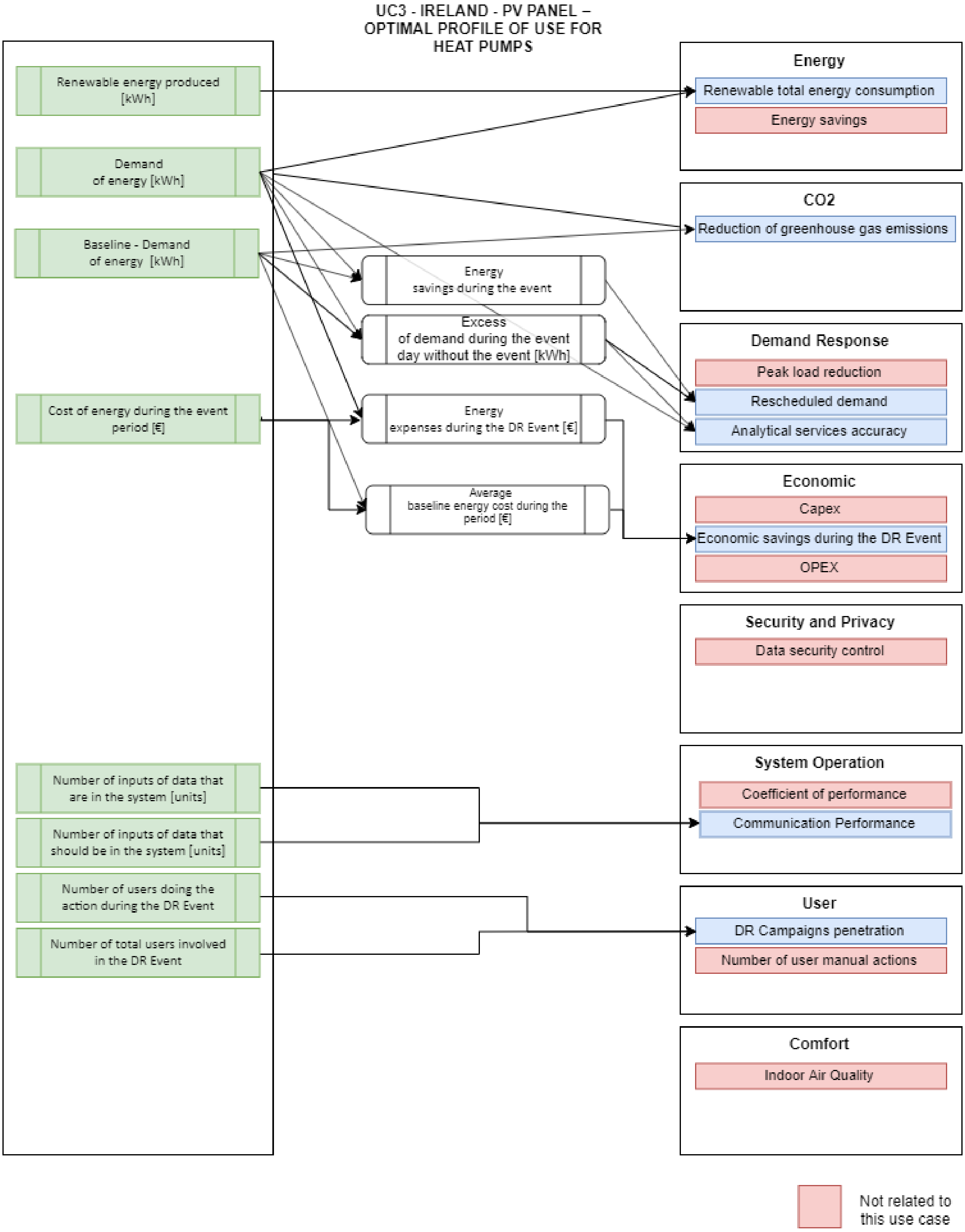

Figure 8 - Correlation between data required and KPIs – UC3

6.1.4 UC4 - Ireland - Peak shaving use case

This use case is applicable for controlling the grid usage based on switching off appliances (washing machine, tumble dryer, heat pumps). The objective is to decrease the use of energy from an aggregated number of dwellings to avoid peak periods, as shown in Figure 9, where a typical peak period, between 17:00 and19:00, in Ireland is reported.

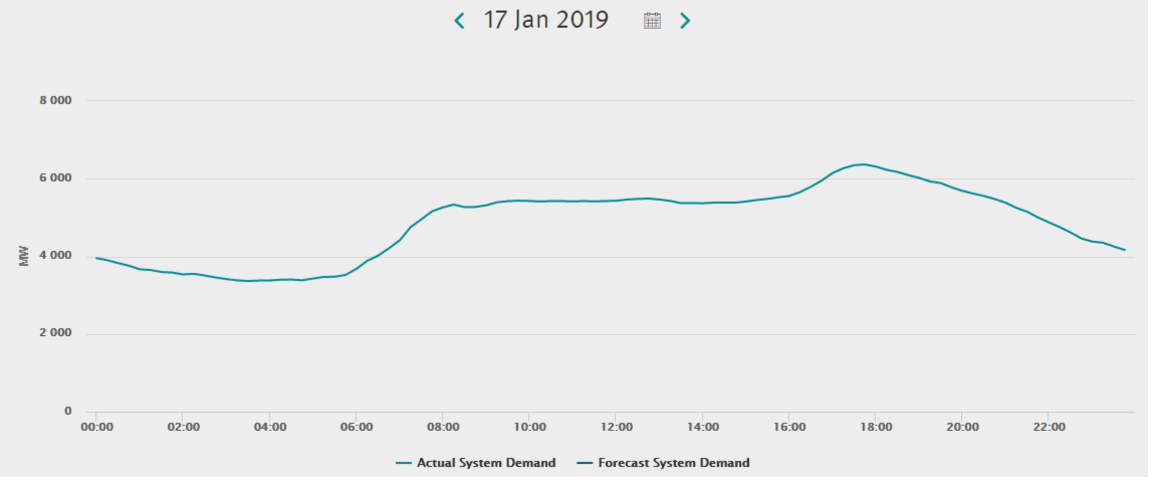

Figure 9 – Screenshot from Eirgrid web site, grid monitoring tool

A virtual extension of this scenario to a large number of buildings involved, it generates an opportunity for potential aggregators, which are allowed in Ireland with minimum size of DSUs equal to 4 MW. As it is possible to aggregate load from anywhere in the country [2], they can control the usage using this type of event.

When the users install the RESPOND app on their smartphone, they are asked whether they want to participate in the DR program. This preference could be modified by the user anytime activating or deactivating the option. If they accept, residents get a notification via app informing about the event and asking the residents to participate.

If residents participate, they will get a message informing the DR event.

If residents don't participate, they will not receive any other message.

This event should not be done more than one a month for guarantee that the customer will participate for the entire validation period.

For measuring the efficiency of this use case, the following KPIs will be used:

- Energy Savings
- Reduction of Greenhouse gas emissions
- Peak load reduction
- Rescheduled demand
- Analytical services accuracy
- Economic savings during the DR event
- Communication performance
- DR campaign penetration

The data needed for measuring all the KPIs are described in Table 23:

Data needed to calculate the KPIs	Unit
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Number of users doing the action during the DR Event	[users]
Number of total users involved in the DR Event	[users]

Table 23- Data needed to calculate the use case 4

The correlation between the KPI and the data is described in Figure 10.

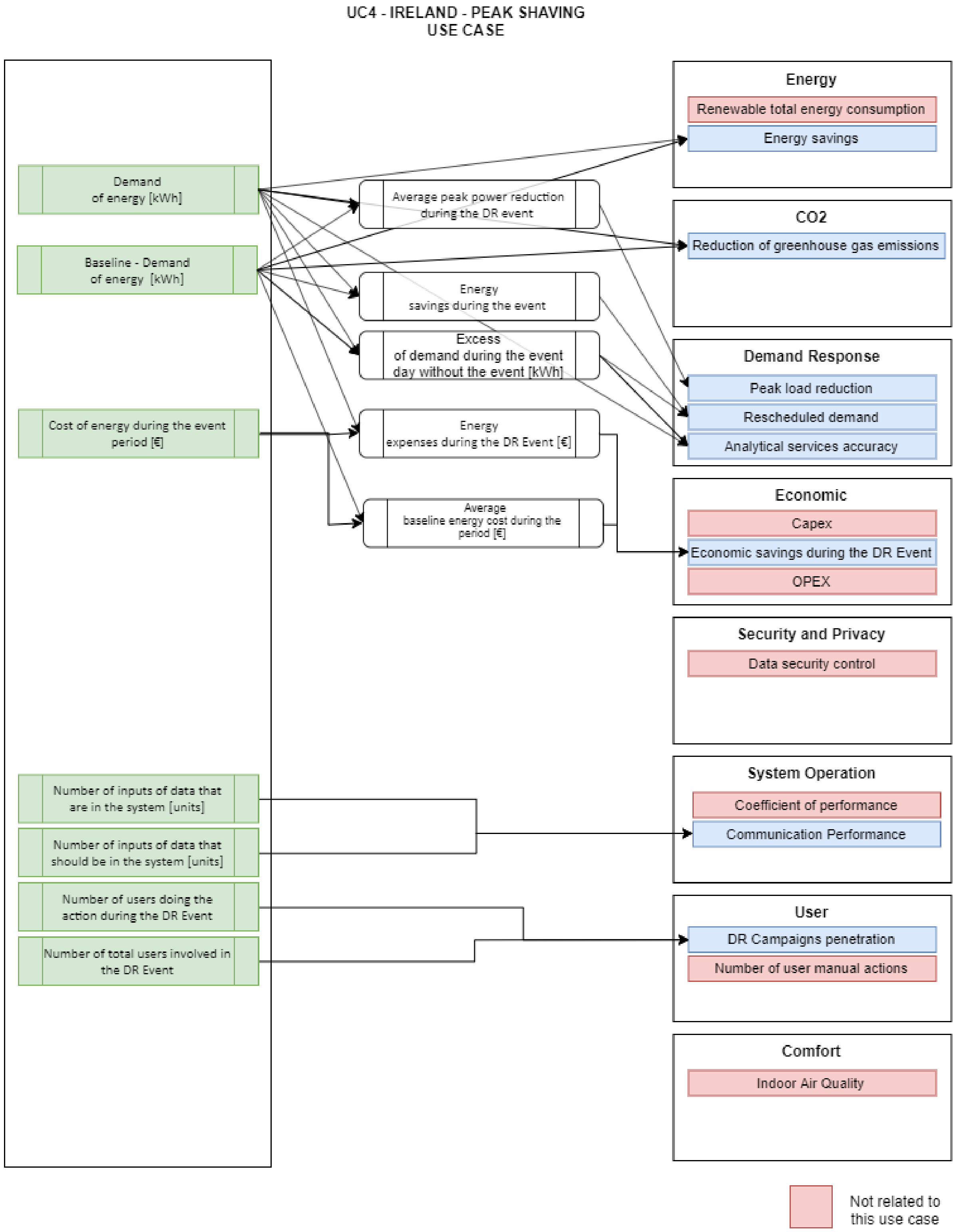

Figure 10 - Correlation between data required and KPIs – UC4

6.1.5 UC5 – Denmark - Load shifting district heating system

The technical purpose of this scenario is to move energy consumption for heating in time through temperature setback in the morning hours. In Figure 11 is possible to see the peak load consumption for the Aarhus pilot. This way, the objective is to reschedule the heat demand in the pilots to avoid the usage of the grid during these periods.

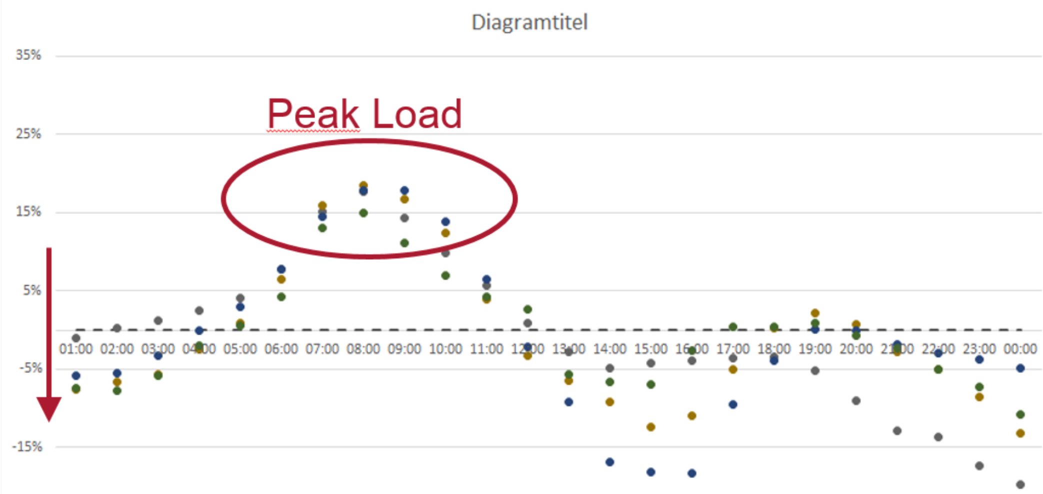

Figure 11 - District Aarhus pilot consumption from AffaldVarme Aarhus [1]

When the users install the RESPOND app on their smartphone, they are asked whether they want to participate in the DR programs. This preference could be modified by the user anytime activating or deactivating the option. By accepting with "Yes", the user accepts that the RESPOND solution will automatically shift the morning heat load, during the morning hours (i.e. between 6 am and 9 am). This scenario will run automatically by the RESPOND platform through automatic control of the thermostat valves, which are installed only in 10 houses in the Aarhus pilot. The scenario can be interrupted by the user at any time, manually overwriting the defined morning set-back.

For measuring the efficiency of this use case, the following KPIs will be used:

- Peak load reduction
- Rescheduled demand
- Analytical services accuracy
- Economic savings during the DR event
- Communication performance
- DR campaign penetration
- Number of user manual actions

The data needed for measuring all the KPIs are described in Table 24.

Data needed to calculate the KPIs	Unit
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Number of users doing the action during the DR Event	[users]
Number of total users involved in the DR Event	[users]
Users that accepted the automated event	[users]

Table 24 - Data needed to calculate the use case 5

The correlation between the KPI and the data is described in Figure 12.

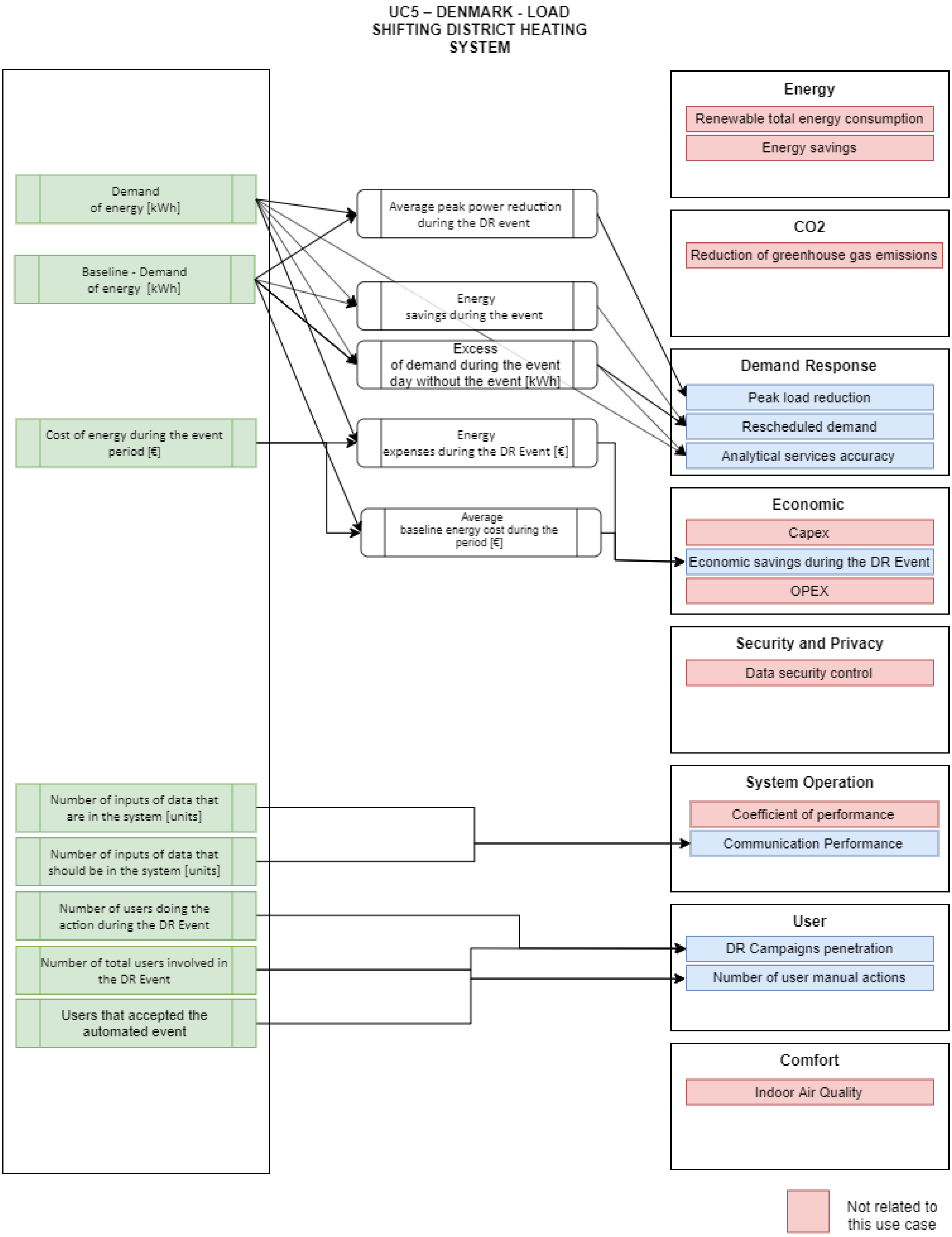

Figure 12 - Correlation between data required and KPIs – UC5

6.1.6 UC6 – DENMARK - MAXIMIZE AUTO-CONSUMPTION FROM GRID CONNECTED PV PANELS

ALBOA has currently a spot price agreement with AURA. ALBOA has decided that everyone in the Danish pilot are settled with a fixed price. The families are charged a payment each month. The payment each month is based on the estimated consumption and with a price, which is a little higher than what the really should have paid so families will always get money back when annually settling.
Once a year, ALBOA determines what the families really should have paid. ALBOA have set the price at DKK 2.21 per kWh.

ALBOA Electricity price	**Price**	**DKK/kWh**
Gen. Spot 2018 (variable market price)	0,3281	kr./kWh
Elhandel tillæg (fee for getting the variable market price)	0,0067	kr./kWh
KONSTANT (Supply company)	0,454	kr./kWh
Parafiscal charge/fee	0,946	kr./kWh
25 % VAT for the State	0,4337	kr./kWh
Total electricity price	2,1685	kr./kWh

Figure 13 - ALBOA Electricity price

The electricity company KONSTANT (Næringen and Nyringens electricity supply company is KONSTANT, AURA is only selling electricity to ALBOA).

In addition, it will not only be the spot prices that changes. The electricity price in DK is made up of several element as you can see in the table.

RESPOND families are settled normally by ALBOA (presumably a conto per month and an annual statement) but we add a RESPOND Bonus settlement model.

REPOND variable price model:

In periods with overproduction of solar electricity from ALBOA's PV, the families can buy the electricity to the same price that ALBOA can achieve by selling it to the grid (0,60 DKK). Other periods are settled as normally. Especially for the

- Test period: When there is overproduction from solar systems, presumably in May, June, July, August 2020
- The families are settled individually and directly with the RESPOND project. (AURA is responsible for settlement)
- RESPOND Bonus is paid when the test period is complete, but families can keep track of how much they have saved on the RESPOND App.
- Only RESPOND Bonus is included for electricity consumption, which is used by appliances with a plug ie. dishwasher, washing machine and tumble dryer + possibly. free style plugs (green, can be purchased?)

The technical purpose of this use case is to optimize consumption of locally generated PV power within the ALBOA housing association. Thus, the aim is to optimize self-sufficiency and avoid exporting excess PV power generation to the grid. The scenario is based on the RESPOND platform and mobile app providing recommendations to the residents on when it is feasible for them to increase consumption of electricity through time-shifting consumption from other hours.

When the users install the RESPOND app on their smartphone, they are asked whether they want to participate in the DR programs. This preference could be modified by the user anytime activating or deactivating the option. If they accept, on days with a predicted local PV power production that exceeds the predicted power consumption of the ALBOA housing association, the residents receive a notification via the app. The notification is issued the evening before the predicted PV surplus production event. The user gets the notification: "Tomorrow between [hour] and [hour], there will be a surplus production of solar power. Consider moving electricity consumption to these hours to utilize the PV power produced."

For measuring the efficiency of this use case, the following KPIs will be used:

- Renewable total energy consumption
- Rescheduled demand
- Analytical services accuracy
- Economic savings during the DR event
- Communication performance
- DR campaign penetration

The data needed for measuring all the KPIs are described in Table 25.

Data needed to calculate the KPIs	Unit
Renewable energy produced	[kWh]
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Number of users doing the action during the DR Event	[users]
Number of total users involved in the DR Event	[users]

Table 25 - Data needed to calculate the use case 6

The correlation between the KPI and the data is described in Figure 14.

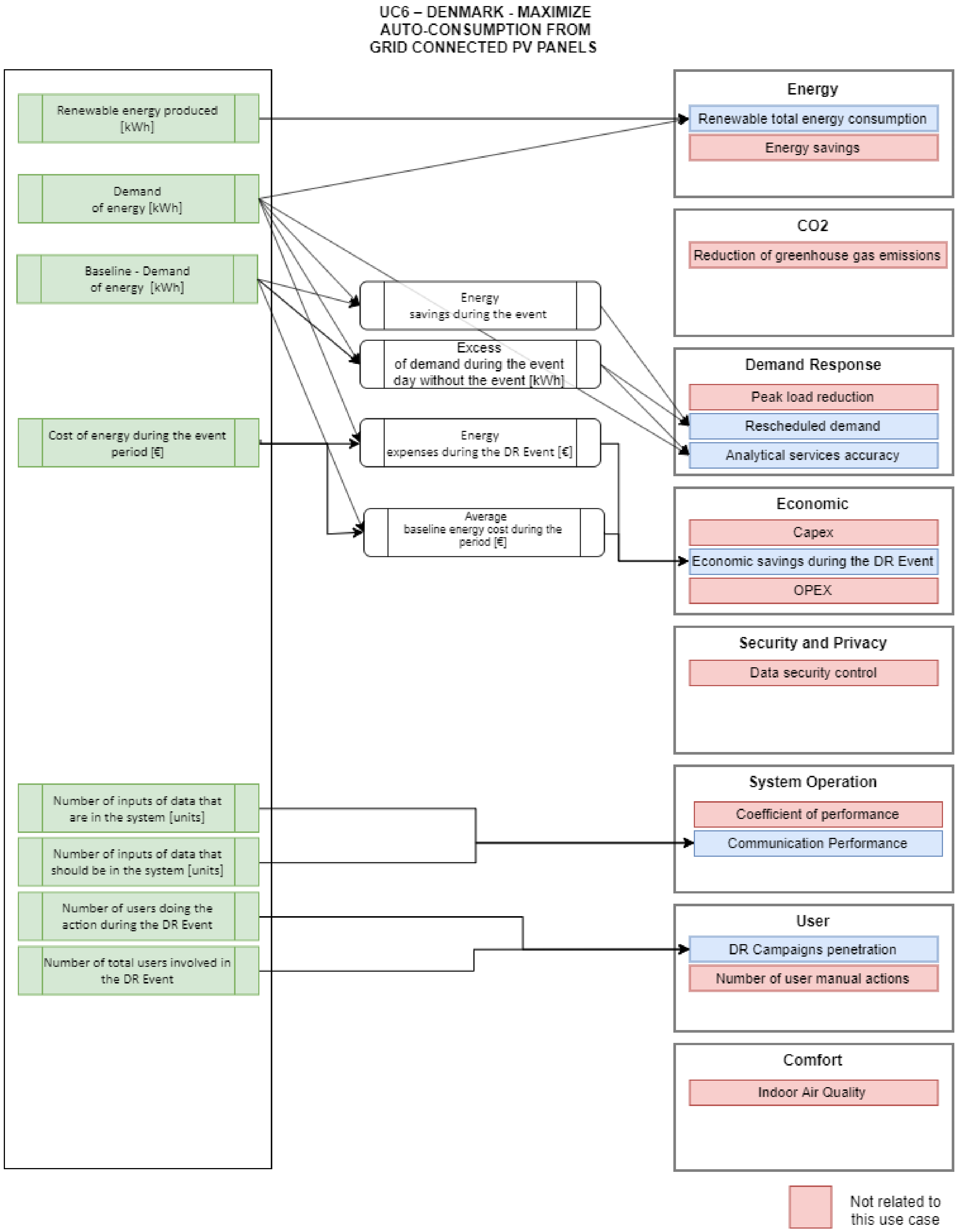

Figure 14 - Correlation between data required and KPIs – UC6

6.1.7 UC7 – Madrid - Price based DR for electrical energy consumption

The technical purpose of this use case is to support the Madrid households in performing DR in relation to electricity price. The Madrid focus group on cooling demonstrated willingness among the participants to time-shift some of their energy consumption, not only related to cooling, which are either supplied by air conditioning or ventilators standing for an important portion of the consumption in summer, but for the whole electric load. The idea is to use mobile app recommendations to make the users aware of when it would be advisable to reduce energy consumption. The option of combining notifications with an option of remote control has also been considered but has been evaluated as less relevant as all focus group participants report that they turn off appliances while they are away from home.

When installing the RESPOND mobile app, the user is asked if s/he would like to receive recommendations when it is advisable to avoid or reduce energy consumption. If the user answers yes to this, the recommendations module of DR is activated.

On days with low electricity prices, the user of the RESPOND mobile receives no notifications. However, if the electricity price exceeds a certain level, the user gets an app notification recommending reducing the use of electricity. An example of App notification is: “The electricity price is high at the moment. It is advisable to reduce consumption. For instance, if you are using air conditioning, you might consider turning it off or increase the temperature setpoint in order to save energy and money. The electricity price is estimated to be high for the next X hours”.

This event doesn’t have limit of interaction with the user as the customer asked to have this module activated for recommendations. It is just recommended not to send more than one interaction a day. As the number of customers in each this pilot is small, A/B tests for messages will not be applied.

For measuring the efficiency of this use case, the following KPIs will be used:

- Energy savings
- Reduction of Greenhouse gas emissions
- Peak load reduction
- Rescheduled demand
- Analytical services accuracy
- Economic savings during the DR event
- Communication performance
- DR campaign penetration

The data needed for measuring all the KPIs are described in Table 26

Data needed to calculate the KPIs	Unit
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]
Number of users doing the action during the DR Event	[users]
Number of total users involved in the DR Event	[users]

Table 26 - Data needed to calculate the use case 7

The correlation between the KPI and the data is described in Figure 15.

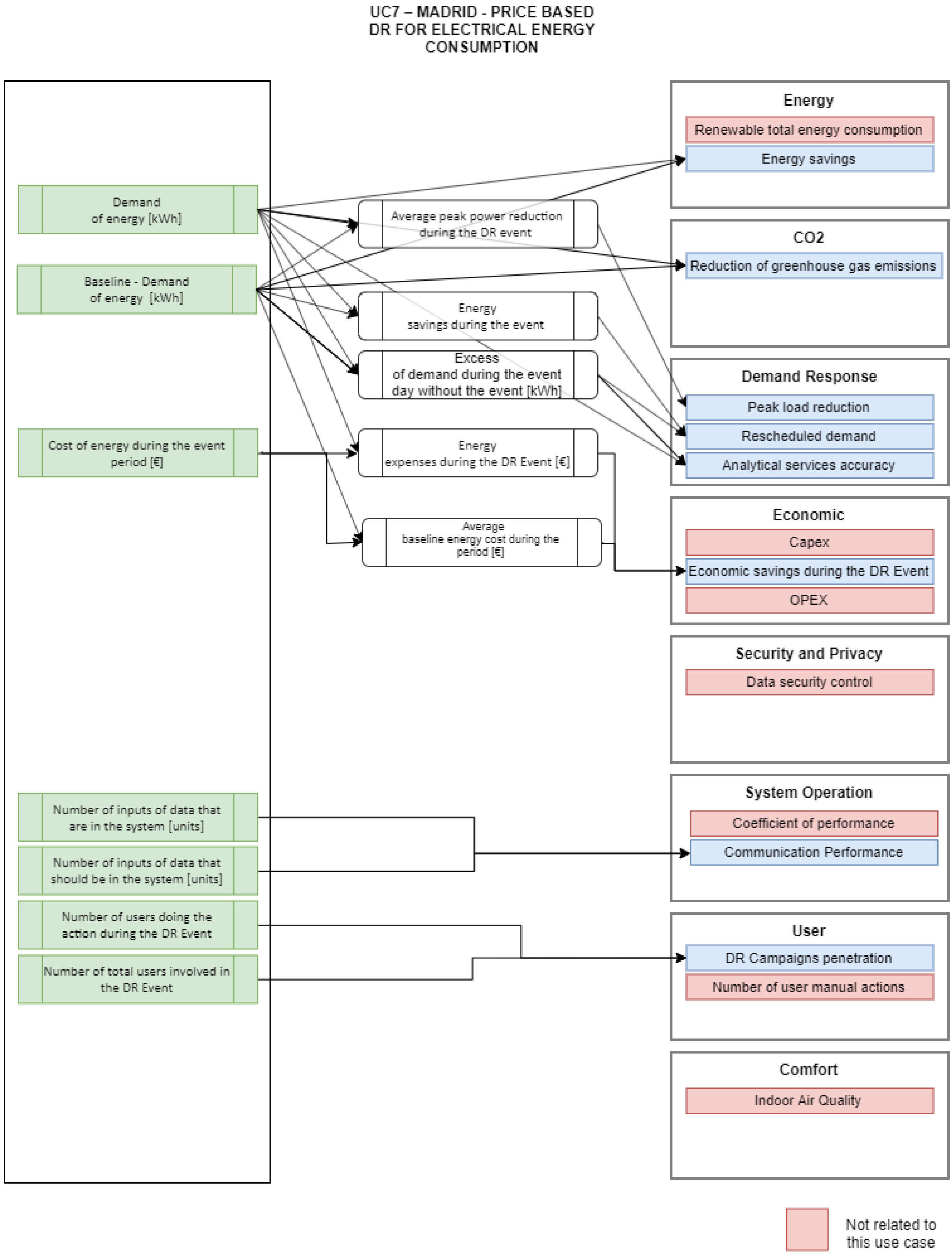

Figure 15 - Correlation between data required and KPIs – UC7

6.1.8 UC8 - Madrid - Maximal exploitation of renewable resources

The objective of this event is to analyze if the thermosolar heat water system is being used preferably during sunny hours and therefore it is decreasing the gas usage for domestic hot water (DHW). Guaranteeing the target of 100% exploitation of renewables in the pilot.

The users will be able to follow in the mobile app the current thermosolar production as well as the temperature of the water in the tanks with the idea to foster DHW consumption in the moments when there are more thermosolar energy available.

This event does not have defined frequency, as the user don't need to be contacted for giving opinion or additional authorization, the systems will just show them current status of the thermosolar production.

For measuring the efficiency of this use case, the following KPIs will be used:

- Energy Savings
- Reduction of greenhouse gas emissions
- Economic savings during the DR event
- Coefficient of Performance
- Communication performance

The data needed for measuring all the KPIs are described in Table 27.

Data needed to calculate the KPIs	Unit
Demand of energy	[kWh]
Baseline – Demand of energy	[kWh]
Cost of energy during the event period	[€]
Production of energy	[kWh]
Baseline – Production of energy	[kWh]
Number of inputs of data that are in the system	[units]
Number of inputs of data that should be in the system	[units]

Table 27 - Data needed to calculate the use case 8

The correlation between the KPI and the data is described in Figure 16.

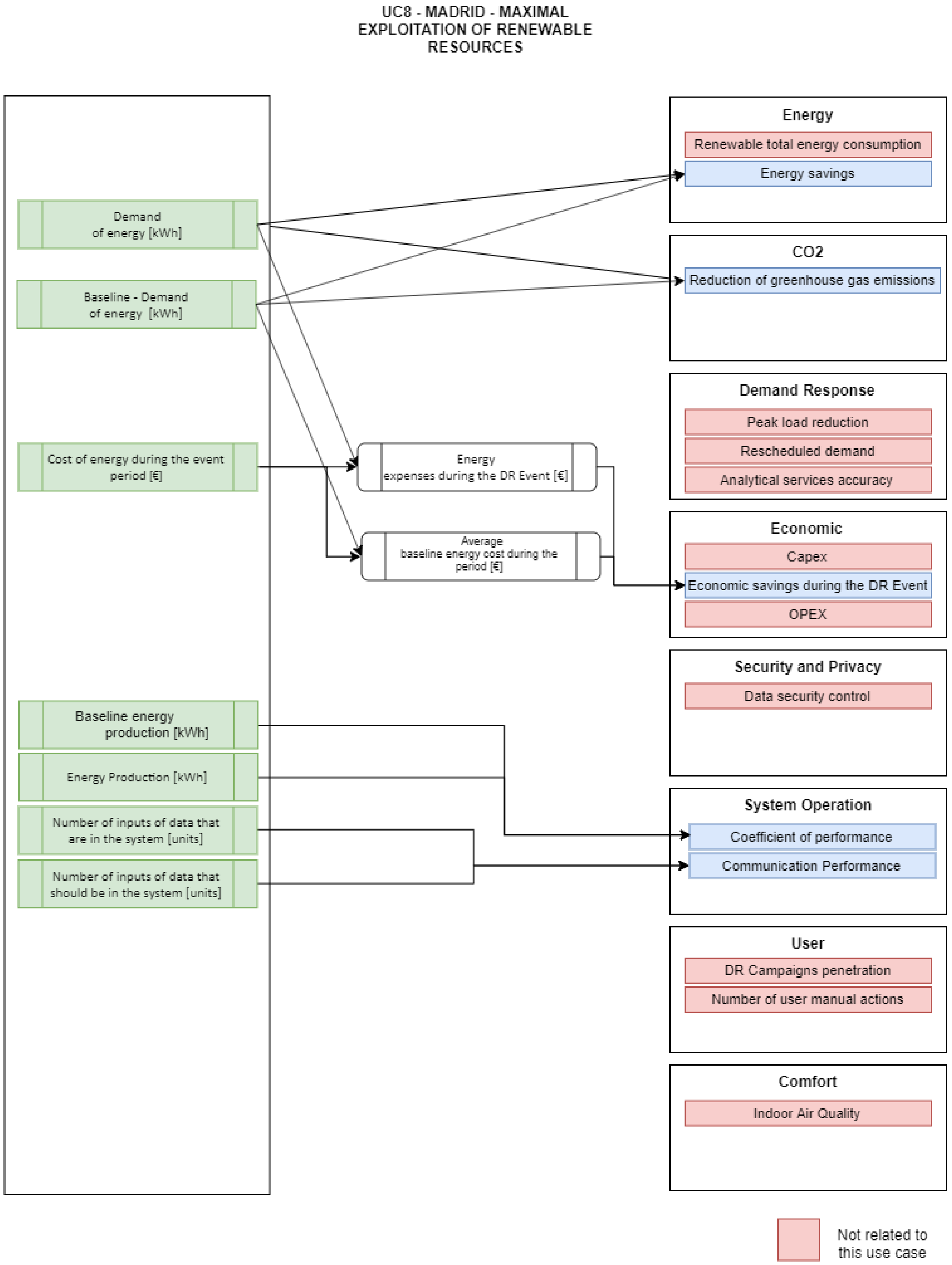

Figure 16 - Correlation between data required and KPIs – UC8

7. CONCLUSIONS

The document contains the RESPOND validation methodology to provide an assessment of project results and related use cases from the prospective of energy/cost saving, carbon emission reduction and economic sustainability. The document provides the data to be collected in a quantitative and qualitative manner, in order to reach user' requirements, considering indoor environmental, functionality, usability, security and safety.

The document provides also the concepts of IPMVP protocol and eeMeasure methodology for energy savings measurements. The most common issues for Performance Measurement & Verification assessment is the development of a baseline, which in RESPOND will be addressed with the adoption of the RESPOND demand forecast, monitoring and repository services. These services aim to provide the most accurate estimation of electrical and thermal energy demand at a dwelling and neighborhood levels via predictive models. The models provide a continuous calibrated baseline to obtain higher accuracy.

A description of the use cases which will be implemented in the pilot cases is also included, as a definition of related KPIs in order to assess the project objectives, see Annex II.

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8. ANNEX

Annex 1 - CORRELATION BETWEEN DATA REQUIRED AND KPIS

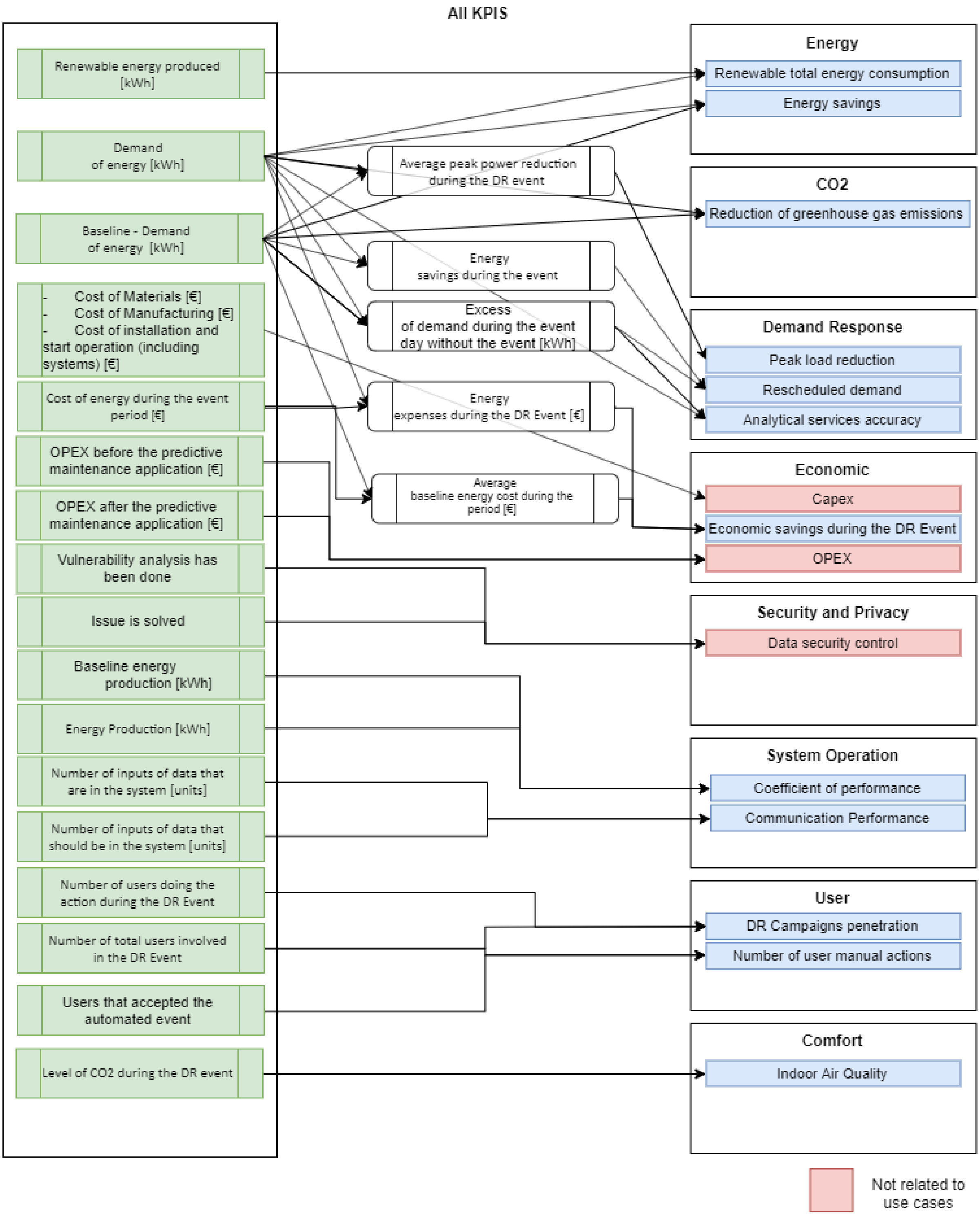

Figure 17 - Correlation between data required and KPIs

Annex 2 - CORRELATION BETWEEN Use Cases – KPIs and Objectives

Country	Use Case	KPIs	RESPOND Objective
All	UC1 – ALL PILOTS – IMPACT OF RESPOND APP TO THE USER	- Energy Savings - Reduction of greenhouse gas emissions - Communication performance - Indoor air quality	GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO1 - REAL-TIME OPTIMISATION OF ENERGY SUPPLY AND DEMAND SIDE SO5 - USER COMFORT
Ireland	UC2 – IRELAND - MAXIMIZE AUTO CONSUMPTION CONTROL SWITCHES FOR APPLIANCES	- Renewable total energy consumption - Reduction of greenhouse gas emissions - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Coefficient of performance - Communication performance - DR campaign penetration	GO1 - COOPERATIVE DEMAND MANAGEMENT TO MAXIMIZE THE USE OF COMMON ENERGY RESOURCES GO2 - ENGAGEMENT OF BUILDING OCCUPANTS GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO1 - REAL-TIME OPTIMISATION OF ENERGY SUPPLY AND DEMAND SIDE SO3 - USER HABITS ADAPTION TO RENEWABLE ENERGY GENERATION
Ireland	UC3 - IRELAND - PV PANEL – OPTIMAL PROFILE OF USE FOR HEAT PUMPS	- Renewable total energy consumption - Reduction of greenhouse gas emissions - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration	GO1 - COOPERATIVE DEMAND MANAGEMENT TO MAXIMIZE THE USE OF COMMON ENERGY RESOURCES GO2 - ENGAGEMENT OF BUILDING OCCUPANTS GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO2 - CLOSING THE DR LOOP WITH OPTIMISED CONTROL ACTIONS SO3 - USER HABITS ADAPTION TO RENEWABLE ENERGY GENERATION SO5 - USER COMFORT
Ireland	UC4 - IRELAND - PEAK SHAVING USE CASE	- Energy Savings - Reduction of Greenhouse gas emissions - Peak load reduction - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration	GO2 - ENGAGEMENT OF BUILDING OCCUPANTS GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO1 - REAL-TIME OPTIMISATION OF ENERGY SUPPLY AND DEMAND SIDE SO2 - CLOSING THE DR LOOP WITH OPTIMISED CONTROL ACTIONS
Denmark	UC5 – DENMARK - LOAD SHIFTING DISTRICT HEATING SYSTEM	- Peak load reduction - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration - Number of user manual actions	GO2 - ENGAGEMENT OF BUILDING OCCUPANTS GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO2 - CLOSING THE DR LOOP WITH OPTIMISED CONTROL ACTIONS
Denmark	UC6 – DENMARK - MAXIMIZE AUTO-CONSUMPTION FROM GRID CONNECTED PV PANELS	- Renewable total energy consumption - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration	GO1 - COOPERATIVE DEMAND MANAGEMENT TO MAXIMIZE THE USE OF COMMON ENERGY RESOURCES GO2 - ENGAGEMENT OF BUILDING OCCUPANTS GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO3 - USER HABITS ADAPTION TO RENEWABLE ENERGY GENERATION
Spain	UC7 – MADRID - PRICE BASED DR FOR ELECTRICAL ENERGY CONSUMPTION	- Energy savings - Reduction of Greenhouse gas emissions - Peak load reduction - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration	GO2 - ENGAGEMENT OF BUILDING OCCUPANTS GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO1 - REAL-TIME OPTIMISATION OF ENERGY SUPPLY AND DEMAND SIDE
Spain	UC8 - MADRID - MAXIMAL EXPLOITATION OF RENEWABLE RESOURCES	- Energy Savings - Reduction of greenhouse gas emissions - Economic savings during the DR event - Coefficient of performance - Communication performance	GO5 - EFFICIENT BUSINESS MODEL AT BUILDING AND DISTRICT LEVEL SO1 - REAL-TIME OPTIMISATION OF ENERGY SUPPLY AND DEMAND SIDE SO4 - PREDICTIVE MAINTENANCE TO REDUCE OPERATIONAL COSTS

Table 28 - CORRELATION BETWEEN Use Cases – KPIs and Objectives