Distribution grid planning and operational principles for EV mass roll-out while enabling DER integration

Deliverable (D) No: 4.1

Report on the definition of the optimization problem and tools specifications

Author: TRACTEBEL

Date: 31.01.2014

Version: 1.6

www.PlanGridEV.eu

Confidential (Y / N): N

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 608957.

Title of the Deliverable	Report on the definition of the optimization problem and tools specifications

WP number	**WP title**	**WP leader**
4	Development of Grid Methods and Tools	TRACTEBEL
Task title	T4.1 Definition of the Optimization Problem and Tools Specifications	

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Type (Distribution level)
■ PU, Public
☐ PP, Restricted to other program participants (including the Commission Services)
☐ RE, Restricted to other a group specified by the consortium (including the Commission Services)
☐ CO, Confidential, only for members of the consortium (including the Commission Services)

Status
☐ In Process
☐ In Revision
■ Approved

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Executive Summary

The scope of the WP4 is to design and develop a new distribution planning tool prototype. This prototype will be based on several methods and models developed by the different PlanGridEV partners involved in this WP.

The planning tool must address the new challenges of distribution, mainly dealing with the increased levels of uncertainty of the system and the new trends in observability and controllability of the network.

The increased levels of penetration of Distributed Generation (DG) accompanied by perspectives of increased load, for instance, with the integration of heat pumps and Electric Vehicles (EVs) are introducing major uncertainties to the planning activity. Typical planning rules explore the worst case scenarios, which in the context of the increased uncertainty may lead to overinvestment.

Furthermore, today's vision for distribution grids introduces greater levels of observability and controllability into distribution, implying a transition from passive grids to active grids. The so called smart grids bring benefits that are currently not considered by the distribution planning tools. Such fact does not allow the clear identification and understanding of the real benefits of having a number of different control options, such as demand response, EV charging control or DG modulation. All these options rely on proper ICT infrastructures, for which investment must be made and should be foreseen, having an impact on the expansion plans.

Finally, due to these changes, new stakeholders are rising as conceivable investors in distribution planning, more specifically in the ICT assets for demand response activation. New business models that are being developed must be studied and the prototype tool should be able to test and capture the different dynamics that these new models bring for expansion planning.

This deliverable provides the high level functionalities and guidelines for the development of the WP4 prototype tool. The goal is to aid distribution planning activity in the development of grid expansion plans. The scope of the prototype will not simply be to aid distribution companies to develop their networks, but also to be able to evaluate and/or integrate other stakeholders' perspectives in this activity. Moreover, the tool will embrace the current and future challenges and paradigm of distribution grid architecture and operation. Hence, it will allow to:

- Develop a concrete set of projects to expand the grid (new lines, transformers or smart equipment, such as smart meters, sensoring, control gear and communications).
- Schedule the set of projects to be implemented in the planning period.
- Recreate grid operational environment for proper simulation of demand response, including EV, DER control and other advanced control actions.
- Include the essential ICT characteristics in the planning process as an alternative to investment in copper, while enabling advanced system controllability.

- Perform robust analyses of a system facing increasing uncertainties. In the past, analysing the yearly peak load conditions would satisfactorily address the distribution planning problem. Nowadays, there are many changing elements besides loads and so the definition of a worst case scenario for which the system must be prepared is more and more unsatisfactory.

- Describe a multi-objective problem that can be adapted to the planners' needs and sensitivities. The planner may also activate multiple technical and economic restrictions. It will be possible to address the perspectives of different actors: DSOs, consumers, EV aggregators, regulators, or others.

The document identifies the objectives of the distribution planning problem of current and future grids, formulates the problem breaking it down into modules that tackle different issues and then addresses each of the topics in greater detail.

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Abbreviations and Acronyms

Table 1 – Acronyms

AC	Alternating Current
AG	Aggregator
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
CP	Charging Point
CS	Central System
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DSM	Demand Side Management
DSO	Distribution System Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EVSP	Electric Vehicle Service Provider
FMS	Facility Management System
GA	Genetic Algorithm
GHG	Greenhouse Gases
GRASP	Greedy Randomized Adaptive Search Procedure
GS	Gaussian Search
HAN	Home Area Network
HEMS	Home Energy Management System
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IP	Internet Protocol
IPSO	Integrated Power Systems Optimizer
KPI	Key Performance Indicator
LAN	Local Area Network

LC	Local Controller
LP	Local Proxy
LV	Low Voltage
MINLP	Mixed Integer Linear Programming
MV	Medium Voltage
NLP	Nonlinear Programming
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
OPF	Optimal Power Flow
RES	Renewable Energy Systems
RQ	Requirement
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SOC	State-of-Charge
ToU	Time of Use
TSO	Transmission System Operator
V2G	Vehicle-to-Grid
WAN	Wide Area Network

1. Introduction

1.1. Scope of the document

This document presents the initial vision of Work Package 4 members for the work to be developed within this work package. It puts together the perspectives of the different partners involved towards the achievement of the final goal for WP4, which is the development of a new prototype distribution planning tool.

The tool will be built on different methods and models that work in cooperation. This report in combination with the review of the state-of-the-art made in deliverable D1.4 will be key elements for guiding the development of the different methods.

Therefore, this deliverable initially presents the target issues to be addressed by the tool, namely concerning the presence of Distributed Energy Resources (DER) in the distribution systems. Then, the foreseen organization of the different methods within the prototype is provided alongside with the presentation of the full conceptual framework to be covered. Subsequently, the different methods and models are presented in greater detail. Specific models for EVs, aggregation and DG will be developed. For supporting the new planning philosophies there will be a grid simulation model at the core of the planning tool to recreate operational conditions, tackle uncertainty and estimate future operational costs embedding these elements in the planning frame. ICT is addressed in a dedicated section since it is a new topic within distribution planning. Finally, traceability concepts are explored in the planning context.

Even though very concrete ideas, with detailed modelling and proposition of algorithms, are described in many of the addressed topics, WP4 has recently started and future work will possibly lead to an evolution of the presented concepts. This evolution may impact chosen algorithms, methodologies or even the envisaged architecture of the prototype tool. In any case, D4.1 will be a centrepiece guideline during the course of WP4 and associated tasks.

1.2. Structure of the document

This report is composed of four main sections:

> 2 – Distribution Planning Problem of PlanGridEV – this section presents the scope and objectives of the distribution planning problem that will be addressed in WP4.
>
> 3 – Functional Specification of the Methods and Tools – this section starts by providing the high level functional specifications of the envisaged distribution planning tool and is followed by a first description of the different methods, for planning and grid simulation, and models, for EVs and DER in general.
>
> 4 – Incorporation of ICT and Information Exchange – this section explores ICT in the context

of distribution network planning and presents an ICT model to be used in the planning activity.

5 – Incorporation of traceability concepts – the concepts of traceability and their importance in the planning stage of distribution networks are discussed in this section.

2. Distribution Planning Problem of PlanGridEV

2.1. Scope

The scope of WP4 is to design and develop a new distribution planning tool prototype. This prototype will be built on several methods and models developed by the different PlanGridEV partners involved in this WP.

The planning tool must address the new challenges of distribution, mainly dealing with the increased levels of uncertainty of the system and the new trends in observability and controllability of the network.

The drivers for this uncertainty are DG expansion and the appearance of new loads, such as heat pumps and EVs. Deliverable D1.4 reviewed typical planning rules. These explore worst case situations that due to the increased uncertainty may result in overinvestment.

Besides the uncertainty, there is another important issue concerning the transition from passive grids to active grids. This fact introduces greater levels of observability and controllability into distribution that should be considered in planning. The so called smart grids bring benefits that are currently not considered by the distribution planning tools. Hence, the real benefits of additional controllability are currently not clearly identified and understood. The foreseen control mechanisms in distribution include demand response, EV charging control or DG modulation. All these options must be supported by an adequate ICT infrastructure, for which investment must be made and should be foreseen, impacting expansion plans.

Finally, due to these changes, new stakeholders are rising as conceivable investors in distribution planning, more specifically in the ICT assets for demand response activation. All the new business models that are being developed must be studied and the prototype tool should be able to test and capture the different dynamics that these new models bring for expansion planning.

2.2. Objectives

The global objective of WP4 is to develop methods and tools to optimize distribution grid development in the presence of DER, EV and other storage devices, considering controllable load management. Hence, novel methods and algorithms will be developed to tackle the new challenges (multi-objective optimization, uncertainty, storage modelling, statistical models, etc.). These will be put together into a prototype tool that will be the main deliverable of WP4.

WP4 is crucial to the success of PlanGridEV, since the main objective of this project is to design new planning rules and operational principles for the optimal integration of EV for different network topologies and with different levels of DER penetration such as PV, wind and solar energy and micro CHP. For that the project will rely on the tools and methods that will be developed permitting DSOs to design new or adapt existing planning rules and investment strategies to ensure technical efficiency and the cost-effective evolution of infrastructures to facilitate the mass roll-out of EV in networks characterized by different levels of DER penetration. Finally, recommendations for the regulatory framework and further developed business models will be elaborated.

WP4 contributes directly to the first of the five sub-objectives defined in the DoW:

“Development of tools and methods to design new planning rules involving DSOs/OEMs Based on a comparative technology (energy grid and communication layer) and regulatory gap analysis including an assessment of stakeholder needs (OEM and DSO requirements and constraints as well as customer needs), methods and tools will be developed to design new planning rules to manage controllable loads, integrate distributed generation and exploit storage options.

Tangible output: PlanGridEV will develop one prototype tool ready for implementation at European DSOs.”

In the concrete case of this deliverable, the main objectives are to set the basis for the development of WP4 and describe the high-level functionalities of the prototype planning tool and all the main methods that compose it.

2.3. High-Level Description

The resulting prototype tool of WP4 will tackle the distribution grid expansion problem. The goal is to aid distribution planning activity in the development of grid expansion plans. The scope of the prototype is not simply to aid distribution companies to develop their networks, but also to be able to evaluate and/or integrate other stakeholders’ perspectives in this activity. Moreover, the tool embraces the current and future challenges and paradigm of distribution grid architecture and operation. Hence, it allows to:

- Develop a concrete set of projects to expand the grid (new lines, transformers or smart equipment, such as smart meters, sensoring, control gear and communications).
- Schedule the set of projects to be implemented in the planning period.
- Recreate grid operational environment for proper simulation of demand response, including EV, DER control and other advanced control actions.
- Include the essential ICT characteristics in the planning process as an alternative to investment in copper, while enabling advanced system controllability.
- Perform robust analyses of a system facing increasing uncertainties. In the past, analysing the yearly peak load conditions would satisfactorily address the distribution planning problem. Nowadays, there are many changing elements besides loads and so the definition of a worst case scenario for which the system must be prepared is more and more unfeasible.
- Describe a multi-objective problem that can be adapted to the planners’ needs and sensitivities. The planner may also activate multiple technical and economic restrictions. It will be possible to address the perspectives of different stakeholders: DSOs, consumers, EV aggregators, regulators, or others.

Even though this prototype will allow performing many different tests, it will not solve the problem of distribution planning alone. Its best usage requires the combination of its computational power to the knowledge of the planner, who is then responsible for inputting the following:

- Data regarding future scenarios (load, generation, future evolution, among others).
- Data for generation of new grid expansion strategies (a catalogue of expansion options, viable sites for new substations and eventual budgetary/funding restrictions).
- Data for grid modelling, technical validation and control (all the electrical parameters and the existing control variables).

To conclude this tool will allow experienced planners to address the demands and challenges brought by a paradigm change in distribution systems, motivated by the proliferation of dispersed generation and the smart grid development.

As described in the DoW, the main end-users of the tool are the DSOs. However, future distribution grids investments may be assured by business models that are not uniquely involving the DSOs, but also different players. Depending on the way the user interacts with the tool, the different perspectives may be covered. Therefore, the tool may address the DSO investment, the overall social welfare or other stakeholders' position. These may be compared by establishing different scenarios to be optimized by the prototype tool. To allow the definition of such scenarios and the proper integration of the different players, the development of WP4 work will be fed by other relevant tasks of PlanGridEV, namely WP2, concerning primarily the business scenarios definition of T2.1, and WP3, regarding ICT and information flows needed to realize added value services with EVs.

Concerning the recreation of the operational conditions, the developed models should be able to capture all the major events / dynamics within operation. Yet, as the focus of the prototype is the distribution planning activity, some simplifications may have to be made. Albeit avoided as much as possible, a trade-off may be necessary between the introduced simplifications and the achievement of reasonable simulation time for the tool, without impacting significantly the quality of the representation of the operational conditions.

3. Functional Specification of the Methods and Tools

3.1. High Level Functionalities and Description of Planning Tool

3.1.1. Objectives

The prototype planning tool must address an increasingly complex system in which the DSO may not be the sole active participant. For example, aggregators and consumers are expected to have a key role within distribution systems.

Therefore, the new planning tool must include as much as possible these interactions in order to internalize the benefits / impacts of the different players and to allow considering possible alternatives to conventional reinforcement.

The PlanGridEV tool must also obey to conventional planning rules that are still valid today, while incorporating all the new aspects of distribution systems. Hence, the main goal of the tool is to define grid expansion planning, considering an up-to-date vision of the distribution planning problem.

3.1.2. Core Modules and Functionalities

In order to achieve the proposed goals the planning tool must perform several actions that may be described by the diagram provided in Figure 1. This figure depicts the currently envisaged architecture defined for tackling the distribution planning problem. As previously stated this may be subject to adaptations or refinements in the course of WP4 developments.

The following modules should then be part of the tool:

- **Definition and expansion options** – the main required inputs are processed at this stage and distributed among the remaining methods and models. It also contains essential information for the tool: a list of investment options for reinforcing the grid, including both conventional options and ICT+control based options.
- **Grid simulation** – this method is one of the key differentiations from traditional approaches. Instead of addressing a fixed loading scenario (traditionally the peak loading conditions) on a mostly passive network, this method allows exploiting active elements within the grid under changing conditions of load and generation. In fact, it studies a given network for different chronological periods of time, representing the average and extreme conditions of load, generation and flexibility. These studies may be conducted in normal operation conditions or in contingency analysis.
- **Investment configurations** – this method works in combination with the grid simulation method, providing it with investment choices that in practice result in different grid topologies and characteristics and in return obtains a set of expected performance indicators from the grid simulation stage. Based on the CAPEX of the investment choices and on expected

operational indicators the best investment alternative is sought.

- **Scenarios** – this module samples the operational scenarios needed to conduct the grid simulation. These scenarios among others refer to load, distributed generation and demand flexibility.
- **DER** – this model(s) provides the grid simulation method with the ability to represent in detail the behaviour of different DER, e.g. in terms of active and reactive power control.
- **EV / aggregator** – this model provides the grid simulation method with the ability to represent in detail the behaviour of EV owners and aggregators, namely concerning their behaviour towards the control of the charging process.
- **ICT** – this model feeds two other modules for different purposes. First, based on the envisaged control requirements or in other words the scenario(s) that the planner wants to address it defines for the investment options the requirements for ICT. Then, it provides the grid simulation model with constraints and rules for activation of controllable elements that depend on the installed ICT equipment.

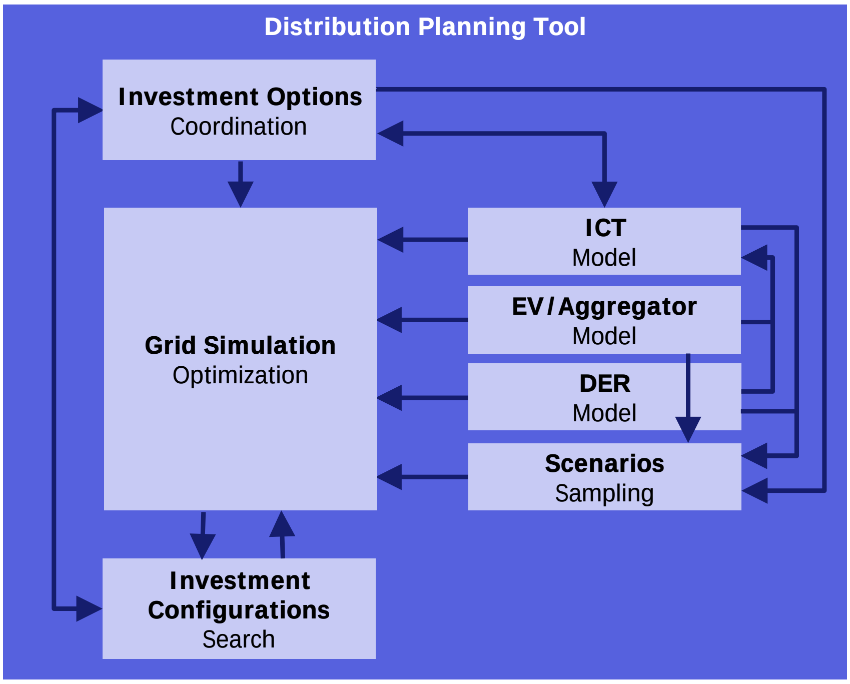

Figure 1 – Main models and functionalities for the distribution planning tool

3.1.3. Conceptual Framework

The conventional approach would define the distribution planning problem as a combined minimization of CAPEX and OPEX where OPEX would be computed in peak load conditions for limited or inexistent grid control options. As new dimensions of the problem are introduced distribution planning grows in complexity, becoming a combined minimization of CAPEX and OPEX, the latter now resulting from the optimal activation of demand response, modulation of DG or EV charging control.

Besides this needed extension to the cost minimization problem, there are other objectives that one might seek separately for planning optimization. Reliability indexes, such as SAIDI, SAIFI or CAIDI, and also greenhouse gases emissions, such as CO2, may be an aim not only for DSOs (the main users of the tool) but also for regulators and other stakeholders. With these objectives in mind, a multi-objective problem can be formulated. For instance, an important stakeholder perspective is that of consumers and the optimization may focus on this aspect using consumer related criteria (required EV charging level, supplied energy…).

So far, the optimization problem could be considered a mere extension of the conventional methods. Yet, the fact that it consists on estimating figures that result from future operation, observing peak power is no longer sufficient. Another key element that breaks with the past methods is the widespread DG integration that may lead to different kinds of issues and reinforce the fact that observing peak load conditions is not sufficient anymore.

In this sense, the behaviour of the grid for different loading conditions must be assessed. This assessment per se is a known optimization problem, the problem of Optimal Power Flow (OPF), with the particularity of possessing inter-temporal constraints to allow for instance the consideration of load shifting measures for grid support.

Nonetheless, this OPF would be lacking inputs if the tool would be considered just in this way. So, another software module must provide to the OPF all the necessary information that is required, load diagrams, generation diagrams, etc. With the patterns related to the loading / generation conditions and the reinforcements made by the investment configuration search, the OPF simulations may be conducted.

To this point the elementary parts of the tool were described in general terms and some new functionalities were highlighted. But there are many subjects to be addressed by the different modules of the tool.

In the context of the investment configuration search, new reinforcement options need to be defined, including ICT control. A method to decide which technologies apply for every specific usage scenario and an estimate of the operational costs relative to this will be developed. To do so, a WAN traffic generator will be used. The usage of the WAN traffic generator will allow the identification of adequate ICT technologies and the accurate estimation of their technical costs (data rate, coverage, response and processing times, availability, robustness or physical medium). These technologies and their associated technical costs depend on the communication requirements defined by the planner.

For the OPF, there are also several methods and considerations required. This is the module that will recreate the "real-life" operational situations and so it should be rather complete, yet sufficiently light to be used within acceptable time frames for the planning activity. The following must be considered:

- Existing business models for aggregators may influence the type of control options, including:
    - Normal control actions versus emergency control actions
    - How much information is shared between aggregators and DSOs
    - EV aggregation models
- Correct optimization cycle to capture the relevant dynamics of the system. For instance, EV charging process.
- Exploring the rules for interactions with other stakeholders, namely concerning conflicts with the usage of flexibility by DSOs, TSOs, the participation in energy trade or support to DER integration. Since not all these levels may be explicitly modelled, specific rules may have to be developed.
- Proper modelling of different DG technologies in terms of potentialities for controlling.
- Demand response activation.
- Limitations / possibilities introduced by ICT.
- Local versus centralized control of DG and load.
- Advanced network components, such as onload tap changer transformers.
- Additionally, the possibility of inclusion of reconfiguration alternatives / self healing in the scope of PlanGridEV is under analysis.

Finally, concerning the module that generates scenarios, several methods will have to be developed to recreate operational conditions. These methods will aim at the generation of profiles (for load, generation, upstream flexibility demands or unavailabilities of different elements) to be given as inputs for the OPF simulation.

To conclude and summarize, the multi-objective problem formulation is key, allowing taking into account the perspectives of the different actors involved. The consideration of demand response and distributed generation management in distribution planning adds consumers and distributed producers as crucial players alongside with DSOs and regulators. Finally, EV owners and OEMs also play a significant role, as EV flexibility and possibly even EV storage capabilities are sought.

3.1.4. Main Inputs and Outputs

The main inputs and outputs envisaged for the different methods and models are presented in Table 2. Once again this may be subject to changes in future developments.

Table 2 – Summary of main inputs and outputs of the different methods / models of the prototype tool

Method / Model	Input	Output	Section / Partner
Definition & Expansion Options	• User inputs for: o Available investment options. o Grid models. o Requirements and KPI for ICT usage. o Mobility data. o Load and generation data. o Other relevant data.	• Processed data to feed the different methods and models with user input data.	Interaction with WP1
Grid Simulation	• Inputs for grid model: o Full load flow data model including the expansion options decided at the "Investment Configurations" method. o Expected end of life date of equipment. • Inputs for grid exploitation scenarios coming from "Scenarios" method: o Load, generation, available load flexibility, requests for load and generation flexibility for usage out of the scope of the DSO activity, unavailabilities of the different elements that compose the grid. • Inputs for the objective function: o Cost coefficients for generation and load control, but also losses or ENS. • Inputs for observable variables: o Upper- and lower voltage limits for each bus. o The maximal flow for every line and every transformer. • Inputs for controllable variables: o For all flexible load and generation, the control range has to be specified. o For each onload tap changer transformer the control limits must be specified. o Reconfiguration options.	• Operational costs associated to the activation of load / generation flexibility and losses. • Reliability indicators such as ENS or time period of unavailability. • Energy exchanges with upstream networks, from DG, consumed and losses.	3.2.1 / TRACTEBEL
Investment Configurations	• Inputs for decision variables: o A list of candidate sites for substations, a list of candidate lines, a list of candidate ICT investments. • Inputs for the objective functions: o Cost factors for all equipment, including detailed data such as amortization period and discount rate. o Information needed to characterize the SAIDI, SAIFI and/or CAIDI indexes, mainly (estimated number of customers served per consumption node and total number of customers). o Emissions factors for greenhouse gases emissions (given in g/kWh). • Inputs for observable variables: o Possible economic constraints (such as investment limitations). • Results from Grid Simulation method.	• Best planning solutions scheduled in time.	3.2.2 / TRACTEBEL 3.5 / INESC

Method / Model	Input	Output	Section / Partner
ICT	• ICT usage scenarios of varying complexity. • Minimum requirements/key performance indicators for ICT.	• Technical costs, such as: o Data rate o Coverage o Response & Processing Times o Availability / Robustness o Physical medium • Identification of adequate ICT technologies.	4 / TUDo
EV/Aggregator			
Statistical Behaviour	• EV input data: o Number of EVs o Type of area o Facilities	• EV data: o ID o Arrival time o Origin location o Departure time o Destination location o Distance driven	3.4.2 / AIT
Model	• Driving pattern data for Statistical Behaviour: o Arrival and departure of each trip. o Parking location (mapping to network). o Trip energy consumption. o Initial state of charge. • Physical constraints: o Battery size. o Minimum and maximum state of charge. o Charge efficiency. o Charge power.	• Technical indicators: o Power o Energy demand o Stored energy o State-of-Charge (SOC) • Flexibility model in the form of a set of constraints for the optimization problem.	3.3 / ETH
DER			
Statistical Behaviour	• Per type of technology: o Number of systems o Location of systems o Time of the year	• Solar radiation and wind speed profiles	3.4.3 / AIT
Model	• Per type of technology: o Output from statistical behaviour o Technical specifications	• Technical indicator: o Power	3.4.3 / AIT
Scenarios	• Ideally, load and generation profiles for a full year or several years. A resolution of one hour is in a first estimate sufficient. At the MV level LV data may be aggregated. • If inexistent, minimum data requirement will be defined so that synthetic data can be generated. • Profiles for availability of load flexibility and for load / generation flexibility requests for non-DSO related activities. • Outputs from the statistical behaviour models.	• Selected profiles for planning purposes of: o Generation o Load (conventional + EV) o Variables that impact availability of flexibility o Demands for flexibility external to DSO	3.2.3 / TRACTEBEL 3.4 / AIT

3.2. Functional Specification of the Main Planning Tool Modules

Within the framework presented in Figure 1 the methods discussed in this section are mainly the ones relative to "Grid Simulation", "Scenarios" and "Investment Configurations". Figure 2 allows the visualization of their positioning within the tool.

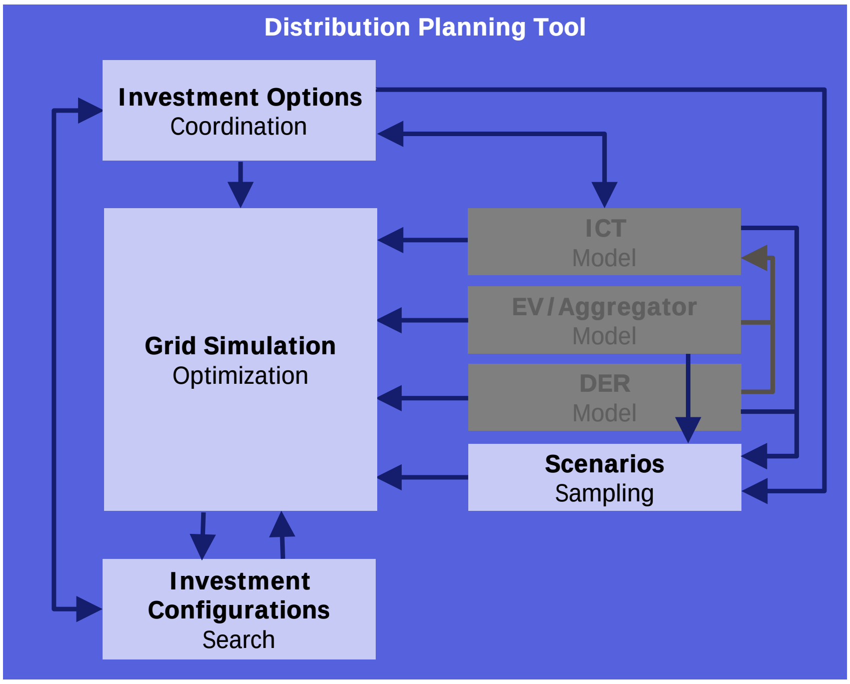

Figure 2 – Highlights of methods addressed in section 3.2

3.2.1. Grid Simulation

The grid simulation module is in fact an Optimal Power Flow (OPF) problem, whose main objective is the minimization of the operational costs of the distribution system (losses, curtailment, activating load flexibility and load and generation shedding).

Yet, instead of handling one operation point it optimizes over a period of time taking into account inter-temporal constraints, for the EV charging process or for conducting load shifting in general.

This problem will be naturally constrained by the equality constraints of the AC power flow and inequality constraints for observable variables (voltage levels, congestion) and control variables (demand response, distributed generation, etc.).

In brief, it is an extension of the conventional OPF formulation with the particularity that it must optimize over a period of time and not only for a specific point of operation.

The grid simulation module will have to be able to mimic operation quite accurately. The developed models will have to be able to capture as well as possible the most relevant operation dynamics/procedures, while remaining as simple as possible in order to decrease problem complexity. This is of particular importance as this module will be run iteratively for every investment hypothesis.

Hence, in order to address these demands different methods have to be developed:

- Statistical behaviour of EV and DER in distribution networks: this method will describe the expected patterns for EV/DER energy consumption and/or generation.
- Storage capabilities offered by EV to optimize distribution grid operation: this method will describe in detail the activation of EV flexibility as flexible demand and even as storage elements.

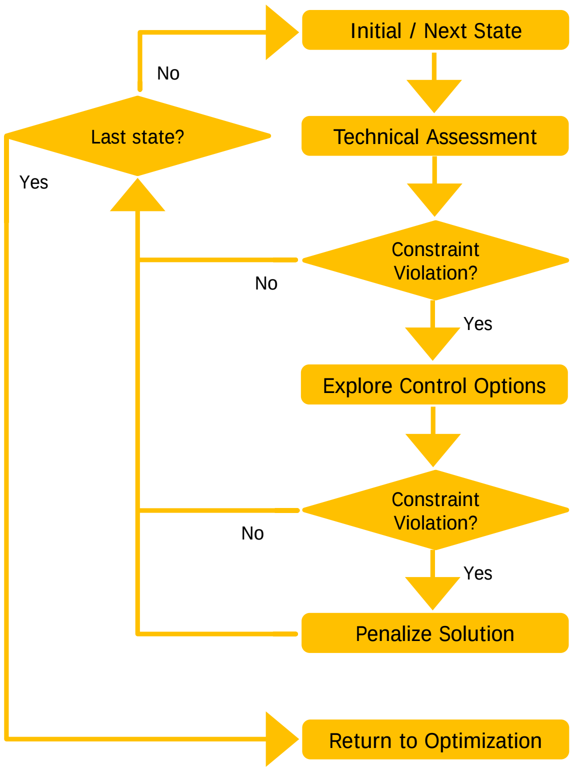

Figure 3 – Grid simulation principle of operation

As presented in Table 2 the grid simulation module takes as inputs grid investment possibilities provided by the investment configurations search module and the sampled load / generation scenarios to assess the feasibility of the investment possibilities and their OPEX.

3.2.1.1 Generic Formulation

In the grid simulation method the objective function can be defined for a single, multiple, or all time slots. A general form of the objective function is:

$$\sum_{t\in T}\sum_{i\in N}\omega_{i,t}\cdot C_{i,t}\left(x,u,h_{i,t}^{a},h_{i,t}^{\min},h_{i,t}^{\max}\right)$$

Where:

T is a user-defined set of time slots

N is the set of considered objectives

ω_i are user-defined weighting factors to scale variables of different nature

C functions can be quadratic, linear, quadratic penalty, or piecewise linear

h^a is the attractor, $h^{\min}$ and $h^{\max}$ are respectively the minimal and maximal value

x are the state variables

u are the control variables

As an example, one of the cost functions, the one that concerns the load flexibility, is shown next. The cost of load flexibility is determined by the unity cost coefficient of flexibility and the hourly usage of flexibility.

$$\sum_{t=1}^{T}\sum_{i\in S_{LD}}P_{i,t}^{LD}\cdot F_{i,t}^{flex}\cdot C_{i,t}^{flex}$$

Where:

S_{LD} is the set of all the loads

$P_{i,t}^{LD}$ is the active power component of the load *i* at hour *t*

$F_{i,t}^{flex}$ is the hourly usage of flexibility for a given load *i*

$C_{i,t}^{flex}$ is the hourly cost of flexibility for a given load *i*

Regarding the constraints, it was already mentioned that all the normal OPF constraints will be present, such as limits on control variables and some observable variables, such as upper and lower bounds on currents and voltages. In addition there may be inter-temporal constraints, like the compensation of used flexibility, as presented below, or even including the consideration of rebound effects for DSM activation.

$$\forall i\in S_{LD}:\sum_{t=1}^{T}P_{i,t}^{LD}\cdot F_{i,t}^{flex}=0$$

If no network reconfiguration is considered, the problem is a Nonlinear Programming (NLP) problem. Otherwise, it becomes a Mixed-Integer Nonlinear Programming (MINLP). The development of this method will grow up on an existing OPF tool developed by Tractebel Engineering called IPSO. IPSO is an OPF developed for analysing large networks, considering the AC power flow equations but without optimizing over a time period. The introduction in the optimal power flow formulation of stochastic variables is also being addressed.

3.2.2. Investment Configurations

The problem aims at the development of a future grid expansion scenario. It receives inputs from the planner regarding the possible investments, investment costs and control options. It should return a list of investments optimized for the given problem objectives and different indicators relative to the quality of the achieved solution. Inputs and outputs for this module are described in detail in Table 2.

The developed prototype should not break completely with the current planning philosophies. On the contrary, due to the importance of the planning activity and its decisions deeply influencing the DSOs success in the long-term it should build upon existing processes, maturing and redeveloping obsolete approaches, but retaining the essential characteristics that are robust against the change of paradigm.

The envisaged formulation of the distribution planning problem is as follows:

$$\min Z = \min[Z_1 \quad Z_2 \quad Z_3]$$

Where, Z_1 is the economic term, which is composed by investment cost, $C_{Investment}$, and the expected operational cost, $E(C_{Operation})$

$$Z_1 = C_{Investment} + E(C_{Operation})$$

$$Z_1 = \sum_{t\in T}\sum_{k\in S_{C-SU}}\sum_{T-SU\in S_{T-SU}} \frac{(Y_{k,t})_{T-SU}\cdot(C_{k,t})_{T-SU}}{(1+t_a)^t} + \sum_{t\in T}\sum_{(i,j)\in S_{C-FE}}\sum_{T-FE\in S_{T-FE}} \frac{(X_{ij,t})_{T-FE}\cdot(C_{ij,t})_{T-FE}}{(1+t_a)^t}$$
$$+\sum_{t\in T}\sum_{k\in S_{C-ST}}\sum_{T-ST\in S_{T-ST}} \frac{(W_{k,t})_{T-ST}\cdot(C_{k,t})_{T-ST}}{(1+t_a)^t} + \sum_{t\in T}\frac{E(C_{L,t}+C_{Flex,t}+C_{ENS,t})}{(1+t_a)^t}$$

The first term of Z_1 gives the investment cost in substations. The *Y* variables are variables that are zero when there is no investment in a given substation, and one when the investment takes place. *C* is a cost factor. The three summations mean that we will sum over all years, all possible locations for the substations, and all possible sizes of substations. The second term gives the investment cost of cables, and the third of ICT equipment. The last term gives the cost of losses, flexibility and energy not supplied.

Z_2 is the reliability term, which is composed by SAIDI, SAIFI and CAIDI. As for the economic term Z_2 results from operation and so it is actually defined by the expected value of the aforementioned reliability terms:

$$Z_2 = \frac{1}{T}\sum_{t\in T} E(\propto_1\cdot SAIDI_t + \propto_2\cdot SAIFI_t + \propto_3\cdot CAIDI_t)$$

Where:

$\propto_1, \propto_2$ *and* $\propto_3$ are weight coefficients attributed to each indicator and

$$SAIDI_t = \frac{\text{sum of interruptions duration determined in Grid Simulation}}{\text{total number of customers served}}$$

$$SAIFI_t = \frac{\text{number of interruptions determined in Grid Simulation}}{\text{total number of customers served}}$$

$$CAIDI_t = \frac{SAIDI_t}{SAIFI_t}$$

Z_3 is the environmental term, which is composed by Greenhouse Gases (GHG) emissions

$$Z_3 = \sum_{t \in T} E(GHG_t)$$

Where:

$$GHG_t = \sum_x \gamma_x \left[\beta_1 \cdot E_{Losses,t} \cdot EF_x + \beta_2 \cdot E_{Trade,t} \cdot EF_x + \beta_3 \cdot \sum_y E_{DG_y,t} \cdot EF_{x,y} \right]$$

EF_x is the emissions factor for gas x

$EF_{x,y}$ is the emissions factor for gas x by DG unit type y

γ_x is a weight coefficient for gas x

$E_{Losses,t}$ is energy of losses in the studied network at time t

$E_{Trade,t}$ is the energy traded with the upstream network at time t

$E_{DG_y,t}$ is the energy generated by DG unit type y at time t

β_1, β_2 and β_3 are weight coefficients for the different energy related terms

This problem may be constrained with inequality constraints regarding investments and budgetary issues as well as eventual constraints regarding minimum yearly reliability levels or caps on emissions.

3.2.3. Scenarios

For conducting the grid simulation analyses the uncertainties of the system must be captured. As explained before the direct introduction in the optimal power flow formulation of stochastic variables is being studied, but there is also the need for a generator of scenarios based on a Monte Carlo process, since not all uncertainties may be captured by the first. Thus, the generation of scenarios with Monte Carlo may be quite valuable for defining profiles for:

- Generation:
    - Solar irradiation

  - Wind speed
  - Other distributed generation units (CHP, …)
- Load:
  - Conventional electrical load
  - EV, including mobility patterns, distinct battery characteristics, different charging types (slow and fast charging) and different user profiles
- External demands for flexibility from:
  - TSOs (for provision of ancillary services)
  - Participation in energy trade
  - Support to DER integration

Yearly profiles will have to be generated and from those specific periods (likely of 1 day to capture the different dynamics of EV and the other elements) will have to be selected to reduce the computational burden, such as:

- High load, low generation
- Low load, high generation
- Availability of flexibility
- …

All the different profiles will have to be sorted once, before the usage of the main optimization problem (the distribution planning problem), for two reasons: it allows decoupling the drawing of the profiles from the main problem and it reduces the simulation burden.

3.2.4. The Role of ICT

As referred before the aim of WP4 is to develop a planning tool prototype that is able to address the new challenges of distribution systems, facing the increasing uncertainty while incorporating active management of load and dispersed generation as a mean to avoid reinforcement.

ICT plays an important role in this context. It will impact the developed tool from the investment planning optimization to the grid simulation module.

When alternatives to grid reinforcements are sought by using DER controllability, ICT acts as an enabler. As such, DSOs must invest in proper ICT infrastructures to achieve certain levels of flexibility from consumers and generators. Hence, ICT, in combination with smart control methodologies, will be considered as an alternative investment to grid reinforcement.

Similarly to investing in lines or substations, this alternative investment has a capital expenditure cost that needs to be considered in the list of reinforcement options. However, the consequences of investing in ICT+control are not those of a direct increase on grid capacity. Instead, they enable the possibility of controlling demand and generation, imposing the consideration of a second type of cost, an operational cost relative to the activation of these control mechanisms. As mentioned before the activation of these control mechanisms will have to be assessed in the grid simulation module.

So, adequate modelling of ICT for planning purposes is required within the tool. Possible limitations will have to be described and incorporated in the grid simulation module. For instance, ICT equipment may be subject to failure or data communication packets may also be subject to losses/failure both impacting the system reliability.

Section 4 provides a more detailed insight on this topic and the expected developments to be made and integrated into the planning tool.

3.3. Required Functionalities of the Methods for Representing EV Storage Capabilities

In this section the models for the "EV/Aggregator" module will be presented. Their interaction with the different modules of the distribution planning tool is depicted in Figure 4.

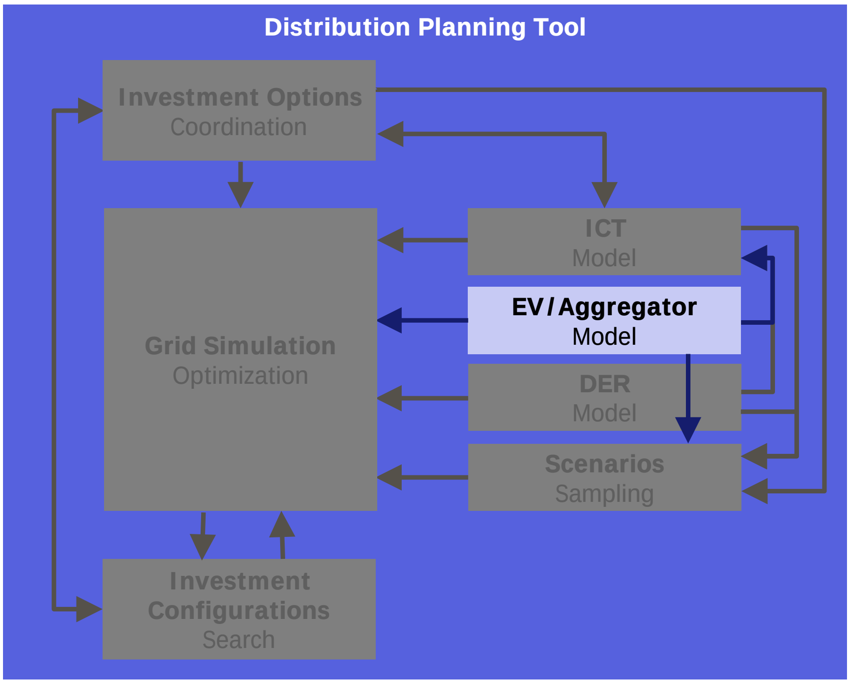

Figure 4 – Highlights of methods addressed in section 3.3

The storage models for EV fleets are envisaged to play an important role in the grid simulation, i.e. in the module that calculates the minimum operational costs for a given investment choice. In this sense, EVs can be generally modeled as a fixed or as a controllable load in the OPF problem that minimizes the operational costs. In the latter case (controllable load), a specific model is needed to represent the available flexibility, i.e. the amount of load that can be shifted without violating end-use constraints.

Four fundamental DSO scenarios are considered in this project, namely, conventional, safe, proactive, and smart grid scenarios. An additional transition scenario between proactive and smart grid will also be considered. The main differences when compared with the Proactive scenario reside in the fact that charge management uses charge modulation and real-time congestion management and DER integration are decentralized. The main characteristics of the four fundamental scenarios are provided in Table 3 (from deliverable D2.1). For the sake of clarity and simplicity, the service provider (either an Electric Vehicle Supply Equipment – EVSE operator or an Electric Vehicle Service Provider – EVSP) will be called “aggregator” in the following. Depending on the explored concepts, the differences and details in modelling will be highlighted whenever relevant in this document and along WP4 development.

	Conventional	Safe	Proactive	Smart grid
Charge management	No	Soft, fleet-focused	Massive	Massive, local
Type of charge management	None	On/off	On/off	Charge modulation
Expected grid reinforcements Non EV-related EV-related	 Yes Yes	 Yes Minimal	 Minimal No	 No No
Energy flow in EVs that are used to provide services	None	Grid → EV	Grid → EV	Grid ←→ EV
Provider of the service	None	EVSE Operator (fleet manager)	EVSE Operator/EVSP	EVSP
Remuneration scheme	None	ToU	Regulated contract	Competitive market
Type of power flow control for[1]: Emergency constraint mgt. Forecasted constraint mgt. Real-time constraint mgt. Ancillary services for the TSO Energy trade DER integration	 Centralised None None None None None	 Centralised Centralised None None None None	 Centralised Decentralised None None None None	 Centralised Decentralised Decentralised Decentralised Decentralised Decentralised

Table 3 – Summary of the business scenarios for EV charging infrastructure.

Each of these scenarios requires a different approach to model the load of the EV fleets and its potential flexibility as explained below. The common input to these models is a set of EVs with given characteristics and samples of driving patterns. These driving patterns are defined as the relevant information on EV trips, i.e. departure and arrival times, parking locations (network and location type), and trip energy consumptions.

[1] Centralised control means that the DSO is controlling the charge, while decentralised means that either the EVSE Operator or the EVSP are taking control.

a) Conventional scenario:

The EV load is considered inelastic in this case. Therefore, a plausible assumption is that vehicles start charging as soon as they park. Thus, for each individual daily driving pattern, a load profile is determined. The derived load profile depends also on the charging infrastructure available at the parking location, with a predefined maximum charging power.

b) Safe scenario:

The EV charging is not directly controlled in this case. However, there is an indirect control based on Time-of-Use (ToU) tariffs, which should set incentives to shape the load to the benefit of the DSO.

Given driving patterns and the ToU tariff, the EV load is modeled in this case as the result of individual charging optimizations. In these optimization problems, each EV determines the load profile that minimizes its costs subject to energy and power constraints, which are derived from physical battery characteristics and driving patterns [1]. Assuming a simplistic battery model, with constant charging efficiency and constant charging power, the optimization problem for a given vehicle can be written as the following linear problem.

$$\min_{P^t} \sum_t \mathrm{ToU}^t P^t \quad \text{Minimization of charging costs}$$

Subject to:

$$E^t = E^{t-1} + P^t \eta \Delta t - E^t_{cons} \quad \text{Energy content dynamics}$$
$$P^t_{min} \leq P^t \leq P^t_{max} \quad \text{Power constraints}$$
$$E^t_{min} \leq E^t \leq E^t_{max} \quad \text{Energy constraints}$$
$$E^0 = E^T \quad \text{Energy recovery}$$

The goal of the vehicle is to choose a charging profile P^t that minimizes the costs of charging given a time-of-use tariff TOU^t. The energy content of the battery E^t increases with the charging power according to an efficiency η and duration of the time period Δt, and decreases with the consumed energy while driving E^t_{cons}. The bounds on the charging power depend on the charging infrastructure. Without Vehicle-to-Grid (V2G), the lower bound P^t_{min} is equal to zero. The bounds on the energy profile are dependent on the size of the battery, and are usually set so as to protect the battery from degrading too fast (e.g. by setting a minimum state of charge). Finally, an equation is required to make sure that the energy content gets back to its initial value. Otherwise, due to the cost minimization, the battery would tend to be depleted over the optimization horizon. If the charging cannot be modulated, but just controlled to be either on or off, then the decision variable P^t is an integer variable, and the problem becomes therefore a mixed-integer program with:

$$P^t = \{0, P^t_{max}\}$$

Although these individual optimization problems can be solved, this task might become computationally intensive if the number of EVs is very large. In such a case, aggregate optimization models will be developed to represent the response of the EV fleet as a whole to a given ToU tariff.

Although ToU tariffs are considered to indirectly control the EV charging, the EV response to the ToU tariff is done off-line, i.e. the EV demand is just represented as a fixed load in the grid simulation problem.

In order to define an appropriate ToU tariff, it is important to take into account the increasing penetration of renewable energies in the distribution network. Thus, a ToU tariff based on load and renewable production forecasts could be defined. The frequency at which this ToU tariff should be changed needs to be analyzed. A day-ahead ToU tariff could be the most appropriate, since it could be set according to the expected renewable production for the following day.

Finally, V2G and charge modulation are not considered in this scenario, i.e. only on/off charging control is possible.

c) Proactive scenario:

In this case, the aggregator is able to start/stop the charging of EVs in response to a request by the DSO. Here, the EV fleet can be modeled as a virtual storage [1], i.e. an aggregated representation of the fleet defined by time-varying power and energy constraints, and a dynamic equation to represent the energy evolution of the virtual storage:

i) Power constraint: $P_{a,min}^{t} \leq P_{a}^{t} \leq P_{a,max}^{t}$
ii) Energy constraint: $E_{a,min}^{t} \leq E_{a}^{t} \leq E_{a,max}^{t}$
iii) Dynamic equation: $E_{a}^{t} = f(E_{a}^{t-1}, P^{t})$
iv) Energy recovery equation: $E^{0} = E^{T}$

This type of model represents the available charging flexibility at any time step.

Alternative approaches, e.g. modeling charging requests as tasks, will be explored and compared with the virtual-storage model.

As in the safe scenario case, V2G and charge modulation are not possible and only on/off charging control is allowed.

d) Smart grid scenario:

From a technical point of view, the only difference between the proactive and the smart grid scenarios is that in the latter charging can be bidirectional and modulated. Thus, a virtual storage model with the corresponding implementation details is also appropriate in this case. However, a task-type model is not adequate here due to the additional degrees of freedom gained in this scenario (i.e. bidirectional charging and charging modulation).

In the smart grid scenario, the service remuneration is the result of a market and thus, this has to be incorporated in the operational costs associated with control options. In this sense, different options for the service remuneration need to be analyzed. For example, reserves bought by TSOs have typically a two-part payment – the capacity payment, for being available, and the energy payment, for the activated reserve. Based on this, a similar definition for DSO services could be explored: with a capacity payment, the DSO can be certain that reserves are available when needed because the aggregator would make a commitment. However, the drawback is that the aggregator needs to be conservative, so most of the time the actual reserves would be actually higher than the ones committed.

e) Transition scenario in the midst of Proactive and Smart Grid:

From a conceptual point of view, and as previously explained, the main differences when compared with the Proactive scenario reside in the fact charge management uses charge modulation and real-time congestion management and DER integration are decentralized.

From a technical perspective, this is closer to the Smart Grid scenario due to the charge modulation possibility.

Table 4 summarizes the proposed modelling of the EV load/flexibility in the different scenarios. Given this general framework, different aspects need to be considered in the implementation of the tool. This is done in the subsections below.

	Conventional	**Safe**	**Proactive**	**Transition**	**Smart-grid**
EV load/flexibility model	Load profile	Load profile (result of off-line optimization)	Virtual storage/task-type model	Virtual storage	Virtual storage

Table 4 – Overview of the EV load/flexibility modeling in the different scenarios.

3.3.1. Integration of EV Stochastic Behavior

The models provided in T4.3 for statistical behavior of EVs will be integrated in the EV load/flexibility model in different ways, depending on the considered DSO scenario:

a) For the conventional and safe scenarios, each driving pattern scenario leads to an EV load scenario. For example, if samples of 100 different daily driving patterns are generated, 100 different load profiles are calculated from them.

b) For the proactive and smart-grid scenarios an aggregated fleet model is used. Thus, it is possible to represent all scenarios with a single probabilistic representation of the EV fleet, i.e. in the previous example, 100 samples would lead to a single probabilistic virtual storage model [2,3]. As a result, the energy and power constraints will be modeled as probabilistic constraints, i.e. they should hold at least with a given probability 1- ε. In practice, this means that tighter power and energy bounds will be defined, which guarantee that violations will only occur with a probability no larger than ε, with violation probability ε as a design parameter in this type of models. Inversely, if the probabilistic constraints are based on Monte Carlo samples, a theoretical bound for the violation probability ε for a given number of extracted samples can be calculated [4,5].

3.3.2. Emergency Control by the Aggregator

In each of the four scenarios considered, it is envisaged that the aggregator is able to remotely stop EV charging in emergency situations. This is supposed to happen only rarely since it would be done arbitrarily and could therefore lead to end-use constraint violations.

The emergency control will be modeled as a load shedding that only concerns EVs and, therefore, will be penalized in the optimization framework.

Possibly control actions can be done in two steps:

i. *Normal* control actions.

ii. If the *normal* control actions do not solve the constraint violations, activate emergency control actions.

Each of these control actions will be represented in the optimization framework with different costs. For example, the emergency control actions will be assigned a high penalty.

The emergency control will be defined in accordance with WP2.

3.3.3. Two entities: DSO vs. Aggregator

There are two entities, DSO and aggregator, whose responsibilities must be defined in advance.

According to the scenario definitions, both the DSO and the aggregator will be able to control the charging of EVs as explained below:

i. The DSO can only directly control the charging in an emergency situation. We assume that the DSO will do so by arbitrarily disconnecting EV loads without knowledge on their state, i.e. bidirectional communication is not considered.

ii. The aggregator is the responsible for managing the load in normal situations in the proactive and smart grid scenarios.

An important issue to analyze is how much information the aggregator will share with the DSO. If the aggregator shares the aggregated EV model with the DSO, the implementation is straightforward since the aggregated EV model would be directly incorporated into the optimization model as a set of constraints. This is eventually a better approach, since the aggregator cannot determine *a priori* how much reserves it can provide at any point in time. This is because its available flexibility at a given time depends on the previous reserve requests by the aggregator, e.g. if charging was curtailed during a certain period, it cannot be further curtailed at a later stage. It could be beneficial for both parties if the aggregator shares its flexibility model with the DSO.

It is also important to discuss which entity, aggregator or DSO, is responsible for making the ICT investment:

i. If the DSO makes the ICT investment, the investment costs can be directly incorporated into the optimization. Thereby it becomes possible to directly evaluate the value of this investment as the relationship between additional investment costs and reduced operational costs.

ii. If the aggregator makes the ICT investment, it is necessary to set the price of reserve provision accordingly so that the aggregator is able to recover its investment costs.

Finally, the aggregator can use the EV flexibility for purposes other than servicing the DSO. In the smart grid scenario, the aggregator is assumed to also provide services to the TSO, to participate in the energy trade and to support DER integration. In order to formalize the conflicting uses of the EV flexibility resource, a virtual storage model seems appropriate [6,7]. In this case, a predefined charging trajectory can be defined, and the requests for reserves of the DSO can be seen as deviations ΔP_a^t from this trajectory, also leading to deviations ΔE_a^t from the energy profile. The constraints on the virtual storage should make sure that no power or energy deviations occur when deviating from the predefined trajectory:

i. Power constraint: $P_{a,min}^t \leq P_a^t + \Delta P_a^t \leq P_{a,max}^t$

ii. Energy constraint: $E_{a,min}^t \leq E_a^t + \Delta E_a^t \leq E_{a,max}^t$

iii. Dynamic equation: $\Delta E_a^t = f(\Delta E_a^{t-1}, \Delta P^t)$

The predefined charging profile would be derived by the aggregator given electricity prices and reserve remuneration, both for TSO and DSO services.

3.3.4. Role of ICT

Although the protocol details are not relevant for the tool, it is important to define the features related to the control capabilities. For example, depending on the scenario definition:

a) The charging can be only on/off controlled or modulated.

b) The constraint management can be done in real-time or only as a forecast.

c) Bidirectional communication between aggregator and EVs is available (required in the proactive and smart grid scenarios).

Additionally, the different protocols as well as the amount of EVs to control lead to the achievement of several levels of reliability in the communications. On one hand, these may fail due to equipment malfunction or communication path unavailability. On the other hand, large volumes of control signal flows might get delayed, impacting the effectiveness of the solution.

It is therefore necessary to identify which ICT infrastructure(s) would be appropriate for each of the scenarios.

3.3.5. Aggregation Levels

The aggregation level depends on the voltage level considered. At the lowest voltage level, vehicles can be modeled individually; while at higher voltage levels, EVs behind a transformer can be modeled in an aggregated way. Thus, a hierarchy of aggregation depending on the network level under consideration will be considered:

i. The highest aggregation level to aggregate the whole fleet, independent of the network location.

ii. Subsequent location-dependent aggregations, depending on the network level considered. This means that all EVs associated to a network node are aggregated at that node.

iii. At the lowest voltage and aggregation level, vehicles are modeled individually.

A crucial point when considering uncertainty is the number of EVs that are aggregated. This is so because while the behavior of individual EVs is highly uncertain, as the number of EVs within a fleet increases, its predictability is also higher [3]. Thus, a small fleet of EVs cannot reliably provide any service at all since there is no guarantee that a given flexibility will be available with high probability.

3.3.6. Optimization Cycle

A multi-period approach will be considered for the grid operation optimization in order to be able to track the energy evolution of EV batteries. A daily cycle should be sufficient to capture the main dynamics associated with EVs/loads.

3.3.7. Real-time vs. Forecast

Based on the charging scenario definition, there is a distinction between being able to manage constraints in real-time or as a forecasted situation. In order to implement this in the tool, two steps are necessary:

i. The forecasted system state.

ii. The actual system state.

In the first step all control actions are available, while in the second one only a few control actions are left and other parameters remain fixed. This ideal approach would completely capture all the dynamics of the system operation. However, it might be too complex to be incorporated in the tool and some simplifications might need to be considered.

3.3.8. Types of Parking Locations

Some model assumptions will be considered depending on the parking location type. For example, the charging power and the controllability will be different if EVs are parked in a parking garage with dedicated EV charging infrastructure or if parked at home.

Moreover, two approaches to model EV aggregators will be analyzed in the proactive and smart-grid scenarios:

i. Charging spot model: location dependent. The aggregator is in charge of one or more charging spots and can control the vehicles connected to them.

ii. Subscription model: not location dependent. The aggregator is responsible for a group of vehicles with which it has a contract. Therefore, it can manage their charging independent of their locations, as long as a communication channel is available.

A virtual storage type of model can be used in both approaches. However, the implementation details need to be adapted to the particularities of each approach. A crucial aspect is how to track the energy contributions of vehicles that move from an aggregation to another.

3.3.9. Input data

The EV load/flexibility models to be developed will use data on driving patterns as input. These data include:

a) Arrival and departure of each trip.

b) Parking location (mapping to network).

c) Trip distance.

d) Initial state of charge.

Apart from these driving pattern data, physical constraints such as battery size, minimum and maximum state of charge, charge efficiency and charge power need to be defined.

Finally, a Monte Carlo simulation, presented in sub-section 3.2.3, will provide a number of samples of driving patterns for individual vehicles.

3.4. Required Functionalities of the Methods for Addressing EV and DER Statistical Behaviour

This section deals with the model for "DER" and the aspects related to the module "Scenarios", highlighted in

Figure 5.

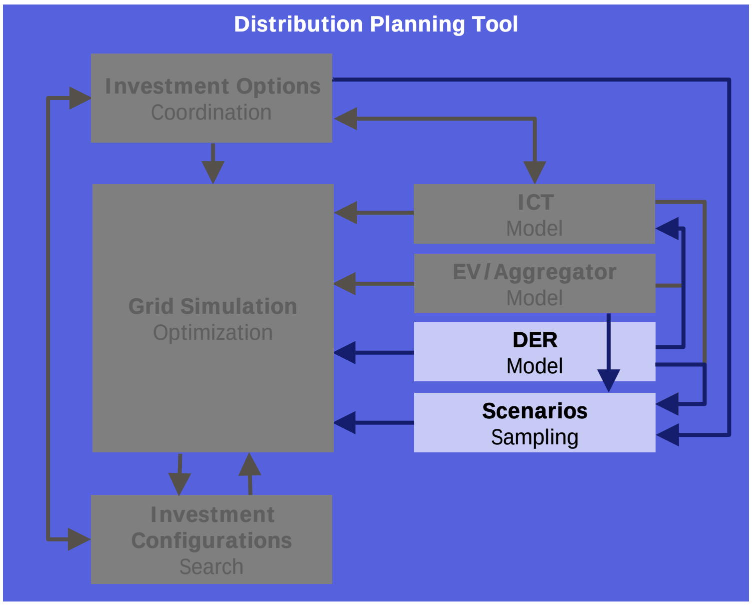

Figure 5 – Highlights of methods addressed in section 3.4

Different approaches for modelling the statistical behavior of EVs and DERs exist (see also D1.4 "State-of-the-art methods report") and are in use for individual purposes. Depending on the method chosen, specific requirements are necessary. As outlined in D1.4, different methods are practical for specific use-cases. The process of choosing the most adequate method for EVs and DERs is highly influenced by the aspired functions to fulfill the objectives of PlanGridEV. This includes the given diversities throughout Europe as well as the requirements of the future use-cases and business scenarios developed during the project. The methods and models for addressing the statistical behavior of DERs have to provide the needed flexibility and degree of freedom to meet these requirements.

The required functionalities of methods for PlanGridEV depend on the use-cases which will be addressed during the validation phase and are currently under development in WP1 and WP2 and will be made public in D1.2 early in 2014. The usability of this algorithms and methods is not exclusively addressing PlanGridEV use-cases but rather aiming for a generic applicability. The DoW includes the following scenarios and use-cases:

- LV/MV grids
- Area/grid topology (rural, urban…)
- Increasing EV market penetration
- Increasing DER penetration
- Charge control scenarios (incl. V2G)
- User behavior models

- Seasonal changes

Methods for describing the statistical behavior of DERs should therefore be capable of addressing these use-cases (detailed information will be provided in D1.2) and additionally the business scenarios developed in WP2 as shown in **Error! Reference source not found.**.

3.4.1. Functionalities in data-poor and data-rich areas

The stochastic nature of DERs (EVs, PV-systems, wind turbines) depends on a variety of parameters and manifests a strong obedience to local environmental circumstances. Due to the objective of PlanGridEV to develop a prototype of a grid planning tool which performs throughout Europe, methods have to perform under different conditions. The availability of appropriate data is essential, but cannot be guaranteed. Especially data about local mobility behavior is not available throughout Europe.

The used methods for PlanGridEV should therefore contain a set of model data for being able to perform at a satisfying level also in data poor areas. This model data could be based on average historical data from different areas in Europe.

3.4.2. Requirements for addressing electric vehicles statistical behavior

The behavior of electric vehicles and its effects to the power grid depends on many factors, for example:

- User-behavior (day-plan)
- Chronological distribution
- Type of area (rural, sub-urban or urban)
- Zone (residential, industrial or commercial)
- Geographical distribution
- Availability and type of charging infrastructure
- Environmental temperature

The following sections will outline the different requirements for addressing the individual topics regarding the statistical behavior of EVs within the objectives of PlanGridEV.

3.4.2.1 Statistical behavior as a function of the user characteristics and level of scope

Naturally the statistical behavior of EVs depends on the day-plan of the corresponding user (also known as customer or agent). This behavior consists of at least two locations and departure and arrival times (and a distance driven in between). The behavior of customers (EV users) is highly stochastic, location specific (e.g. rural or urban areas) and depends on a variety of independent parameters. Methods for describing the stochastic nature of mobility patterns therefore use data (from specific areas if available) from vehicle fleets for pre-calibration purposes.

Describing the statistical behavior of EVs also depends on the level of aggregation (or voltage level). The statistical behavior of a single EV in a LV grid is highly stochastic and considerably more difficult to predict than an aggregated fleet of a few hundreds of EVs at a MV node. This circumstance affords different strategies and methods for modeling the specific behavior.

3.4.2.2 Statistical behavior as a function of charging locations

Two of the main components are the time-wise and geographical behavior. The link between these two components is the charging infrastructure, which is also the interface to the power grid. From a power grid perspective, the availability of charging infrastructure is the most essential component for charging activities of EVs. Whilst times of departure and arrival of EVs can be defined with help of statistics from historical data, the availability and location of charging points depend on the individual grid topology and customer structure behind it. In general, charging infrastructure can be categorized as such (these categories were also defined in the OEM-charging scenarios in D1.1):

- Private charging spots
- Semi-Public charging spots
- Public charging Spots

Each of these categories can host different types of charging locations related to facilities, as there are for example:

- Households
- Workplaces
- Shops
- Multi-Storey car parks

For the development of appropriate algorithms for the prototype, the information about the locations (and its type) is essential and has to be provided from areal or power grid data (e.g. customer structure).

Table 5 – Allocation of examples of facilities to charging location categories

	Private charging	Semi-Public charging	Public charging
Households	X		
Workplaces	X	X	X
Shops	X	X	X
Multi-Storey car parks	X	X	X
Curb side		X	X

3.4.2.3 Statistical behavior as a function of the grid type

As defined in the DoW and D1.1 the following types of grid topologies, which are covering corresponding different typical area types, are considered:

- Rural grids
- Sub-urban grids
- Urban grids

These types are also relevant for allocating EVs and its patterns to a specific scenario or use-case. Statistically, urban areas are more densely populated than rural or sub-urban areas. However, as Table 6 shows, the vehicle-penetration per person decreases with rising population density.

Table 6 – Vehicle-penetration in different areas (rural, sub-urban and urban)

Area	Population	Vehicles	Vehicles/1000 persons
Rural[2]	20835	10960	~526
Sub-urban[3]	115986	58347	~503
Urban[4]	1700000	679492	~399

As Table 7 shows, the number of vehicles per person differs not only by different areas, but it also varies across the countries of Europe.

Additionally, the number of vehicles (in this case EVs) which are commuting from or to an area varies. This depends, if the specific area (power grid) is hosting mainly out-commuters, or if it attracts more in-commuters. For being able to address this matter sufficiently, information about number and location-type (working place, shops…) is essential, which depends on the individual power grid topology and customer type.

Table 7 – Average number of vehicles/1000 persons in exemplary countries

Country	# Vehicles/1000 persons[5]
Austria	578
Belgium [6]	471
Germany	572
Ireland [6]	430
Italy	679
Portugal[6]	355

[2] Data Source: www.statistik.at Lungau 2008
[3] Data Source: www.statistik.at Vienna-Suburbs 2012
[4] Data Source: www.statistik.at Vienna 2012
[5] Data Source: http://data.worldbank.org/indicator/IS.VEH.NVEH.P3
[6] Data source: http://www.eea.europa.eu/data-and-maps/figures/passenger-car-ownership-in-the-eea

Spain	593

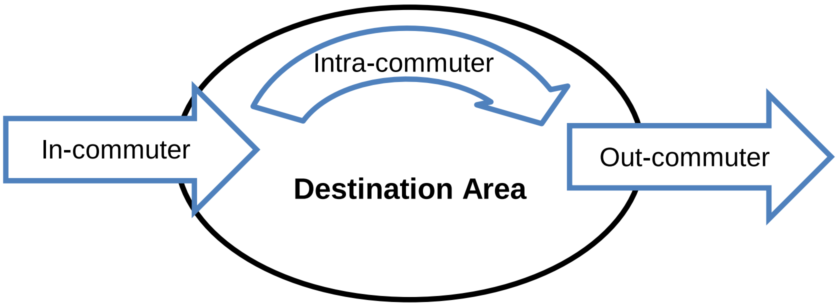

Figure 6 – Schematic of types of commuters

However, the overall limiting criteria for the number of connected vehicles to the electricity grid is the availability of charging infrastructure.

3.4.2.4 Statistical behavior as a function of charging strategies

For the work in PlanGridEV it is assumed that the user behavior or day plan of the EV driver is not affected by external optimization of the charging process through specific charging strategies. Even if charging is scheduled or V2G is performed, the EVs will depart or arrive according to customer premises. As shown in Table 3 before, the following business charging scenarios were developed in WP2 (D2.1):

- Conventional - Uncontrolled charging: No load management is considered and EV integration must be faced through grid reinforcements and, generally, investing on widening the existing hosting capacity.
- Safe load management: Fleet-focused load management to the conventional grid reinforcements, possibly reducing the effort in widening the hosting capacity only through copper investments.
- Proactive load management: Deals with massive EV penetration and minimizing the needs for grid reinforcements.
- Smart-grid load management (incl. V2G): Granular control of EVs load management which allows optimisation of hosting capacity and additionally considering the local connection of DERs that can benefit from EV penetration.

In D1.1 the following charging scenarios from the OEM point of view were defined (besides the characterization of private, semi-public and public charging):

- Fleet charging on their own premises
- Fleet charging on others premises

Table 8 shows the correspondence between the business scenarios defined in WP2 and the OEM-scenarios defined in D1.1.

Table 8 – Correspondence between business and OEM scenarios

		OEM – Scenarios from WP1-D1.1	
		Fleet charging on their own premises	Fleet charging on other premises
Business scenarios from WP2-D2.1	Conventional Charging	X	
	Safe load management		X
	Proactive load management		X
	Smart grid load management (incl. V2G)		X

Whilst the time-wise behavior will not be affected by whatever charging strategy or business scenario is operated (according to our assumptions), different levels of sophisticated models are needed for controlled charging and for the uncontrolled use-case. The models upon the patterns of the behavior (arrival- and departure times, distance driven) of the EVs require information about vehicle specifications as charging constraints and battery size.

3.4.2.5 Additional requirements and optimization criteria

Additionally to the above, there are parameters which also affect the charging process and further on affect the power grid itself.

- Environmental temperature (temperature dependent energy consumption of EVs)
- Technical constraints and life-time issues (especially battery issues)
- ICT characteristics (response times)
- EV specifications (battery size, maximum charging power …)
- Charging point specification (maximum power …)

However, these parameters are not related with the statistical behavior of EVs and are more relevant to model the storage capabilities of EVs.

3.4.2.6 Specific requirements of methods

Based on the literature review in D1.4 on state-of-the-art methods of existing methods, this section indicates the necessary requirements for selected methods. Additionally the functions outlined in the previous sections are also included in this analysis. Feasible approaches, which permit the required functionalities for achieving PlanGridEV objectives, are:

- Multi-agent approach

- Markov chains
- Semi-Markov chains

All of these methods rely on historical time-series data for parameterizing. For addressing specific use-cases, additional data has to be provided, such as:

- Type/area of power grid (urban, rural)
- Location of charging infrastructure (facility type)
- Population data of the specific area (population, number of households, etc.)

3.4.3. Requirements for addressing DG statistical behavior

3.4.3.1 Statistical behavior as a function of weather data

Several methods for modeling the statistic behavior of DGs were investigated in D1.4. Even though methods without the need for historical data for pre-conditioning exist, the most accurate methods rely on these data. By this reason, for PlanGridEV purposes only approaches based on historical data will be followed. Further on the availability of such data can be:

- Wind speed data (m/s)
- Solar irradiation data (on ground level - W/m²)
- Environmental temperature (°C)

For ensuring the workability of the chosen methods in data-poor areas, default values will be provided. An appropriate format for importing available local data has to be defined through the ongoing development of the methods and the prototype in WP4.

3.4.3.2 Statistical behavior as a function of the aggregation level

Similar to EVs, aggregated clusters of DGs (PV, wind …) are easier to model than individual systems on LV-level. The average error between the modelled forecast and the (historical) real date decreases with the rising number of DG devices.

3.4.3.3 Options for optimizing DG

In addition to the stochastic character of DGs, some of the DGs are able to contribute to the system operation by, for example:

- reactive power provision
- reactive power-based voltage control

- active power curtailment in emergency cases
- active power limitation in case of over-frequency

While all these items are not specifically stated in the project objectives, the degree of freedom of the distributed generators must be modeled.

3.4.4. DER Methods in the context of the planning tool architecture

Figure 7 shows an example for a possible integration of the statistical methods into the proposed tool architecture. The generation of the statistical behavior is in this approach external from the future tool. The generated profiles will be fed into models which are part of the grid simulation.

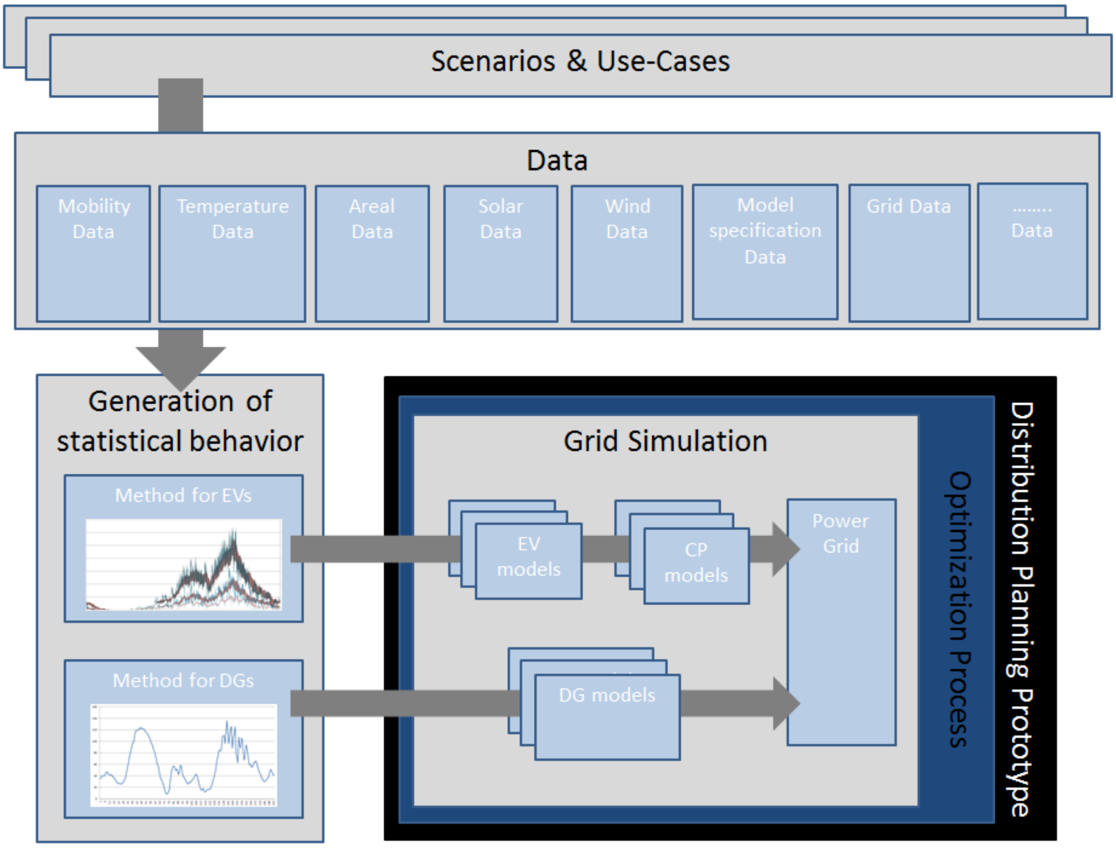

Figure 7 – Overview of a possible architecture for the methods within the planning tool

Table 2, presented in section 3.1.4, provides an overview of input and output variables of methods and models for the tool. This set of variables applies for simulations within data-rich environments. In case of insufficient data availability, input variables for methods will be replaced by default values.

3.5. Functionalities of the Methods for Multi-Objective Optimization

This section proposes a combination of methods to target the "Investment Configurations" module, shown in Figure 8.

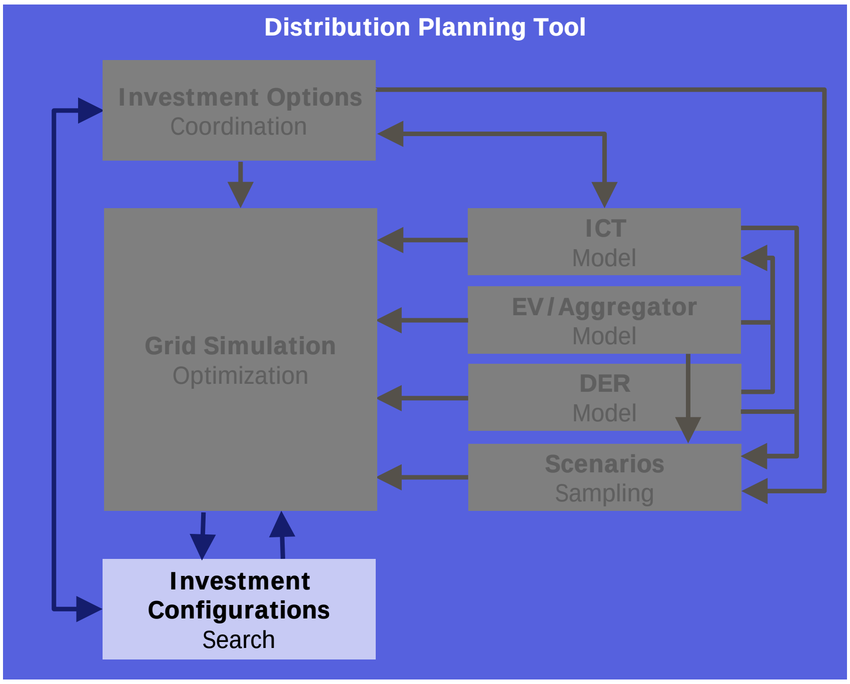

Figure 8 – Highlights of methods addressed in section 3.5

Optimization techniques should be employed in the design of electrical distribution networks, leading to a better allocation of limited financial resources. Network planning optimization should take into account both design and operational aspects of distribution networks: new networks and expansion of existing networks, installation and maintenance of facilities and conductors, expected losses and supply interruptions.

The main goal of the methods to be used for multi-objective optimization is to search for investment configurations, such that the set of investments and their corresponding time periods lead to a minimum overall value of the objective function. Therefore, the adequate analysis of the optimization problem with more than one objective should be undertaken with multi-objective optimization approaches, as these approaches can lead to meaningful results that would not be reached with single objective methods [8].

Distribution network planning consists in scheduling a set of system reinforcements and nodal control investments, named here as projects. Let us represent a distribution network by a graph *G*, where the vertices represent the network loads, while the edges represent the existing lines and transformers. ICT (vertex) investments can be considered in order to reduce demand impact through demand/DER control, whereas line/transformer (edge) reinforcement investments can be considered in order to relieve overloads and avoid voltage drop/rise beyond predefined acceptable levels.

The planning solution is a schedule of projects, both vertex and edge type projects that aim to minimize investment and operational costs while respecting key planning criteria like adequate voltage levels under normal and contingency situations and loading limits for lines and transformers.

Even though a thorough review of the state of the art was made in deliverable D1.4, it is useful to recall that distribution planning used to rely on a set of methods for deciding the location and type of reinforcements needed in order to cope with the traditional sources of uncertainty such as expected load forecast, at minimum cost. Several approaches have been taken in the past to solve the planning problem [9-16].

Some models deal with a fixed horizon year and single network solution topology [17-22] and are thus known as single stage models. Other models deal with the dynamic nature of demand through time as well as with a sequence of network solution topologies (one per stage) and are hence known as multistage models [10,11,13,16,23].

In either single or multistage models, optimization techniques were used to solve the problem. These involve genetic algorithms [24], Benders' decomposition [25], simulated annealing [26], tabu search [27], GRASP [28] and game theory [29]. The common output of all these former approaches is the conception of a plan, i.e., a set of projects where the system reinforcements and equipment additions are scheduled.

The problem at hand has several specificities that impact on the possible solution methods:

- The planning horizon is large enough (10-15 years) for not being able to neglect that some important decisions gain by being postponed to the later stages, which makes the problem intrinsically multi-stage;
- The decision space involves traditional investments on network reinforcements and also a new type of investments on demand control, which must be evaluated altogether making the solution space larger than before.
- The future operation will be complex involving demand and DER response that needs to be optimized to correctly represent future operation, which makes the evaluation of a plan computationally expensive precluding search for the optimal investment based on massive solution space exploration.

3.5.1. Problem formulation

3.5.1.1 Notation

The following notation is used throughout this section:

f_j objective function j
P set of projects
O set of orders for project analysis

p_i project i of P, $i = 1, 2, ..., N$
o order of O
k_i timing of project *i* of *P* (p_i), $k_i \in \{1, 2, ..., T+1\}$
$(\overline{p}, \overline{k})$ decision schedule: two indexed arrays, one of projects, $\overline{p}$, and another of project timings, $\overline{k}$
N number of projects
T number of stages of the planning period
G graph that represents the existing nodes (vertices) and branches (edges) of the current distribution network configuration and also its possible branches (edges) in alternative network configurations

3.5.1.2 Formulation

Consider a set of projects $P = \{p_1, p_2, ..., p_N\}$. A decision schedule is a pair of indexed arrays ($\overline{p}, \overline{k}$) where $\overline{p}$ is an array of projects ($\overline{p} = \{p_1, p_2, ..., p_N\}$) and $\overline{k}$ is the corresponding array of time periods for the projects ($\overline{k} = \{k_1, k_2, ..., k_N\}$).

As a multi-objective one, the problem may be formulated as in the following:

$$\min_{(\overline{p}, \overline{k})} \left\{ f_1(\overline{p}, \overline{k}), f_2(\overline{p}, \overline{k}), ..., f_j(\overline{p}, \overline{k}) \right\} \quad (1)$$

$$\text{s.t.} \quad \begin{matrix} p_i \in P, i = 1, 2, ..., N \\ k_i \in \{1, 2, ..., T+1\} \end{matrix} \quad (2)$$

Where $f_j(\overline{p}, \overline{k})$ represents the objective function *j* to be minimized for the planning period *T*. For instance, objective functions can be investment costs, operational costs, communication costs, greenhouse gas emission costs, etc. An optimization procedure will have to be run in order to provide the lowest possible value of the objective function for a given set of investments in a given stage of the planning period.

3.5.2. Example solution approach

Decisions being multi-stage, the decision space being large-scale and the decision schedules being computationally expensive to evaluate make the possible effective solution approaches very confined. Note that the scheduling problem is alone a NLP-Hard problem [30] and therefore the search cannot guarantee the global optimum to be found. The solution approach must therefore be able to provide close-to-optimal plans involving short-term and longer-term investment decisions that need to be evaluated thoroughly.

Project schedules can be found by a classical local search Gaussian algorithm with moderate search effort. However, such Gaussian algorithm is a local optimization approach and being the stated problem a nonconvex one [31], it does not guarantee close-to-optimum solutions [32]: solutions typically get trapped in local optima. The Gaussian Search (GS) is very sensitive w.r.t. the *order* by which the different system reinforcements are analysed [33]. Therefore, to find close-to-optimum schedules we propose to learn about the best order to be solved by GS procedures with a specific Genetic Algorithm (GA). The overall solution approach can be formulated as a hybrid algorithm.

In the following we propose a hybrid optimization approach to the multi-objective problem at hand. This solution approach for the optimization problem is possible to formulate given the known methods for multi-objective optimization.

A simplified problem formulation maybe be the following:

$$\min_{(\bar{p},\bar{k})}\left\{ f\left(\bar{p},\bar{k}\right), g\left(\bar{p},\bar{k}\right), h\left(\bar{p},\bar{k}\right)\right\} \quad (1)$$

$$\begin{aligned} s.t. \quad & p_i \in P, i = 1,2,\ldots,N \\ & k_i \in \{1,2,\ldots,T+1\} \end{aligned} \quad (2)$$

Where $f\left(\bar{p},\bar{k}\right)$ intends to represent the present value associated with the projects investment schedule, $g\left(\bar{p},\bar{k}\right)$ the present value of the system operational costs and $h\left(\bar{p},\bar{k}\right)$ the present value of other costs (reliability, emissions, etc.), all of the costs associated with the schedule of projects along the planning period *T*. The system operational costs can incorporate different performance measures like number and severity of expected overloads and system losses that may occur along the planning period *T*.

The problem can be addressed by combining a classical local optimization technique, Gaussian Search (GS), to search for the best project timings given a project analysis sequence $\bar{p}$, with a global optimization technique, a specific Genetic Algorithm (GA), to search for the best project analysis sequence. The best possible costs for a given set of investments at a given stage of the planning period are then provided through the Grid Simulation module.

Thus, GS would be used to find the best project schedule given an order to analyse the projects and the GA would be used to find the best order for the GS optimization. This hybrid approach has proven to yield robust solutions in several planning contexts [33].

If a multi-objective function is to be addressed explicitly, one may define GS and GA selection criteria to address search as multi objective and return a population of Pareto non-dominated schedules. If not, one may scale weights for the different objectives and run a single objective search procedure several times for different weightings.

<u>Gaussian Search</u>

Step 1. Initialize $n=1$.

Step 2. Take the n^{th} project of the project sequence $\bar{p}$ and choose the best timing for its implementation, k_n (the best can be interpreted as single or multi-objective here); add the project to the network graph *G*.

Step 3. Go to the next project in the sequence ($n \leftarrow n+1$) and go back to Step 2 until the end of the project sequence is reached.

Step 4. If the end of the project sequence is reached, go back to Step 1 until the project timing array $\bar{k}$

remains unchanged from the previous GS iteration.

Hybrid GA search

Step 1. Initialize a population (set) of possible orders for projects

Step 2. Evaluate the population of orders by running GS on each possible order

Step 3. Select the best orders from the population (selection can be single or multi-objective, Pareto based)

Step 4. Subject the best orders to genetic manipulation (recombination and mutation) and go back to Step 2 until convergence is achieved.

A specific GA can be designed [33] for the ordering problem. We take the genotype to represent the order by which the projects are to be analysed by GS. The genotype is taken to be a string *O* of order values indexed to a string of projects. See Figure 9 for illustration.

Projects	p_1	p_2	p_3	p_4	p_5	p_6	p_7
Order *O*	1	7	2	5	3	6	4

Figure 9 – Coding of the sequence of projects $\overline{p} = (p_1, p_2, p_3, p_4, p_5, p_6, p_7)$

The recombination is taken to be a one-point crossover operation where projects relative order is exchanged between parents in order to generate two other offspring. The operation changes the relative order as we illustrate in Figure 10 and report in the recombination algorithm. Offspring *v* is obtained from Parent *v* and subject to order relation contained in sub-string o_u (5, 6, 7). By swapping p_7 with p_6 the offspring *v* respects the order relation contained in sub-string o_u as indicated in bold. Similar procedure is applied for offspring *u*.

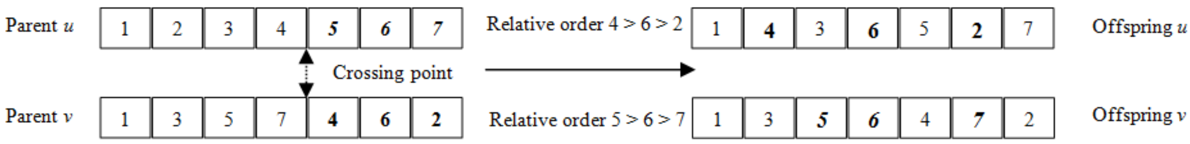

Figure 10 – Crossover operation and recombination.

Recombination

Given two parents, say *u* and *v*, the following procedure can be used to submit a sub-string o_u to the solution genotype O_v.

Step 1. Divide the order relation o_u into pairs of successive order relations. E.g., o_u={4>6>2} is divided into pairs (4,6), (6,2)

Step 2. Check for each pair of successive order relations o_u the order relation contained in O_v

Step 3. If in genotype O_v the pair of successive order relation is not respected *swap* the genes of O_v

Step 4. Repeat *Step 3* until the order relation of sub-string o_u is respected in genotype O_v

The overview of the presented solution approach is represented in the following figure:

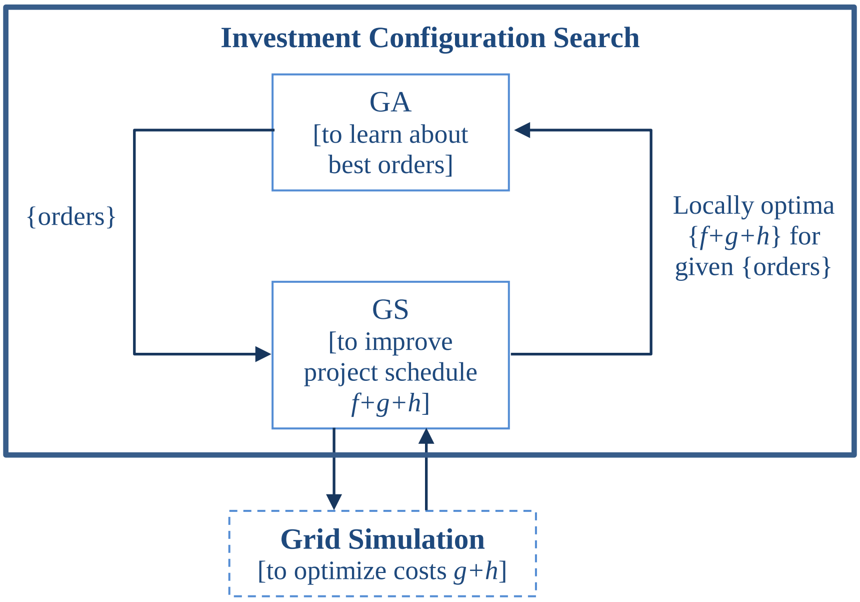

Figure 11 – Overview of the hybrid optimization method (GA+GS)

4. Incorporation of ICT and Information Exchange

Section 4 presents the models and method proposed for addressing ICT integration in the planning tool. Figure 12 highlights its positioning within the planning tool architecture.

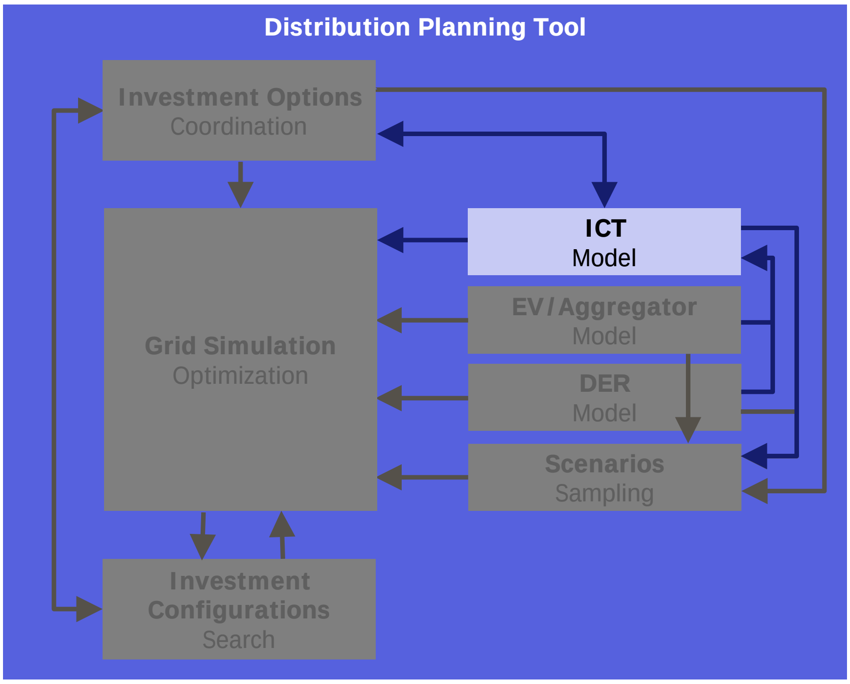

Figure 12 – Highlights of methods addressed in section 4

4.1. Development of ICT Models and Methods for Integration in Distribution Planning

This chapter deals with concepts for ICT inclusion into an electricity smart grid planning tool with an optimal EV integration. For this purpose, the basic methodology is illustrated in Figure 13 and described in detail subsequently.

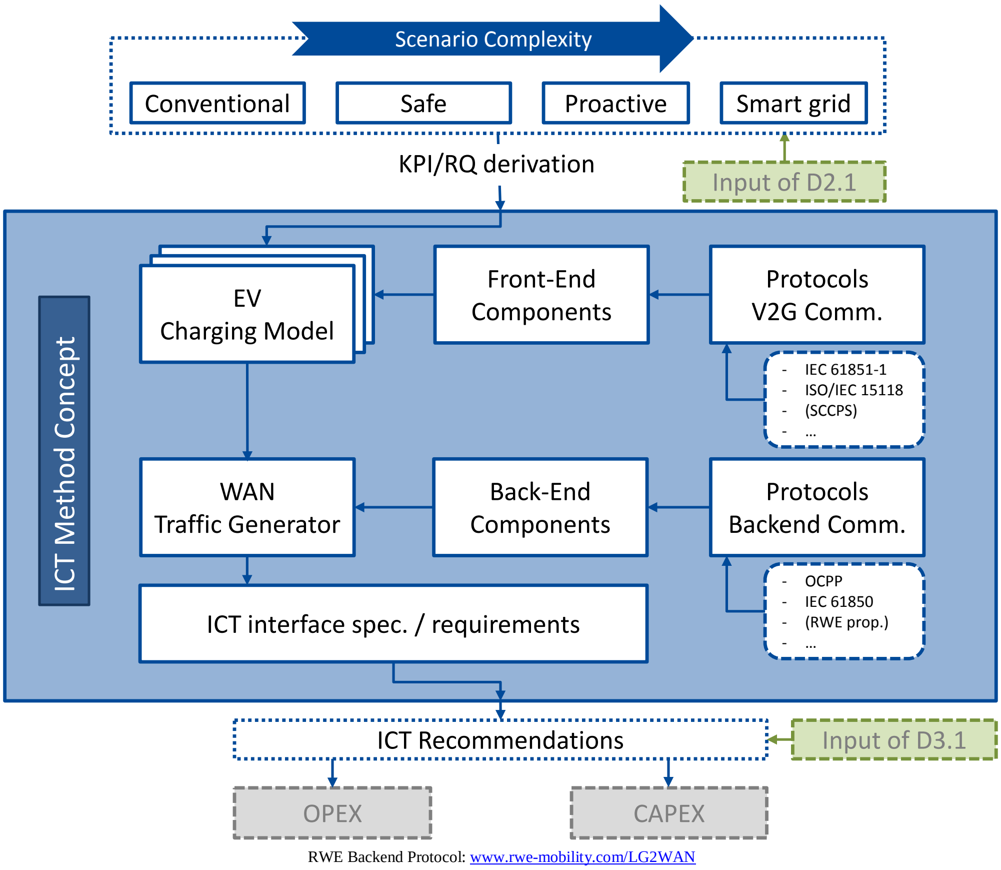

Figure 13 – Basic methodology for ICT modelling

4.2. ICT Method Input

The method for ICT integration is based on scenarios of varying complexity. These scenarios allow the identification of requirements/key performance indicators (RQ/KPI) for ICT.

All derived KPIs need to be considered by the developed ICT method, to ensure that requirements to the entire scenario set are met.

The KPIs are used to identify the minimum requirements of the ICT infrastructure that allows performing a given action on dispersed resources.

4.3. ICT Interface Description & ICT Networking Topologies

The proposed ICT method identifies key components for all relevant ICT interfaces depending on a given input scenario (see D2.1). In addition, a distinction between different charging infrastructure locations is reasonable, since they have an impact on potential ICT networking topologies:

- Public charging
- Semi-public/private charging
- Private charging

Public charging points (CP) can either communicate directly with a central system (CS) [option A] or be connected to a local/regional aggregator (AG), which consolidates data of different CP and forwards it to a CS [option B]. The ICT interface between a central system and a third party will not be considered separately.

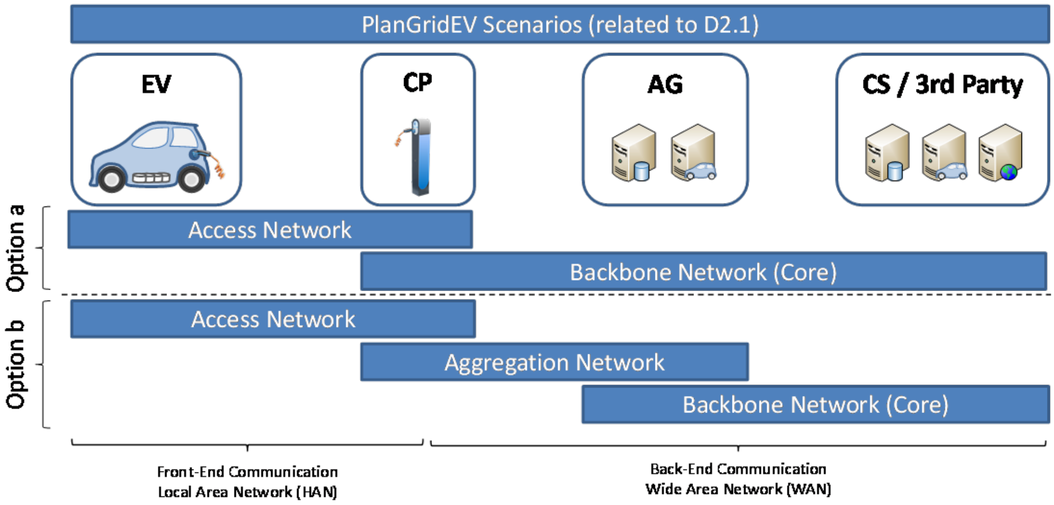

Figure 14 – PlanGridEV ICT scenarios I

In addition to public charging infrastructure many CPs are also established within semi-public/private premises or private homes and may be embedded into existing Local/Home Area Networks (LAN/HAN). Basically the two options described above are also applicable here, but in contrast to public charging infrastructures, which are directly linked to AG or CS, private or semi-public CPs are linked to home/facility internal communication hardware, e.g. Facility Management Systems (FMS) or Home Energy Management Systems (HEMS). Consequently, both approaches are implemented using different ICT components.

For such network topologies, the ICT method identifies main technical components for Front-End and Back-End communication. To this end the following sections describe how individual components are determined and composed to fulfil PlanGridEV scenario needs.

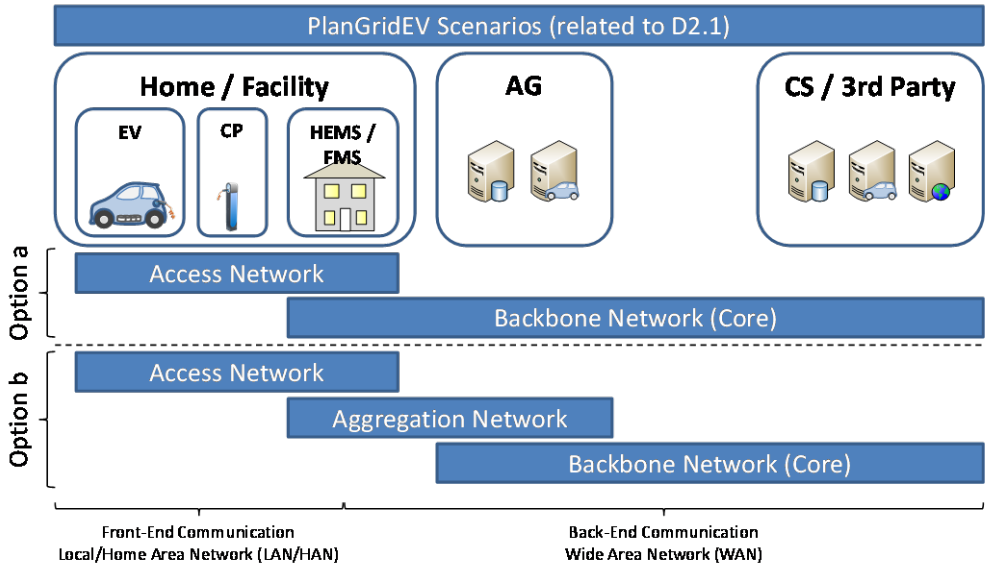

Figure 15 – PlanGridEV ICT scenarios II

4.4. EV Charging Models (Front-End Communication)

Depending on the input scenario and the ICT networking topologies, one or more charging models are applicable, distinguishing between three different technologies – AC, DC and inductive. In this context, various V2G protocols can be mapped to the charging models and have different ICT requirements, architectures as well as information exchange patterns. The following figure illustrates the mapping of each charging model to its specific ICT components depending on communication quality.

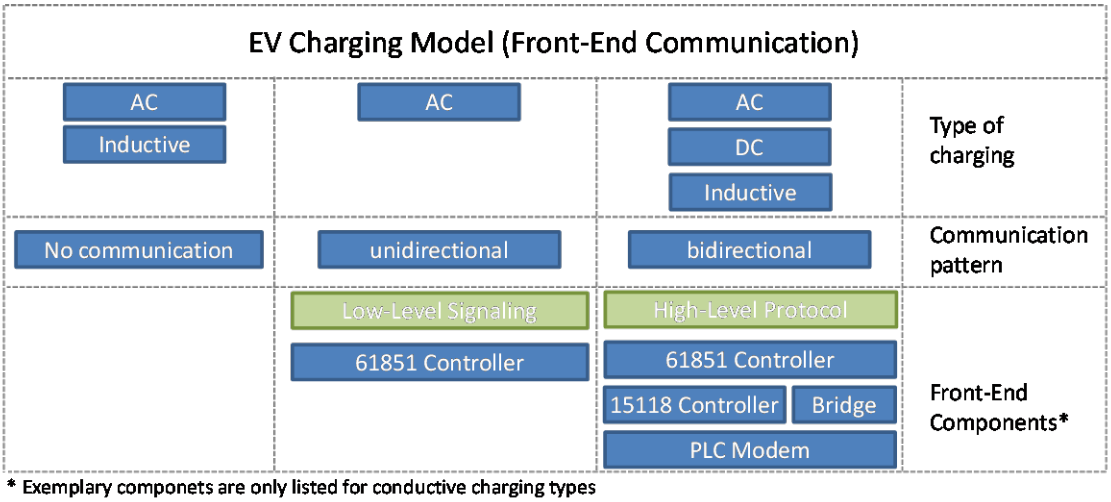

Figure 16 – EV charging model

The different charging processes may condition the flexibility of the EV, the ICT requirements and information exchange patterns.

4.5. WAN Traffic Generator (Back-End Communication)

In addition to front-end communication and according to the scenarios, e.g. in order to implement a smart demand side management (DSM), several technical units need to communicate to central backend systems. Therefore the WAN traffic generator should take all scenario patterns into account, to generate an averaged ICT traffic for each potential backend communication protocol solution, e.g. based OCPP or IEC 61850-90-8, etc.

In this context different ICT network topologies for Back-End communication are conceivable. As described above CPs can either communicate directly with a CS or are connected to an aggregator (AG), which forwards data to CS. In case of using an aggregator unit, it is implemented as Local Proxy (LP) or Local Controller (LC). An LP connects CS to several CP and acts as a message router with no additional intelligence. The idea behind this concept is to reduce the overall amount of WAN links necessary for establishing a connection between the CS and several CPs. LPs replace internal IP addresses of CP messages with their own remote IP address, such that CS will respond to LP. LP identifies target CPs by ChargePointId and forwards messages to the corresponding receiver CP.

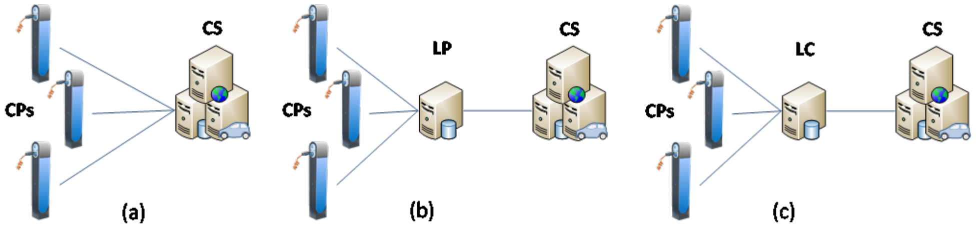

Figure 17 – Possible ICT charging paths

In contrast to LP a Local Controller (LC) acts as subordinate of the CS with local/regional intelligence in order to perform local smart charging cases.

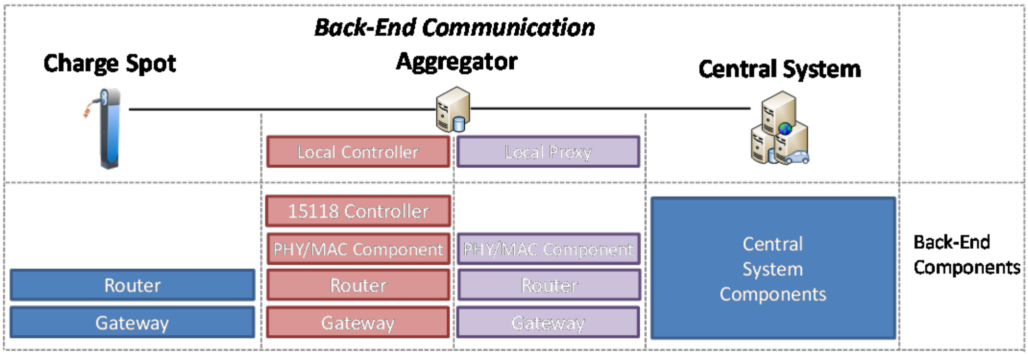

Figure 18 – Backend communication

In case of using an LC the ISO/IEC 15118 Controller of CP Front-End components (bidirectional high-level communication) is replaced by a simple bridge and is transferred to LP components, in order to enable a local smart charging. CS ICT components do not need to list in detail, since DSOs should already equip with necessary components.

Furthermore various levels of WAN traffic generators are conceivable:

1. WAN traffic generator, considering only primary communication traffic related to smart grid applications (dedicated ICT infrastructures).
2. WAN traffic generator, considering primary traffic related to smart grid applications plus additional traffic caused by reasonable types of value added services (shared ICT infrastructures).

4.6. ICT Method Output

As a function of identified components for Front-End and Back-End communication the ICT method output could deliver technical costs, such as:

- Data rate
- Coverage
- Response & Processing Times
- Availability / Robustness
- Physical medium

Using state of the art analysis within deliverable D3.1, it is possible to identify ICT technologies, which fulfil ICT method output.

The proposed ICT technologies can be parameterized with monetary costs in terms of:

1. Operational costs (OPEX)
2. Investment costs (CAPEX)

A detailed description of the inputs and outputs was provided in Table 2 of section 3.1.4.

5. Incorporation of traceability concepts

5.1. Introduction and concept

The innovation of the traceability concept consists in the possibility of having information concerning the exact origin of the electricity used for a specific end use, in this case EV charging. Traceability requires the knowledge of the type and location of the real system that at a given moment is supplying the vehicle charging with electricity, quantifying RES proportion.

In this context, it is a concept deeply linked with the operation of the system and as such will be mainly developed within the framework of WP5. Nevertheless, this subject should be presented at this stage in WP4 so that the business models associated with traceability may be captured by the tool.

Using traceability concepts would enable the recognition of the origin of the energy used by EVs. At present there are certifications intended to ensure the customer that an amount of energy "equal to" the one he consumed was produced by plants from a renewable source in a certain period of time. The issue is that stating that it is "equal to" involves a calculation of the energy balance, which, although correct, does not include all the characteristics of "real data".

With traceability the user has, in fact, a confirmation concerning the type of plant which at that any given moment is supplying him. By enabling the possibility to trace the sources of the energy needed for charging an EV, a certificate of origin of the energy may be generated.

User reporting of this information may be done in different ways: either by instant traceability of a single charge or through a periodic report (day / week / month).

The first consists in giving an indication about the plant that has supplied the EV charging process, giving an immediate traceability, with immediate visualization on a display or subsequent communication of the actual data in real-bills or other channels of communication.

The second method, however, provides the opportunity to give an indication of the amount of energy actually produced by one or more renewable energy plants to be used for charging the electric vehicle, with a budget communicated regularly on the bill or over other communication channels (e-mail, sms, app, ...).

The traceability aims at certifying that EV battery recharge was made by renewable with self-production (grid connected) or that the grid management is able to guarantee the energy source of production and even the exact installation that produced the energy used in the global energy balance for the charging of the vehicle.

The main concern of traceability in this context is the indication of the specific renewable energy content of EV charging process.

5.2. Goals

5.2.1. Identification of the objective to be reached

The objectives to be reached by the development and application of a real time traceability protocol in the electrical power production and distribution field are:

- Allowing the optimization of RES integration in the grid by the exploitation of controllable load resources (in particular the EVs).
- Allowing the satisfaction of the end-user by providing a set of data regarding the consumed energy (in particular the RES content).

For pursuing these objectives it is necessary to:

- Define a set of appropriate and useful information, which has to be defined from production to distribution and finally reach end-user.
- Definition of a method for the exchange and the distribution of the information.

5.2.2. Identification of the constraints

On one hand, traceability has to take into account the constraints imposed by the user to the provider and by the provider to the user. These constraints will regard the amount of energy provided, the related timing or the distances. On the other hand, the traceability itself is subject to the constraints related to the information production and exchange.

In general, the privacy policies and the security protocols related to the information managing will be a strong constraint in the traceability protocol definition.

5.2.3. Identification of the control variables and degree of freedom

For the energy traceability it is necessary to define a label (set of information related to the energy production and distribution) to be associated to the produced energy.

The information for generating this label will be for example:

- the plant localization
- the source (solar, wind, biomass…)
- the plant features:
    - technology (mono/poly crystalline PV panels, vertical/horizontal wind turbine…)
    - size (kW, MW…)

- production profile
- the profile of users and the updating parameters

The label should be as much possible dynamic: it should be able to contain information variant in time and geographical position. An important point to be defined is the relation in between the label and the labeled object.

Contrarily to other fields where the object to be traced contains the features useful for the traceability (for example in the food chain, some chemical contained in the food detectable via simple analysis can be itself a traceability element), the electrical energy do not have useful features which can be employed to discriminate it depending on the origin. The information allowing the tracking process has to be created ad hoc, collected and sent where required.

5.2.4. Degree of freedom

The degrees of freedom related to the tracking process have to be minimized, in order to make the information exchange as much as possible exact, correct and precise.

Instead, the exchange process in between the energy provider and the end- user has some degree of freedom that the tracking process will have to be able to handle.

In particular, in order to optimize the DER integration via the load management, the freedom degree will be related to:

- the plant localization: taking into account the typology of source required / preferred by the user or more adequate to a certain load, the choice of the plant will be constrained only by the minimization of the distances for the losses minimization.
- the distribution management of the energy surplus: the DSOs will be free to apply the best storage profile taking into account the total storage capability made available by the users (by EVs), that will be in general inhomogeneous over the geographical areas.

5.3. Prerequisites and perspectives

To define the application protocol of the traceability concept, different activities are required:

- Method analysis addressing statistical load of EV for distribution networks: analysis of diverse scenarios of EV distribution based on statistical data of the future impact of these vehicles.
- Method analysis addressing statistical load of DER for distribution networks: analysis of the load profile of DER existing system.
- Method analysis addressing to maximize integration of EV and DERs: optimization of the integration between EV and DER.

The definition and the application of a traceability protocol will be developed in WP5 where the functional requirements for active load management in distribution grids will be defined.

Taking into account: (i) the analysis of diverse scenarios of EV distribution based on statistical data of the future impact of electric vehicles; (ii) the analysis of the load profile of DER existing system; (iii) the optimization of the integration between EV and DER; in WP5 use cases will be selected in order to implement and test the traceability concepts here introduced.

6. Conclusions

This deliverable presents the initial guidelines for the development of the core output of WP4, the distribution planning prototype tool. In the pursuit of this objective it was crucial to define a joint strategy amongst all WP4 participants, so that individual contributions may be integrated in the prototype tool. Each participant is tackling one or more relevant topics within the distribution planning problem by developing methods and / or models to tackle them.

There are new challenges on distribution planning that must be addressed in the tool, mainly dealing with the increased levels of uncertainty of the system and the new trends in observability and controllability of the network. The increased levels of penetration of Distributed Generation (DG) accompanied by perspectives of increased load, for instance, with the integration of heat pumps and Electric Vehicles (EVs) are introducing major uncertainties to the planning activity.

Moreover, extended levels of observability and controllability are leading to a transition from passive grids to active grids. Yet, their benefits are currently not considered by the distribution planning tools. Hence, there is no identification and internalization of the possible benefits of having a number of different control options, such as demand response, EV charging control or DG modulation. All these options rely on proper ICT infrastructures, for which investment must be made and should be foreseen, having an impact on the expansion plans.

Finally, due to these changes, new stakeholders are rising as conceivable investors in distribution planning, more specifically in the ICT assets for demand response activation. All the new business models that are being developed must be studied and the prototype tool should be able to test and capture the different dynamics that these new models bring for expansion planning.

In this context, the prototype tool of WP4 will integrate the different innovation drivers of distribution networks and model them explicitly for application on expansion planning.

Briefly, the tool will be comprised by the following modules:

- **Definition and expansion options** – it also contains essential information for the tool: a list of investment options for reinforcing the grid, including both conventional options and ICT+control based options.
- **Grid simulation** – this method is one of the key differentiations from traditional approaches. Instead of addressing a fixed loading scenario (traditionally the peak loading conditions) on a mostly passive network this method allows exploiting distribution grid active elements for different chronological periods of time under changing conditions of load and generation.
- **Investment configurations** – this method works in combination with the grid simulation method, providing it with investment choices that in practice result in different grid topologies and characteristics and in return obtains a set of expected performance indicators from the grid simulation stage. Based on the CAPEX of the investment choices and on expected operational indicators the best investment alternative is sought.

- **Scenarios** – this module samples the operational scenarios needed to conduct the grid simulation. These scenarios among others refer to load, distributed generation and demand flexibility.

- **DER** – this model(s) provides the grid simulation method with the ability to represent in detail the behaviour of different DER.

- **EV / aggregator** – this model provides the grid simulation method with the ability to represent in detail the behaviour of EV owners and aggregators, namely concerning their behaviour towards the control of the charging process.

- **ICT** – this model feeds two other modules for different purposes. First, it defines for the definition and expansion options stage the requirements for ICT depending on the scenario(s) that the planner wants to address. Then, it provides the grid simulation model with constraints and rules for activation of controllable elements that depend on the installed ICT equipments.

Traceability will be mainly developed within the framework of WP5. Nevertheless, this subject was also introduced at this stage in WP4 so that the business models associated with traceability may be captured by the tool.

As mentioned throughout this document, this report is the initial systematization of the next steps for WP4 and as such the presented concepts may evolve. This evolution may impact chosen algorithms, methodologies or even the envisaged architecture of the prototype tool. Nevertheless, the guiding principles for WP4 will be provided by this document, with its identification of main inputs and outputs for the tool and its methods and models as well as the links between the different modules.

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8. Revisions

8.1. Track changes

Name	Date (dd.mm.jjjj)	Version	Changes	
			Subject of change	page
Pedro Rocha Almeida	11.12.2013	1.0	First version.	-
Pedro Rocha Almeida	20.12.2013	1.1	Inserted DSO inputs.	-
Pedro Carvalho	08.01.2014	1.2	Review of 1.1.	-
Pedro Rocha Almeida	15.01.2014	1.3	Integration of review 1.2.	-
Eduardo Zabala	21.01.2014	1.4	Overall Review.	-
Pedro Rocha Almeida	30.01.2014	1.5	Integration of review 1.4.	-
Armin Gaul	31.01.2014	1.6	Final and approved.	-