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enabling new Demand REsponse Advanced, Market oriented and secure technologies, solutions and business models

DELIVERABLE: D4.1 Specification for Improved Decision Making and DR Optimization toolset V1

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Executive Summary

This document describes deliverable D4.1 related to the Task 4.1 of work package four and entitled "Specification for Improved Decision-Making and DR Optimization toolsets V1".

The main objective of this deliverable is to define the initial specifications and general architecture of improved decision-making and DR optimization toolset, interfacing of the toolset with other components of eDREAM framework, defines the specific requirements of the UK and Italian sites and formulize the optimization problem.

The eDREAM project aims to develop new solutions for DSOs, as well as improving decision-making of aggregators and energy retailers using a new decentralized and community-driven energy ecosystem by fully integrating the micro-grid and VPPs to local power disruption network. The Improved Decision-Making and DR Optimization toolset is one of the core platforms of eDREAM system and have a significant impact on functionality and objectives of the projects. The toolset will be used by the prosumers, aggregators and DSOs to provide optimized DR solutions considering various objectives such as economic, comfort and environmental indicators. The toolset will be developed and implemented taking into account the participation of flexible resources, active microgrids and VPP management systems. The aim is to maximize local self-consumption and reduce the energy exchange to the higher-level grid. The toolset will be integrated with visualization modules allowing enhanced end-user interaction and improved energy management capabilities.

The report provides an updated overview of inputs received from WP 2 , in particular from tasks T2.1, T2.2 and T2.4 related to deliverables D2.1 User Group Definitions, End-User Needs, Requirement Analysis & Deployment Guidelines; D2.2 Use Case Analysis and Application Scenarios Description; and D2.4 System requirement and technical specifications. As such, it describes a framework for stakeholder's identification, use cases as well as business, user and system requirements. Two scenarios have been identified, scenario 1: "Prosumers DR flexibility aggregation via smart contract" for Italian pilot site and scenario 3: "Virtual power plant in Energy Community" for UK pilot sit. Business context and stakeholder requirements, functional and non-functional requirements for both sites have been listed and defined. Based on these scenarios and main KPIs the optimization problem has been defined and formulated. The main objective is to optimally plan DR events by minimizing the cost, maximizing the comfort or improving environmental impact of delivering aggregated flexibility while considering a number of constraints.

The document describes the key features of the Improved Decision-making and DR Optimization toolset and outlines its generic specifications, architecture, implementation and interfacing to eDREAM framework. The components of the toolset and how they interact with other components of eDREAM system have been described. The document also describes the use of generic optimization programs and solvers as optimization engine of the Improved Decision-Making and DR Optimization toolset, providing a focus on interfacing of these programs to the other eDREAM components. Generic and specific requirements, implementation and interfacing of the toolset subject to the identified demo sites have been listed.

Finally, it can be expected that DR Optimization toolset developed in eDREAM project will contribute to the adoption of DR programs, such that it would benefit all the stakeholders involved. The second version of D4.1

related to D.4.5 will leverage on the framework description and optimization problem formulation presented in this report to develop a multi-factor decision support system for flexible resource management. Furthermore, the second version report will refine the toolset architecture and optimization algorithm specifications along with the approach implementation.

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List of Acronyms and Abbreviations

eDREAM	enabling new Demand Response Advanced, Market oriented and secure technologies, solutions and business models
WP	Work Package
DSO	Distribution System Operator
DR	Demand Response
VPP	Virtual Power Plant
RES	Renewable Energy Sources
PV	Photovoltaic
FD	Field Data
BRs	Business Requirements
URs	User Requirements
MF	Macro-Functionality
HL-UC	High Level Use Case
LL-UC	Low Level Use Case
ELD	Economic Load Dispatch
UC	Unit Commitment
MIP	Mixed-integer programming
MILP	Mixed-integer linear programming

Preface

1. Introduction

1.1. Scope and objectives of the deliverable and relevance in the eDREAM framework

The purpose of this deliverable is to describe the initial specifications and architecture of the improved decision-making and DR optimization toolset one of the core components of the eDREAM project. The eDREAM project aims at developing innovative technologies in the field of DR management and balancing of energy resources taking into account participation of flexible resources (micro-grid connected to grid and RES generation) toward exploiting local capacities and Virtual Power Plant-oriented optimization.

The core objective of deliverables related to Task 4.1 and associated Task 4.5 is to formulate and develop a series of advanced DR Optimization strategies that will meet the expectations of all the stakeholders (DOSs, aggregators and the services offered to customers). The optimization formulation would improve forecasting of electrical generation of RES resources and consider dealing with unscheduled events and presence of uncertainties with respect to multi-factor load dispatch.

In particular, three specific components will be developed: VPP and DR services Optimization Engine, VPP and Active Micro-grid Flexibility Profiling and PV/RES Degradation and Trend Analysis. These models are part of eDREAM framework, and they will be implemented and deployed with specific technical requirement, which allows seamless interconnections and exchange of data with other eDREAM components. This deliverable refers to the first part of the task where the preparatory work is done, while in the final part of the task another deliverable (D4.5) will take care of actual development of the components.

The DR optimization toolset and hence the components which will be developed in these deliverables will be integrated through a scalable cross-functional backbone platform and implemented across demo sites to provide series of advanced DR optimization solutions that will meet the expectations of the stakeholders and in extension, achieving the goals and objective of the eDREAM project. The optimization toolset will be enhanced as value added service in T4.3 and T4.4 to integrate multi-objective optimization function and interactive visualization mechanism.

1.2. Structure of the deliverable

The deliverable is structured into seven sections in which the generic specifications of the DR Optimization toolset are described. The introductory chapter describes the scope and objectives of the deliverable and relevance in the eDREAM framework, and contributions of partners. The remainder of this report is organized as follows:

- Chapter 2 provides the Use case identification from related deliverables. It summarizes the main actor, business context and stakeholders' requirements per pilot and End-user needs.
- Formulation of optimization approach is presented in chapter 3. This includes the problem formulation, identifying the objectives, constraints and main KPIs that will be used for the optimizations.

- Chapter 4 presents the generic specifications of Improved Decision-Making and DR Optimization toolset. This describes the generic architecture and implementation specifications for all pilot sites and defines functional and non-functional requirements.
- Interfacing of the components of the toolset to other components of eDREAM framework and the general specification for the implementation of all sites is discussed in Chapter 5.
- Validation and analysis approach for Improved Decision-Making and DR Optimization toolset is presented in Chapter 6
- Chapter 7 presents the conclusions of the report together with the contributions and overall impact of D4.1 on other WPs and tasks.

1.3. Contribution of Partners

Partners contributed to this deliverable are ENG, CERTH and TU. ENG contributed to the chapter 2 identifying of the scenario and use cases, business and user requirements related to Improved Decision-Making and DR Optimisation toolset of the Italian site. CERTH contributed to the chapter 3 formulation of the optimization problem and chapter 6 validation and analysis approach. TU contributed to overall organization, writing and editing of the document, describing of the initial specification and architecture of the Improved Decision-Making and DR Optimization toolset. Interfacing the components of the toolset to the other components of eDREAM framework. Identifying of the scenario and use cases, business and user requirements related to Improved Decision-Making and DR Optimisation toolset of the UK site.

2. Use Case Identification from related Deliverables

The actors involved in the use cases defined in the eDREAM project, were defined in D2.2 Use Case Analysis and Application Scenarios Description V1, and will be refined in the subsequent versions of the same deliverable.

2.1. Summary of main actors

In order to properly set the business context and describe the use cases that have been developed, it is first necessary to provide brief descriptions of the (main) actors that have been identified in the context of Improved Decision-Making and DR Optimization.

A summary of the main actors among those identified in task 2.2 is presented below. Please refer to Deliverable D2.2 and subsequent D2.7 and D2.9 for the whole list.

Actor	Description	Type
DSO	Distribution System Operator. The entity responsible for: distribution network planning and development; the safe and secure operation and management of the distribution system; for data management associated with the use of the distribution system; procurement of flexibility services	Organization

Actor	Description	Type
Aggregator	Accumulates energy or flexibility from prosumers and Consumers and sells it to the Supplier, the DSO or the TSO	Organization
Prosumer	An entity that consumes and produces energy connected to the distribution grid. No distinction is made between residential end-users, small and medium-sized enterprises or industrial users	Person
Consumer	An entity connected to the distribution grid, that consumes energy, i.e. a prosumer without any production capabilities	Person

Table 1 Main actors involved in the use cases

2.2. Business Context and stakeholder requirements

Requirement analysis is part of Deliverable D2.1 User Group Definitions, End-User Needs, Requirement Analysis and Deployment Guidelines V1 and will be further refined in subsequent D2.6 and D2.8.

2.2.1. Business Context and Stakeholders requirements for Italian pilot site

In relation to Italian pilot site, the business requirements that the platform must guarantee are many and go through all the four macro-functionalities defined in the deliverable D2.1.

The requirements related to the "**field data aggregation**" FD are essential for the aggregators to determine the prosumer flexibility availability and to estimate the prosumer electricity production and consumption based on data retrieved from the field and weather services.

The requirements related to the "**DR optimal design**" are essential for the aggregators to determine the prosumer flexibility availability and to estimate the prosumer electricity production and consumption with the aim to dynamically assess, formulate and validate their DR strategies.

The requirements related to the "**DR Services and big data technologies for optimizing flexibility**" are essential for the aggregators to raise prosumers awareness of the DR programs, and for the DSO to detect day ahead congestion points in the grid and have a decision support system in the case where the DSO must directly intervene to avoid an overload.

The requirements related to the "**Secure blockchain-based applications for DR management, control and financial settlement**" result essential to guarantee secure data handling and to establish the self-enforcing smart contract for flexibility between aggregators and prosumers and between aggregators and DSO monitoring and validating these services.

2.2.2. Business Context and Stakeholders requirements for UK pilot site

In relation to the UK pilot site, the business requirements that the platform must guarantee are defined in the deliverable D2.1. These requirements are essential for the aggregators to provide some balancing and ancillary services such as reserve services, frequency services, intraday trading and imbalance market.

The requirements related to the "**Field Data Aggregation**" together with the requirements related the "**DR optimal design**" are essential for the aggregators or VPP energy managers to receives data of short term generation forecasting, customers' behaviour, and power demand and supply in community's nodes to categorize and assign each prosumer to a specific profile pattern.

The requirements related to the "**DR Services and big data technologies for optimizing flexibility**" are essential for the aggregators or VPP energy managers to perform big data analysis to profile loads to be shed and to identify setpoints of dispatchable generators in order to balance energy demand.

2.3. Tables of Identified use cases related to improved decision making and DR Optimisation toolset

The use cases, functional requirements and non-functional requirements were defined in D2.2 Use Case Analysis and Application Scenarios Description V1 and D2.1 User Group Definitions, End-User Needs, Requirement Analysis and Deployment Guidelines V1, and will be further refined in the subsequent versions: D2.7, D2.9, D2.6 and D2.8 respectively.

2.3.1. Identified Use cases for Italian site

The Italian pilot site is described in the Scenario 1: Prosumer DR flexibility aggregation via smart contracts. For each scenario described in D2.2 and D2.4, one high level use case has been developed, composed by several low level use cases.The following table, describes the identified high level use case and the related low level use cases. Please refer to D2.4 for further details.

HL UC01: Prosumers DR flexibility aggregation via smart contract
HL-UC01_LL-UC01: Prosumers enrolment with the aggregator
HL-UC01_LL-UC02: Contract Setting
HL-UC01_LL-UC03: Potential energy flexibility evaluation
HL-UC01_LL-UC04: Energy demand/production forecasting for day-ahead trading of flexibility
HL-UC01_LL-UC05: Flexibility request
HL-UC01_LL-UC06: Flexibility offering
HL-UC01_LL-UC07: Flexibility acceptance
HL-UC01_LL-UC08: Flexibility provisioning

Table 2 Use Cases of Italian site

2.3.2. Business requirements for Italian site

Business requirements
FD-BR01: Electric meters, edge and field device electric measures
FD-BR02: Weather data availability
MF01-BR01: Multi-Building DR characterization through thermal, optical and LIDAR information fusion
MF01-BR02: Forecast of electricity production/consumption

Business requirements
MF01-BR03: Baseline load calculations in DR programs
MF01-BR04: PV/RES Degradation and Trend Analysis
MF01-BR05: Graph-based analytics
MF02-BR04: Decision Making and DR Optimization
MF02-BR06: Forecast of electricity production/consumption at the grid level
MF02-BR07: EVSEs and EV fleet monitoring
MF02-BR08: EVSE remote control
MF02-BR09: Baseline flexibility estimation
MF02-BR10: Interactive Multi-purpose Visualization for system flexibility services
MF03-BR01: Secure data handling
MF03-BR02: LV grid congestion control through flexibility management
MF03-BR03: Prosumers flexibility monitoring and DR tracking
MF03-BR05: Interactive Visualization to customize self-enforcing smart contracts for prosumer bidding and scheduling in electricity markets
MF03-BR06: Closed loop DR verification and Financial settlement

Table 3 Business requirements for Italian site

2.3.2.1 Associated user requirements

Deliverable D2.1 describes the identified user requirements in section 5.2. A list of functional and non-functional requirements associated to the first high level use cases has been extracted below. Please refer to D2.1 for further information.

Macro functionality/Business requirement	Relative User requirement	Type
FD-BR01	UR01	Functional Requirement
FD-BR02	UR01	Functional Requirement
MF01-BR01	UR01	Functional Requirement
MF01-BR02	UR01	Functional Requirement
MF01-BR02	UR02	Functional Requirement
MF01-BR02	UR03	Functional Requirement
MF01-BR02	UR04	Functional Requirement
MF01-BR02	UR05	Functional Requirement

Macro functionality/Business requirement	Relative User requirement	Type
MF01-BR03	UR01	Functional Requirement
MF01-BR04	UR01	Functional Requirement
MF01-BR04	UR02	Functional Requirement
MF01-BR04	UR03	Functional Requirement
MF01-BR04	UR04	Functional Requirement
MF01-BR04	UR05	Functional Requirement
MF01-BR05	UR01	Functional Requirement
MF01-BR05	UR02	Functional Requirement
MF01-BR05	UR03	Functional Requirement
MF01-BR05	UR04	Functional Requirement
MF02-BR04	UR01	Functional Requirement
MF02-BR06	UR01	Functional Requirement
MF02-BR06	UR02	Functional Requirement
MF02-BR06	UR03	Functional Requirement
MF02-BR07	UR01	Functional Requirement
MF02-BR07	UR02	Non-functional requirement
MF02-BR07	UR03	Non-functional requirement
MF02-BR07	UR04	Non-functional requirement
MF02-BR07	UR05	Functional Requirement
MF02-BR07	UR06	Functional Requirement
MF02-BR07	UR07	Non-functional requirement
MF02-BR08	UR01	Non-functional requirement
MF02-BR08	UR02	Functional Requirement
MF02-BR08	UR03	Functional Requirement
MF02-BR09	UR01	Functional Requirement
MF02-BR09	UR02	Functional Requirement
MF02-BR10	UR01	Functional Requirement
MF02-BR10	UR02	Functional Requirement
MF02-BR10	UR03	Functional Requirement

Macro functionality/Business requirement	Relative User requirement	Type
MF02-BR10	UR04	Functional Requirement
MF02-BR10	UR05	Functional Requirement
MF02-BR10	UR06	Functional Requirement
MF02-BR10	UR07	Functional Requirement
MF03-BR01	UR01	Functional Requirement
MF03-BR01	UR02	Non-functional requirement
MF03-BR01	UR03	Non-functional requirement
MF03-BR01	UR04	Non-functional requirement
MF03-BR02	UR01	Functional Requirement
MF03-BR02	UR02	Functional Requirement
MF03-BR02	UR03	Functional Requirement
MF03-BR02	UR04	Functional Requirement
MF03-BR03	UR01	Functional Requirement
MF03-BR03	UR02	Functional Requirement
MF03-BR03	UR03	Functional Requirement
MF03-BR03	UR04	Functional Requirement
MF03-BR05	UR01	Functional Requirement
MF03-BR05	UR02	Non-functional requirement
MF03-BR06	UR01	Functional Requirement
MF03-BR06	UR02	Functional Requirement
MF03-BR06	UR03	Functional Requirement
MF03-BR06	UR04	Functional Requirement
MF03-BR06	UR05	Functional Requirement

Table 4 user requirements for Italian site

2.3.3. Identified Use cases for UK site

The UK pilot site is described in the Scenario 3: VPP in Energy Community. For each scenario described in D2.2, one high level use case has been developed, composed by several low level use cases.The following table, describes the identified high level use case and the related low level use cases. Please refer to D2.2 for further details.

HL UC03: VPP in Energy Community
HL-UC03_LL-UC01: Prosumers Profiling
HL-UC03_LL-UC02: VPP capability evaluation
HL-UC03_LL-UC03: VPP for reserve services
HL-UC03_LL-UC04: VPP for frequency services
HL-UC03_LL-UC05: VPP export evaluation
HL-UC03_LL-UC06: VPP for wholesale market – intraday trading
HL-UC03_LL-UC07: VPP for imbalance market

Table 5 Use Cases of UK site

2.3.4. Business requirements for UK site

Business requirements
FD-BR01: Electric meters, edge and field device electric measures
FD-BR02: Weather data availability
MF01-BR01: Multi-Building DR characterization through thermal, optical and LIDAR information fusion
MF01-BR02: Forecast of electricity production/consumption
MF01-BR03: Baseline load calculations in DR programs
MF01-BR04: PV/RES Degradation and Trend Analysis
MF01-BR05: Graph-based analytics
MF02-BR01: Big Data Clustering at Multiple Scale
MF02-BR02: VPP & Customer Segmentation and Profiling
MF02-BR03: Virtual Power Plant Generation Modelling and Optimal Coalition Forecasting
MF02-BR04: Decision Making and DR Optimization
MF02-BR05: Interactive Visualization for VPP coalition

Table 6 Business requirements for UK site

2.3.4.1 Associated user requirements

Deliverable D2.1 describes the identified user requirements in section 5.2. A list of functional and non-functional requirements associated to the first high level use cases has been extracted below. Please refer to D2.1 for further information.

Macro functionality/Business requirement	Relative User requirement	Type
FD-BR01	UR01	Functional Requirement
FD-BR02	UR01	Functional Requirement
MF01-BR01	UR01	Functional Requirement
MF01-BR02	UR01	Functional Requirement
MF01-BR02	UR02	Functional Requirement
MF01-BR02	UR03	Functional Requirement
MF01-BR02	UR04	Functional Requirement
MF01-BR02	UR05	Functional Requirement
MF01-BR03	UR01	Functional Requirement
MF01-BR04	UR01	Functional Requirement
MF01-BR04	UR02	Functional Requirement
MF01-BR04	UR03	Functional Requirement
MF01-BR05	UR01	Functional Requirement
MF01-BR05	UR02	Functional Requirement
MF01-BR05	UR03	Functional Requirement
MF01-BR05	UR04	Functional Requirement
MF02-BR01	UR01	Functional Requirement
MF02-BR01	UR02	Functional Requirement
MF02-BR01	UR03	Functional Requirement
MF02-BR01	UR04	Functional Requirement
MF02-BR01	UR05	Functional Requirement
MF02-BR02	UR01	Functional Requirement
MF02-BR02	UR02	Functional Requirement
MF02-BR02	UR03	Functional Requirement
MF02-BR02	UR04	Functional Requirement
MF02-BR02	UR05	Functional Requirement
MF02-BR02	UR06	Functional Requirement
MF02-BR02	UR07	Functional Requirement
MF02-BR02	UR08	Functional Requirement
MF02-BR02	UR09	Functional Requirement
MF02-BR03	UR01	Functional Requirement
MF02-BR03	UR02	Functional Requirement
MF02-BR03	UR03	Functional Requirement

Macro functionality/Business requirement	Relative User requirement	Type
MF02-BR04	UR01	Functional Requirement
MF02-BR05	UR01	Functional Requirement
MF02-BR05	UR02	Functional Requirement
MF02-BR05	UR03	Functional Requirement
MF02-BR05	UR04	Functional Requirement
MF02-BR05	UR05	Functional Requirement
MF02-BR05	UR06	Functional Requirement
MF02-BR05	UR07	Functional Requirement

Table 7 User requirements for UK site

3. Formulation of Optimization Problem

The main component of this toolset will be an optimization mechanism for the Demand Response programs' optimal scheduling. The main objective of this mechanism will be to satisfy the business plans of the system's stakeholders who are the aggregators considering also the services to be offered to their customers, as well as to DSOs.

The ultimate scope is the economic operation of the electric power system considering the cost and the emissions reduction taking also into account the customers' comfort. The economic operation of an electric power system involves the unit commitment (UC) and economic load dispatch (ELD) problem. The first one refers to the optimal selection of the available generation assets (units) to supply a specific load demand economically. The second one is related to the optimum power generation from each of the committed (selected) generation units in order to supply dynamically varying load demand economically. More specifically, the main objective is to determine which generators are going to be scheduled in an ON state and after that, to calculate the optimal schedule of online generating units, so as to meet the demand power at minimum operating cost under various system and operating constraints. Thus, in the planning of power systems, the unit commitment problem should be initially solved [10].

As a next step, the economic load dispatch problem should be considered. The importance of economic dispatch is to get maximum usable power using minimum resources. Conventionally, the economic dispatch problem of a power system is solved in the environment of unit commitment and real time operation plants by assuming that each of the dispatchable on-line units can be regulated continuously between its minimum generation limit, Pmin and its maximum generation limit, Pmax.

Thus, the economic load dispatch (ELD) problem is formulated as an optimization problem of minimization of total cost of power generation to meet a particular load demand subjected to the constraints related to the generator's power output [11].

Unit Commitment and Economic Load Dispatch Problem Formulation

The UC problem is considered as a non-convex, large-scale, non-linear, and MIP combinatorial optimization problem with constraints. The binary nature of UC decision (ON/OFF) causes the non-convexity of the problem. Non-linearity is due to the non-linear generation cost curves and non-linear transmission constraints. The combination of the binary and non-linear variables leads to the formulation of the problem as a MILP mathematical problem. The selections indicating the ON/OFF status of the generating units in various operating phases (offline, start-up, dispatch, and shutdown) are modeled using binary variables, while the power output, reserve contribution and flow decisions are represented using continuous variables.

The following MILP formulation is based on a single binary variable to describe the UC status and the corresponding hourly transition of generating units. The MILP deterministic UC problem can be formulated as:

Minimize Operation Cost (OC):

$$OC = \sum_{i=1}^{N}\sum_{t=1}^{T} FC_{it}(P_{it})I_{it} + NL_i I_{it} + ST_{it} + SD_{it} \tag{1}$$

where OC is the operating cost, N is the number of generating units, T is the time horizon (24h) and I_{it} is a binary variable modeling UC decision of unit i at hour t. $FC_{it}(P_{it})$ is the fuel cost, NL_i is the no-load cost of unit i, ST_{it} and SD_{it} are respectively the start-up and shutdown costs of unit i at hour t.

$FC_{it}(P_{it})$ is the input/output curve that is modeled with a quadratic function of the power output:

$$FC_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i \tag{2}$$

where a_i, b_i and c_i are the cost coefficients.

Problem Constraints

Towards minimizing the OC, the UC problem solution must take into account both generator physical constraints and system operational constraints. These constraints can be one or more of the following types:

I. Generating limits constraints

Each generating unit has minimum and maximum power output limits. This means that the power output cannot exceed these limits:

$$P_{it}(min) < P_{it} < P_{it}(max) \tag{3}$$

where $P_{it}(min)$ and $P_{it}(max)$ are respectively the minimum and maximum real power output of unit i at hour t.

II. Power balance constraint

The equilibrium between load demand and power supply in each hour is given by:

$$\sum\nolimits_{i=1}^{N} P_i(\max)\,(t) \cdot I_i(t) = D_t \tag{4}$$

where D_t is the total demand at hour t.

III. Minimum up /down time constraints

Minimum up-time is defined as the minimum number of hours of operation at or above the minimum generation capacity. It is formulated as follows:

$$T_i^{on} > MUT_i \tag{5}$$

where T_i^{on} and MUT_i are the total up-time and the minimum up-time of unit i.

Minimum down-time is the minimum number of hours once the generator is shut-down, before it can be brought online again to generate power:

$$T_i^{off} > MDT_i \tag{6}$$

where and are the total downtime and the minimum downtime of unit i.

IV. Ramp rate up/down constraints

The generator power output is not changing instantaneously. Its variation depends on ramp rate limits. These constraints are formulated based as on the following conditions:

$$P_{i,t} - P_{i,t-1} \leq UR_i \tag{7}$$

$$P_{i,t-1} - P_{i,t} \leq DR_i \tag{8}$$

where UR_i and DR_i are the ramping up and ramping down of unit i.

V. Spinning reserve constraint

Spinning reserve is an indicator of the amount of power that is required to fulfill percentage of forecasted peak demand or it can be considered as a unit/s being able to cover the loss of the most important loaded unit in each time. The formulation for spinning reserve can be expressed as:

$$\sum_{i}^{N} (I_{it} \cdot P_{it}) \geq (D_t + R_t), \qquad 1 \leq t \leq T \tag{9}$$

where R_t is the spinning reserve at hour t.

VI. Must run and must out units

The must run units are prescheduled units that must be online, due to operating reliability or economic purposes. The RES units (batteries and EVs can be also included) are necessary run units for better economic system operation. Must out units are considered those units that are unavailable for commitment, because of forced outages or maintenance interventions.

VII. Transmission constraints

Transmission constraints should be also considered, in order to satisfy customer load demands and maintain transmission flows and bus voltages within admissible limits. Generally, linear DC (direct current) transmission constraints are integrated in UC problem formulation for system security considerations.

The recent years, due to the increased needs in electricity consumption and hence the worsening of air pollution, two more parameters are considered concerning the customer satisfaction and the environmental impact during the planning of power systems.

VIII. Customer Constraints

The Demand Response concept plays a significant role in the formulation of the day-ahead load profile and electricity prices that should be considered during the unit commitment and load dispatch operations. The produced optimal results may cause unwanted load shedding and impact the customer satisfaction. Thus, the customers may reject the participation in demand response programs and the system operator will not be able to take advantage of these types of flexible assets, as the DR events. For this reason, the following parameters concerning the customer comfort and satisfaction should be considered:

a. Temperature limits
b. Luminance limits
c. Economical rewards

IX. Finally, environmental constraints/indicators must be also considered during the optimal scheduling, such as the CO_2 emissions reduction.

4. Improved Decision making and DR Optimization toolset specifications

The main objective of this deliverable is to develop a toolset that enables the operators (e.g. DSO, Aggregator and prosumers) to optimally plan the DR programs, in particular, dealing with participation of flexible resources (e.g. active assets in micro-grids fully or partially connected to the grid, RES generation, other DERs). The aim is to optimize from one side the energy plans and on the other side to maximize the social welfare, minimize of electricity generation and delivery costs, and reduce renewable energy supply uncertainty. The integration of flexible resources into power system operation is very challenging and introduces a lot of uncertainty. These challenges can be overcome to a great extent by using a virtual power plant concept, which is based on creating a single operating profile by aggregating the capacity of many and different distributed energy resources including generation, storage, and demand. Several strategies have been proposed in the literature to manage DR programs. In general, these strategies can be classified into two main categories: Price-Based Programs and Incentive-Based Programs. In Price-Based Programs, the electricity price varies as a function of variables such as the time of use or the total demand. On the other hand, in Incentive-Based Programs customers are offered a reward if they reduce their demand when the utility company desires. In order to implement an improved and advanced DR strategies within eDREAM project, DR optimization engine will be developed and deployed. Two approaches will be investigated to develop the optimization engine; in first approach, integration of external generic optimisation tools with eDREAM framework will be considered. The generic optimisation tools will provide access to several advanced optimisation algorithms, which can be applied to achieve optimal scheduling of Demand Response programs'. When these tools are used in an effective way, important time savings are obtained within the development process of optimization methods. The second approach is to develop a custom optimal scheduling algorithm taking into account the objectives, constraints and requirements as defined by eDREAM project. In the sections below the general architecture, implementation, requirements and interfacing of the toolset are described.

4.1. Generic optimization and improved decision making architecture

The general architecture of the optimization engine is illustrated in Figure 1. The algorithm requires data acquisition, data clustering and segmentation and prediction models to enable the optimization and decision-making. In the data acquisition phase, measurements of the current state of the system (e.g. consumption, production) and related data (e.g. weather forecasts) are acquired. The current and historical state measurements are then employed to predict the future energy demand, supply and baseline as well as to estimate the flexibility availability. The data clustering and segmentation are used to improve the predictions. During the optimisation phase, the optimal corrective strategies to balance supply and demand across the horizon using the available options for generating, storing, buying or selling energy are determined. A decision support system is used to maximize the benefits of the applied strategies and help in selecting of the optimal scheduling taking into account a number of KPIs that will come in collaboration with the end-users (KIWI, ASM). Techniques of big data science for customer clustering and segmentation will contribute to decision support system and DR optimization functionalities.

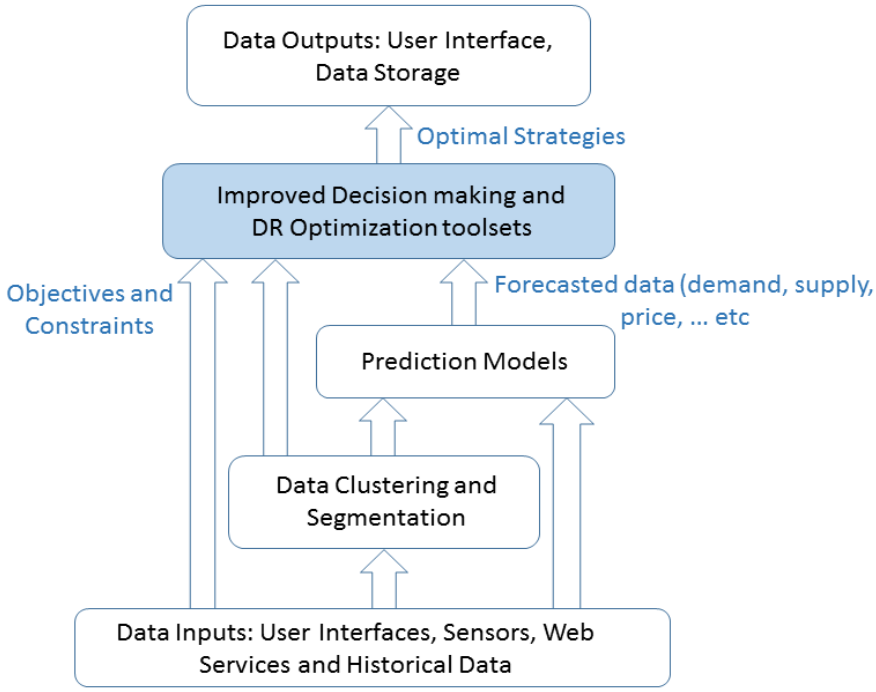

Figure 1 Generic optimization and improved decision-making architecture

In terms of generic support for optimization, many commercial or open-source optimisation programs and environments are available (e.g. the open source LP Solver available from *http://lpsolve.sourceforge.net/5.5/*, generic optimization program GenOpt from *https://simulationresearch.lbl.gov/GO/index.html* and Dakota toolkit from *https://dakota.sandia.gov/*). The generic optimization tools are found as libraries which can be called from programming languages (ex. C++, Java) or standalone toolkits and can be interfaced with different simulation programs. There are different ways to exchange the data with generic optimization tools; via API or input files. The API is a set of routines that can be called from host software to build the model in memory, solve it and return the results to the host software. The generic optimization tools can be also coupled to any simulation program that reads its input from files and writes its output to files, different file formats can be supported. The interfacing of generic optimization tools to other software is shown in Figure 2.

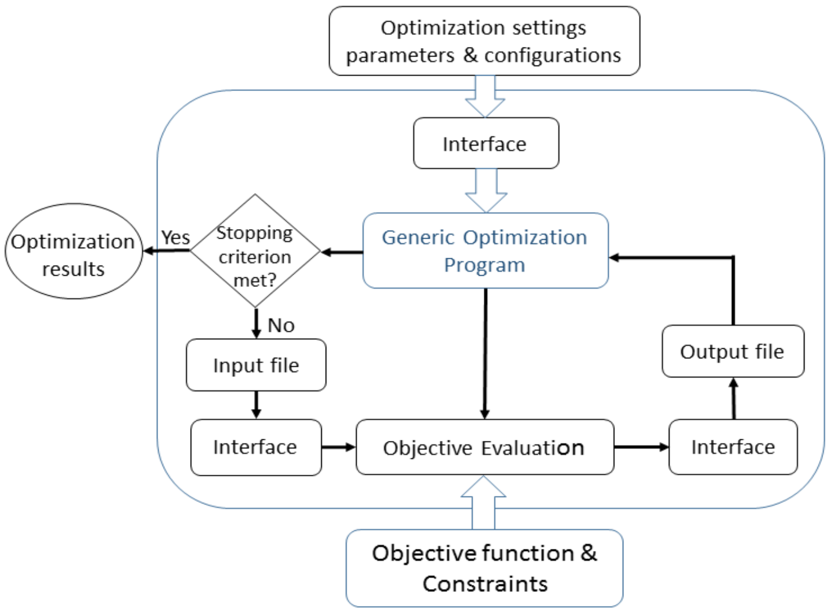

Figure 2 Coupling of generic optimization program

The generic optimization tools also allow users to add their own optimization algorithms which enable the users to exploit the methods and utilities offered by the optimizer and other components of the tool. For example the optimizer of the generic optimization tool may offer methods to retrieve the required settings for specific algorithm, reporting the results of the optimization run or access to linear algebra, line-search or checking the optimality conditions. Thus, the user has only to deal with the actual mathematical formulation of the optimization algorithm and not with the data handling, output writing, syntax checking and other work when coupling of the algorithm with external simulation programs.

The optimization engine aims at providing optimization services to the DSO, aggregators and prosumers which the VPP and microgrid is connected to by gathering the demand and supply, forecasted data and flexibility contributions. In this optimization problem, usually trade-offs between two or more conflicting objective functions need to be simultaneously optimized, for instance maximizing of social welfare while minimizing cost. The proposed optimisation toolset relies upon a single-objective optimisation algorithm that is able to handle a single objective function. In practice, problems with multiple objectives are reformulated as single-objective problems which can be optimized and treating the other objectives by constraints. Forming a weighted combination is another method to resolve optimizing of multiple objectives in which the functions are combined in a single one, which is then minimized with traditional single-objective optimization methods.

The optimization engine performs the optimization by calling the generic optimization program to generate input parameters and analysis program to evaluate the value of necessary functions. Generic optimization program will change the output parameters (inputs to the analysis program) in order to minimize or maximize a defined objective function subject to an identified constraints or limits. To achieve this, generic optimization program calls the analysis program repeatedly while searching for the optimum. In general, the engine solves an optimization problem consist from an objective function OBJ, a set of constraints N and a specification of the types (continuous, integer, binary), and bounds of the decision variables x. The goal is to find the values of decision variables that maximize or minimize the objective, while satisfying all the constraints, types and bounds. This can be expressed numerically as: find the values of N variables contained in x that will minimize or maximize OBJ = F(x) subject to number of constraints defined by $X_i^L \leq X_i \leq x_i^U$ and $X_i \geq 0$ where i = 1, N.

It is possible to find a huge number of generic tools either open-source or commercial to solve optimization problems, since optimization has wide applications in many industries such as financial services, retails, supply chain, scheduling and energy. In the section below some of the tools that widely used in energy sector will be described.

4.1.1. GenOpt (Generic Optimization)

GenOpt is a generic optimization program developed by University of California (through Lawrence Berkeley National Laboratory) and designed for finding the values of user-selected parameters that minimize a given objective function. The objective function is calculated using an external simulation program, such as SPRK, EnergyPlus, DOE-2, TRNSYS, etc. Generally, it is possible to couple the GenOpt to any simulation program or any user-written program with text-based input and output, on any operating system that can run Java. The only requirement of the external program is that it must read its input from text files and write the cost function value to a text file. The optimization algorithms that implemented within GenOpt library are listed below:

- Generalized Pattern Search algorithms (the Hooke-Jeeves and the Coordinate Search algorithm), which can be run using multiple starting points.
- Particle Swarm Optimization algorithms (for continuous and/or discrete independent variables), with inertia weight or constriction coefficient and velocity clamping, and with a modification that constricts the continuous independent variables to a mesh to reduce computation time.
- A hybrid global optimization algorithm that uses Particle Swarm Optimization for the global optimization, and Hooke-Jeeves for the local optimization.
- Discrete Armijo Gradient algorithm.
- Nelder and Mead's Simplex algorithm.
- Golden Section and Fibonacci algorithms for one-dimensional minimization.
- The following algorithms can be used for parametric studies:
- Mesh generator to evaluate a function on all points that belong to a mesh with equidistant or logarithmic spacing between the mesh points.
- Parametric search where only one independent variable is varied at a time.

Additionally, users can easily add their minimization algorithms to GenOpt's library using algorithm interface capability of the program. The algorithm interface separates the optimization algorithm and GenOpt's kernel which allows implementing additional algorithms without being familiar with the kernel or having to recompile it. The algorithms can access utility classes that are commonly used for minimization, such as optimality check, line-search and also uses methods which helps with data handling, output writing and syntax checking. Thus, enables the user to only deal with the actual implementation of the optimization algorithm.

GenOpt has successfully solved various optimization problems and has been widely coupled to a several energy simulation programs, Wetter [1] combined GenOpt and EnergyPlus to minimize source energy consumption of an office building and GenOpt with TRNSYS to minimize auxiliary electrical energy of a solar domestic hot water system. Futrell [2] coupled a light environment analysis software and GenOpt to optimize building's daylighting design. EnergyPlus and GenOpt are also used by Karaguzel [3] to minimize the life cycle costs of an office building subject to building materials. Asadi et al. [4] combined GenOpt, TRNSYS and MATLAB to minimize energy use in the building while considering the occupant's requirements. The GenOpt coupling framework for simulation-based optimizations is presented in Figure 3. The GenOpt requires four input files to launce coupling simulation program these files are initialization file, command file, configuration file and simulation file. On each simulation cycle, GenOpt generates a specific set of input variables for the simulation program which is responsible for calculating the output of the objective function. This process is repeated until a minimum objective function value is found or after a certain stooping criteria imposed on the system. The optimization algorithm is responsible for the specification of new parameters on each cycle.

GenOpt comunication interface

As illustrated in Figure 3, GenOpt primarily consists of two parts: Kernel that is responsible for controlling the text files and calling the simulation program and optimizer that works with the different optimization algorithms. Initialization, configuration, selection of the algorithm, and definition of the different input variables all is done by modifying the contents of input text files. The necessary text files that needed to start the optimization with GenOpt are:

- Initialization file. In this file the location of the input files, simulation input and simulation output files are specified. The location of the objective function is also defined in this file.
- Configuration file. This file contains information related to the simulation program selected and it has to be written only once for each simulation program. This file specifies in what format the independent parameters will be written to the simulation input file and what string must be used to start the simulation program.
- Command file. It contains information about the optimization settings such as selected optimization algorithm, independent parameters and stopping criteria.
- Simulation input template. The template is used by GenOpt to write the value of the independent variables to the simulation input files. To do so, each variable name specified in command file must present in the simulation input template and surrounded by % then at run time GenOpt will replace the name by the numerical value of the corresponding variable.
- Simulation input file. This file is generated by GenOpt based on the simulation input templet and it contains the value of independent variables which will be read by the simulation program.
- Simulation output file. GenOpt reads the result of the cost function evaluated by the simulation program from this file. GenOpt will search the file for the number that occurs after the last occurrence of the string specified by the variable delimit. In the simulation output file, the cost function value must be indicated by a string (specified in the configuration file) that stands in front of the cost function value.

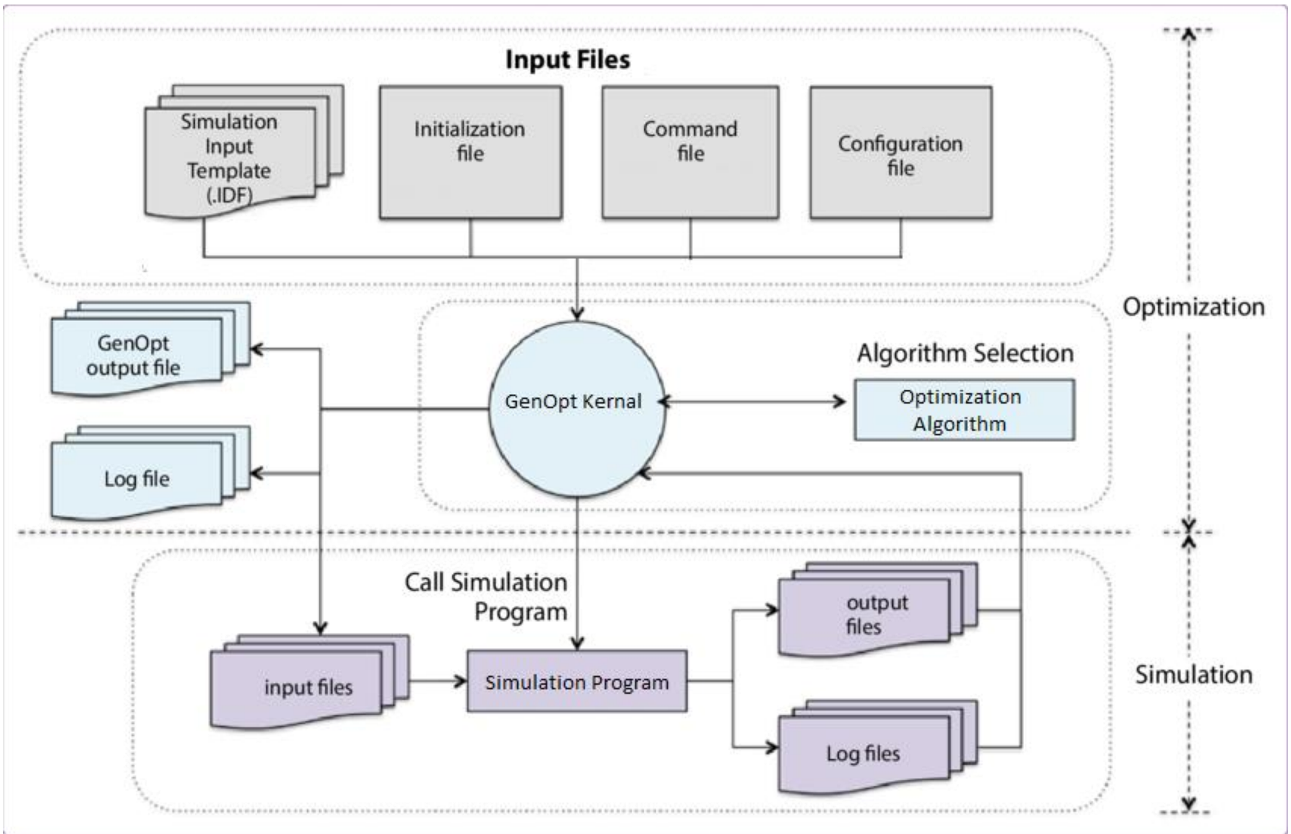

Figure 3 GenOpt-Simulation program coupling framework [5].

4.1.2. lp_solve (Mixed Integer Linear Programming solver)

Linear programming is widely used to solve diverse types of optimization problems in industry such as transportation, energy, telecommunications, and manufacturing. It has been reported [7] that over 100 LP tools are available. The studies [7] and [8] have identified lp_solve, CLP, GLPK, MINOS and SCIP as the most popular and well-known open source solvers. In this section lp_solve tool will be described as it is an active project, referenced in several sources, used in academia, and several studies (example [9]) showed that it is able to handle DR optimization problems.

lp_sovle is an optimization tool developed at Eindhoven University of Technology and is released as open source under a GNU Lesser General Public License and is available for free download. lp_solve is a mixed integer liner programing solver based on the revised simplex method and Branch-and-bound method for integers. It is distributed as an API that can be called from any programing language capable of calling external libraries (DLLs under Windows, Shared libraries (.so) under Unix/Linux). Exchanging data with the lp_solve library can be done using API, input files or an IDE.

The lp_solve API can be included into the host software as a linkable library implementing the solver and associated header file. Figure 4 depicts a typical way of including the lp_solve API into application code. lp_solve API can be linked dynamically or statically to the application code. Dynamically means that the library is linked to the application code when the executable is started. In this case, the library must be distributed separately with the application code to make it work. Statically means that the library is contained in the executable hence the application code does not need extra files to call lp_solve.

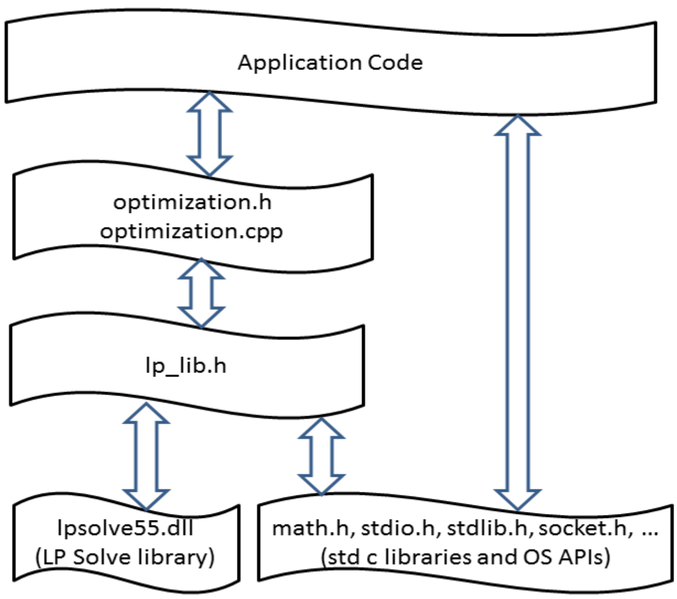

Figure 4 Library structure of software developed using lp_solve

lp_solve library contains several routines and functions to perform many tasks and to set several options of the optimization algorithms. Once the library is linked these routines can be accessed and called directly from the application program. Figure 5 shows a very simple example to illustrate the use of the lp_solve library.

```
#include "lp_lib.h"
int main(void)
{
     lprec *lp;
     lp = make_lp(0, 0); // Create a new LP model

    // Add constraint  e.x 10*Ax + 12*Bx + 8*Cx + 18*Dx >= 55000
    double row[] = { 0 , 10 , 12 , 8 , 18 };
    add_constraint( lp , row , GE , 55000 ); //GE is Greater than or Equal

   // Maximize the Objective Function
    // Objective Function e.x 4.5*Ax +5.5*Bx + 6.5*Cx + 7*Dx
    double row[ ] = { 0 , -4.5 , -5.5 , -6.5 , -7 };
    set_obj_fn( lp , row );

    solve( lp );  // call solver

   get_objective( lp );  // The value of the objective function
    get_variables( lp , solution );  // The solution

   delete_lp( lp );
return;
}
```

Figure 5 lp_solve example formulated in c/c++

4.1.3. Dakota (Design Analysis Kit for Optimization and Terascale Applications)

Dakota is an optimization toolkit developed at Sandia National Laboratories in Albuquerque, New Mexico and is released as open source under a GNU Lesser General Public License and is available for free download. Several optimization strategies and a flexible interface to simulation programs have been implemented within Dakota toolkit. Dakota can handle gradient and nongradient-based optimization; uncertainty quantification with sampling, reliability, and stochastic methods; parameter estimation with nonlinear least squares methods; and sensitivity/variance analysis. Dakota can be executed as a stand-alone application or as an embedded library service.

To execute Dakota a text file (Dakota input file) contains the type of analysis to be performed and the file names associated with the simulation program need to be supplied by the user. Six specification blocks may appear in Dakota's input file: variables, interface, responses, model, method and environments. The environment block is used to specify the general Dakota settings such as Dakota's graphical output. The method block specifies the iteration method which Dakota will employ and associated method options. The model block specifies the model which will be used by the iterator to map a set of variables into set of responses. The variable block specifies the number, type and characteristic of the parameters that will be varied by Dakota. The interface block specifies how Dakota will pass data to and from the simulation code. The type of data that the interface will return is specified in response block. Figure 6 shows an example of Dakota's input file.

Dakota can be coupled to simulation programs using text files or through direct interface. The coupling method need to be specified in the input file. Direct coupling interface eliminates the overhead from creation and file I/O processes. Dakota can be coupled directly to a simulation program either by modifying the simulation code to behave as a function or subroutine under Dakota software or by using Dakota as an algorithm service library within another application.

```
# Dakota Input File: xxx.in

environment
   graphics

method
    multidim_parameter_study   //calls for multidimensional parameter study
        Partitions = 8    8          // specifies the number of intervals per variable

model
     single     // single interface instance is used to map variables into responses

variables
    continue_design = 2          //type and number of parameters (two continues design variables)
        lower_bound -2.0  -2.0   // characteristics
        upper_bound 2.0 -2.0
        descriptors 'x1'  'x2'

interface
     analysis_drivers = 'xxx'    //name of the objective function
        direct                   // specifies how Dakota will pass data to and from the simulation code

responses
     response_function = 1   //there is only one response function
```

Figure 6 Dakota input file

When text files approach is used, Dakota reads the simulation program outputs from results file, and writes the inputs into parameters file. This means that an interface needs to be constructed in the simulation program side to read the input values from the parameter file and write the objective function outputs into the results file. The name of the parameters and results files need to be added to the interface block of the input file. Figure 7 depicts a typical way of coupling Dakota to a simulation program. During operation, Dakota generates a specific set of input variables, automatically executes the user's simulation code and receives the output of the objective function from the simulation program. Simulation program must implement passing or converting information (data pre-processing and data post-processing). Dakota writes the parameter file in either standard or APREPRO format. The former option uses simple "value tag" format, whereas the latter option uses a "{tag = value}" format.

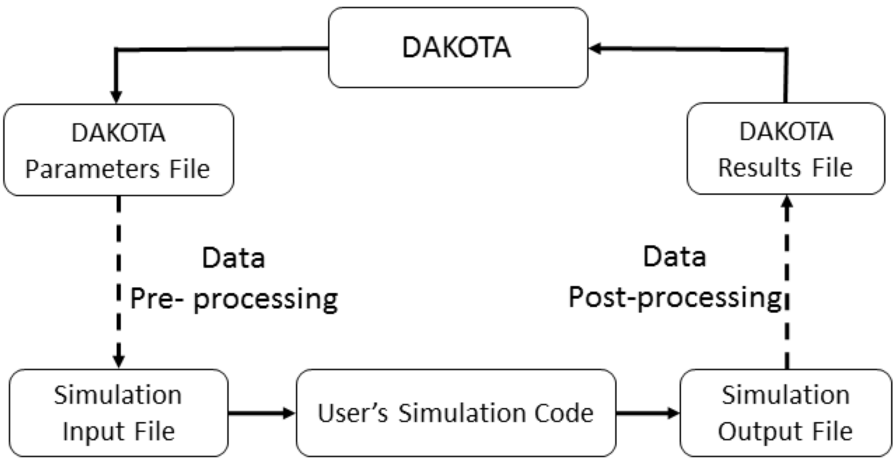

Figure 7 Dakota interface to simulation programs [6].

4.2. Implementation for the eDREAM Project

In order to implement a fully functional Improved Decision-Making and DR Optimization toolset architecture as well as develop all its necessary components, C++ libraries and runtime environment are required. Software development of the toolset will be primarily conducted in C/C++, with communications structured by web standard protocols and formats e.g. REST, JSON, SFTP, HTTPS. The data exchange between the improved decision-making and DR optimization components and other components of eDream Architecture shell be done through reading the inputs and writing the outputs into files. The files type can be JSON or CSV and data types can be integer, string or float. Figure 8 shows the interconnections between the decision-making and DR optimization toolset and other components as represented in eDream Architecture.

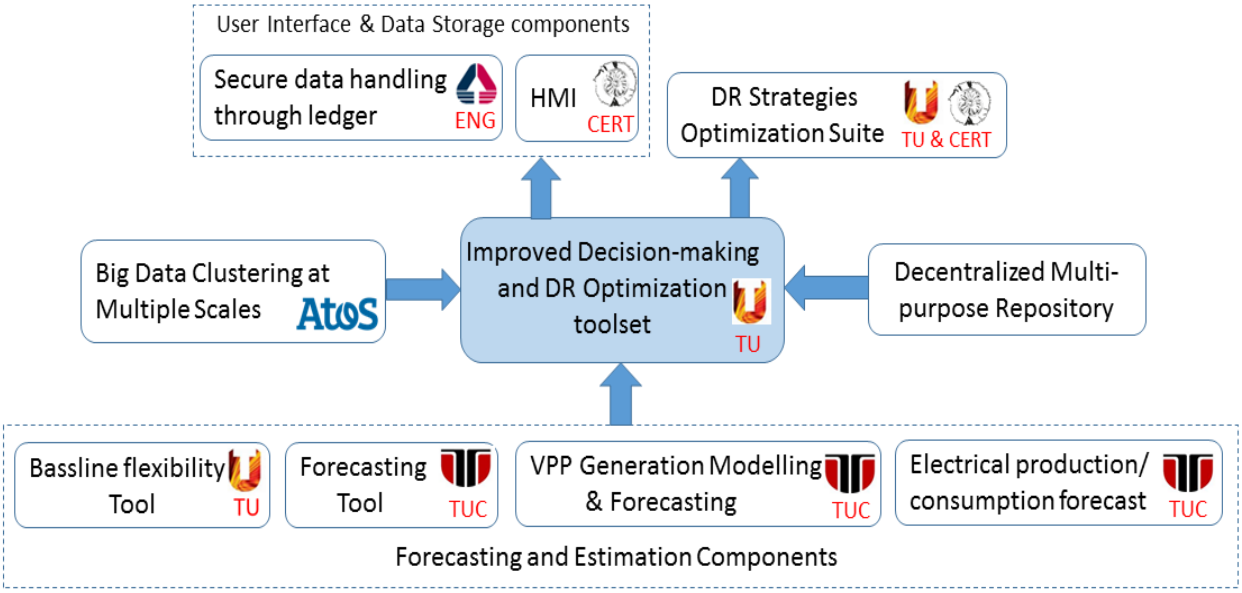

Figure 8 Interconnections between the toolset and other components as represented in eDream Architecture

Implementing of improved Decision-Making and DR Optimization Toolset requires development and deployment of three different components: VPP and DR services Optimization Engine, PV/RES Degradation and Trend Analysis and VPP and active Micro-grid flexibility profiling. These modules will be implemented into an architectural layer with individual specific interfaces to exchange the data between themselves as well as with other components of eDREAM project. The toolset will improve the forecasting of RES energy generation with degradation and trend analysis algorithm, evaluate the flexibility margins of the prosumers generation assets based on the baseline calculations, calculate optimal set points for generators and load curtailment and produce optimal DR scheduling. The Figure 9 shows the interfacing of the toolset components' to other components of eDREM project.

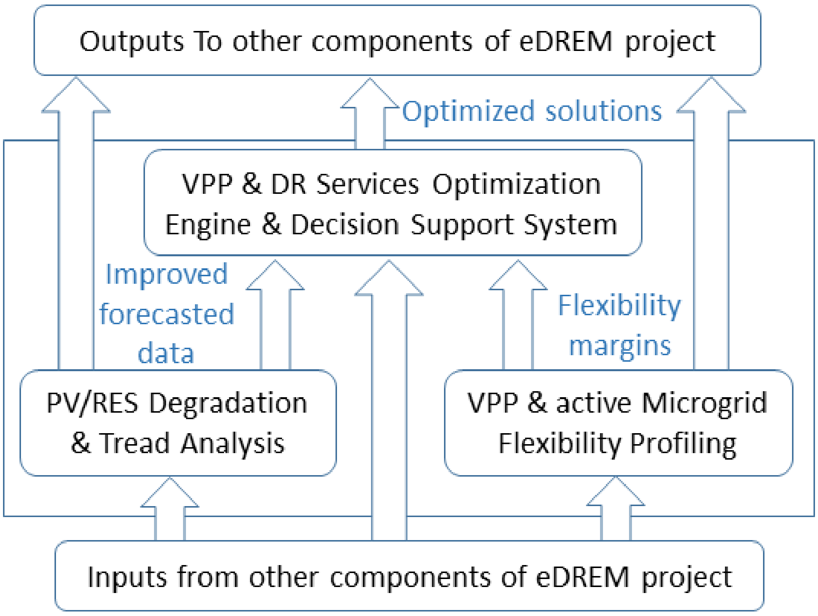

Figure 9 Interfacing of the improved Decision Making and DR Optimization Toolset components

4.2.1. Generic requirements for all Demo sites

The Improved Decision-Making and DR Optimization toolset must accomplish all the requirements defined in the scenarios and use cases descried in D2.1, D2.2 and D2.4. Generic requirements of each individual component of the toolset as described in D2.4 are listed in the tables 8, 9, 10 and 11.

Functional ID	Description
MF01_BR04_UR01_FR01	Obtain data for field devices' physical parameters and constraints
MF01_BR04_UR02_FR02	Receive forecasted data for weather conditions
MF01_BR04_ FR03	Receive historical data for measurements related to generation assets from Decentralized Repository
MF01_BR04_ FR04	Receive historical data for weather conditions

Table 8 Requirements of PV/RES Degradation and Trend Analysis

Functional ID	Description
MF02_BR02_UR08_FR01	Receive prosumers' load profiles
MF02_BR02_UR02_FR02	Receive historical data for generation of prosumers' energy assets
MF02_BR02_UR08_FR03	Obtain physical parameters and constraints of field devices in order to calculate the flexibility margins of assets
MF02_BR02_UR04_FR04	Process EV (Battery SoC, residual autonomy etc.)
MF02_BR02_UR05_FR05	Process EVSE data (power, voltage, current etc.)
MF02_BR02_UR06	Identify generation patterns

Table 9 Requirements VPP and active Micro-grid flexibility profiling

Functional ID	Description
MF02_BR04_UR01_FR01	Receive analysed data for the efficacy of the implemented DR strategies
MF02_BR04_FR02	Receive consumption/production forecasted data
MF02_BR04_FR03	Obtain energy prices
MF02_BR04_FR04	Receive economic, conform, environmental and business KPIs
MF02_BR04_FR05	Get potential Incentives for the final users
MF02_BR04_FR06	Obtain the loads profiles of the registered prosumers
MF02_BR04_FR07	Obtain the generation profiles of the participating flexibility resources
MF02_BR04_FR08	Identify patterns among the input data
MF02_BR04_FR09	Calculate optimal set-points for generators and load curtailment
MF02_BR04_FR10	Produce optimal DR scheduling

Table 10 Requirements of VPP and DR services Optimization Engine

Functional ID	Description
MF02_BR04_UR01_FR01	Receive analytics data for the efficiency of the currently implemented DR strategies from Graph-based Analytics
MF02_BR04_FR02	Receive optimized parameters from the VPP & DR Services Optimization for the loads to be shed and the set points of dispatchable generators
MF02_BR04_FR03	Store optimized parameter in the Decentralized Repository
MF02_BR04_FR04	Communicate with the Operator's application via web interface

Table 11 Decision Support System & DR Strategies Optimization

4.2.2. Specific requirements for the Italian demo site

The Italian pilot site is described in deliverable D2.2 Scenario 1: Prosumer DR flexibility aggregation via smart contracts (HL-UC01). In this scenario, prosumers and consumers are able to offer via smart contracts their flexibility resources, both production and loads modulation to specific aggregator. Once DSO identifies a congestion point and grid connections to this congestion point the aggregators in that region are activated and contract prosumers and consumers, connected to this congestion point contacted to offer their flexibility. In this scenario the Improved Decision-Making and DR Optimization toolset is used in:

- PV/RES Degradation and Trend Analysis component is used in use case HL-UC01_LL-UC04 Energy demand/production forecasting for day-ahead trading of flexibility.
- VPP and DR services Optimization Engine can contribute to the use cases HL-UC01_LL-UC01 Prosumers enrolment in demand response programs and HL-UC01_LL-UC06 Flexibility offering.

Use Case	Description	Functional ID
HL-UC01_LL-UC01	Receive baseline flexibility estimations	MF02_BR04_FR11
	Receive energy consumption and production forecasted data	MF02_BR04_FR02
	Get potential Incentives for the prosumer	MF02_BR04_FR05
	Identify the suitable DR program for the prosumer	MF02_BR04_FR10
HL-UC01_LL-UC04	Obtain RES device parameters & constraints	MF01_BR04_UR01_FR01
	Receive forecasted data for weather conditions	MF01_BR04_UR02_FR02
	Receive historical data for RES generation	MF01_BR04_ FR03
	Receive historical data for weather conditions	MF01_BR04_ FR04
HL-UC01_LL-UC06	Receive subset of the prosumers enrolled with the aggregator	MF02_BR04_FR12
	Receive agreed flexibility that can be delivered by the subset of the prosumers	MF02_BR04_FR13
	Calculate the optimal scheduling of the subset of the prosumers	MF02_BR04_FR10

Table 12 Requirements for Italian demo site

4.2.3. Specific requirements for the UK demo site

The UK pilot site is described in deliverable D2.2 Scenario 3: VPP in Energy Community (HL-UC03). The scenario aims to maximize the profit of the combined generation or the flexibility services within a local microgrid through the use of a VPP. Aggregators will be able to participate in balancing and ancillary markets such as reserve services, frequency services, intraday trading and imbalance market by modelling the combined output of their prosumers' assets (e.g. wind-turbine, small hydro, PV and backup generators) as a VPP.

In this scenario the Improved Decision-Making and DR Optimization toolset is used in three use cases: HL-UC03_LL-UC02 'VPP capability evaluation', HL-UC03_LL-UC03 'VPP for Reserve services' and HL-UC03_LL-UC04 'VPP for Frequency services'. The specific requirements are listed in the table 13.

- PV/RES Degradation and Trend Analysis component is used in the three use cases, HL-UC03_LL-UC02, HL-UC03_LL-UC03 and HL-UC03_LL-UC04.
- VPP and DR services Optimization Engine is used in HL-UC03_LL-UC03 and HL-UC03_LL-UC04.

Use Case	Description	Functional ID
HL-UC01_LL-UC02	Obtain RES device parameters & constraints	MF01_BR04_UR01_FR01
	Receive forecasted data for weather conditions	MF01_BR04_UR02_FR02
	Receive historical data for RES generation	MF01_BR04_ FR03
	Receive historical data for weather conditions	MF01_BR04_ FR04

Use Case	Description	Functional ID
HL-UC03_LL-UC03 HL-UC03_LL-UC04	Obtain optimal coalition of prosumers	MF02_BR04_FR12
	Receive consumption and production forecasted data for prosumers' assets	MF02_BR04_FR02
	Obtain the degradation rate of the prosumers' RES devices	MF02_BR04_FR14
	Receive prosumers' baseline flexibility estimations	MF02_BR04_FR11
	Calculate the optimal set point while maximizing the revenues	MF02_BR04_FR09

Table 13: Requirements for the UK demo site

5. Interface for Optimization toolset

This section provides a description of the data and commands exchanged between the Improved Decision-Making and DR Optimization toolset and the other elements of the eDREAM framework. Generic specification of the interfacing of the components of Improved Decision-Making and DR Optimization toolset to the other components and data sets received and sent as defined in the eDREAM architecture of deliverable 2.4 are revisited and detailed in this section. The generic and specific requirements of the UK and Italian sites based on the scenarios and use cases presented in deliverable 2.4 are defined. The full details and descriptions of the technical implementation and protocols of the connectivity between optimization toolset and other components will be included in deliverable D4.5.

5.1. Generic Specifications for all Demo sites

The interconnections between the three components of Improved Decision-Making and DR Optimization toolset and other eDREAM components are described in this section.

5.1.1. PV/RES Degradation and Trend Analysis

The main functionality of this component is to improve electricity generation forecasting of PV and other RES models. The component will calculate the degradation rate at which models lose their performance over time. The calculation is based on the device parameters, historical data of the weather and electrical generation of the device received from Decentralized Multi-purpose Repository and current weather condition information. The component calculates long-term and short-term degradation rates of PV which will contribute to the calculation of the improved electricity production forecasting. The output of this component is sent to the VPP Generation Modelling & Forecasting, Electricity Consumption/Production forecasting and VPP & DR Services Optimization Engine. Various methods and techniques can be used for calculating PV degradation rate such as regression modelling, normalized and scaled ratings, measurement qualification and filtering, statistical analysis and year-on-year degradation calculation.

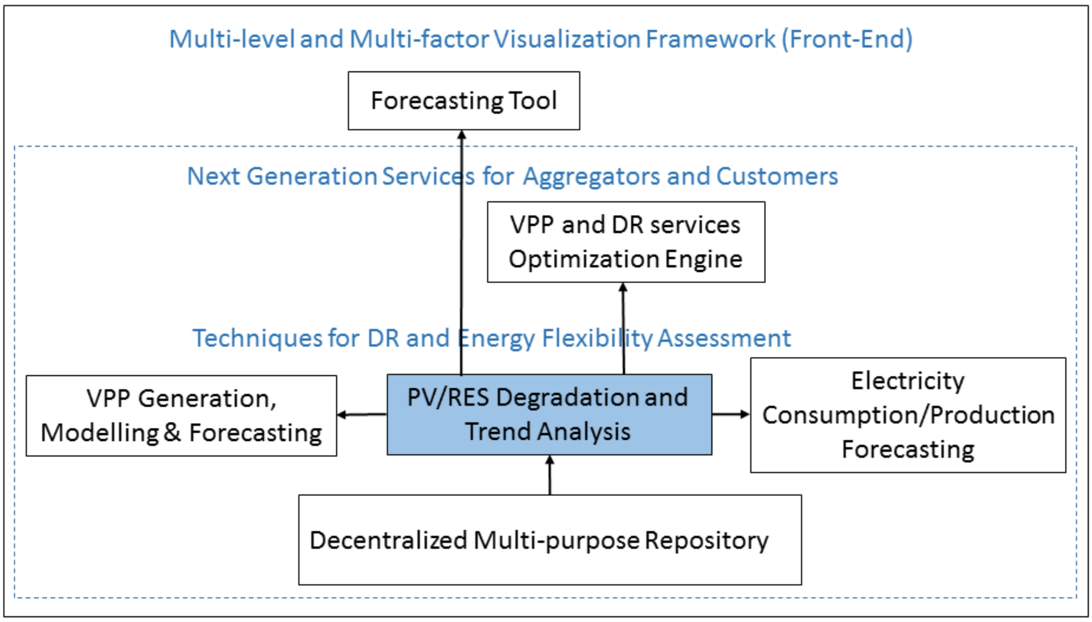

Figure 10 Interconnections between the PV/RES Degradation and Trend Analysis and other components as represented in eDream Architecture

PV/RES Degradation and Trend Analysis	
Input Connections: *From which components it receives input*	
Component	Data Type
• Decentralized Multi-purpose Repository	- PV historical data for the generation and weather condition - Solar PV characteristics from datasheet (device Id, parameter, value) - Weather information (location, solar irradiation, cloudiness, date and time)
• Electrical Consumption / Production Forecasting	- Consumption / Production Forecasting (prosumer Id, device Id, granularity, property, value, timestamp)
Output Connections: *To which components it sends the results*	
Component	Data Type

• VPP and DR services Optimization Engine
• Forecasting tool
• VPP Generation, Modelling and Forecasting
	Degradation rate
	{
	[{ "timestamp" : "2019-04-01T01:00:00"
	"value": "50.04"}…],
	"deviceId" : "8bb6e98-8429-4162-8236-cc4f231bb2a4",
	"frequencyMin" : "10"
	}

File type	JSON / CSV
Communication	REST API /edream/degradationRate/{deviceId}/{starttime}/{endtime} deviceId: is the id of the RES device that the degradation is requested for. starttime: the timestamp representing the start limit of the timeframe for which the degradation is requested. endtime: the timestamp representing the end limit of the timeframe for which the degradation is requested.

Table 14 Interfacing of PV/RES Degradation and trend Analysis

5.1.2. VPP and active Micro-grid flexibility profiling

The functionality of this component is to provide the production flexibility margins of the prosumers' assets participating in the VPP. The component shell receive a list of the prosumers that part of the optimized VPP from VPP Generation Modelling & Forecasting component and estimated energy consumption and production flexibility values from Baseline Flexibility Estimation component. The Aggregators can use this component to manage DSOs requests in case of grid instability.

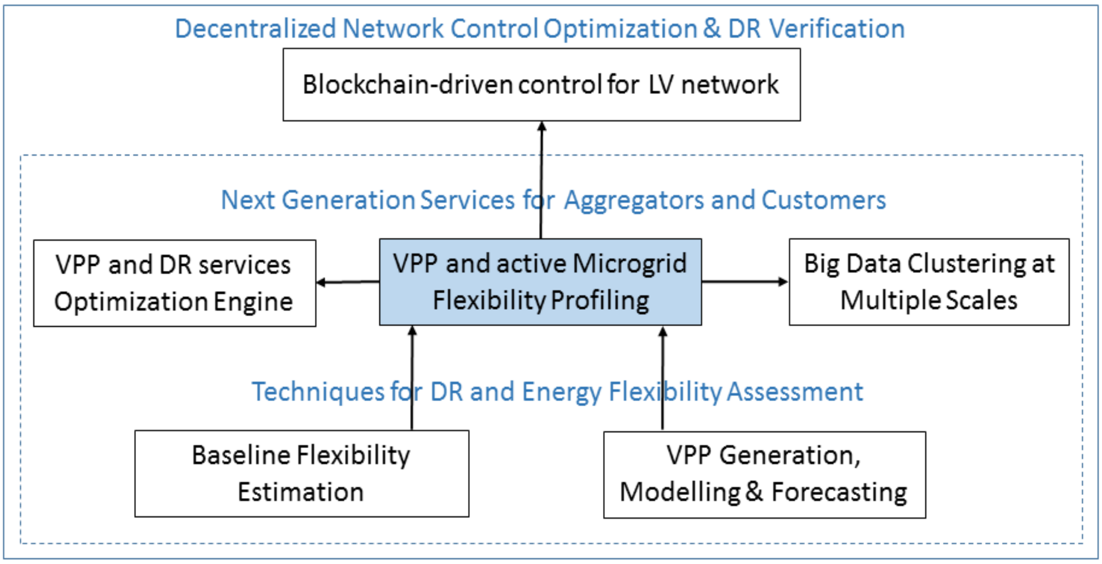

Figure 11 Interconnections between the VPP and active Micro-grid flexibility profiling and other components as represented in eDream Architecture

VPP and active Micro-grid flexibility profiling	
Input Connections: From which components it receives input	
Component	Data Type
• VPP Generation, Modelling and Forecasting	- List of prosumers aggregated in VPP (prosumer Id)
• Baseline Flexibility Estimate	- Estimated consumption flexibility (prosumer ID, timestamp, granularity, consumption flexibility) - Estimated production flexibility (prosumer ID, timestamp, granularity, production flexibility)
Output Connections: *To which components it sends the results*	
Component	Data Type

• VPP and DR services Optimization Engine
• Big Data Clustering at Multi Scales
• Block chain driven Control for LV network
	Flexibility margins
	{
	[{ "timestamp" : "2019-04-01T01:00:00"
	"value": "50.04"}...],
	"prosumerId" : "8bb6e98-8429-4162-8236-cc4f231bb2a4",
	"deviceId" : "8bb6e98-8429-4162-8236-cc4f231bb2a4",
	"frequencyMin" : "10"
	}

File type	JSON / CSV
Communication	REST API /edream/flexibilityMargins/{prosumerId}/{deviceId}/{starttime}/{endtime} prosumerId : is the id of the prosumer's device that the flexibility margins are requested for

	deviceId: is the id of the device that the flexibility margins are requested for starttime: the timestamp representing the start limit of the timeframe for which the flexibility margins are requested. endtime: the timestamp representing the end limit of the timeframe for which the flexibility margins are requested.

Table 15 Interfacing of VPP and active Micro-grid flexibility profiling

5.1.3. VPP and DR services Optimization Engine

The component will deliver a generic optimization capability for demand response services in order to improve the DR strategies in VPP level. Several factors will be taken in to account during the optimization process (e.g. demand, generation, classification of customers and financial KPIs identified by the end-users KIWI and ASM). The component shell receives optimal coalition of the prosumers that part of the VPP, the forecasting and estimation data (baseline flexibility, flexibility margins, electricity consumption and production), and degradation rates. The component will improve the production forecasted data of prosumers' assets, calculate the optimal set point of the prosumers' generators and produce optimal DR scheduling. The Figure 12 shows the interconnections between this component and other components of eDREAM framework.

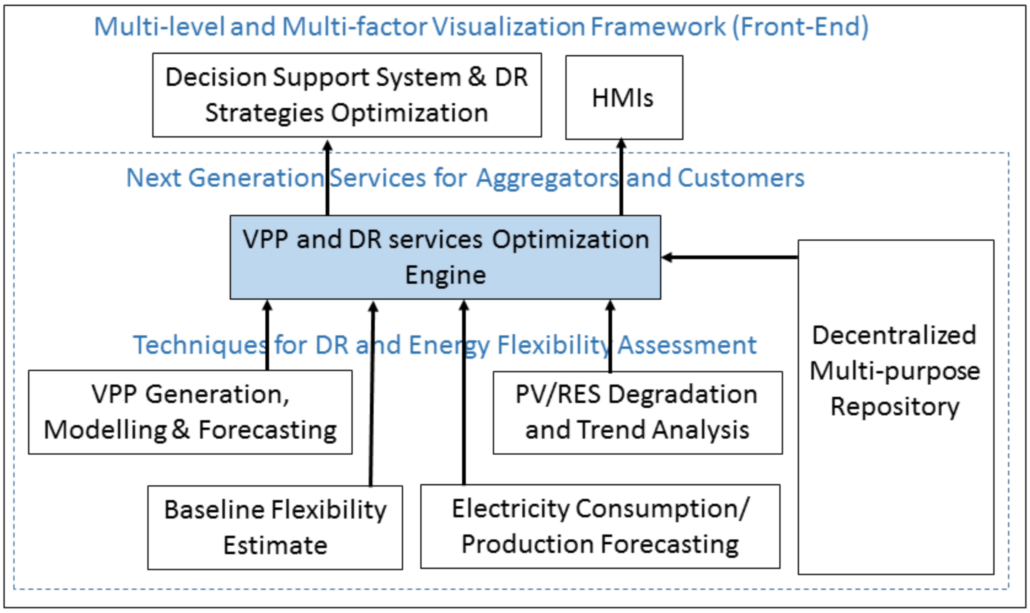

Figure 12 Interconnections between the VPP and DR services Optimization Engine and other components as represented in eDream Architecture

VPP and DR services Optimization Engine	
Input Connections: From which components it receives input	
Component	Data Type
• Decentralized Repository	- DR related KPIs and Energy prices
• Electrical Consumption / Production Forecasting	- Consumption / Production Forecasting (prosumer Id, device Id, granularity, property, value, timestamp)
• PV Degradation & Trend Analysis	- Degradation rate (deviceId, timestamp, value, frequencyMin)

• VPP and active Microgrid Flexibility Profiling • Baseline Flexibility Estimate	- Flexibility margins (deviceId, prosumerId, timestamp, flexibility margin, frequencyMin) - Estimated consumption flexibility (deviceId, prosumerId, timestamp, consumption flexibility) - Estimated production flexibility (deviceId, prosumerId, timestamp, production flexibility)
Output Connections: To which components it sends the results	
Component	Data Type
• DR Strategies Optimization Suite (Tool). • HMIs	- Optimal set points for generators and load curtailment - Optimal DR programs - Optimal DR scheduling
File type	CSV / JSON
Communication	REST API

Table 16 Interfacing of VPP and DR services Optimization Engine

5.2. Specific requirements for the Italian demo site

Specific requirements for the Improved Decision-Making and DR Optimization toolset for Italian site were developed based on the Use cases HL-UC01_LL-UC01, HL-UC01_LL-UC04 and HL-UC01_LL-UC06. The HL-UC01_LL-UC01 requires that a user interface is available for the aggregators to interact with the VPP & DR services Optimization Engine and the interconnection between VPP & DR services Optimization Engine and Electrical consumption/production forecasting and Baseline flexibility estimation has been established. Thus, the VPP & DR services Optimization Engine can have access to prosumer's electrical consumption, production and baseline load data. The interaction between VPP & DR services Optimization Engine and other components as presented in use case HL-UC01_LL-UC01 is shown in Figure 13.

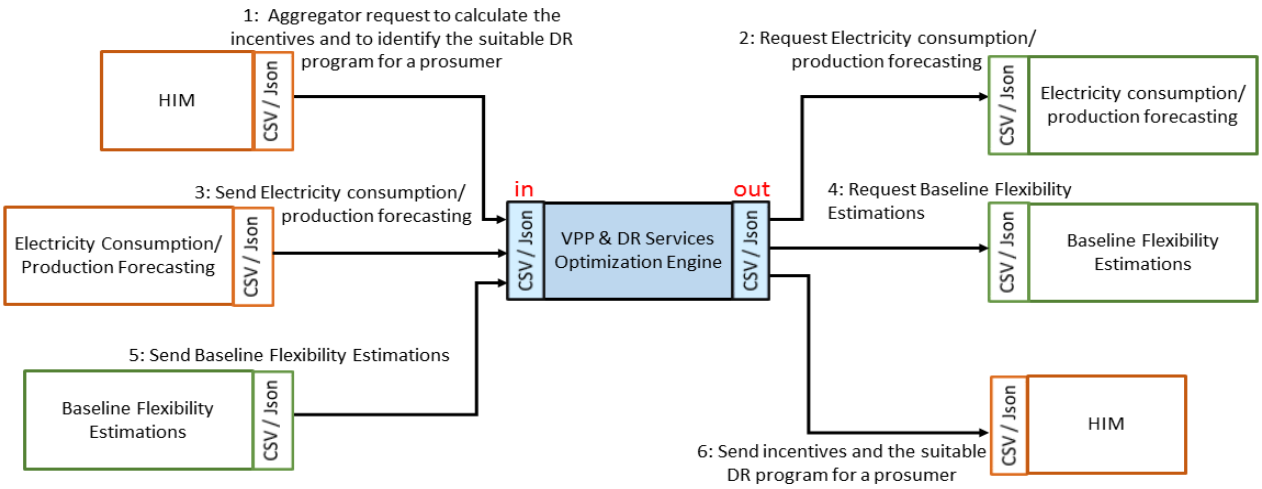

Figure 13 Interactions of VPP & DR services Optimization Engine as designed in use case HL-UC01_LL-UC01

In the use case HL-UC01_LL-UC04 "Energy demand/production forecasting for day-ahead trading of flexibility" the PV/RES Degradation and Trend Analysis component is requested by electricity consumption/production forecasting to provide the degradation and trend analysis for day ahead with frequency rate around 10 minutes. The use case requires that the interconnections between PV/RES Degradation and Trend Analysis component and Electrical Consumption/Production Forecasting and Decentralized purpose Repository have been established. The received data need to be with a frequency rate around 10 minutes to enable the component to produce output with 10 minutes frequency rate. The weather condition needs to include location, solar irradiation, cloudiness, data and time. Device parameters such as panel area, efficiency, slop of the panel and azimuth may be needed by the algorithm, the exact parameters needed will be identified in the deliverable D4.5.

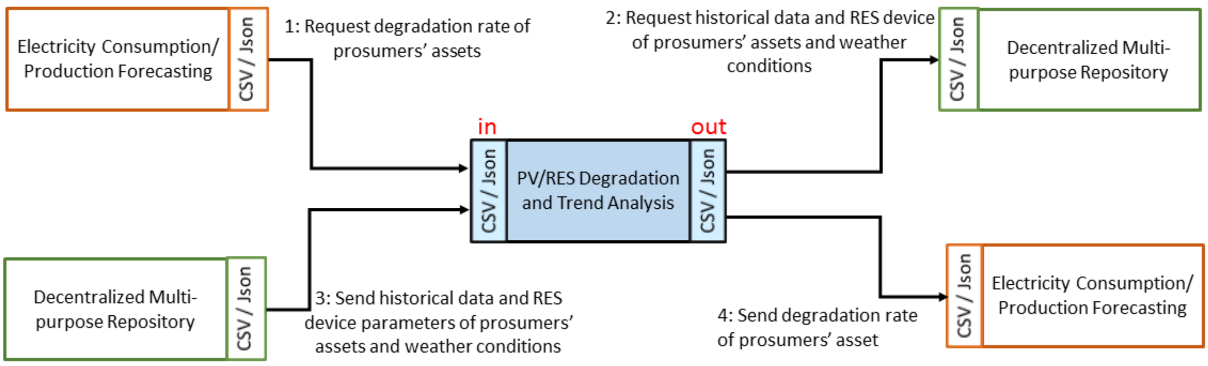

Figure 14 Interfacing of PV/RES Degradation and Trend Analysis as designed in use case HL-UC01_LL-UC04

In the use case HL-UC01_LL-UC06 the aggregator aims to define the optimal scheduling of the subset of enrolled prosumers that may deliver the expected flexibility. The use case requires that a user interface is available for the aggregators to interact with the VPP & DR services Optimization Engine and the interconnection between VPP & DR services Optimization Engine and Big Data Clustering and Blockchain-driven control LV network estimations has been established. In order to initiate the use case the aggregator must has received flexibility request by the DSO and the Smart Contracts' conditions are available and accessible.

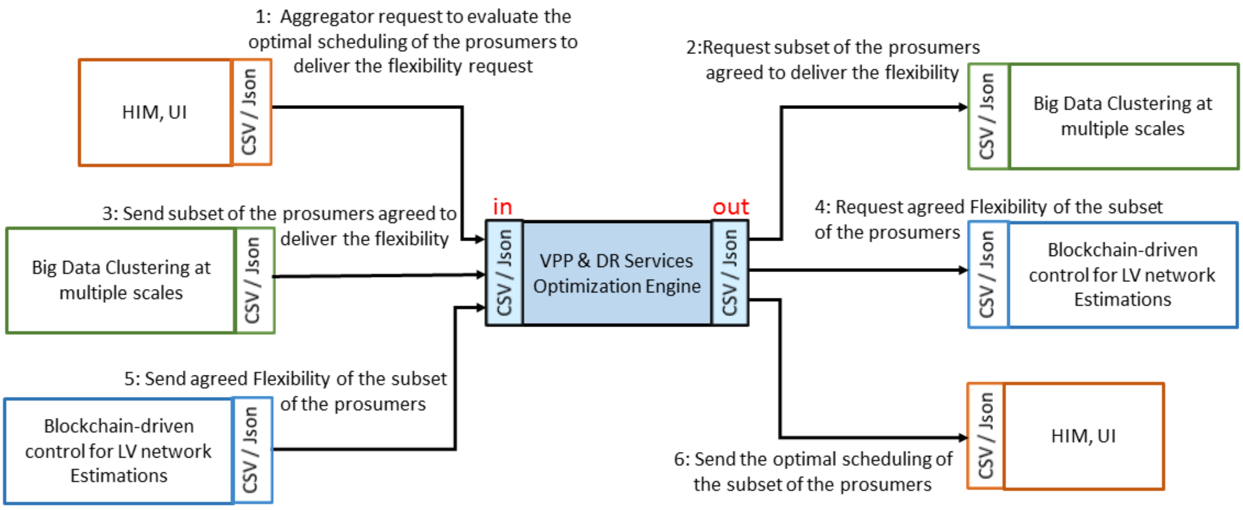

Figure 15 Interfacing of VPP & DR services Optimization Engine as designed in use case HL-UC01_LL-UC06

5.3. Specific requirements for the UK demo site

Specific requirements for the improved decision-making and DR optimization toolset for UK site were developed based on the Use cases HL-UC03_LL-UC02, HL-UC03_LL-UC03 and HL-UC03_LL-UC04. The use case HL-UC03_LL-UC02 "VPP capability evaluation" requires that the interconnection between VPP & DR services Optimization Engine and Decentralized Multi-purpose Repository, Electrical consumption/production forecasting, and VPP Generation Modelling and Forecasting has been established.

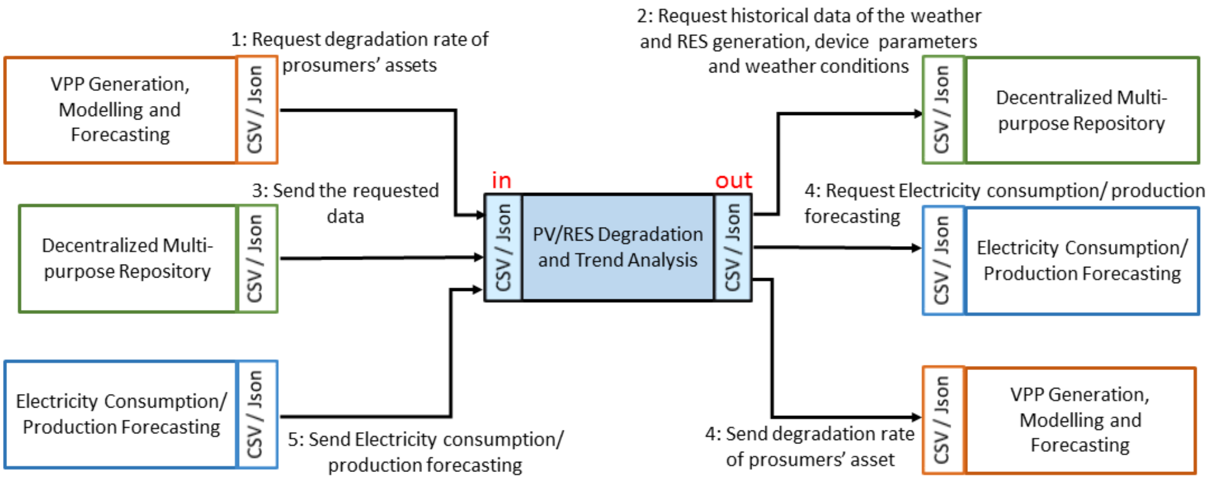

Figure 16 Interfacing of PV/RES Degradation and Trend Analysis as designed in use case HL-UC03_LL-UC02

In the use case HL-UC03_LL-UC03: VPP for Reserve services and HL-UC03_LL-UC04: VPP for Frequency services the VPP & DR services Optimization Engine is requested to calculate the optimal set points for generators and capacity of curtailable loads of a subset of prosumers. The use case requires that the interconnection of the necessary components has been established, thus the VPP & DR services Optimization Engine can has access to prosumers' consumption and production data. Generators parameters such as generation capacity, ramp rate limits and spinning reserve need to be supplied.

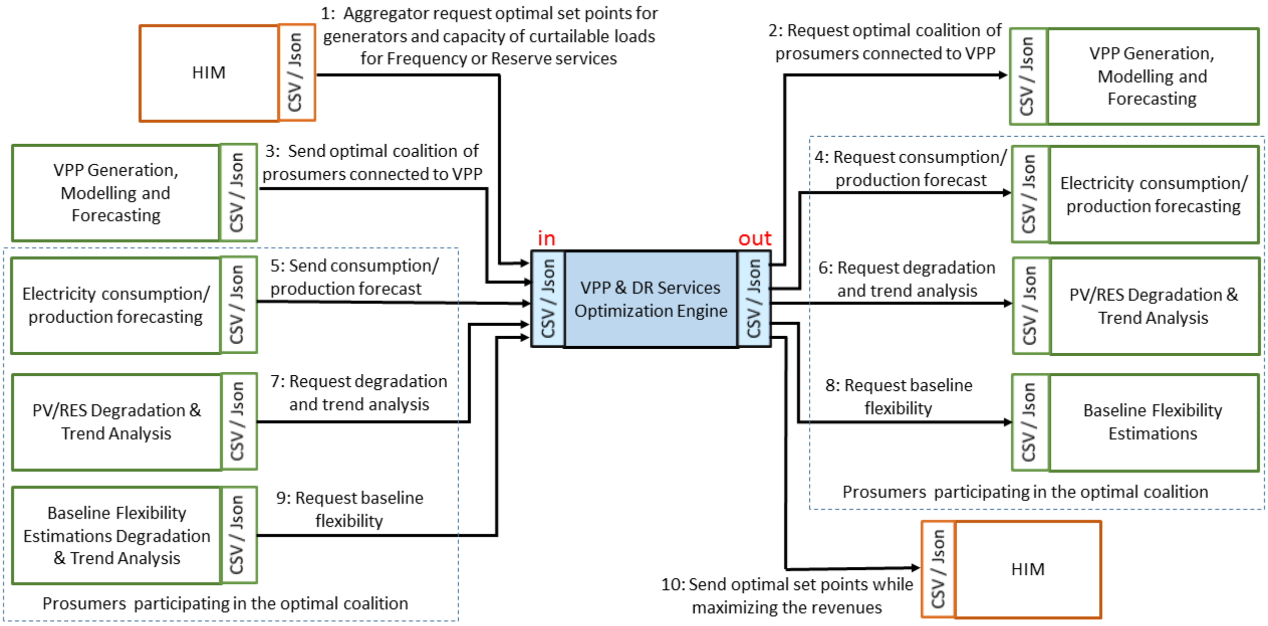

Figure 17 Interfacing of VPP & DR services Optimization Engine as designed in use case HL-UC03_LL-UC03 and HL-UC03_LL-UC04

6. Validation and Analysis approach

The optimization mechanism will be validated using measured datasets of prosumers assets and relevant KPI metric will be considered for the evaluation of the algorithm. Various types of generation assets from the two projects' pilot sites will be considered during the optimization problem. The outcome of solving of the optimization problem which has been formulated in section 4 is the optimal scheduling of the output of the available generation assets.

As an example, the load curve of a company on a one-day time horizon is considered. In order to cover the curve in the most economical way, specific units should be shut down when the load decreases and turned on when the load increases. One way of dealing with an optimal unit commitment problem is to meet the different demand levels between maximum (e.g. 1200 MW) and minimum load demand (e.g. 550 MW), considering at least a step of 50 MW.

The outcomes of the calculation are presented in the table 17. The committed generators are depicted with "1" and non-committed generators are depicted with "0". For each hour, the program finds the potentially feasible states. As feasible states are considered the states when demand can be supplied by the committed generators. It should be mentioned that the values in the below table are based on a hypothesis.

Demand	Units ON/OFF			Combined Power Limits		Power Output (MW)			Unit Function Cost (€)			Total Cost
(MW)	UN1	UN2	UN3	(MW)		P1	P2	P3	FC1	FC2	FC3	(€)
550	1	0	0	600	150	550	0	0	4658	0	0	4658
600	1	0	0	600	150	600	0	0	5078	0	0	5078
650	1	1	0	1000	250	349	301	0	3041	2459	0	5500
700	1	1	0	1000	250	377	323	0	3258	2634	0	5892
750	1	1	0	1000	250	405	345	0	3476	2811	0	6287
800	1	1	0	1000	250	432	368	0	3698	2991	0	6689
850	1	1	0	1000	250	460	390	0	3918	3169	0	7088
900	1	1	0	1000	250	500	400	0	4245	3249	0	7494
950	1	1	0	1000	250	550	400	0	4658	3249	0	7907
1000	1	1	0	1000	250	600	400	0	5078	3249	0	8327
1050	1	1	1	1200	300	600	400	50	5078	3249	506	8833
1100	1	1	1	1200	300	600	400	100	5078	3249	506	9282
1150	1	1	1	1200	300	600	400	150	5078	3249	506	9755
1200	1	1	1	1200	300	600	400	200	5078	3249	506	10252

Table 17 Results of the program calculations

7. Conclusions

The report outlines the initial specifications and architecture of the optimization toolset along with the general implementation requirements and specific requirements of Italian and UK pilot sites. Three different generic optimization tools and the mechanisms which can be used to integrate them to the eDREAM framework have been detailed. The generic optimisation tools provide access to several advanced optimisation algorithms and mechanisms, which can be applied to develop Improved Decision-Making and DR Optimization toolset. Furthermore, custom designed optimal scheduling algorithms can be added to these tools.

In this document, the optimization problem for the Demand Response programs' optimal scheduling has been formulated and objective functions and constraints have been defined. The main objective is to determine the optimal schedule of online generating units, to meet the demand power at minimum operating cost under various system and operating constraints.

The document also describes the interconnections between the components of the toolset and the other components of eDREAM framework including communication, data inputs and outputs, interfacing and implementation requirements. The generic and specific requirements of the UK and Italy demo sits have been identified and listed.

7.1. Contribution to overall picture

In this deliverable, an Improved Decision-Making and DR Optimization toolset was presented. In particular, three specific components: VPP and DR services Optimization Engine, VPP and active Micro-grid flexibility profiling and PV/RES Degradation and Trend Analysis were described. The toolset and hence the components which will be developed will be integrated through a scalable cross-functional backbone platform and implemented across demo sites to provide series of advanced DR optimization solutions that will meet the expectations of the stakeholders and in extension, achieving the goals and objective of the eDREAM project.

The toolset is an essential part of eDREAM framework that will help on successful deployment of demand side response technologies that consider virtual power plants towards achieving a reduction in peak grid demand and saving for all stakeholders. The toolset can be structured into three layers in first layer, the forecasted data are improved using PV/RES Degradation and Trend Analysis component and the VPP flexibility is calculated using the VPP and active Micro-grid flexibility profiling. In the second layer, optimized solutions are obtained using VPP and DR services Optimization Engine subjected to various objectives and constraints. In the third layer, a decision support system will be used to select the optimal scheduling solution considering a number of key indicators.

Finally, it can be expected that improved decision-making and DR optimization toolset developed in eDREAM project will contribute to the adoption of DR programs and Virtual Power Plants-oriented optimization approach. This adaptation aims to the transformation of traditional market approaches into novel community-driven energy systems that enable a smooth integration of renewables and fully exploring of local capacities, such that it would benefit all the stakeholders involved.

7.2. Impact on other WPs and Tasks

This deliverable refers to the task 4.1 of WP4 and forms the first part toward development of one of the core components of the eDREAM framework. In this deliverable, preparatory work for development and deploying of an Improved Decision-Making and DR Optimization toolset was described. This part describes the initial specification of the toolset whereas the final part of the task related to deliverable (D4.5) will take care of actual development and deploying of the toolset components.

The second version of D4.1 related to D.4.5 will leverage on the framework description and optimization problem formulation presented in this report to develop a multi-factor decision support system for flexible resource management. Furthermore, the second version report will refine the toolset architecture and optimization algorithm specifications along with the approach implementation.

The toolset presented in this deliverable is part of the eDREAM core platforms and it interacts with components from number of work packages within the eDREAM project, mainly WP3, WP4 and WP5. This optimization toolset will be enhanced as value added service in T4.3 and T4.4 to integrate multi-objective optimization function and interactive visualization mechanism. The components of the toolset will be implemented and deployed with specific technical requirement, which allows seamless interconnections and exchange of data with other eDREAM components.

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