OptEEmAL

OPTIMISED ENERGY EFFICIENT DESIGN PLATFORM FOR REFURBISHMENT AT DISTRICT LEVEL

Optimised Energy Efficient Design Platform for Refurbishment at District Level
H2020-WORK PROGRAMME 2014-2015 – 5. Leadership in enabling and industrial technologies
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# D4.1: Requirements and design of the Optimisation Module

## WP4, Task 4.1

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## Abbreviations and Acronyms

| Acronym | Description |
|---|---|
| OptEEmAL | Optimised Energy Efficient Design Platform for Refurbishment at District Level. |
| BIM | Building Information Model |
| DDM | District Data Model |
| DPI | District Performance Indicator |
| DMM | Data Management Module |
| ECM | Energy Conservation Measure |
| GUI | Graphical User Interface |
| MAVT | Multi Attribute Value Theory |
| AHP | Analytic Hierarchy Process |
| HM | Harmony Memory |
| HMCR | Harmony Memory Considered Rate |
| HS | Harmony Search |
| PAR | Pitch Adjusting Rate |
| RSR | Random Selection Rate |
| IPD | Integrated Project Delivery |
| IPC | Integrated Project Coordinator |

# Executive Summary

The objective of OptEEmAL is to develop an Optimised Energy Efficient Design Platform for refurbishment at district level. The platform will deliver an optimised, integrated and systematic design based on an Integrated Project Delivery (IPD) approach for building and district retrofitting projects. This will be achieved through the development of an Optimisation Module that will consider targets, boundaries and barriers from the district under study to define the best ranking of refurbishment scenarios.

This deliverable is the outcome of the Task 4.1 "Optimisation process requirements and specification and optimisation algorithm definition" composed by Subtask 4.1.1 "Optimisation process requirements and specification" and Subtask 4.1.2 "Optimisation algorithm definition".

The main objective of this task is to establish specifications that adequately represent the refurbishment plan and the stakeholder's priorities. The output of the algorithm will provide a ranking of best scenarios based on different combinations of solutions from the ECMs catalogue.

The combination of strategies will be evaluated based on the DPI calculation through the Simulation Module. The combination of strategies will be evaluated following a heuristic optimization method such as harmony search approach. In this task it will be identified how to represent all parameters needed to describe each scenario as a combination of solutions, taking as a reference the ECMs catalogue developed in WP3.

The heuristic algorithm will follow a continuous refinement of the candidate set of retrofitting scenarios starting from an initial population. The parameterisation of each individual scenario will be the basis for the appropriate construction of the optimization algorithm and the selection of the Probabilistic Operators that will be the core of the Optimisation Module. The probabilistic operators that define the behaviour of the evolutionary strategy are the application of selection, recombination and mutation operators to the previous population. In this task, these operators will be also defined at a first approach.

Harmony Search (HS) algorithm has been selected for the OptEEmAL approach. HS is a population-based meta-heuristic algorithm which has obtained excellent results in the field of combinatorial optimization. It mimics the behavior of a music orchestra when aiming at composing the most harmonious melody, as measured by aesthetic standards. When comparing the improvisation process of musicians with the optimization task, we can realize that each musician corresponds to a decision variable that plays a note for finding the best harmony; the musical instrument's pitch range refers to the alphabet of the decision variable; the musical harmony improvised at a certain time corresponds to a solution vector at a given iteration; and audience's aesthetic impression links to the objective fitness function of the optimization problem at hand. Just like musicians improve the melody time after time, the HS algorithm progressively enhances the fitness of the solution vector in an iterative fashion. The main difference between the HS and the genetic algorithm is the use of improvisation operators that will enhance the explorative search beyond parent solutions.

The Data Management Module (DMM) plays a key role to ensure the interoperability between the different modules of the OptEEmAL platform. The Optimisation Module will remain a black box that will connect with the Data Management Module through internal interfaces. The Data Management Module will be the link between the Optimisation Module and the Simulation Module.

The Optimisation Module will connect with the Communication Logic Layer to request the project data, the applicable ECMs and the results of the simulation. Furthermore, the ranking of best scenarios will be stored into the Project Repository Connector.

The Optimisation Module has to fulfil a set of requirements in order to offer the functionality required by the platform, to assure the interoperability with other modules and repositories and to comply with the condition of quality in the data. For this purpose, different groups of requirements have been defined:

- Input data requirements
- Data quality requirements
- Interoperability requirements
- Implementation requirements

The Optimisation Module is composed by three main components:

- Scenario Generator
- Evaluator
- Optimisation algorithm

As a final result of the task, the functionalities of each component and their connexion will be defined.

In the course of carrying out Task 4.1, inputs and results from other tasks have been incorporated to the work. Especially, the results of Task 3.2 “ECMs catalogue prototype deployment and validation” and Task 5.2 “Functional architecture, interfaces definition and overall platform design”.

# 1 Introduction

## 1.1 Purpose and target group

This report constitutes the Deliverable "D4.1. Requirements and design of the Optimisation Module", the main outcome of task "Task 4.1 Optimisation process requirements and specification and optimisation algorithm definition".

One of the main objectives of this document is to define the requirements that have to be met by the Optimisation Module.

The second main objective is to design the Optimisation Module. Within this deliverable, the main functionalities of each component of the Optimisation Module and its interoperability with the Data Management Module have been defined.

## 1.2 Contributions of partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

| Participant short name | Contributions |
|---|---|
| TEC | Task coordination. Defines the objectives of the Optimisation Module. Coordinates the design of the Optimisation Module. Responsible of the Scenarios Generator and the Optimisation algorithm design. Within the Evaluator, TEC develops the bi-objective function. Develops the relation between the Optimisation Module and the ECM catalogue; combination rules, parametrisation and constraints. |
| CAR | Coordinates the specification of requirements of the Optimisation Module. Collaborates in the architecture development and in the integration in the OptEEmAL platform. Develops the methodology to define the multi-criteria global objective function within the Evaluator. |
| NBK | Collaborates on the understanding definition of the refurbishment scenario codification and the Simulation Data Model to allow the calculation of environmental DPIs. |
| TUC | Collaborates in the definition of the Optimisation Module architecture development and the interoperability between the Data Management Model and the Simulation Module to allow the calculation of the metrics (DPIs). Defines the procedure to reduce the computational cost of the optimisation process. |
| ACC | Justify the IPD-based approach within the Optimisation Module. Collaborates in the definition of the process to create refurbishment scenarios from passive ECMs. |
| UTRC-I | Defines the input data needed to define scenarios. Collaborates in the definition of the process to create refurbishment scenarios from control ECMs; combination rules, parametrisation and constraints. |
| ES | Define the high level architecture of the Optimisation Module. Defines the implementation requirements. |

## 1.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities (or deliverables) developed within the OptEEmAL Project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

| Deliverable Number | Contributions |
| --- | --- |
| D1.2 | Definition of input data. This information will be used to create scenarios and to stablish the stakeholders' priorities (targets, boundaries and barriers and prioritisation criteria). |
| D1.6 | Output data of the Optimisation Module to be processed by the end users. |
| D2.1 | Interoperability with the District Data Model. |
| D2.2 | DPIs to define the objective function. |
| D2.3 | Define the requirements of the data repositories to store the information related to the definition and evaluation of the scenarios generated. Define the requirements to store the final ranking of best scenarios. |
| D2.5 | Define the information exchange protocols between the Optimisation Module and the Data Management Module. |
| D3.2 | ECMs combination rules, constraints and parameters needed to create scenarios. |
| D4.2 | Outputs from D4.1 will be used to develop the Optimisation Module. |
| D4.4 | The requirements and the specifications from scenarios to generate the simulation models. The time consuming of the simulation process will be critical when evaluating the computational cost of the optimisation process. |
| D5.1 | Define the Uses Cases related to the Scenarios Generator. |
| D5.2 | Defines the architecture of the Optimisation Module and its interoperability with the Data Management Module and the Communication Logic Layer. |

# 2 Optimisation Module

## 2.1 Objectives of the Optimisation Module

The Optimisation Module is one of the core elements of the OptEEmAL solution, since it automates one of the most complex processes involved in the design of a refurbishment project.

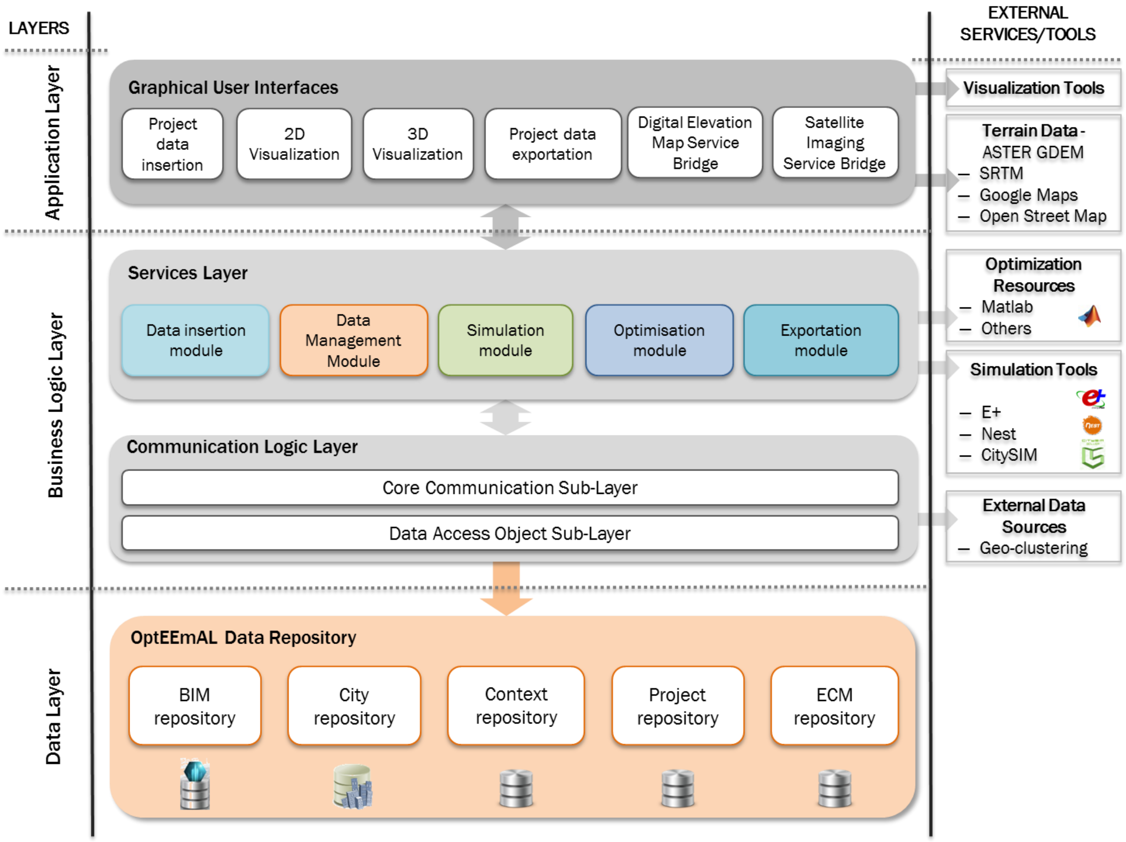


Figure 1: OptEEmAL high-level architecture

Particularly, this module is in charge of generating the scenarios and evaluating the results of simulating different refurbishment solutions (scenarios) taking into account:

- the initial situation of the district, represented by different District Perfomance Indicators (diagnosis DPIs) and all the information required to describe the district contained within the District Data Model,
- the Energy Conservation Measures that can be implemented in the district under study (applicable ECMs), according to the specific boundaries and barriers that have been identified by the different stakeholders involved in the design project,
- the available District Simulation Data Models to be modified with the implementation of ECMs, and
- the priorizitation criteria and the specific targets that the stakeholders have selected to assess the results of the scenarios' evaluation (ponderation of the evaluation DPIs or multiobjective optimisation)

Using the previous elements to calculate the metrics of each refurbishment scenario (DPIs), the Optimisation Module will be able to optimise the scenarios and generate a ranking of best scenarios that fulfil the established criteria. The ranking of best scenarios will be stored in the Project Repository.

To be able to reach this final objective (provide a ranking of appropriate scenarios), the Optimisation Module has to implement the process presented in **¡Error! No se encuentra el origen de la referencia.**. The main objectives of this process are:

- Generating a first population (candidate scenarios created by the Scenarios Generator) using an initial combination of different parameters belonging to a unique or multiple ECMs. This first scenario should comply with the barriers and boundaries established for the district and buildings under study. This scenario vector will be sent to the instance creator, which will launch the information to the simulation model input generator to be able to obtain the simulation models. These will be evaluated using external tools and the results of this process (DPIs) will be stored into the Project Repository.
- Assessing the first population (Evaluator) according to the objective function created from the targets, boundaries and prioritisation criteria defined and the DPIs caculated. Sending the evaluation information to the optimisation algorithm.
- According to these results, the optimisation algorithm proposes a new population (based on previous and new combination of ECMs and new parameters) through the use of the probabilistic operators.
- Repeating the process for this second scenario, and for others coming taking into account the DPIs, the priorisitation and the stopping criteria.
- Once this process ends (when all the possible combinations of ECM parameters have been considered or the stopping criteria of the optimisation algorithm have been met) the Optimisation Module stores the best scenarios (in form of scenario vector, calculated DPIs and objective function) into the Project Repository.

## 2.2 Overall approach

The Optimisation Module has an essential role in the platform, generating the different scenarios to be simulated and evaluating the results of these simulations in order to find the best possible scenarios. For this general purpose, the module needs to communicate with different parts of the platform: different modules and repositories.

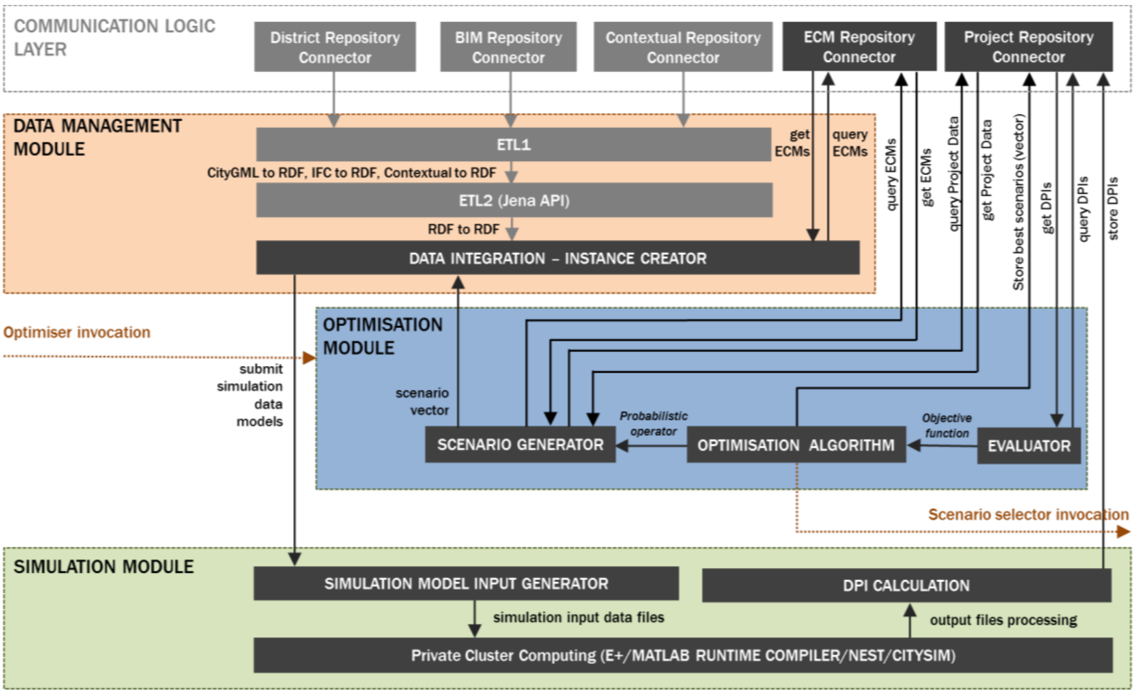


Figure 2: Optimisation process

The inputs needed by the Optimisation Module are:

- Targets, boundaries and barriers
- Applicable ECMs
- Diagnosis DPIs
- Prioritization criteria

These inputs have to be stored in the repository following the District Data Model before the optimisation process starts, being inserted by the end users or generated in the previous phases.

The outputs of the stage, i.e., the scenarios classified by the module as best scenarios, will be passed on at the end of this phase to the Project Repository Connector, which will store these results in the Project Repository.

The process followed in the optimisation, and represented in the Figure 2, is:

- The Optimisation Module, based on diagnosis DPIs for the baseline scenario and Project Data (targets, boundaries, and barriers) launches the optimisation process.
- The Scenarios Generator queries the ECM Repository to check the applicable ECMs checked by the end users. Based on the applicable ECMs and their combination rules the refurbishment scenarios are generated and codified. Once the result of the codification (in a form of a vector as a combination of passive, active and control strategies) is obtained the "instance creator" is launched, in order to create the new instance of the Simulation Data Model through mapping the data contained in the ECMs catalogue over the existing models for the baseline.
- Once the instance is created, the Simulation Model Input Generator is in charge of generating the simulation input data files, configuring the simulation and launching the simulation process. This Simulation Module is like a black box for the Optimisation Module using as input the files and configuration provided by the simulation model input generator, and providing as outcome the calculated and processed DPIs to be temporally stored into the Project Repository as result of the evaluation of the scenario n. The Simulation Module that consists of the simulation model input generator, the simulation process and the DPI calculation is being defined and designed in task 4.5.
- Once DPIs are calculated and stored, the optimiser retrieves and evaluates these results transformed into the objective function. At every iteration, the new generated solution vectors are sorted.
- Based on the evaluation results, the Optimisation Module launches the new iteration through modifying the ECMs variables that are parametrised and, thus, restarting again the process through the Scenario Generator and applying the probabilistic operators.
- The process is a loop and it will finish when the stopping criteria are reached.

The Optimisation Module will be developed in Python 2.7. It will consist on an iterative process based on the Harmony Search algorithm (HS) for which different probabilistic operators, named HMCR, PAR and RSR have been defined under this task and will be developed in task 4.2.

## 2.3 Optimisation Module and implementation of an IPD-based approach

The criteria ensuring the representativeness of the stakeholders through the IPD approach affects the design of the refurbishment scenarios, through:

1. Establishing certain barriers and checking of the applicable ECMs
2. Establishing targets, boundaries and prioritisation criteria that affects the objective function

The End Users will select the applicable ECMs from the list to allow creating feasible scenarios. The objective of this stage is that the End Users delete all the ECMs that cannot be implemented according to their knowledge. All the decisions taken must be correctly justified by the end users inserting a text file explaining the reasons to delete ECMs or choosing from a closed list pre-defined.

This process will allow checking reasons to the rest of end users. Possible reasons for avoiding the implementation of a specific measure are:

- Lack of suppliers for the ECM in the geographical area
- Lack of experience using the ECM by the actor involved in its implementation.
- Explicit statement by the owner of the non-use specific ECM
- Limitations given by legislation

In order to assist the decision making process, different profiles should take decisions at different levels and for different building uses:

Table 3: Profiles and responsibilities to assess applicable ECMs

| Scale | Entity denomination | Role in IPD |
|---|---|---|
| **Solutions at district scale** | Municipality | Owner, IPC, Prime designer |
| **Solutions for public buildings** | Municipality | Owner, IPC, Prime designer |
| **Solutions for private buildings** | Building owners | Owner (in order to being able of having this role, it should have technical help) |
| **Solutions for residential buildings** | Neighbourhood associations, owners | Owner (in order to being able of having this role, it should have technical help) |

The Optimisation Module has to use decision made by consensus of every IPD actor involved as it is stated in the IPD specification Figure 3 to define targets and boundaries to define the refurbishment scenarios; more precisely, to define the objective function that will be used to optimise the refurbishment scenarios.

Furthermore, End Users will select the OptEEmAL scenario from the final ranking of best scenarios taking into account combination of ECMs, calculated DPIs and prioritisation criteria. The information that will be displayed to End Users will be defined in depth in D1.6. Based on this information, outputs of the Optimisation Module will be clearly defined.

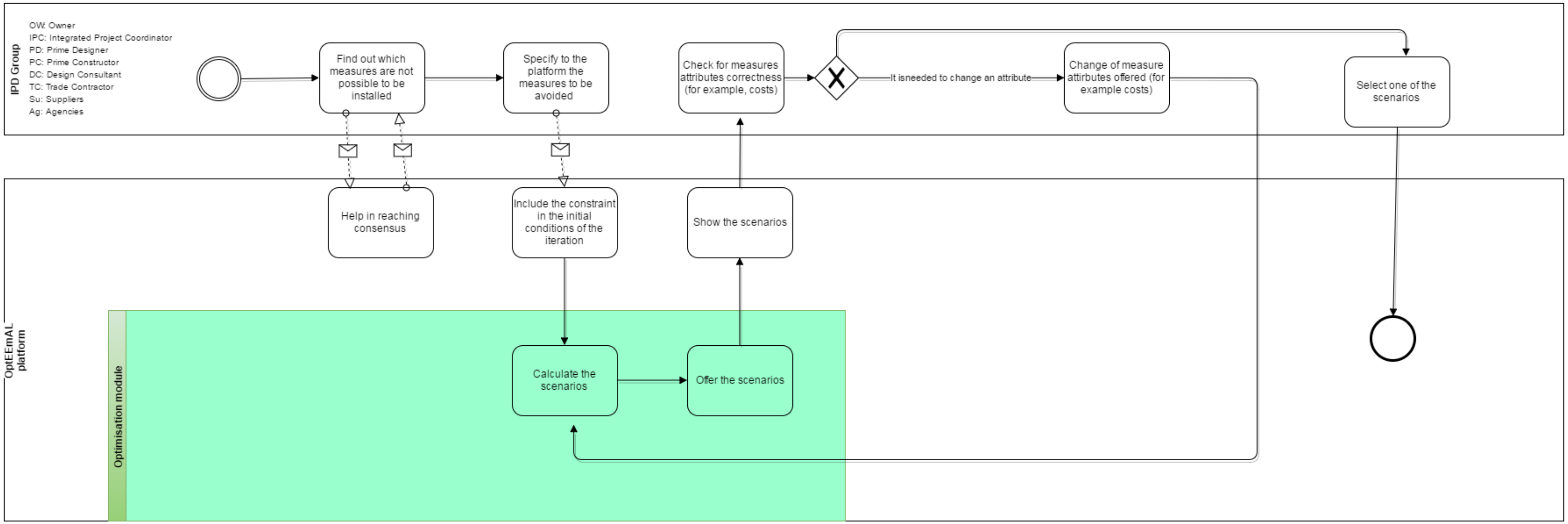


Figure 3: Interaction between the End Users and inputs-outputs of the Optimisation Module

# 3 Specification of requirements

The Optimisation Module has to fulfil a set of requirements in order to offer the functionality required by the platform, to assure the interoperability with the Data Management Module and the Data Repositories and to comply with the condition of quality in the data. For this purpose, different groups of requirements have been defined: Input data requirements, data quality requirements, interoperability requirements and implementation requirements.

These requirements were identified in the subtask 4.1.1 and they have been updated taking into account the advances in the different tasks of WP4 related to the optimisation, and also considering the last version of the OptEEmAL architecture developed within D5.2.

## 3.1 Input data requirements

The Optimisation Module will query the Communication Logic Layer to obtain the information needed from the data repositories (Project and applicable ECM data) to create the feasible refurbishment scenarios. The DPIs calculated into the Simulation Module will be stored into the Project Repository. The DPIs will be requested by the Optimisation Module to calculate the objective function that will be used to continue the optimisation process.

The following sub-sections reflect the input data requirements.

### 3.1.1 Project data requirements

The Optimisation Module will interact with the Project Repository Connector to obtain the information needed to generate feasible scenarios, evaluate and optimise the refurbishment scenarios. The final rank of best scenarios will be stored into the Project Repository, containing specific information from the selected ECMs and their parameters (scenarioId and scenario codification).

Table 4: Project input data requirements

| Req. Identifier | Description |
|---|---|
| R3.1.1.1 | To define feasible refurbishment scenarios, the Scenario Generator will need to check the relation between targets, boundaries and barriers of the project under study and each ECM. This information will be asked by the Optimisation Module to the Project Repository Connector. |
| R3.1.1.2 | To define the objective function, the Evaluator will ask the Project Repository Connector for the targets, the baseline DPIs and the prioritisation criteria. Targets and prioritisation criteria will be asked previously to the end users by the platform. |
| R3.1.1.3 | The Evaluator will query the scenario DPIs to calculate the Objective Function. |
| R3.1.1.4 | The Optimisation Algorithm will query the project targets and boundaries to optimise the scenarios generated. |

### 3.1.2 ECM data requirements

Table 5: ECM data requirements for the Optimisation Module

| Req. Identifier | Description |
|---|---|
| R3.1.2.1 | To generate feasible scenarios, the Scenario Generator will ask the ECM Repository Connector the applicable ECMs, their parametrisable variables, their relation with |

| | |
|---|---|
| | targets, boundaries and barriers and their combination rules. |
| R3.1.2.2 | The Scenarios Generator will create all the refurbishment scenarios for a project with a fixed list of ECMs from the catalogue. Each column of the scenario matrix will correspond to a specific ECM. |
| R3.1.2.3 | Each ECM should express its information in terms of parametrisable variables. These variables will be identified into the solution vector as specific codification. |
| R3.1.2.4 | ECMs combination matrix will establish the combination rules between ECMs. It will express if two ECMs can be installed at the same time in one building. |

## 3.2 Data quality requirements

The data quality requirements represent the specifications desired for the data to be used in the Optimisation Module, that is, the degree of detail, availability, accuracy, coherency, completeness and persistency of the data used in the optimisation process.

As indicated in the previous section, several data have been identified as necessary to operate the Optimisation Module. For these data, several data quality requirements are initially identified:

Table 6: Data quality requirements for the Optimisation Module

| Req. Identifier | Description |
|---|---|
| R3.2.1 | The input data for the Optimisation Module should be complete and accurate enough before being introduced in the Optimisation Module. |
| R3.2.2 | The input data of the Optimisation Module should be stored in a persistent repository in order to have them available during the optimisation process. |
| R3.2.3 | The input data of the Optimisation Module (when numerical information with measurements units are managed) should be represented using the International System of Units. |
| R3.2.4 | The same type of information should be represented in the same format (integer, float, double, number of decimals, separator, etc.) and using the same measurement units |
| R3.2.5 | The results of the Optimisation Module should be stored in a persistent repository in order to guarantee their recovery. |
| R3.2.6 | The results of the Optimisation Module should be represented in the same format (integer, float, double, number of decimals, separator, etc.) and using the same measurement units. |

## 3.3 Interoperability requirements

The interoperability requirements represent the specifications desired to guarantee the communication and understanding among several elements that work together towards a common objective. In the case of the Optimisation Module, these requirements represent the need of guaranteeing the interoperability among this Optimisation Module and other functional blocks of the OptEEmAL solution.

In that sense, several interoperability requirements are initially identified:

Table 7: Interoperability requirements

| Req. Identifier | Description |
|---|---|
| R3.3.1 | The Optimisation Module should take into account the common model representation used in OptEEmAL, that is, the common District Data Model (DDM). All the information exchanged and internally used by this module should be represented using this common data representation.<br>The DDM will be used as the common scheme to ensure the interoperability at syntactic and semantic levels. Therefore the Optimisation Module should comply with the common DDM defined in the project. |
| R3.3.2 | The Optimisation Module should interoperate with the DMM, which will interoperate with the Simulation Module to perform the processes required by the optimiser. The DMM must understand the scenario codification to generate the Simulation Data Model of each scenario. |
| R3.3.3 | To query the information described in section 3.1 “Input data requirements”, the Optimisation Module must interoperate with the Communication Logic Layer. |
| R3.3.4 | The Optimisation Module should define and implement the appropriate interfaces to guarantee the communication and understanding with other internal elements of the OptEEmAL solution: the DMM and the Communication Logic Layer. |
| R3.3.5 | In case that the Optimisation Module needs to use, internally or externally, other existing modules (for example, the tool to generate energy models), the Optimisation Module should implement the appropriate existing interfaces to guarantee the communication with these inherit modules. |

## 3.4 Implementation requirements

The implementation requirements have been defined taking into account that the Optimisation Module has to perform a set of evaluation processes in parallel. Furthermore, the optimization process is complex and takes some time to be performed, requiring a high amount of computational resources. The following table describes the identified implementation requirements:

Table 8: Implementation requirements

| Req. Identifier | Description |
|---|---|
| R3.4.1 | Provide the maximum number of tasks that can be processed at the same time. This allows managing and balancing the requests to the Optimisation Module. |
| R3.4.2 | Provide a unique ID for each task of optimization submitted. This allows managing the responses of the module, when the Optimisation Module ends a task of evaluation and provides the result of the evaluation/optimization performed. |
| R3.4.3 | Manage one request queue for each scenario. The Optimisation Module allows a specific number of parallel elaborations for the different scenarios of a population. A queue dedicated to each starting scenario allows grouping requests to be submitted. |
| R3.4.4 | Manage a set of request queues. Different starting population, different queues to manage. The policy of submission to the Optimisation Module depends on the maximum number of tasks that can be processed at the same time and the number of starting scenarios that at the same time should be optimized. |

For each population, the set of scenarios generated are submitted to the Optimisation Module. The Optimisation Module creates dynamically one queue for each scenario, allowing to create the simulation models and to launch the simulation process in an orderly manner, balancing the load of Optimisation Module.

When the Optimisation Module ends an evaluation, it returns the results to a temporal data repository, linking them to the scenario analyzed and to the population. Only the best ranking of scenarios will be stored into the Project Repository.

# 4 Design of the Optimisation Module

The Optimisation Module is composed of three main components with specific functionalities listed in the table below, and that will interact with the Data Management Module and with the Communication Logic Layer through a specific interface implemented for this aim, ensuring the proper communication to:

- Retrieve the required input data from the Project repository
- Retrieve the required input data from the ECM repository
- Export the codification of each generated scenario to be mapped in the DDM and generate the Simulation Data Models.
- Retrieve the results of the calculation of indicators for each scenario generated
- Export the final set of best scenarios to the Project Repository

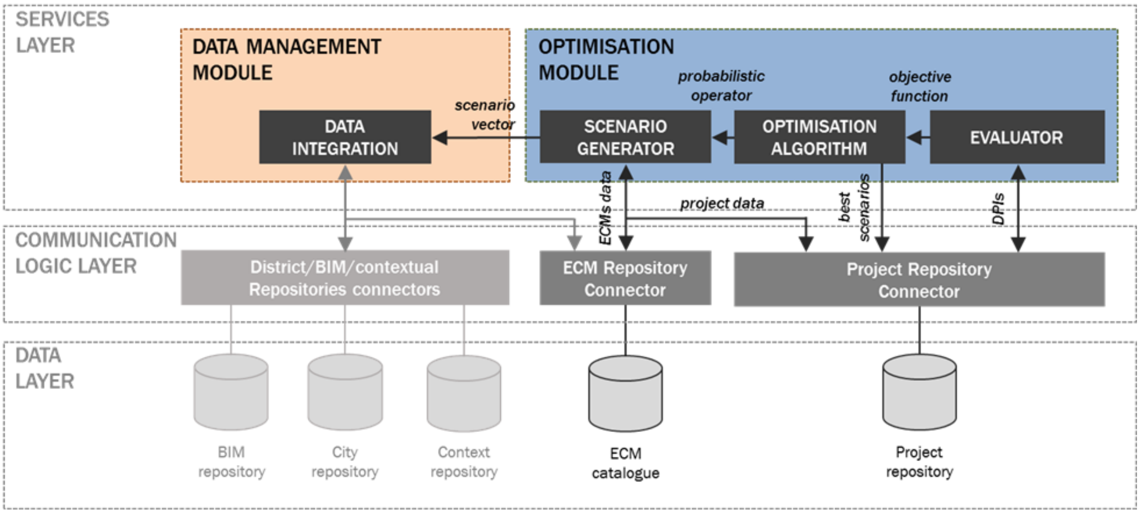


Figure 4: Components scheme of the Optimisation Module

The table below depicts the main components integrating the Optimisation Module, and their related use cases as they have been identified in D5.2: "Functional architecture specification, interfaces definition and overall platform design".

Table 9: Components integrating the Optimisation Module and related use cases

| Module | Component | Use case associated |
|---|---|---|
| Optimisation Module | Scenario generator | getProjectInfo()<br>queryApplicableECMs()<br>generateApplicableECMMatrix()<br>generateScenarioCodification() |
| | Evaluator | queryDPIs()<br>generateWeighSchem()<br>generateObjFunction()<br>calculateObjFunction() |
| | Optimisation algorithm | checkStoppingCriteria()<br>optimiseScenarios() |

## 4.1 Scenarios Generator

The Optimisation Module contains the Scenario Generator. The main functionality of the Scenarios Generator is to automatically create feasible refurbishment scenarios to be implemented into the district under study.

To create feasible scenarios, the Optimisation Module must take into account the characteristics of the district and of each building typology and also the applicable ECMs filtered by the platform according to the end user's objectives and validated by the End Users.

The Scenarios Generator will create scenarios considering combination rules between ECMs, their relation with the targets, boundaries and barriers of the project under study and other specific rules established within the optimization algorithm.

Each scenario will contain at least, the set of ECMs and the quantity to be implemented at district scale. Other variables related to the ECMs, like the square meters of solar panels to be installed or the insulation thickness, are under study to be implemented as ECM parametrization.

The first generated population will have a predefined memory size. Through the use of the Probabilistic Operators and taking into account the objective function calculated, the Optimisation Module will create from this initial population, optimized populations with the same memory size until achieving the stopping criteria.

### 4.1.1 Input data required for the generation of scenarios

The formulated scenarios will take into account different refurbishment options at building and district level. In particular, refurbishment actions may include interventions on the envelope of the building (so called passive strategies) as well as installation of new components for energy supply and storage (active strategies, such as boilers, photovoltaic panels or water storage tanks) or adoption of advanced control strategies. It can be foreseen that some of the configurations will satisfy the design requirements, which can be conveniently expressed as a set of boundaries on the relevant DPIs. The objective of the optimization process will be to select the configurations which are suitable to meet the objective function. However, it is not possible to guarantee one unique solution of such complex optimisation problem. It is therefore expected that the optimizer will provide more alternative solutions, among which the designer will choose the one that will be eventually implemented.

The evaluation of building or district performances before and after the refurbishment process requires the knowledge of a number of information enabling the physics-based simulations of possible scenarios. Relevant input data for the simulation process are detailed in D1.2 on "Requirements and specification of input data process to evaluate user objectives and current conditions" [01]. These include BIM related data, CityGML related data, and contextual data.

This deliverable focuses on the input data used to create and evaluate scenarios which are generated and selected by the scenario generator, for the optimization algorithm. For this purpose, the platform will access the Repository to obtain the information of applicable ECMs and targets, boundaries and barriers. The latter comes in the form of baseline DPI evaluations. The next step is the formulation of various combinations of ECMs (scenarios).

Type of inputs for the scenarios and examples are listed in the table below.

Table 10: List of Inputs for Scenarios Formulation

| INPUTS FOR SCENARIOS FORMULATION | | |
|---|---|---|
| Inputs | | Examples |
| Applicable ECMs | ECM category | - Passive<br>- Active<br>- Renewable |

| | | |
|---|---|---|
| | | - Control |
| | Type of ECM | - ETICs<br>- Condensation Boiler<br>- PV-Mono-crystalline<br>- System Scheduling |
| | Variables to parametrized | - Useful roof surface covered by PV panels<br>- Thickness of insulation |
| | Targets, boundaries and barriers related to ECMs | - Don't apply in protected envelope<br>- Need access to Natural Gas |
| inputs: district and building typologies | Targets | - Minimize Payback time<br>- Reduce GWP during the use phase |
| | Boundaries | - Useful roof surface<br>- Maximum investment: 1.000.000 EU |
| | Barriers | - Access to natural gas |
| | Baseline DPIs | - Energy use cost/year<br>- GWP/year |
| | Prioritisation criteria | - Preferred optimization order of importance for global objective function |
| | scenario DPIs | - Energy use cost/year<br>- Investment<br>- GWP/year |

## 4.1.2 Matrix of applicable ECMs

### 4.1.2.1 Identification of building energy types

The objective of aggregating buildings per typologies is to reduce the number of solution vectors and to reduce the computational cost of the optimisation process. The main conditions to belong to the same typology are to share the energy simulation model and the constraints limiting the application of ECMs. The following example aims at explaining the process to define building typologies (figure 5 and figure 6). In figure 6, a mock-up of the interface that will be used when entering the information of buildings is reflected.

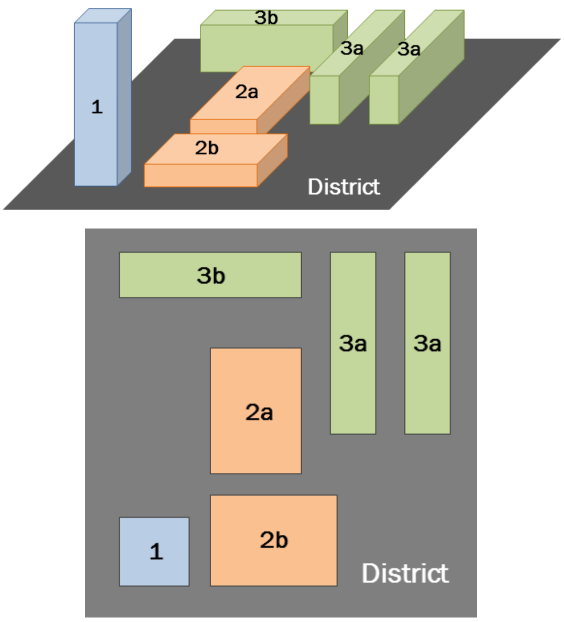


Figure 5: Example of a district with 5 building typologies corresponding to 6 buildings

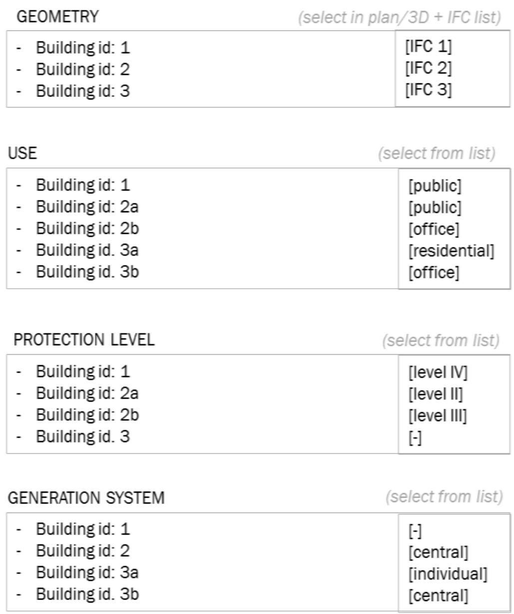


Figure 6: Mock-up of the buildings characterisation lists

The geometry and the use of the buildings will characterise the schedule and the energy demand simulation. Furthermore, the building protection level and the characteristics of the generation system (individual or central system) will limit the implementation of certain ECMs (see section 4.1.2.3 about "Constraints blocking the implementation of measures").

Considering the characteristics defined above, for the example of district under study, we will have five building typologies.

Table 11: Typologies identification

| Building typology | IFC | Protection level | Use | Generation system |
|---|---|---|---|---|
| 1 | IFC_1 | IV | Public | - |
| 2a | IFC_2 | II | Public | central |
| 2b | IFC_2 | III | Office | central |
| 3a | IFC_3 | - | Residential | individual |
| 3a | IFC_3 | - | Residential | individual |
| 3b | IFC_3 | - | Office | central |

### 4.1.2.2 End-user selected measures

According to Figure 7, the selection of applicable ECMs from the ECM catalogue will be carried out by the End Users through specifically developed GUI. The GUI will be managed by the Strategies Checker, integrated into the Data Insertion Module.

The Optimisation Module will interact with the ECM Repository Connector to query the list of applicable ECMs and their properties.

The list of applicable ECMs at district level and for each building typology will be queried by the Scenarios Generator to the Instance Creator to create the population of refurbishment scenarios.

Apart from list of ECMs, the Scenario Generator will query their constraints and the variables to be parametrised.

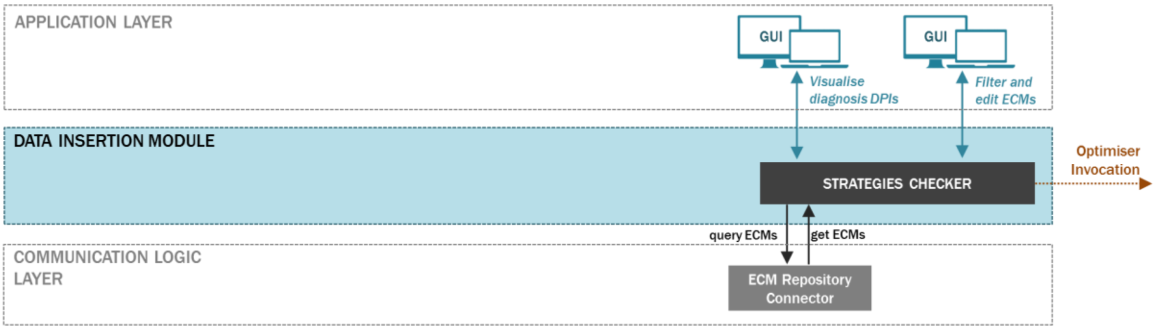


Figure 7: ECM selection process

### 4.1.2.3 Constraints blocking the implementation of measures

In order for the platform to be able to optimise scenarios, it is necessary for the user to define the problem they want to solve in OptEEmAL. Some of the inputs required for this process are the targets, boundaries and barriers. There are two annexes devoted to this input definition, namely annex 1 and annex 2; however, a brief description is provided below:

- **Targets**: defined both at district and building level and are directly related with the implementation of one or more ECMs. Accepting one of these targets will imply that one of the related ECMs should be applied in the district. Marking "no" as answer will block all the related ECMs to that target.

- **Barriers**: defined both at district and building level and impose certain constraints to the use of the ECMs, such as the maximum space the user wants to devote for the implementation of a determined ECM.
- **Boundaries**: defined both at district and typology level, they are related to some DPIs calculated within the platform and the user can impose some maximum values or a range of values between which the results of the newly generated scenario should be.

Specifically for the Scenario Generator to perform its task it is necessary to consider the both targets and barriers, since they are the ones affecting the use of the ECMs and this module will be in charge of combining the applicable ECMs in order to obtain the different scenarios to be evaluated. Boundaries will be deployed to validate or not the generated scenarios according to the DPI calculation.

Therefore, the Scenario Generator will consider this information (retrieved from the data repository) to generate the list of applicable ECMs in the form of a matrix which is represented in Table 12 for the example depicted above.

### 4.1.2.4 Generation of the applicable measures matrix

According to Table 12, the ECMs matrix will connect the list of applicable ECMs (represented by columns) with the list of building typologies (represented by rows) in a binary matrix. This step will be the first step to generate the first population; identify which ECMs cannot be implemented in each building and also which ones cannot be implemented at district scale. The refurbishment scenarios created subsequently will have the same “0 positions” than the first population. However, according to the combination rules and the probabilistic operators, the “1 positions” don’t have to be maintained.

Table 12: Example of applicable ECMs matrix

| Building typology | Model ID | Use | APPLICABLE ECMs | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | P1 | P2 | P3 | P4 | A1 | A2 | A3 | A4 | A5 | A6 | A7 | D1 | C1 | C2 | C3 |
| | | | Façade insulation | Roof insulation | Ground floor insulation | Openings | Individual energy generation | BIPV (roof) | BIPV (façade) | BIST (roof) | BIST (façade) | Geothermal | Biomass boiler | District heating | System scheduling | Optimal start-stop | Opt. based control |
| 1 | IFC_1 | Public | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2a | IFC_2 | Public | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2b | IFC_2 | Office | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3a | IFC_3 | Residential | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 |
| 3b | IFC_3 | Office | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 |
| District | CityGML_1 | Mixed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

### 4.1.3 Generation of scenarios

#### 4.1.3.1 ECM combination rules

The ECM symmetric matrix will define the combination rules that establish which ECMs can be applied simultaneously for one building typology or at district scale.

| | ECM1 | ECM2 | ECM3 | ECM4 | ... | ECMn |
|---|---|---|---|---|---|---|
| ECM1 | 1 | 1 | 0 | ... | ... | ... |
| ECM2 | 1 | 1 | 1 | ... | ... | ... |
| ECM3 | 0 | 1 | 1 | ... | ... | ... |
| ECM4 | ... | ... | ... | 1 | ... | ... |
| ... | ... | ... | ... | ... | 1 | ... |
| ECMn | ... | ... | ... | ... | ... | 1 |

Figure 8: ECMs symmetric matrix

The symmetric matrix defined above exposes that ECM1 and ECM3 cannot be installed at the same time. However, ECM2 can be combined with ECM1 and ECM3. The symmetric matrix needs to contain 1 in its diagonal in order to allow the correct working process of the Scenarios Generator.

In Annex 2, the symmetric matrix has been developed for the current list of ECMs from WP3.

#### 4.1.3.2 ECM variables parameterisation

In addition to the combination rules, the Scenario Generator will check the variables that can be parametrised for the applicable ECMs and will optimise their values according to the results of the Evaluation process. Some of these variables are directly linked to the "boundaries" of the buildings and district (e.g. PV panels implementation surface must be smaller than the total useful roof surface).

Annex 3 represents the first list of variables to be parametrised for each ECM. The rest of properties of each ECM should be defined as a function of these variables. This task will be improved in Task 3.2. The way in which the measures are parameterized will have an effect on the development of the probabilistic operators and the optimisation algorithm. The following example of BIPV panes parametrisation has been integrated into the scenario matrix (Table 14).

Table 13: Example of ECM parameterisation

| BIPV (roof) PARAMETERISATION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A2<br>BIPV (roof) | Option | Type | No. installed panels | Panel dimension | | Panel power (W) | | |
| A2.1 | A2.1a | Mono-crystalline | range = f(available roof, panel dimension) | 450x470 | 600x900 | 180 | 200 | 220 |
| | A2.1b | Polycrystalline | range = f(available roof, panel dimension) | 450x470 | 600x900 | 180 | 200 | 220 |

#### 4.1.3.3 Codification of solutions: the scenario matrix

The definition of a good encoding for the refurbishment solutions is closely linked to the cardinality of the problem at hand, i.e. the number of dimensions of the solution space.

The refurbishment scenario resulting from the OptEEmAL project will be a matrix solution. The rows of the matrix will represent the vector solution for each building typology and specific solutions at district scale. Each column of the matrix solution is related to a specific ECM from the catalogue. This is the reason why the types of ECMs into the catalogue must be fixed and not modifiable (specific constraint to develop the ECM catalogue in WP3).

In terms of HS Algorithms theory, the optimization problem is translated to a set of parameters to be optimized, named phenotypes. In OptEEmAL, each candidate scenario consists of a set of and each ECM consists of a set of phenotypes.

As a part of the optimization process, phenotypes (specific value for the variable parametrized for each ECM) are converted to genotypes by using a coding procedure. Given the limits of each optimized parameter, the parameter can be represented using a suitable string. This representation is named “encoding”. In OptEEmAL, most of the ECMs’ parameters will be continuous variables (refer to D3.1). Hence, two encoding methods could be used: the “binary encoding” and the “floating-point encoding” (Wright, 1991).

As the discussion above attests, the codification of solutions at each case study is highly related to a well-defined ECM catalogue, which will provide the list of ECMs and the variable parameters in a specific position. The codification of solutions needs to be understood by the Instance Creator and therefore, by the Simulation Data Model, implementing into the baseline scenario the selected ECMs into the right buildings and with the correct parameters.

According to the figure below, a refurbishment scenario is a list of ECMs to be applied in specific building typologies and into the district with specific parameters, defined as solution vectors that generate the scenario matrix.

As reflected in the matrix, the scenario 1 can be represented as the following vectors at building and district level:

- Building_01 = (P1.2, P2.2.2, 0, P4.1, 0, A2.1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
- Building_02a = (0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
- …
- District = (0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, D1.1.3.5, C1.1, C2.3, C3.1)

Table 14: Example of scenario 1 generation

| Building typology | Model ID | Use | SCENARIO MATRIX | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | P1 | P2 | P3 | P4 | A1 | A2 | A3 | A4 | A5 | A6 | A7 | D1 | C1 | C2 | C3 |
| | | | Façade insulation | Roof insulation | Ground floor insulation | Openings | Individual energy generation | BIPV (roof) | BIPV (façade) | BIST (roof) | BIST (façade) | Geothermal | Biomass boiler | District heating | System scheduling | Optimal start-stop | Opt. based control |
| 1 | IFC_1 | Public | P1.2 | P2.2.2 | 0 | P4.1 | 0 | A2.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2a | IFC_2 | Public | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2b | IFC_2 | Office | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0- | 0 | 0 | 0 | 0 | 0 | 0 |
| 3a | IFC_3 | Residential | P1.1 | P2.1.2 | 0 | P4.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3b | IFC_3 | Office | P1.1 | P2.1.2 | 0 | P4.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| District | CityGML_1 | Mixed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | D1.1.3.5 | C1.1 | C2.3 | C3.1 |

## 4.2 Evaluator

Districts can be considered as a system of complex interconnections, interactions, relationships and flows. Therefore a comprehensive approach is essential for effective decision-making with regard to energy efficiency improvement. When facing retrofitting processes in districts, the set of possibilities for integrating low energy technologies is wider considering a group of buildings and their interactions with the urban infrastructures as a unique energy unit. In this sense, the boundaries for the analysis cover all these sub-entities (buildings) demanding energy for certain services (reach comfort levels depending on their uses) and all the energy generation systems (both renewable and non-renewable) along with the distribution and delivery systems. For enabling the evaluation, every single piece or subset needs to be evaluated under a common framework, considering especially the interactive effects among the different technologies.

Being an optimisation problem defined as the one aimed at finding the solutions that are optimal or near-optimal with respect to some goals, and translated into an objective function, the Evaluator will be in charge of calculating the value of this function, considering targets, boundaries and the prioritisation criteria, and performing the evaluation at both building and district level. This function can be bi-objective (based on the optimisation of two indicators at the same time), or consider more dimensions being therefore a global multi-criteria objective function. These two methods can also be combined, choosing one important DPI and integrating the rest of relevant DPIs into a second function. The selection of the method highly depends on how the decision maker is formulating the problem and on establishing properly the importance of the criteria that is used for the evaluation. Therefore, in OptEEmAL, this objective function depends on the prioritisation scheme established to represent the importance of each DPI.

In task 4.2 the use of different objective functions will be explored. Considering the results obtained and the OptEEmAL objectives, the suitable alternative/s will be implemented.

### 4.2.1 Prioritisation criteria selection

Consistent with Rowley (2012) [02] "environmental decision makers are often charged with choosing an alternative (e.g. a technology, material, product, or management strategy) from the set of alternatives". From those decision situations usually encountered in sustainability decision processes (Roy 1996, 2005), in OptEEmAL the *choice problematic* is the decision process objective, which should not be confused with the project objective(s) that are the targets and boundaries defined when started the process and reviewed after the finalisation of the diagnosis phase.

The prioritisation criteria to be used for the definition of the global function are the District Performance Indicators (DPIs) defined in D2.2: Report on district sustainability indicators to formulate and optimise scenarios. According to this document, the DPIs assess seven different categories, namely: energy, comfort, environment, economic, social, urban and global and will be calculated through external tools, depending on their topic. All of the DPIs deal with measurable aspects, which cannot be biased.

These indicators (reflected in Annex 5: List of District Performance Indicators) are used during three different stages of the OptEEmAL platform use, which are relevant for the optimisation process depicted in this document, which are:

- **Input data insertion stage**. The platform user will be asked to specify the main objectives of the design in the input data insertion stage. In this process, targets, boundaries and barriers are defined among others, some of them related to DPIs.
- **Diagnosis stage**. Current conditions of the district before refurbishment (baseline) will be evaluated using DPIs. Establishing the diagnosis of the district is very important to understand the district performance before and after the implementation of OptEEmAL design for refurbishment.

- **Evaluation of retrofit scenarios**. Once the refurbishment scenarios are formulated based on the ECMs catalogue and satisfying targets, boundaries and barriers, the next step is the evaluation. During this phase, each scenario will be evaluated by calculating the set of DPIs for that scenario.

According to this, the end users will be allowed to select which DPIs suit best the problem formulation, the prioritisation criteria. The Evaluator will use them to calculate the objective function and the optimisation algorithm will subsequently rank the scenarios based on the obtained results.

As mentioned above, selecting the right prioritisation criteria is a critical part of OptEEmAL project optimisation approach. The decision to select one of the methods that OptEEmAL will be offering to the user must be taken under consensus, while if no consensus is reached, the IPD guides establish the following in the document "*Integrated Project Delivery: A Guide*".

"*Although the team may present alternatives and counsel the owner, goals remain the owner's province. The owner determines its program and what it wants to achieve. However, standards based upon goals and used to judge project success and compensation are jointly agreed upon.*" This restricts the domain in which the stakeholders can state their priorities to standards based upon goals and used to judge project success and compensation (their goals, and thus, their priorities are the same for all of them in a project using the IPD approach).

### 4.2.2 Multi-objective function

Multi-objective optimization, also called multi-criteria optimization, can be defined as the problem of finding a solution vector of decision variables which satisfies the project constraints introduced by the end users and optimizes a vector function whose elements represent individual objective functions. These functions form a mathematical description of performance criteria (DPIs).

Hence, the term "optimize" means finding such a solution vector (refurbishment scenario) which would give the values of selected DPIs acceptable according to the predefined targets and boundaries.

Formally, a multi-objective optimization problem is defined so as to find the solution vector $\mathbf{x} = [x_1, x_2, \ldots, x_n]^T$ which optimizes the district performance vector defined as:

$$D(x) = [f_1(x), f_2(x), \ldots f_n(x)]^T$$

In other words, the goal is to determine among the set of all feasible refurbishment scenarios that satisfies the constraints, the particular set **x** which yields the optimum values of the selected DPIs defined in equation f(**x**). Note that in general there is not a single point optimizing the set of objective functions, whereas a set of optimal solutions considered being non-dominated solutions or Pareto set approximation. Therefore, the notion of "optimum" varies with respect to mono-objective approaches, which aims at achieving a unique solution that simultaneously meets the constraints and provides the best value for the objective function. In multi-objective approaches, a solution vector **x** is Pareto optimal if there does not exist another **x**, such that $f_i(\mathbf{x}) \leq f_i(\mathbf{x})$ for all i > {1,..., n} and $f_j(\mathbf{x}) < f_j(\mathbf{x})$ for at least one *j*. This definition means that **x** is Pareto optimal if no feasible vector of decision variables exist which would decrease some criterion without causing a simultaneous increase in at least another criterion. The plot of the objective functions whose non-dominated vectors are in the Pareto optimal set is called the Pareto front.

#### 4.2.2.1 Bi-objective function

Bi-objective functions are usually used when the optimization process focus on two DPIs of which objective functions generally conflict with each other (e.g. the cheapest refurbishment scenario doesn't imply the highest energy consumption reduction).

In the next figure, a bold line is used to represent the Pareto front for a bi-objective optimization problem, in which the minimization of both objective functions $D(\mathbf{x}) = [f_1(\mathbf{x}), f_2(\mathbf{x})]$ is sought.

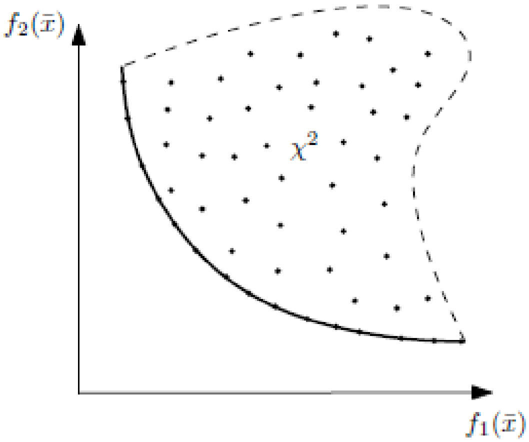


Figure 9: An example of a Pareto set approximation (bold line) for a bi-objective minimization problem

Once the Pareto optimal set has been encountered, the next step involves the choice of a practical solution for the multi-objective problem, which usually represents a compromise solution from the non-dominant prioritisation criteria.

### 4.2.3 Global multi-criteria objective function

Another option to solve the district performance vector is to integrate all the prioritisation criteria into a global objective function through the definition of a normalisation process and a weighting scheme.

The figure below reflects the overall evaluation process within the Optimisation Module when generating a global objective function. Once each DPI has been calculated (through the Simulation Module for each scenario including the baseline scenario), selected indicators have to be normalised and aggregated in order to generate a unique result (District performance index) for each iteration.

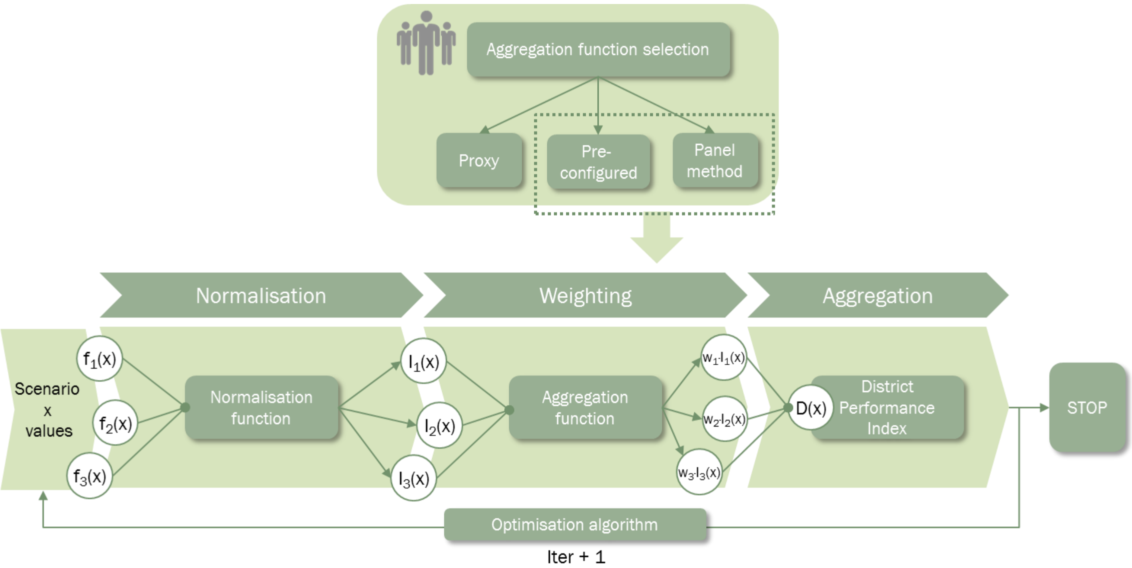


Figure 10: Scheme of the evaluation process

According to Rowley (2012) [02], weighting methods (in this case to solve LCA problems) can be classified into four major classes, being:

- Proxy approaches, in which the evaluation is based on selecting one or a few indicators which represent the total impact, being the weight of these indicators 1 and the weight of the others 0.
- Monetisation methods in which environmental impacts are translated into common monetary units using discount rates as appropriate, and considering thus willingness-to-pay.

- 'Distance-to-target' methods in which scores are related to externally derived targets (for example political, scientifically estimated 'limits', thresholds, etc.)
- Panel methods, in which people are asked to assign weights and which can be distinguished by the method employed, the composition of the panel, the procedure and the outcome.

In OptEEmAL it is proposed to assess three different methods. These proposed methods are:

1. A **proxy method**, in which the users select the two indicators most relevant for the evaluation of the candidate scenarios, and implementing therefore a bi-objective function in which indicators are not weighted nor normalised, as described in section 4.2.2.1.
2. A **set of pre-configured weighting schemes**, in which five pre-configured scenarios will be available for the user selection. The user will have the possibility to select among the following alternatives the evaluation strategy to be used for the global function definition. These evaluation alternatives can be implemented into OptEEmAL as different weighting schemes according to these prioritisation criteria:
    - Priority to achieve a nearly Zero Energy District
    - Priority to achieve a neutral carbon district
    - Priority to reduce the energy bill and fuel poverty in the area
    - Priority to very low investment cost
    - Priority to highest comfort improvement while reducing the energy consumption
3. A **panel method**, which better reflects the aims and objectives of the IPD defined approach. In this evaluation procedure, the users will be able to establish the weights of the selected indicators through a specific method implemented for this aim, and depicted below.

The possibility to select the evaluation method can be shown once the user is provided with the results of the diagnosis showing the baseline evaluation, and before the selection (or edition) of candidate ECMs.

Both the pre-configured scenarios, as well as the panel method, will follow the same principles for their deployment, as it is reflected in the following sections, being the difference that under the last, will be the user the one establishing the weights of the criteria, while for the first, an experts' panel will be implemented to establish the fixed weights related to each pre-configured scheme.

#### 4.2.3.1 Normalisation and scaling

One of the most important features that a decision making procedure must assess is to assure that data are comparable among different variables and for different examples, in this case, indicators and sub-indicators for different scenarios and for each retrofitting project under evaluation in OptEEmAL.

Normalisation is aimed at transforming current values for each criterion that is measured under different units, into a common new criterion that follows the same unit. According to Barba-Romero and Pomerol [05], three different methods can be applied, being the most suitable to address a synthetic transformation of the value of the indicators following a fixed scale unit change.

Thus, following this reasoning, it is necessary to transform the criteria into a homogenous framework that can be weighted and aggregated. There exist many normalisation techniques, while two factors should be ensured when selecting the most appropriate approach. According to Ebert & Welsch [06], both robustness (insensitivity against the existence of extreme values) and efficiency (estimated value close to the expected optimum when the real data distribution is unknown) must be balanced. Through the application of normalization, the values used to feed the evaluation matrix will turn into non-dimensional, taking all of them values in the interval [0,1], and where in all of them 0 represents the worst value for the indicator (the less sustainable) and 1 represents the best value (the most sustainable).

It is necessary then, to establish a normalisation framework aiming at comparing in a standardized manner the families of technologies to be implemented and to ensure the applicability potential of this methodology under different urban, climatic, social and economic environments. Given that advanced techniques such as the z-score need a very representative sampling not possible to be implemented considered the needed effort to this aim to collect data for each indicator, a min-max normalisation approach will be used. This technique requires the definition of the minimum $f_{i\_min}$ and maximum $f_{i\_max}$ values for each individual variable to ease the transformation.

Once defined these two values $f_{i\_min}$ and $f_{i\_max}$, the transformation is carried out in two different ways, depending if the objective is to maximize the value of the variable (the higher the score, the better contribution to the District Index as for example in the RES production) or to minimize the value of the variable (the lower the score, the better contribution to the District Index as in the case of energy demand or global investment). As the DPI ranges from zero to one, in the second case, it is needed to apply an inverse transformation.

Thus, if the objective is to maximize the variable:

$$I_i(x) = \begin{cases} 0 & \forall f_i(x) < f_{i\_min} \\ \dfrac{f_i(x) - f_{i\_min}}{f_{i\_max} - f_{i\_min}} & \forall f_{i\_min} \le f_i(x) \le f_{i\_max} \\ 1 & \forall f_i(x) > f_{i\_min} \end{cases}$$

And, if the objective is to minimise the variable:

$$I_i(x) = \begin{cases} 1 & \forall f_i(x) < f_{i\_min} \\ \dfrac{f_{i\_max} - f_i(x)}{f_{i\_max} - f_{i\_min}} & \forall f_{i\_min} \le f_i(x) \le f_{i\_max} \\ 0 & \forall f_i(x) > f_{i\_min} \end{cases}$$

Where $I_i(x)$ is the transformed value of the variable$f_i$ for the scenario $x$, $f_i(x)$ is the original value of the variable, $f_{i\_max}$ and $f_{i\_min}$ are respectively, the maximum and minimum values established for the variable $f_i$.

Following this approach, it is only needed to clarify how this $f_{i\_max}$ and $f_{i\_min}$ are defined for each specific variable. As a first approach, the case studies involved in OptEEmAL will be used in order to define a representative sampling space to identify the $f_{i\_max}$ and $f_{i\_min}$ variables for each prioritisation criteria. Since these are real examples of already carried out interventions, they can provide a first definition of these variables to be further refined with other examples for which a deep research will be conducted within D4.2.

It should be noted that although linear scaling based on these predetermined values for the maximum and minimum works most of the times, it might be that certain indicators may need a higher sensitivity though a non-linear scaling. This matter, which is difficult to be identified in advance, will be analysed during the implementation of the Optimisation Module and its testing.

The following table shows an example of minimum and maximum values for certain indicators (some of them applicable to OptEEmAL) according to a research work [12] based on analysing and comparing international standards as CASBEE, LEED, HQE, BREEAM, DGNB and LBC:

Table 15: Maximum and minimum values for certain sustainability indicators

| Indicator | Criteria | Units | Interval $]f_{i\_min} - f_{i\_max}[$ |
|---|---|---|---|
| **Energy consumption** | Gas and electricity consumption | $kWh_{final}/m^2a$ | ]50 – 300[ |
| **Renewable energies** | RES production | $kWh_{RES}/m^2a$ | ]0 – 50[ |
| **$CO_2$ emissions** | $CO_2$ emissions | $kgCO_2eq/m^2a$ | ]5 – 145[ |

| | | | |
|---|---|---|---|
| **Olfactory comfort** | Olfactory satisfaction level | % | ]0 – 100[ |
| **Visual comfort** | Views in the envelope | % | ]0 – 50[ |
| | Maximum distance to views | m | ]0 – 5[ |
| | Illumination level | Lux | ]250 – 2500[ |
| **Acoustic comfort** | Noise level | dB(A) | ]32 – 50[ |
| **Thermal comfort** | Indoor temperature | ºC | ]17 – 25[ |
| | Indoor air velocity | m/s | ]0.15 – 0.25[ |
| | Relative humidity | % | ]40 – 60[ |
| | Thermal satisfaction | % | ]0 – 100[ |

#### 4.2.3.2 Definition of the weighting scheme based on the prioritisation criteria

The weighting problem can be formulated as a prioritisation criteria matrix whose objective is to link each selected criteria $f_i$ (set of indicators) with a specific weight $w_i$ which can be established based on different approaches.

$$\begin{array}{ccccc} \text{criteria} & f_1 & f_2 & \dots & f_i \\ \text{weights} & w_1 & w_2 & \dots & w_i \end{array}$$

$$\text{alternatives} \quad x = \begin{matrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{matrix} \begin{pmatrix} f_1(x_1) & f_2(x_1) & \cdots & f_i(x_1) \\ f_1(x_2) & f_2(x_2) & \cdots & f_i(x_2) \\ \vdots & \vdots & \ddots & \vdots \\ f_1(x_m) & f_2(x_m) & \cdots & f_i(x_m) \end{pmatrix}_{mxn}$$

Therefore, for the OptEEmAL problem, each of the rows can be aggregated into an index that represents the district performance D for each scenario x, being calculated:

$$D(x) = \sum_{j=1}^{6} \sum_{i=1}^{n} w_j \cdot w_{j,i} \cdot I_i(x)$$

Where:

$D(x)$ is the value of the district index for the scenario x

$w_j$ is the weight of each index (j) over the goal: e.g. energy ($w_{ENE}$), comfort ($w_{COM}$), etc.

$w_{j,i}$ is the weight of each indicator (i) belonging to each index (j): e.g. Percentage of buildings compliant with EPBD standard ($w_{URB01}$)

$I_i(x)$ is the normalised value for an indicator $f_i$ for an evaluated scenario $x$

The table below shows an example of the matrix integrating the global function:

Table 16: DPIs evaluation matrix

| DPI code | Weight ($w_i$, $w_j$) | Range | | Objective* | DPI value for scenario x $f_i(x)$ | Normalised DPI value $I_i(x)$ | Normalised and weighted DPI |
|---|---|---|---|---|---|---|---|
| | | min ($f_{i\_min}$) | max ($f_{i\_max}$) | | | | |
| ENERGY INDEX | $w_{ENE}$ | - | - | - | - | - | - |
| ENE$_i$ | $w_{ENEn}$ | $f_{ENEi\_min}$ | $f_{ENEi\_max}$ | 0 | $f_{ENEi}(x)$ | $I_{ENEi}(x) = \frac{f_{ENEi\_max} - f_{ENEi}(x)}{f_{ENEi\_max} - f_{ENEi\_min}}$ | $w_{ENE} \cdot w_{ENEi} \cdot I_{ENEi}(x)$ |
| j INDEX** | $w_j$ | - | - | - | - | - | - |
| Indicator$_{j_i}$ | $w_{j,i}$ | $f_{j,i\_min}$ | $f_{j,i\_max}$ | 0 | $f_{j,i}(x)$ | $I_{j,i}(x) = \frac{f_{j,i\_max} - f_{j,i}(x)}{f_{j,i\_max} - f_{j,i\_min}}$ | $w_j \cdot w_{j,i} \cdot I_{j,i}(x)$ |
| DISTRICT INDEX | $D(x) = \sum_{j=1}^{6} \sum_{i=1}^{n} w_j \cdot w_{j,i} \cdot I_i(x)$ | | | | | | |

*Note that in this example objectives are set to 0 (i.e. minimising the indicator). For each indicator, the specific objective will be set.

**Corresponding to the 6 indexes defined for the global function (energy, comfort, environment, economic, urban and social).

#### 4.2.3.3 Building a panel method scheme: Analytic hierarchy process

Panel methods to elicit the criteria, as above mentioned, it highly depends on the selected method (questionnaires, interviews, or group discussions), panel composition (experts, laypeople, or stakeholders), procedure (single-round, Delphi) and outcome (consensus, statistical analysis of results). In the case of OptEEmAL, and according to the IPD principles, the panel will be composed by the stakeholders being articulated through the IPD contract, and must result into a consensus to elicit the weighting parameters.

There are several panel methods which can be implemented, being those more relevant (Boyssou et al., 2006 [06]): direct rating, simos' cards methods, ranking the criteria, pair-wise comparison (for example in the analytic hierarchy process, AHP), and the classical multi-attribute value theory (MAVT) which may be adapted for other procedures.

The same method proposed below will be used to both generating the pre-configured weighting schemes, related to the proposed evaluation alternatives, and to the panel method in which the user of OptEEmAL will be the one establishing the importance of criteria through a specific GUI developed for this aim. This GUI will establish a friendly and easy tool to allow the user establishing the relative importance of each comparison of indicators and indexes in a pairwise process.

Below, the main scheme of an Analytic Hierarchy Process (AHP) is presented, which establishes that [07]: a decision making process can be decomposed into 4 steps, namely: defining the goal, structure the decision hierarchy, construct a set of pairwise comparison matrices and use the priorities obtained from the comparison to weight the priorities in the level immediately below.

The AHP process is a well-known method that allows in an intuitive and easy manner establishing the importance associated to each criterion based on comparing indicators per pairs. It has been demonstrated to be a consistent method which can be applied to many decision making problems, as it is the case of prioritising project alternatives, which OptEEmAL aims at solving.

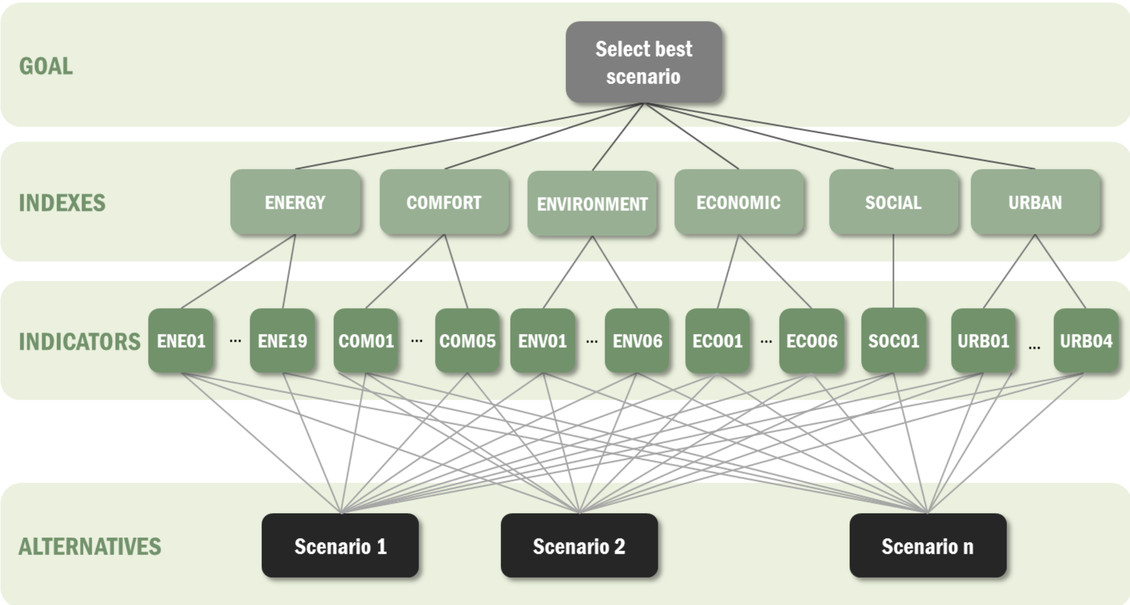


Figure 11: Hierarchy of indexes and indicators

In order to build the weighting scheme, a pair-wise comparison strategy is proposed, comparing per pairs the main criteria with respect to the goal first (indexes) and the sub-criteria with respect to the prioritisation criteria secondly (indicators).

The values related to the intensity of importance, according to Table 14, have to be set by consensus of the decision making panel (or experts' panel for fixed weighting schemes), in which each participant is individually asked to compare the criterion in a pairwise method setting whether a criterion is more important than the pair, and by how much. Then individual comparisons have to be discussed among the panel representatives to reach consensus on their values. If consensus is not reached, average values among the individual intensities can be used, and then the algorithm allows translating the collaboratively-agreed comparisons into weights.

Table 17: The fundamental scale of absolute numbers

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate importance | Experience and judgement slightly favour one activity over another |
| 5 | Strong importance | Experience and judgement strongly favour one activity over another |
| 7 | Very strong or demonstrated importance | An activity is favoured very strongly over another; its dominance demonstrated in practice |
| 9 | Extreme importance | The evidence favouring one activity over another is of the highest possible order of affirmation |
| **Reciprocals of above** | If activity *i* has one of the above non-zero number assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i* | A reasonable assumption |
| 1.1-1.9 | If the activities are very close | May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities |

According to this method, the pairwise comparison matrices have to be built in order to establish the importance of each criteria at the different hierarchy levels to achieve the defined goal. Thus, for this case, 6 pairwise comparison matrices will be built in order to compare:

1. Pairwise comparison matrix of the 5 criteria with respect to the goal
2. Pairwise comparison matrices (5) of each group of indicators under each criteria –*energy, comfort, environmental, economic, urban*– (e.g. a matrix to compare the 19 indicators that represent the energy index). There are only 5 comparison matrices since for the social index, being only one social indicator, it represents a weight of 1 over the index.

Below, an example of the 5 criteria comparison matrix is given:

Table 18: Pairwise comparison matrix of the main criteria with respect to the goal

| | Energy | Comfort | Environmental | Economic | Urban |
|---|---|---|---|---|---|
| Energy | 1 | ENE/COM | ENE/ENV | ENE/ECO | ENE/URB |
| Comfort | COM/ENE | 1 | COM/ENV | COM/ECO | COM/URB |

| | | | | | |
|---|---|---|---|---|---|
| Environmental | ENV/ENE | ENV/COM | 1 | ENV/ECO | ENV/URB |
| Economic | ECO/ENE | ECO/COM | ECO/ENV | 1 | ECO/URB |
| Urban | URB/ENE | URB/COM | URB/ENV | URB/ECO | 1 |

The principles of AHP establish that the matrix is reciprocal, being thus the comparison of each criteria against itself equal to 1, while the comparisons on the left of the diagonal are equal to the inverse of those located on the right, meaning that, the comparison of comfort against environmental, is the inverse of the comparison of the environmental criteria against comfort.

After generating the matrices of comparison, the weight of each indicator is calculated through solving the eigenvector, which is based on a three steps process [07]:

1. Raise the pairwise matrix to powers that are successively squared each time
2. Row sums are then calculated and normalised
3. Computing is stopped when the difference between these sums in two consecutive calculations is smaller than a prescribed value

Through the implementation of this process, weights of each criteria (indexes) and sub-criteria (indicators) can be obtained as follows:

$$\begin{bmatrix} w_{ENE} \\ w_{COM} \\ w_{ENV} \\ w_{ECO} \\ w_{URB} \end{bmatrix} = eig \begin{bmatrix} 1 & ENE/COM & ENE/ENV & ENE/ECO & ENE/URB \\ COM/ENE & 1 & COM/ENV & COM/ECO & COM/URB \\ ENV/ENE & ECO/COM & 1 & ENV/ECO & ENV/URB \\ ECO/ENE & ECO/COM & ECO/ENV & 1 & ECO/URB \\ URB/ENE & URB/COM & URB/ENV & URB/ECO & 1 \end{bmatrix}$$

### 4.2.4 Building and district scale evaluation and optimisation

Considering the strategies defined in WP3, most of the ECMs will be implemented at building scale. In order to simplify the problem, buildings will be aggregated per building typologies. Buildings from a same building typology will require the same refurbishment scenario, or solution vector.

Some of the ECMs need to be analysed at district scale like district heating/cooling systems (considering their generation, fuels and distribution equipment) or electricity generation (like photovoltaic panels) and will have impacts at building scale. The relation between district ECMs and impacts at building scale and on the other hand, the link between the building characteristics and the district ECMs performance need to be defined by the simulation model.

According to the objective function previously defined each solution vector from the refurbishment solution matrix will be optimised. In this way, the Optimisation Module will solve the OptEEmAL problem.

In order to define the best ranking of refurbishment scenarios, the Optimisation Module must evaluate DPIs at district scale. Different solutions are under analysis:

- Transferring impacts of district ECMs and district characteristics to the buildings, will allow the Optimisation Module working at the solution vector level.
- Combining final scenarios for each building typology and for the district to generate optimised scenarios at district scale in order to evaluate boundaries and choose the best scenarios.
- Integrate the district DPIs calculation during the optimisation process. This alternative can complicate too much the problem.

Furthermore, other facts must be considered by the simulation models and by the Optimisation Module, like energy transfer between buildings.

## 4.3 Optimisation algorithm

The optimisation process will be based on the Harmony Search Algorithm (HS algorithm).

It is widely known that the outperforming convergence and behaviour of any meta-heuristic algorithm cannot be claimed in a general manner. The selection of the optimization algorithm depends on the shape of the solution space drawn by the metric function at hand, the certain problem to solve and its side constraints. However, even though a globally optimal algorithm that renders the best performance in all optimization schemes does not exist (in line with the statements of the so-called No Free Lunch Theorem [08]), the HS algorithm has so far elucidated in practice a great potential and efficiency in comparison with other meta-heuristic methods in a wide spectrum of real applications.

HS possesses a similar structure to other existing population-based meta-heuristic solvers, but it incorporates some distinctive features that make it widely utilized in the literature.

Similarly to other related population-based algorithms, i.e. Genetic Algorithms or Ant Colony Optimization, the HS relies on a group of solutions that can be simultaneously exploited for improving the efficiency of the algorithm.

However, the naïve Genetic Algorithm considers only two vectors (referred to as parents) for generating a new solution or offspring, whereas the original implementation of HS takes into account, component-wise and on a probabilistic basis, all the existing solutions (melodies) in the harmony memory.

The HS Algorithm, in its original version, is able to infer new solutions merging the characteristics of all individuals by simply tuning the values of its probabilistic parameters. Besides, it independently operates on each constituent variable (note) of a solution vector (harmony), to which stochastic operators for fine-tuning and randomization are applied. As opposed to gradient-search techniques, the convergence rate of HS and the quality of its produced solutions are not dramatically affected by the initialized values of the constituent melodies in the harmony memory. Besides, HS utilizes a probabilistic gradient which, in contrast to traditional gradient-based mathematical methods, does not require the derivative of the fitness function to be analytically solvable, nor even differentiable over the whole solution space. Instead, the probabilistic gradient converges to progressively better solutions iteration by iteration, since the operators driving the algorithm behaviour intelligently guide the harmony memory to regions of the solution space with better fitness without addressing at all the differentiability of the metric function.

As a result, HS has been shown to perform satisfactorily in both continuous and discrete optimization problems: indeed, it is able to handle both decimal and binary alphabets without modifying the definition of the original HMCR (Harmony Memory Considered Rate) and PAR (Pitch Adjusting Rate) parameters of the algorithm.

Another remarkable strength of HS hinges on its improvisation operators, which play a major role in achieving a good trade-off between diversification and intensification. As mentioned before, the correct choice of the parameters becomes essential in order to attain progressively better candidate solutions, and HS facilitates this refinement stage by significantly reducing the number of configurable parameters. In addition, the steps and the structure of the HS algorithm are relatively simple, which makes it flexible for its combination with other meta-heuristics and implementation in parallel hardware architectures.

For all these reasons the HS algorithm has been selected for the OptEEmAL approach with the aim at looking for the trade-off of different refurbishment solution vectors.

### 4.3.1 Probabilistic operators

An important task is the definition of the probabilistic operators that lead the optimization process. Regarding HS algorithms: selection, crossover and mutation operators must be defined. In case of Harmony Search: HMCR, PAR and RSR metrics. Also, the value for these probabilistic operators must be optimized in order to ensure both explorative and exploitative search of the solution space avoiding a premature convergence.

**Improvisation operators:** (based on the Harmony Search Algorithm)

**HMCR** (Harmony Memory Considered Rate): Establishes the probability that the new value for a certain note is taken uniformly from the values of the same note in the rest of the harmonies (taking the ECMs information of another vector solution).

**PAR** (Pitch Adjusting Rate): Establishes the probability that the new value for a certain note is obtained by adding or subtracting a small random amount to the existing value (slightly changing the ECM parameters).

**RSR** (Random Selection Rate): Establishes the probability that the new value is randomly obtained between all possible values (all possible ECMs).

**Local Search procedure:** (to be considered in order to improve the iterative process).

As previously mentioned, HS is a population-based algorithm; it hence maintains a set of solutions in the so-called Harmony Memory (HM). An estimation of the optimal solution is achieved at every iteration by applying a set of optimization parameters to the HM, which produces a new harmony vector every time. Figure 10 illustrates the flow diagram of the HS algorithm, which can be summarized in four steps: (i) initialization of the HM; (ii) improvisation of a new harmony; (iii) inclusion of the newly generated harmony in the HM provided that its fitness improves the worst fitness value in the previous HM; and (iv) returning to step (ii) until a termination criteria (e.g. maximum number of iterations or fitness stall) is satisfied.

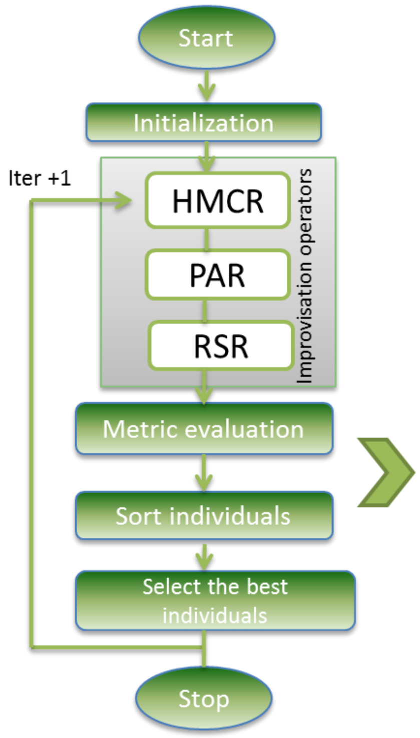


Figure 12: Probabilistic operators to generate the scenarios

## 4.4 Class diagram of the Optimisation Module

The class diagram is the structure or skeleton of the future code. In the present section the class diagrams of the three components of the Optimisation Module are shown.

| ScenarioGenerator |
| --- |
| -projectInfo : ProjectInfo<br>-applicableECMs : list <ECM><br>-ECMSymetricMatrix : boolean[][]<br>-applicableECMMatrix : boolean[][]<br>-scenarioCodification : xml<br>-scenarioId : int |
| + getProjectInfo(projectID : string) : ProjectInfo<br>+ queryApplicableECMs(projectID : string) :  list<ECM><br>+ generateApplicableECMMatrix(projectInfo : ProjectInfo, applicableECMs : list <ECM>, ECMSymetricMatrix) : xml<br>+generateScenarioCodification(applicableECMMatrix, applicableECMs.ECMsParametrisableVariables): xml |

| Evaluator |
| --- |
| -projectInfo : ProjectInfo<br>-DPIs : list <DPI><br>-weightingScheme : vector<br>-scenarioId : int |
| + queryDPIs(scenarioId): list <DPI><br>+ generateWeighSchem(projectInfo.targets, projectInfo.prioritisationcriteria):  vector<br>+ generateObjFunction(projectInfo.targets, DPIs(scenario0), weightingScheme): function<br>+ calculateObjFunction(ObjFunction, DPIs(scenarioId)): object |

| OptimisationAlgorithm |
| --- |
| -scenarioId : int<br>-projectInfo : ProjectInfo<br>-numberOfIteration : int<br>-stopptingCriteria: function<br>-ProbabilisticOperators: function |
| + checkStoppingCriteria(ObjFunctionResult(scenarioId), numberOfIteration (scenarioId), projectInfo.targets.boundaries, stopptingCriteria): function<br>+ optimiseScenarios(scenarioCodification(scenarioId), ObjFunctionResult(scenarioId), projectInfo.targets.boundaries, ProbabilisticOperator): function |

Figure 13: Class diagram of the Optimisation Module

The Scenario Generator needs input data from the ECM and from the project repositories to generate feasible scenarios. The scenario codification will be used by the DMM to generate the simulation data models.

The Evaluator will use targets, prioritisation criteria and diagnosis DPIs to generate the objective function/s. Using the scenario DPIs, the Evaluator will calculate the objective function and send it to the Optimisation Algorithm.

The Optimisation Algorithm will optimise the scenarios through the use of the probabilistic operators, the objective function results and the targets and boundaries introduced by the end users. Furthermore, the Optimisation Algorithm will stop the optimisation process when it will achieve the stopping criteria.

## 4.5 Sequence diagram of the Optimisation Module

The figure below depicts the sequence diagram for the Optimisation Module. The objects of the diagram represent the different component and modules involved in this sequence.

The process starts with the Optimisation Module invocation by the platform. At this point, the Optimisation Module will query to the Project Repository Connector the project input data needed by the three components of the Module.

The Scenario Generator will query to the ECM Repository Connector the ECM input data: applicable ECMs, prioritisation criteria, combination rules, ECM symmetric matrix and constraints. With the combination of applicable ECMs and project data, it will generate the first population (scenario codification).

The scenario codification will be sent to the DMM to generate the Simulation Data Model of each scenario and will send them to the Simulation Module. The scenario DPIs will be stored into the Project Repository Connector.

The Evaluator will query the scenario DPIs to calculate the objective function/s of each scenario to send them to the Optimisation Algorithm.

Finally, the Optimisation Algorithm will optimise the populations through the use of the probabilistic operators.

This process will be iterative and will stop when the Optimisation Algorithm reaches the stopping criteria. At this stage the ranking of best scenarios will be send and stored into the Project Repository Connector.

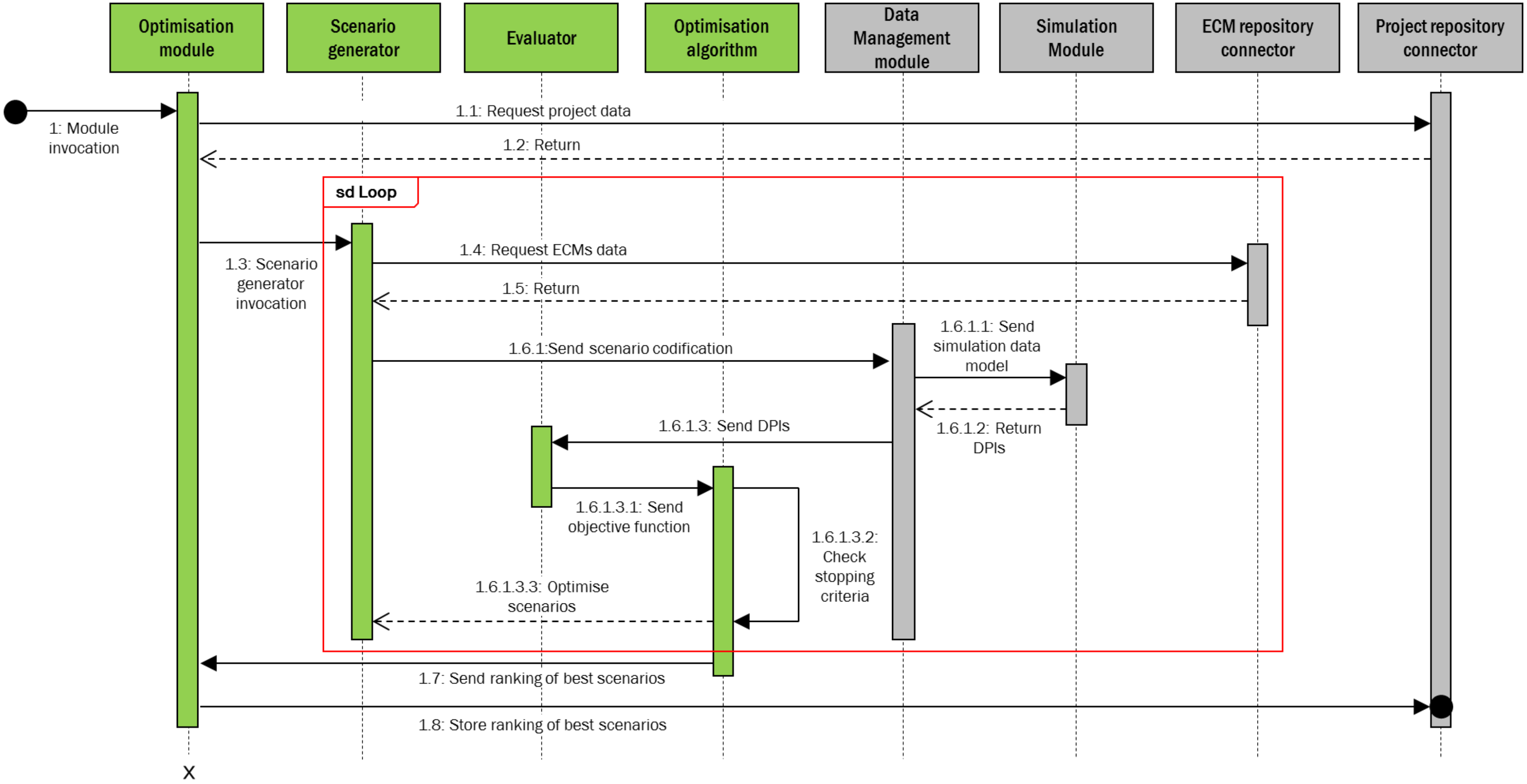


Figure 14: Sequence Diagram of the Optimisation Module

## 4.6 Outputs of the Optimisation Module

According to the sequence diagram described in the section above, the ranking of best scenarios is the output of the Optimisation Module.

As described in Figure 15, the best scenarios are stored in the Project Repository. The information stored will be showed to the End Users through specific GUIs after the invocation of the Scenario Selector.

The outputs from the Optimisation Module should contain the information required by the End Users to select the optimal scenario:

- List of prioritisation criteria, targets and boundaries
- List of best scenarios ordered following the prioritisation criteria
- Scenario matrix relaying the applicable ECMs with the building typologies and the district for each scenario
- Parameters defining the ECMs for each solution vector within the scenario matrix (e.g. m$^2$ of photovoltaic panels installed into the building ID32)
- District current conditions and evaluation DPIs

It is pending to decide (D4.2) if the maximum number of scenarios to be showed will be internally established.

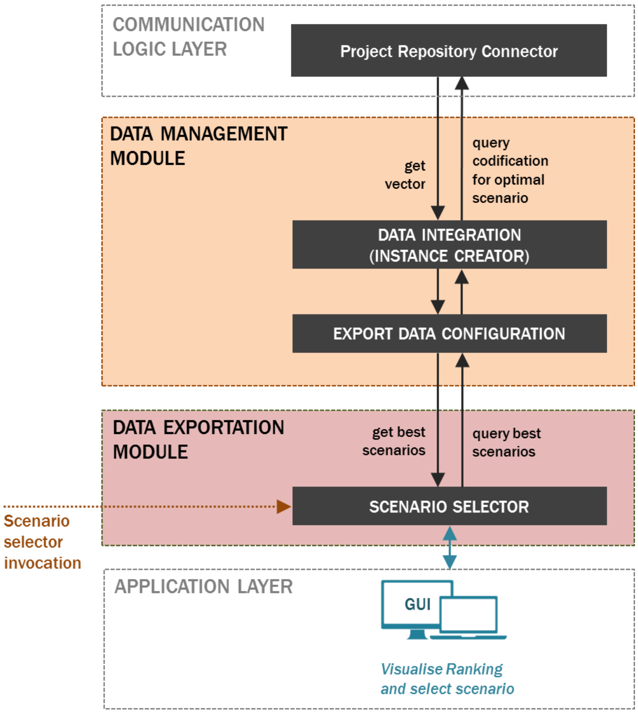


Figure 15: Diagram explaining the pathway of the outputs of the Optimisation Module

## 4.7 Computational cost optimisation process

The selection of the number of individuals in the population directly impacts on the computational time taken by the algorithm to converge: if the size of the population increases, the computational time increases accordingly, but also the diversity of the solution is enhanced and the probability of getting trapped in suboptimal regions is minimized.

There are multiple factors which affect the overall computational time of the optimization process. Some are related to the structure of the optimization process and others to the evaluation of the candidate solutions, which is carried out via simulation.

One of the factors affecting the computational cost of the optimization process, which is related to the structure of the optimization process, is the stopping criteria. The stopping criteria determine the condition to be met to consider the execution of the algorithm completed. The objective is to limit the complexity or ensuring a minimum quality level in the solutions. The most common are: 1) to fix a maximum number of iterations or generations; 2) to stop the execution when the diversity of the population is below a certain threshold; or 3) to stop the execution when the objective functions of the best individual in the memory has not improved for a determinate number of iterations. The stopping criteria will be defined in D4.2.

Another factor, related to the structure of the optimization process, which affects the execution time of the optimization, is the size of the selection of individuals during each optimization loop. The selection of the number of individuals in the population directly impacts on the computational time taken by the algorithm to converge: if the size of the population increases, the computational time increases accordingly, but also the diversity of the solution is enhanced and the probability of getting trapped in suboptimal regions is minimized.

As far as the evaluation of the candidate solutions is concerned, a major factor which affects the overall computational time of the optimization process is the simulation execution time.

Concerning the building scale simulation runtime, since high complexity and prohibitive simulation execution time are predominantly due to the full-scale, detailed, geometry representation of the demonstration buildings, geometry reduction approaches, documented in D4.4 [09] are required. Moreover, in common practice, a full-scale thermal simulation model treats each room of a building as an individual thermal zone. Such an assumption increases the simulation runtime significantly, since computational effort is more than proportional to the number of zones, since increased number of zones corresponds to increased number of ordinary differential equations to be solved. Hence in many cases, building simulation modelers incorporate the HVAC zones definition, where each zone consists of one or more rooms and a thermostat assigned to that zone. At this level of detail, the thermal simulation model, where each HVAC zone is a thermal zone, can be still expensive for computationally demanding tasks. Concerning a further zoning reduction, building simulation experts are able to reduce the number of HVAC-thermal zones, but such a reduction is usually based on some similarity between the regions being combined (e.g. similar internal loads). Towards an automatic methodology to reduce the number of zones, utilizing simulation results of a full-scale, validated, thermal simulation model, in D4.5 [10], two approaches are presented. The first approach utilizes the Hierarchical Clustering theory [11], while the second approach adopts the Koopman modes theory [12]. The Koopman modes, as a systematic approach to zoning and model reduction, has recently been proposed in [13], where motivational results are presented for a real building.

Concerning the district scale simulation, its execution time can be reduced if certain quantities, which do not depend on the ECMs, are pre-calculated for the whole district and used as inputs to the simulation processes which are used to evaluate the multiple candidate retrofitting scenarios. An example of such quantity is the solar radiation on building surfaces which can be evaluated for the whole district and for a period of a whole year only once and then inserted as input to the multiple simulation calls of the optimization process. Finally, since the simulation execution time depends proportionally on the number of the buildings involved, another factor which will eventually reduce the simulation time and consequently the overall optimization computational cost, is the knowledge of the inter-building shading effect. In other words, the knowledge of which building shades which, during the simulation time. Using this knowledge, the number of buildings involved in the simulation can be reduced significantly because only the buildings shading each other will be considered, resulting to a subsequent reduction of the overall simulation runtime.

# 5 Conclusions

The work presented in this document furnishes a vision of the Optimisation Module requirements and the functionalities of their three main components: the Scenario Generator, the Evaluator and the Optimisation Algorithm.

According to this concept, the Optimisation Module will be a black box that will be interoperable with the Data Management Module to generate the Simulation Data Models and with the Communication Logic Layer to query applicable ECMs and specific project data: targets, boundaries, barriers, DPIs and prioritisation criteria.

Each refurbishment scenario will compose a scenario matrix, with the ECMs in the columns and the building typologies and the district represented by the rows. To define the relation between columns and rows in the scenario matrix, the following information is required: relation between targets, boundaries and barriers of one project and the constraints of each ECM, the combination rules for the list of ECMs and the variables to be parametrised. First approaches of these developments are presented as annexes of this deliverable, but will be further developed in D3.2.

The variables to be parametrised will be used to define the Optimisation Algorithm and the Probabilistic Operators to be implemented.

The Evaluator will be in charge of the development of the objective function that can be a bi-objective or a multi-criteria global objective function. The first one will optimise two DPIs at the same time. The second option will be based on a normalisation and weighting process to integrate the selected DPIs into a unique objective function to be optimised.

Harmony Search algorithm has been selected for the OptEEmAL approach with the aim at looking for the trade-off of different refurbishment solution vectors. Harmony Search is a population-based meta-heuristic algorithm which has obtained excellent results in the field of combinatorial optimization.

The work described in this document is part of WP4 ”Scenarios evaluation and optimisation according to stakeholders priorities”, which will continue in Task 4.2 “Optimisation Module prototype development and validation”. In the subsequent development of the Optimisation Module, the specifications presented in this document will need to be further enhanced.

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## Annex 1: Targets, boundaries and barriers related to ECMs

| Type | Description | End User /*Automatic + User revision | A1.1-Ventilated Facade | A1.2-ETICS | A2.1-Protected Wall - Internal lining | A3.1-Cavity wall - Air chamber insulation | B1-Flat roof | B2- Pitched Roof | C1-Slab without crawlspace | C2- Slab over crawlspace - under slab | D1 - Window replacement | District Heating | Biomass boiler | ST-Flat collector | ST-Tube collector | PV-Mono-crystalline | PV-Multi-crystalline | Geothermal-horizontal | Geothermal-vertical | High efficient boiler | Condensation boiler | Cogeneration | High efficient chiller (electricity) | High efficient heat Pump | Energy storage-water tank | Energy storage-Phase change materials units | Reduction of distribution losses | System Scheduling | Optimal start-up shut down | Weather compensation | Load following | Optimization-based control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TARGETS | **1 – District level** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Implement district heating | [YES/ NO / NO ANSWER] | | | | | | | | | | X | | | | | | | | | | | | | X | X | X | X | X | X | X | X |
| | Implement electricity production facilities | [YES/ NO / NO ANSWER] | | | | | | | | | | | | | | X | X | | | | | X | | | | | | | | | X | X |
| | Implement renewable heat generation systems | [YES/ NO / NO ANSWER] | | | | | | | | | | X | X | X | X | | | X | X | | | | | | | | | X | X | X | X | X |
| | **2 – Building level** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Change façades externally | [YES/ NO / NO ANSWER] | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Change façades internally | [YES/ NO / NO ANSWER] | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Change roofs externally | [YES/ NO / NO ANSWER] | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Change roofs internally | [YES/ NO / NO ANSWER] | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | |
| | Change ground floor insulation | [YES/ NO / NO ANSWER] | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | |
| | Replace windows | [YES/ NO / NO ANSWER] | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| | Change energy generation system | [YES/ NO / NO ANSWER] | | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | | | | |
| | Implement renewable generation systems | [YES/ NO / NO ANSWER] | | | | | | | | | | | X | X | X | X | X | X | X | X | | | | | | | | | | | | |
| | Implement control measures | [YES/ NO / NO ANSWER] | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | X | X | X |
| BARRIERS | **1 – District level** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Functional space to implement DH boilers | [YES/NO] & [value] | | | | | | | | | | X | | | | | | | | X | X | X | X | X | | | | X | X | X | X | X |
| | Legal classification of plot doesn't allow to intervene | [YES/NO] | | | | | | | | | | X | | | | | | X | X | | | | | | X | X | | | | | | |
| | **2 – Building level** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Access to natural gas | [YES/NO] | | | | | | | | | | | | | | | | | | X | X | X | | | | | | | | | | |
| | Generation systems type | [central/individual] | | | | | | | | | | X | X | X | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| | Maximum value façades can grow externally | [value] | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Maximum value façades can grow internally | [value] | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Maximum value roofs can grow externally | [value] | | | | | X | X | | | | | | X | X | X | X | | | | | | | | | | | | | | | |
| | Maximum value roofs can grow internally | [value] | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | |
| | Maximum value for ground floor insulation | [value] | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BOUNDARIES | 1 – District level | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Useful land surface | [YES/NO] & [value]* | | | | | | | | | | X | | | | | | X | X | | | | | | X | X | | | | | | |
| | 2 – Building level | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Useful land surface | [YES/NO] & [value] | | | | | | | | | | X | | | | | | X | X | | | | | | X | X | | | | | | |
| | Opening surface | [value] or [%] | | | | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| | Opaque surface | [value] or [%] | X | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Roof Surface | [value] | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | | | |
| | Useful roof surface | [value] or [%] | | | | | | | | | | | | X | X | X | X | | | | | | | | | | | | | | | |
| | Functional space to implement biomass boiler | [YES/NO] | | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | |

## Annex 2: Boundaries related to DPIs

| Type | Description | End User inserted data | | Related DPIs |
|---|---|---|---|---|
| BOUNDARIES | **1 – Economic – per typology and district level** | | | |
| | Minimum operational energy cost | Less than… | [numeric value] | DPI - ECO01 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |
| | Minimum investment | Less than… | [numeric value] | DPI - ECO02 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |
| | Maximum return on investment | More than | [% value] | DPI - ECO04 |
| | | Between… | [two numeric values] | |
| | | Minimum value | [numeric value] | |
| | Reduce total energy cost | In more than | [% value] | DPI - ECO05 |
| | | Between… | [two numeric values] | |
| | | Minimum value | [numeric value] | |
| | **2 – Energy – per typology and district level** | | | |
| | Reduce energy demand | In more than | [% value] | DPI - ENE01 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |
| | Reduce final energy consumption | In more than | [% value] | DPI - ENE02 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |

| | | | | |
|---|---|---|---|---|
| | Degree of energetic self-supply | In more than | [% value] | DPI - ENE05 |
| | | Between… | [two numeric values] | |
| | | Minimum value | [% value] | |
| | Energy demand coverted by renewable sources | In more than | [% value] | DPI - ENE09 |
| | | Between… | [two numeric values] | |
| | | Minimum value | [numeric value] | |
| | **3 – Comfort – per typology and district level** | | | |
| | Increase internal comfort | In more than | [% value] | DPI - COM01 |
| | | Between… | [two numeric values] | |
| | | Minimum value | [numeric value] | |
| | **4 – Environmental – per typology and district level** | | | |
| | Reduce Global Warming Potential | In more than | [% value] | DPI - ENV01 / ENV03 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |
| | Reduce Primary Energy Consumption | In more than | [% value] | DPI - ENV04 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |
| | Minimum embodied energy of refurbishment scenario | Maximum value (of total energy) | [% value] | DPI - ENV05 |
| | | Between… | [two numeric values] | |
| | | Maximum value | [numeric value] | |
| | **5 – Urban – per typology and district level** | | | |
| | Increase % of buildings with an A rating in the Energy Performance Certificate | In more than | [% value] | DPI - URB02 |
| | | Between… | [two numeric values] | |
| | Increase % of buildings compliant with nZEB standards | In more than | [% value] | DPI - URB04 |
| | | Between… | [two numeric values] | |

| 6 – Social – per typology and district level | | | |
|---|---|---|---|
| Reduce energy poverty | In more than | [% value] | DPI - SOC01 |
| | Maximum value | [% value] | |

## Annex 3: ECMs symmetric matrix

| | A1.1-Ventilated Façade | A1.2-ETICS | A2.1-Protected Wall - Internal lining | A3.1-Cavity wall - Air chamber insulation | B1-Flat roof | B2- Pitched Roof | C1-Slab without crawlspace | C2- Slab over crawlspace - under slab | D1 - Window replacement | D2 – Door replacement | District Heating | Biomass boiler | ST-Flat collector | ST-Tube collector | PV-Mono-crystalline | PV-Multi-crystalline | Geothermal-horizontal | Geothermal-vertical | High efficient boiler | Condensation boiler | Cogeneration | High efficient chiller (electricity) | High efficient heat Pump | Energy storage-water tank | Energy storage-Phase change materials units | Reduction of distribution losses | System Scheduling | Optimal start-up shut down | Weather compensation | Load following | Optimization-based control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1.1-Ventilated Facade | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| A1.2-ETICS | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| A2.1-Protected Wall - Internal lining | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| A3.1-Cavity wall - Air chamber insulation | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| B1-Flat roof | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| B2- Pitched Roof | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| C1-Slab without crawlspace | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| C2- Slab over crawlspace under slab | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| D1 - Window replacement | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| D2 - Door replacement | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Connection to district Heating | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biomass boiler | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ST-Flat collector | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ST-Tube collector | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PV-Mono-crystalline | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PV-Multi-crystalline | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Geothermal-horizontal | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Geothermal-vertical | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| High efficient boiler | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Condensation boiler | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cogeneration | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| High efficient chiller (electricity) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| High efficient heat Pump | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Energy storage-water tank | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| Energy storage-Phase change materials units | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Reduction of distribution losses | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| System Scheduling | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Optimal start-up shut down | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Weather compensation | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Load following | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Optimization-based control | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |

## Annex 4: List of variables to be parametrised for each ECM

| Passive ECMs | Variables to parametrise ECMs | Units | Values |
|---|---|---|---|
| A1.1-Ventilated Facade | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| A1.2-ETICS - External Thermal Insulation Composite System | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| A2.1-Protected Wall - Internal lining | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| A3.1-Cavity wall - Air chamber insulation | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| B1-Flat roof | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| B2- Pitched Roof | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| C1-Slab without crawlspace | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| C2- Slab over crawlspace - Insulation under the slab | Thermal resistance | (m²K)/W | 1-1,5 - 2 - 2.5 - 3 - 3. 5 - 4 - 4. 5 - 5 - 6 - 8 |
| | Thickness | m | 0,03 - 0,05 - 0,07 - 0,08- 0,1 - 0,12 - 0,15 - 0,2 - 0,25 - 0,3 |
| D1 - Window replacement | Thermal conductivity - glazing | W/m²K | 2,7 - 2,1 - 1,8 - 1,3 - 1 - 0,8 |
| | Thermal conductivity -frame | W/m²K | 5 - 4 - 3 - 2 |
| D2 - Door replacement | | | |

| Active ECMs | Variables to parametrise ECMs | Units | Values |
|---|---|---|---|
| District Heating | Buildings connected to district heating | [value] or % | |
| Biomass Boiler - individual | Quantity of individual boilers replaced by biomass boilers | [value] or % | |
| | Energy performance | % | 80 -82 - 85 - 97 - 90 - 95 |
| Biomass Boiler - central / DH | Power | KW | |
| | Energy performance | % | 80 -82 - 85 - 97 - 90 - 95 |
| High efficient boiler- individual | Quantity of individual boilers replaced by high efficient boilers | [value] or % | |
| | Energy performance | % | 80 -82 - 85 - 97 - 90 - 95 |
| High efficient boiler- central / DH | Power | KW | |
| | Energy performance | % | 80 -82 - 85 - 97 - 90 - 95 |
| Condensation boiler- individual | Quantity of individual boilers replaced by condensation boilers | [value] or % | |
| Condensation boiler- central / DH | Power | KW | |
| Cogeneration | Electric Power | KWe | |
| | Energy performance | % | 80 -82 - 85 - 97 - 90 - 95 |
| High efficient chiller (electricity) | Quantity of systems replaced by high efficient chillers | [value] or % | |
| | Energy performance | % | |
| High efficient heat Pump | Quantity of systems replaced by high efficient heat pumps | [value] or % | |
| | COP | [value] | 2,5 - 3 - 3,5 - 4 - 4,5 - 5 |
| Geothermal - horizontal | Land use | $m^2$ | |
| | Power | kW | |
| Geothermal - vertical | Land use | $m^2$ | |
| | Power | KW | |
| ST-Flat collector | Useful roof used | $m^2$ or % | |

| | | | |
|---|---|---|---|
| | Energy performance | % | |
| ST-Tube collector | Useful roof used | m² or % | |
| | Energy performance | % | |
| PV-Mono-crystalline | Useful roof used | m² or % | |
| | Energy performance | % | |
| PV-Multi-crystalline | Useful roof used | m² or % | |
| | Energy performance | % | |

| Control ECMs | | Variables to parametrise ECMs | Units | Values |
|---|---|---|---|---|
| System Scheduling | | Building/Zone Temperature | [C Degree] | |
| | | Component Output Power Set-Point | [kW] | |
| | | Start Time | [hours : minutes] | |
| | | Stop Time | [hours : minutes] | |
| Optimal Start-Up and Shut-Down | | Thermal load profile for different start/stop time (DPI ENE04) [hours : minutes] | [kW] | |
| | | Comfort level associated to the profiles above (DPI COM02) | | |
| | | Economic DPIs associated to the profiles above (most important for controls: DPI ECO01) | | |
| Weather Compensation | | Outdoor ambient temperature | [Celsius Degree] | |
| | | Building/zone temperature set-point | [Celsius Degree] | |
| | | Actual building/zone temperature (simulated) | [Celsius Degree] | |
| Load Following | Electrical Load | Electrical load profile (DPI ENE03) | [kW] | |

| | | | | |
|---|---|---|---|---|
| | Following | Thermal load profile (DPI ENE04) | | |
| | Thermal Load Following | Electrical load profile (DPI ENE03) | [kW] | |
| | | Thermal load profile (DPI ENE04) | | |
| Optimization Based Control | Energy Based | Electrical load profile (DPI ENE03) | [kW] | |
| | | Thermal load profile (DPI ENE04) | | |
| | Cost Based | Electrical load profile (DPI ENE03) | [kW] | |
| | | Thermal load profile (DPI ENE04) | | |
| | Emission Based | Electrical load profile (DPI ENE03) | [kW] | |
| | | Thermal load profile (DPI ENE04) | | |

## Annex 5: List of District Performance Indicators

| DPI IDENTIFICATION | | | |
|---|---|---|---|
| CODE AND NAME | | UNIT | SCALE |
| ENERGY INDEX | | | |
| ENE01 | Energy demand | kWh/m² | District |
| ENE02 | Final energy consumption | kWh/m² | District |
| ENE03 | Peak load and profile of electricity demand | kW | District |
| ENE04 | Peak load and profile of thermal energy demand | kW | District |
| ENE05 | Degree of energetic self-supply | kWh/kWh | District |
| ENE06 | Net fossil energy consumed | kWh/m² | District |
| ENE07 | Total energy use per capita | kWh/hab · year | District |
| ENE08 | Total residential electrical energy use per capita | kWh/hab· year | District |
| ENE09 | Energy demand covered by renewable sources | % | District |
| ENE10 | Total residential natural gas energy use per capita | kWh/hab· year | District |
| ENE11 | Total residential butane gas energy use per capita | kWh/hab· year | District |
| ENE12 | Energy consumption of public buildings per year | kWh/year·m² | District |
| ENE13 | Energy use from District Heating | kWh/year·m² | District |
| ENE14 | Energy use from Biomass | kWh/year·m² | District |
| ENE15 | Energy use from PV | kWh/year·m² | District |
| ENE16 | Energy use from Solar Thermal | kWh/year·m² | District |
| ENE17 | Energy use from Hydraulic | kWh/year·m² | District |
| ENE18 | Energy use from Mini-Eolic | kWh/year·m² | District |
| ENE19 | Energy use from Geothermal | kWh/year·m² | District |
| COMFORT INDEX | | | |
| COM01 | Local thermal comfort | Level | District |
| COM02 | Local temperature deviation from set point | Δ °C | District |
| COM03 | Percentage outside range | %, Δ (COMOi)xtime | District |
| COM04 | Indoor air quality | n.a. | District |
| COM05 | Visual comfort | lux | District |
| ENVIRONMENTAL INDEX | | | |

| | | | |
|---|---|---|---|
| ENV01 | Global Warming Potential - GWP (kg $CO_2$) | kg $CO_2$ eq/m²/year | District |
| ENV02 | GWP investment | kg CO2 eq/m² | District |
| ENV03 | GWP reduction | kg CO2 eq/m² | District |
| ENV04 | Primary energy consumption | MJ/a·m² | District |
| ENV05 | Embodied energy of refurbishment scenarios | MJ/ m² | District |
| ENV06 | Energy payback time | years | District |
| ECONOMIC INDEX | | | |
| ECO01 | Operational energy cost | €/year | District |
| ECO02 | Investments | €, €/m² refurbished area | District |
| ECO03 | Life cycle cost | €, €/m² refurbished area | District |
| ECO04 | Return on investment | % | District |
| ECO06 | Payback Period | years | District |
| SOCIAL INDEX | | | |
| SOC01 | Energy poverty measured as % of inhabitants that use more than 10% of their incomes to pay energy bills | % | District |
| URBAN INDEX | | | |
| URB01 | Percentage of buildings compliant with EPBD standard | % | District |
| URB02 | Percentage of buildings compliant with Passivhaus standards | % | District |
| URB03 | Percentage of buildings compliant with EnerPHit standards | % | District |
| URB04 | Percentage of buildings compliant with nZEB standards | % | District |
| GLOBAL INDEX | | | |
| GLO01 | kWh energy saved / euro invested | kWh/yr/ € | District |
| GLO02 | $CO_2$ saved / euro invested | kg $CO_2$/yr/ € | District |