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## WP2

### Toolbox specification, support tools and test cases

# Toolbox Specification

## D2.2



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AUTHOR(S)	Clara Bagnasco, Christian Biasuzzi, Kaan Hakan [Tech Rain], Florin Capitanescu [LIST], Martin Bolfek, Dora Mešić [HEP ODS], Eduardo Alejandro Martínez Ceseña [UNIMAN], Miguel Ángel Sanz Bobi [COMILLAS], Micael Filipe Simões, Justino Rodrigues [INESC TEC], Mirna Gržanić, Tomislav Capuder [ICENT], Dajana Vrbicic Tendra, Petra Sagrestano Stamuk [HOPS], Hrvoje Keko [KONCAR-KET]
OFFICIAL REVIEWER(S)	Carlos Mateo Domingo, Miguel Ángel Sanz-Bobi [COMILLAS], Filipe Soares [INESC TEC], Martin Bolfek [HEP ODS], Dajana Vrbicic Tendra [HOPS]

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## Abbreviations and Acronyms

AS	Ancillary Service
CAPEX	CAPital EXpenditure
CDF	Common Data Format (IEEE)
CHP	Combined Heat and Power
CIM	Common Information Model
CO2	Carbon dioxide
CSV	Comma-Separated Value
DA	Day Ahead
DER	Distributed Energy Resources
DG	Distributed Generation
DSO	Distribution System Operator
EMS	Energy Management System
ENS	Energy Not Supplied
GIS	Geographic Information System
HDF	Hierarchical Data Format
ICT	Information and Communication Technologies
JSON	JavaScript Object Notation
LCOE	Levelized Cost of Energy
LV	Low Voltage
MDT	Mean DownTime
MES	Multi-Energy Systems
MPC	MATPOWER Case Struct
MTBF	Mean Time Between Failures
MTTF	Mean Time To Failure
MTTM	Mean Time To Maintain
MTTR	Mean Time To Repair
MV	Medium Voltage
NPC	Net Present Cost
NPV	Net Present Value
RES	Renewable Energy Source
OLTC	On-Load Tap Changer
OPEX	OPerating EXpenditure
OPF	Optimal Power Flow
SCADA	Supervisory Control And Data Acquisition

SG	Smart Grid
SCOPF	Security-Constrained Optimal Power Flow
TSO	Transmission System Operator
WP	Work Package

## 1. Executive Summary

The present deliverable introduces the modular open source toolbox to be developed and operationalized in the project “Advanced Tools Towards cost-efficient decarbonisation of future reliable Energy SysTems” (ATTEST). This open source toolbox comprises a suite of innovative tools to support TSOs / DSOs planning, operating and maintaining the energy systems of 2030 and beyond in an optimized and coordinated manner, considering technical, economic and environmental aspects. This deliverable should be considered as a living document, that will be amended and completed during the first phases of tools development.

This document reports the requirements for the tools that will be developed in WP3 (planning tools), WP4 (operation tools) and WP5 (asset management tools). In order to identify these requirements, the inputs and outputs of all tools are analysed as well as the interactions between individual tools that compose the toolbox. This includes examining the data sources and defining the format types that will be used, which requires specifying common data formats to be adopted for exchanging data between the several sources and tools. As different formats may be used internally by the different tools, a set of data converters need to be developed in order to translate the data between different formats.

Finally, the high-level functionalities interface between the components of the toolbox and the ICT platform that will be developed in WP6 are described.

The remainder of the document is structured as follows:

Chapter 2 details the three modules of the toolbox (planning, operation and asset management) and each of tools to be developed within the modules;

Chapter 3 addresses the tools and data that supports the toolbox;

Chapter 4 summarizes the technical requirements for each tool;

Chapter 5 resumes the main conclusions obtained in the previous chapters.

## 2. Open source toolbox

The modular open source toolbox will embed all the tools developed in the ATTEST project.

The toolbox will be prepared to handle a wide variety of networks challenges in a timeframe ranging from the day-ahead and real-time operation, covering medium and long-term asset management and ending at long-term reinforcement / expansion planning.

Despite being incorporated in a common ICT platform, represented in the figure below, each tool will be designed to be used individually, in an offline mode, according to the users' preference.

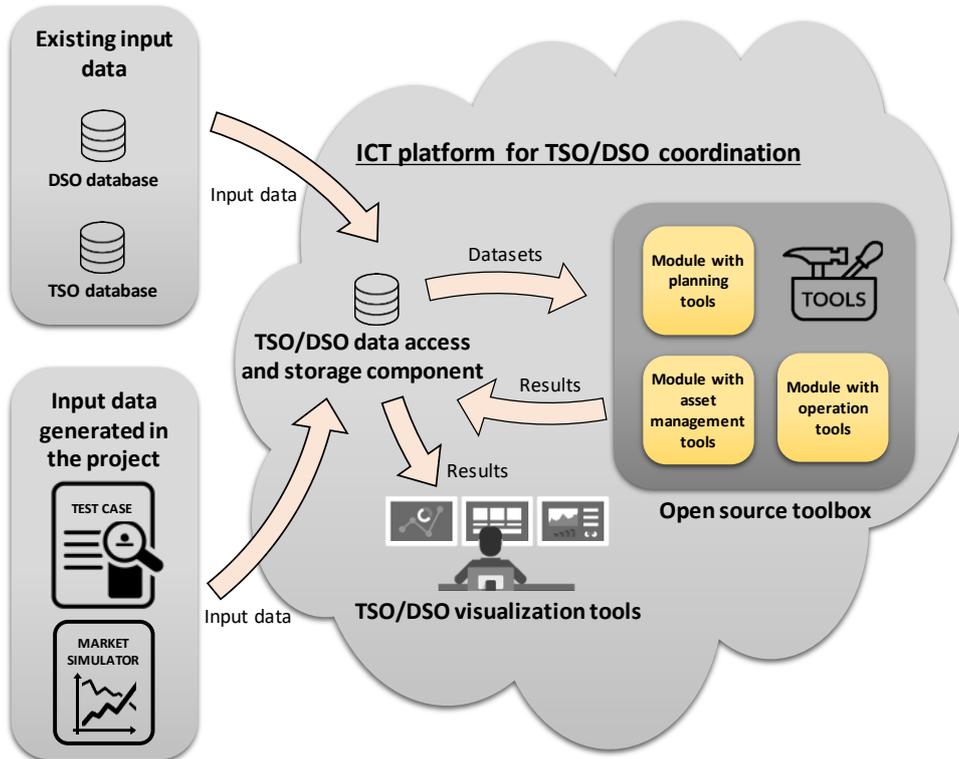


Figure 2.1: ICT platform for TSO/DSO coordination and toolbox operationalization

The open source toolbox will include 3 main modules: planning, operation and asset management. Each module incorporates a set of tools, as depicted in the figure below. All the tools, for each module, are described in the following sections. For each tool are described its test cases, the expected dependencies with other tools in the project and, its input and output requirements (data format, expected data size, etc.).

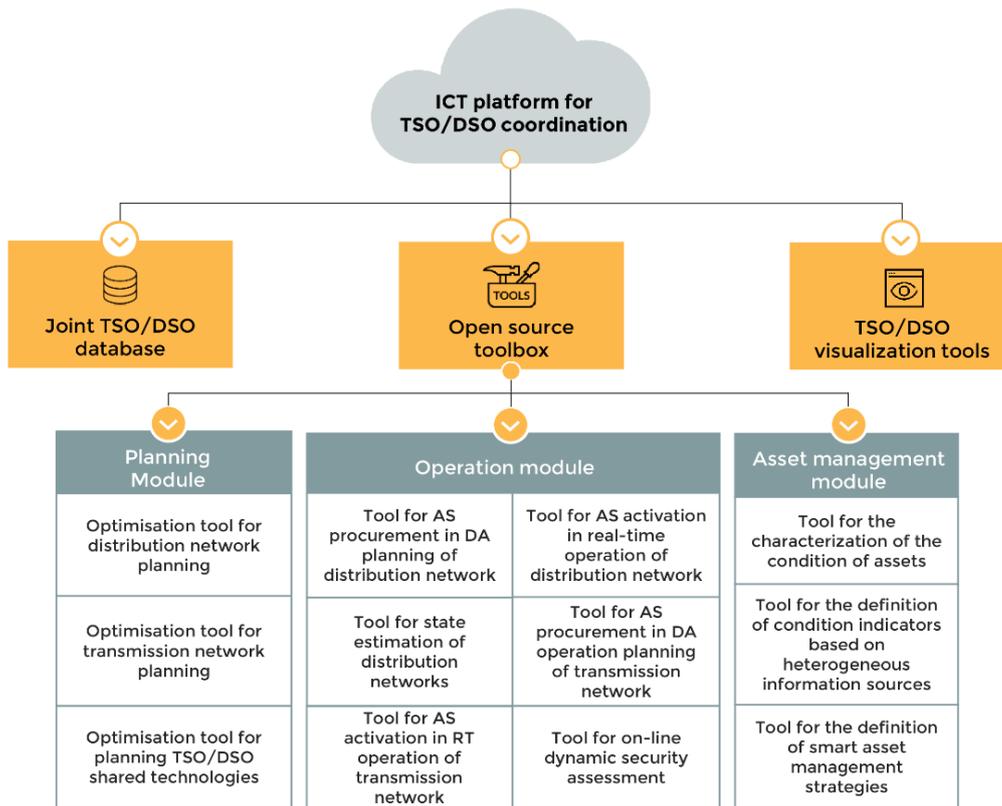


Figure 2.2: The tools in the open source toolbox

## 2.1. Planning Module

The planning module of the open source toolbox will incorporate three distinct network planning tools, all of them aiming at minimizing CAPEX (thus maximising asset utilisation), increasing reliability and reducing environmental impacts (including CO2 emissions reductions and improving air quality). Some of the tools will also consider that operating expenses (OPEX), as well as investments in assets (captured by CAPEX) can also impact the trade of flexibility in TSO/DSO markets and the associated network operation costs.

The relationship between the three planning module tools can be described in the diagram below.

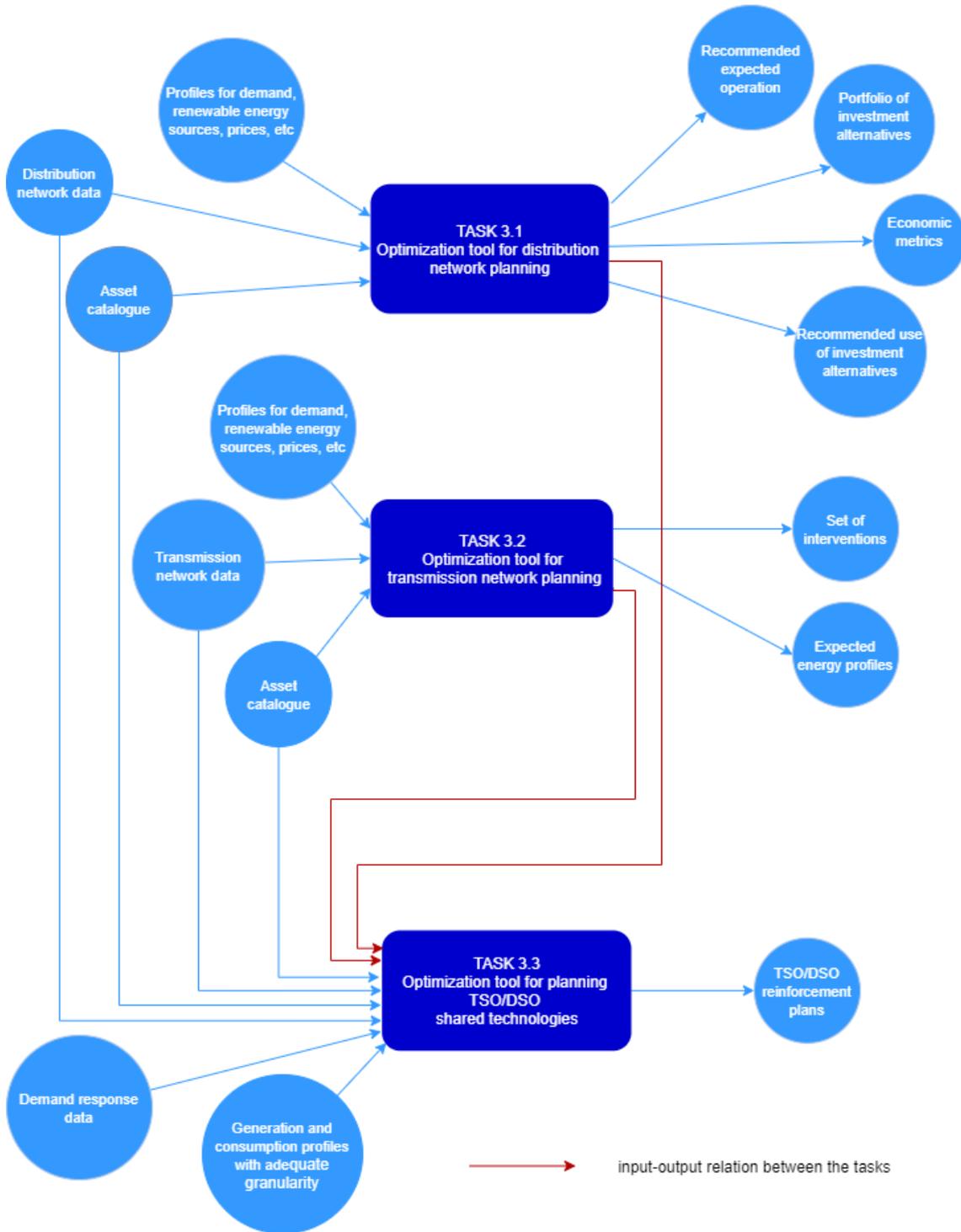


Figure 2.3: Planning Tools Relationship

### 2.1.1. Optimization tool for distribution network planning (Task 3.1)

The tool optimises a series of investment decisions at different times (years) throughout one or multiple scenarios (e.g., scenario tree). The impacts of each decision on the availability and costs of future network upgrades, called path-dependency, are modelled in consideration of the potential use of traditional asset-based solutions such as line and transformer upgrades, as well as and non-asset-based solutions such as demand side flexibility procured in DSO and TSO markets.

### *2.1.1.1. Test cases*

- Three representative MV distribution networks (e.g., 6.6 kV and 11 kV networks in the UK) representing urban, semi-urban and rural areas.
- (To be defined) Additional networks at a higher distribution voltage level are being considered (e.g., 33 kV).

### *2.1.1.2. Expected dependencies from other ATTEST tools*

Some dependencies and interactions are expected for the Optimization tool for distribution network.

In a nutshell, information is needed that changes the demand profiles and the flexibility available to deal with network constraints, as well as additional costs/benefits. The profiles are affected by MES aggregation, and procurement of ancillary services in the market. The available flexibility (and to some degree also the profiles) would be defined by TSO/DSO coordination and introduction of shared technologies. New asset management strategies would impact the CAPEX and OPEX and should also be considered.

In terms of our outputs, asset investment dictates the available network capacity and the need for network support from TSO/DSO markets.

In detail, the dependencies are:

- D2.5 (subsection 3.2) Day-ahead and real-time optimization tools to support MES aggregation which provides aggregated MES energy profiles and the expected potential to provide additional ancillary services.
- D4.1 (subsection 2.2.1) Ancillary services procurement in day-ahead operation planning of the distribution network, which defines energy profiles at different buses, considering the use of different ancillary services to meet network constraints while minimising operation costs. The network constraints would be based on the available assets and upgrades defined in T3.1.
- D2.4 (subsection 3.1) TSO/DSO coordination mechanisms which dictates the available flexibility that can be traded and impact investment and operation at the DSO (T3.1) and TSO (T3.2) levels.

Potentially relevant dependencies:

- D2.6 (subsection 3.3) Market simulator will impact the operation tools and use of assets, as well as the TSO/DSO mechanisms, also affecting investments.
- D3.3 (subsection 2.1.3) Optimisation tool for planning TSO/DSO shared technologies, which will affect the use of flexibility at one or both levels (TSO and DSO).
- D5.3 (subsection 2.3) Tool for the definition of smart asset management strategies, which will affect operation costs and influence (through the objective function) alternative asset investments.

### *2.1.1.3. Inputs*

- Distribution network data: Connectivity, line impedances and capacities, voltage levels.
- Asset and interventions catalogue, e.g., line and substation upgrades (lists of candidate assets with technical data and costs), managed connections and demand side flexibility services from DSO/TSO markets, etc.

- Profiles/scenarios across different zones for demand, renewable energy sources, prices, carbon intensities, etc.

### 2.1.1.3.1. Distribution network data

An example of network distribution data is provided below, in MATPOWER format (i.e., \*.m files which can be opened as text files). Since the applicability of existing import export tools and functions will depend on the MPC version (MATPOWER format detailed in Annex I), a new version for the ATTEST extension will be defined and properly handled by the importers during the implementation.

MATPOWER example (excerpts):

Busbars including demand data

Table 2.1: MATPOWER example – Busbars

```

% bus data
% bus_i type Pd      Qd      Gs Bs  area Vm  Va  baseKV zone Vmax  Vmin
mpc.bus=[
    1 1  0.0000  0.0000  0 0  1  1.0000  0 11 1  1.06  0.94
    2 1  0.0000  0.0000  0 0  1  1.0000  0 11 1  1.06  0.94
    3 1  0.0000  0.0000  0 0  1  1.0000  0 11 1  1.06  0.94
    4 1  0.0000  0.0000  0 0  1  1.0000  0 11 1  1.06  0.94
    5 1  0.0000  0.0000  0 0  1  1.0000  0 11 1  1.06  0.94

```

Branches data:

Table 2.2: MATPOWER example – Branches

```

% branch data
% bus tbus r      x      b      rateA B  C ratio angle status angmin angmax
mpc.branch=[
    22 21  0.00364463  0.00185124  0.000000  6.949992e+00  8.339991e+00  8.339991  0.000000  0.000000  1 360 -360
    7  2  0.00000030  0.00000030  0.000000  1.000000e+02  1.200000e+02  120.000027  0.000000  0.000000  1 360 -360
    2  4  0.00000030  0.00000030  0.000000  1.000000e+02  1.200000e+02  120.000027  0.000000  0.000000  1 360 -360
    4  5  0.00000060  0.00000060  0.000000  1.000000e+02  1.200000e+02  120.000027  0.000000  0.000000  1 360 -360
    10 5  0.00000018  0.00000018  0.000000  1.000000e+02  1.200000e+02  120.000027  0.000000  0.000000  1 360 -360
    8 10  0.00000035  0.00000035  0.000000  1.000000e+02  1.200000e+02  120.000027  0.000000  0.000000  1 360 -360

```

Note that this format has limitations to model no load losses in transformers. If needed, it will be extended with additional information.

Generators' technical data:

Table 2.3: MATPOWER example – Generators' technical data

```

% Generator data
% bus Pg      Qg      Qmax Qmin Vg      mBase status Pmax Pmin Pc1 Pc2 Qc1min
% Qc1max Qc2min Qc2max ramp_acg ramp_10 ramp_30 ramp_q Apf
mpc.gen=[
    7 0.00  0.00  2.17  0.00  1.00  100.00  1  23.75  0 0 0 0 0 0 0 0 0 0
];

```

Generators' economic data:

Table 2.4: MATPOWER example – Generators' economic data

```

%% generator cost data
% 1 startup shutdown n x1 y1 ... xn yn
% 2 startup shutdown n c(n-1) ... c0
mpc.gencost = [2 0 0 2 0 0];

```

The MATPOWER format (detailed in ANNEX I), and other available formats, do not provide all the information that would be required for this project. Accordingly, additions have been made to the data templates to cater for additional information, such as the coordinates and demand profiles presented below.

Coordinates of busbars:

The information follows the same order as `mpc.bus` (i.e., row 1 is for bus 1)

Table 2.5: MATPOWER example - Coordinates

```
%% Coordinates
mpc.coordinates = [
    -484 17;-484 18;-484 17;-484 18;-484 18;-484 17;-484 18;-484 18;
    -484 17;-484 18;-849 102;-653 -59;-831 96;-814 -138;-801 256;-891 264;
    -1087 177;-1089 180;-1305 81;-1305 142;-1209 -15;-1021 -90;-991 98;
    -1201 -4;-1466 278;-1417 170;-1550 332;-1460 -85;-1529 -46;-1548 -37
];
```

If needed, list of points for power lines in order to have their layout and length can be represented.

Active power time series

Table 2.6: MATPOWER example – Active power time series

```
%----- Demand data -----
% Time series (MW)
mpc.demandP = [
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
```

Reactive power time series

Table 2.7: MATPOWER example - Reactive power time series

```
% Time series (MVAR)
mpc.demandQ = [
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
```

Other formats could be used to represent network data, as IPSA, PSS/E and OpenDSS. However, for the sake of consistency and to facilitate interactions between WPs, the MATPOWER format would be preferred, for both transmission and distribution network data. The entities described, for the ATTEST purposes, should be the same, with the expected differences (e.g. distribution networks lower voltage level with respect to the transmission networks voltages). Some variations would be needed to define profiles, alphanumeric values, lines length.

### 2.1.1.3.2. Asset catalogue

An asset catalogue refers to the types of assets (e.g., lines, transformers, etc.) that would normally be used to reinforce the networks (some network operators keep specific assets in store). The catalogue normally is a list of assets, such as cables and transformers typically installed at different voltage levels. For example:

Table 2.8: Asset catalogue data example

Asset ID	Type	Size (mm <sup>2</sup> )	Capacity (A)	R (ohm/km)	X (ohm/km)	Cost per km (€)	Maintenance costs (€/km year) *	Investment costs (€/km year) *
1	UG 33 kV	95	180	0.3200	0.1088	10,800	154.00	870.333
2	UG 33 kV	185	270	0.1640	0.1000	14,400	298.12	1160.444
3	UG 33 kV	300	370	0.1000	0.0963	18,000	389.40	1450.555

There should not be any differences, in terms of the type of attributes, between transmission assets and distribution assets.

2.1.1.3.3. Profiles/scenarios across different zones for demand, renewable energy sources, prices, carbon intensities, etc.

Profiles/scenarios refers to (i) measured or representative data and (ii) forecasted scenarios that some operators may use to plan their networks. Examples of the forecasted scenarios for UK distribution and transmission companies are (i) UK distribution Future energy scenarios, <https://www.enwl.co.uk/get-connected/network-information/dfes/> and (ii) UK transmission future energy scenarios, <http://fes.nationalgrid.com/>. These scenarios provide assumptions for the integration of renewable and low carbon energy sources (e.g., PV, heat pumps, EVs, etc), reductions in the carbon intensity of the electricity sector, etc. the information is currently forecasted for every year until 2050.

The demand profiles can be taken from measurements at different substations such as from the primary substation supplying a distribution network. It is also an option to use the profile for the whole country to represent demand in large areas, such as those covered by the transmission network.

For planning tools, it would be ideal if the information is provided for different zones (i.e., from substation measurements) but also aggregated country level data can be used.

Time series data (e.g. metered half-hourly electricity demand) are reported in the transmission T3.2 example (see subsection 2.1.2.3.1).

2.1.1.4. Input data size

Depends on the size of the network (or level of detail). Each system will take a couple of MB (~10MB). This can become large if it is needed to store data from multiple networks.

2.1.1.5. Outputs

- Economic metrics (NPV, LCOE, CO2, etc.)
- Portfolio of investment alternatives, e.g., line reinforcement, substation upgrade, demand response contract, flexibility services from DSO/TSO market, etc.
- Recommended/expected operation, e.g., power flows, and set points for devices.
- Recommended use of investment alternatives throughout a scenario tree, i.e., recommended investments across every year of the planning horizon (45 years in the UK per scenario).

#### 2.1.1.5.1. Portfolio of investment alternatives

The portfolio of investment alternatives will be represented using the MATPOWER format by adding the new infrastructure (e.g., using `mpc.bus` and `mpc.branch`) as disconnected assets (using the status `on/off` option). To be more specific, different investment alternatives throughout multiple future energy scenarios (e.g., forming a tree) will be optimized and stored using excel files (as above). Afterwards, the list of interventions selected by the model will be added to the MATPOWER format, taking the data of the assets relevant to the interventions from the asset catalogue. The status of the new assets would be set to be off. Finally, the different network designs associated with the different years and scenarios throughout the tree will be coded as binary [0,1] matrices to be incorporated into the MATPOWER format (this work is in progress).

Based on this approach, specific conditions of a network can be modelled by selecting a future energy scenario and year. Afterwards, the corresponding network design and conditions, in MATPOWER format, can be produced by selecting the relevant values from the binary matrix to enable the relevant assets.

#### 2.1.1.5.2. Recommended/expected operation

The investment planning strategies will include consideration of flexibility services procured in DSO/TSO markets. To make such services available, the operation of centralised and distributed resources across the transmission and distribution networks must be modelled. The specific approach to model these services will be defined in deliverable

#### 2.1.1.6. Output data format

The outputs of the model (e.g., portfolio of investment alternatives) can be produced in different formats such as HDF5, JSON, and CSV. However, in the context of this project, the use of the MATPOWER format is preferred.

#### 2.1.1.7. Output data size

A couple of MB (e.g., ~15 MB) per network.

### 2.1.2. Optimization tool for transmission network planning (Task 3.2)

The planning tool provides adaptive transmission network investment strategies for different regions under consideration of deep uncertainty.

#### 2.1.2.1. Test cases

Simplified versions of the transmission networks across large areas (e.g., cities) or whole countries will be considered.

#### 2.1.2.2. Expected dependencies from other ATTEST tools

Some dependencies and interactions are expected for the Optimization tool for transmission network.

- D2.5 (subsection 3.2) Day-ahead and real-time optimization tools to support MES aggregation, which, after further aggregating results to the grid connection point levels (i.e., interfaces between DSOs and TSOs) provides MES energy profiles and the expected potential to provide additional ancillary services.
- D4.4 (subsection 2.2.4) Tool for ancillary services procurement in day ahead operation planning of the transmission network, which provides energy profiles, considering the use of ancillary services to meet network constraints while minimising operation costs.

The network constraints would be based on the available assets and upgrades defined in T3.2.

- D2.4 (subsection 3.1) TSO/DSO coordination mechanisms which dictates the available flexibility that can be traded and impact investment and operation at the DSO (T3.1) and TSO (T3.2) levels.

Potentially relevant dependencies:

- D2.6 (subsection 3.3) Market simulator will impact the operation tools and use of assets, as well as the TSO/DSO mechanisms, also affecting investments.
- D3.3 (subsection 2.1.3) Optimisation tool for planning TSO/DSO shared technologies, which will affect the use of flexibility at one or both levels (TSO and DSO).
- D5.3 (subsection 2.3) Tool for the definition of smart asset management strategies, which will affect operation costs and influence (through the objective function) alternative asset investments.

### *2.1.2.3. Inputs*

- Transmission network data: Connectivity, line/transformer impedances and capacities, voltage levels, line length.
- Asset catalogue, e.g., lines, transformers, storage, etc.
- Profiles/scenarios across different zones for demand, renewable energy sources, prices, carbon intensities, etc.

#### *2.1.2.3.1. Transmission network data*

To be consistent with the approach taken to model the distribution network, the MATPOWER format will also be used and extended to model transmission networks (see subsection 2.1.1.3.1, in the T3.1 section). Please note that MATPOWER format is not normally used and it is not expected to be provided by operators; conversion to MATPOWER from other formats will be carried out by the dedicated integration tasks.

#### *2.1.2.3.2. Asset catalogue*

The same approach taken for the Asset catalogue (in subsection 2.1.1.3.2, in the T3.1 section), is used here.

#### *2.1.2.3.3. Profiles/scenarios across different zones for demand, renewable energy sources, prices, carbon intensities, etc.*

The same approach taken in the T3.1 section is used here (ref. subsection 2.1.1.3.3 for a general “profiles/scenarios” description).

The resolution requirements will vary for different countries. The most typical will be 1h and half an hour. However, there will be cases where 5min or 1min resolutions are required.

Taking the UK as an example, most studies relevant to market applications (e.g., trade of DSO/TSO services) could be done with a half hourly resolution. However, detailed analysis of network constraints (e.g., voltage issues) require a 1 min resolution.

### *2.1.2.4. Input data formats*

- Network models in MATPOWER (\*.m) format.
- Other inputs (e.g., profiles) in MATLAB (\*.mat), JSON, CSV and excel formats.

For the tool's purpose, MATPOWER format could be used to describe a transmission network, provided that it is extended/integrated with all the data needed that MATPOWER doesn't cover directly e.g. MATPOWER describes connectivity, line/transformer impedances and capacities, voltage levels, but does not include line length, explicitly.

MATPOWER component IDs are expressed as numbers; In practice, generators' IDs, buses, etc. would be alphanumeric values, so it is needed to keep mapping between MATPOWER ID's and real, alphanumeric designations, e.g. using a link table with the correspondence between numeric and alphanumeric IDs.

#### *2.1.2.5. Input data size*

Depends on the size of the network (and level of detail). Each system will take a couple of MB (~20MB).

#### *2.1.2.6. Outputs*

- Set of interventions across different areas, e.g., investments in DG and heating technologies, as well as line reinforcement, substation upgrade, flexibility services from DSO/TSO market, etc.
- Recommended investments and network stress across different areas and scenarios, i.e., recommended investments across every year of the planning horizon (45 years in the UK per scenario).
- Expected energy profiles, e.g., seasonal weekday/weekend and peak day profiles with hourly resolution.
- Techno-economic metrics including losses, NPV, NPC, carbon emissions, etc.

T3.1 output and T3.2 outputs should be similar, so refer to section 2.1.1.6 for information about output.

#### *2.1.2.7. Output format*

HDF5 and JSON, but other formats (e.g., CSV) can also be used.

#### *2.1.2.8. Output data size*

A couple of MB (e.g., ~20 MB) per network, but it can grow substantially (~1GB) even for a single network if detailed information across multiple zones is also stored.

#### *2.1.2.9. TSO data source*

Croatian TSO (HOPS) can provide transmission network data: connectivity, line/transformer impedances and capacities, voltage levels, line length in excel format.

### **2.1.3. Optimization tool for planning TSO/DSO shared technologies (Task 3.3)**

Optimization tool for planning TSO/DSO smart grid technologies, which may be managed in coordination between TSO and DSOs.

#### *2.1.3.1. Test cases*

Shared TSO-DSO reinforcement plan datasets.

### *2.1.3.2. Expected dependencies from other ATTEST tools*

Some dependencies and interactions are expected for the Optimization tool for planning TSO/DSO shared technologies.

T3.1- Optimization tool for distribution network planning (subsection 2.1.1);  
T3.2 - Optimization tool for transmission network planning (subsection 2.1.2)

Potentially relevant dependencies:

- D2.4 TSO/DSO coordination mechanisms (subsection 3.1)

### *2.1.3.3. Inputs*

- Distribution network reinforcement plans (T3.1, subsection 2.1.1.5)
- Transmission network reinforcement plans (T3.2, subsection 2.1.2.6)
- Generation and consumption profiles with adequate granularity (preferably sub-hourly)
- Demand response data (clients who participate, flexibility models)
- Network data (transmission and distribution): Connectivity, line/transformer impedances and capacities, voltage levels, line length.
- Asset catalogue, e.g., storage, capacitor banks, transformers, etc.

### *2.1.3.4. Input data formats*

- Network models in MATPOWER (\*.m) extended format.
- Other inputs (e.g., profiles) in MATLAB (\*.mat), JSON, CSV and excel formats.

MATPOWER format could be used to describe the transmission and distribution networks, provided that it is extended/integrated with all the data. Distribution and transmission investments are received from T3.1 and T3.2, respectively, in a pre-defined format (e.g., HDF5, JSON, CSV). Other inputs, such as energy demand and production profiles, can be received in MATLAB, JSON, CSV and excel formats, with pre-defined structure.

### *2.1.3.5. Input data size*

Depends on the size (and level of detail) of the transmission and distribution networks. Since this tool takes as inputs transmission and distribution networks' data, and load/generation profiles with a high granularity, each system might require a few hundred MB of storage space (~200 MB).

### *2.1.3.6. Outputs*

- TSO/DSO reinforcement plans with TSO/DSO shared technologies

### *2.1.3.7. Output data format*

- JSON, excel and CSV, but other formats (e.g. HDF5) can also be used

### *2.1.3.8. Output data size*

A few MB (e.g., ~10 MB) per network.

### *2.1.3.9. TSO data source*

HOPS provides transmission network reinforcement plans (T3.2) in HOPS' Ten Year Network Development Plan (TYNDP), generation and consumption profiles (granularity is to be specified)

and demand response data (clients who participate, flexibility models). Data can be provided in excel or doc format.

## 2.2. Operation module

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The operation module is subdivided in two subgroups of tools, one for distribution networks and the other for transmission networks. The tools belonging to the distribution network subgroup aim at minimizing OPEX while maintaining the reliable operation of distribution network under massive deployment of renewable energy sources. These tools will take into account the future envisioned electricity markets functioning, including the constraints and uncertainty of variable renewable generation and the optimal utilization of networks assets.

The tools belonging to the transmission network subgroup have similar objectives to the distribution network tools. These tools will also take into account the envisioned markets functioning, including the constraints and uncertainty of variable renewable generation, N-1 contingency constraints, and the optimal utilization of networks assets.

The relationships among the tools to be developed are depicted in the following picture:

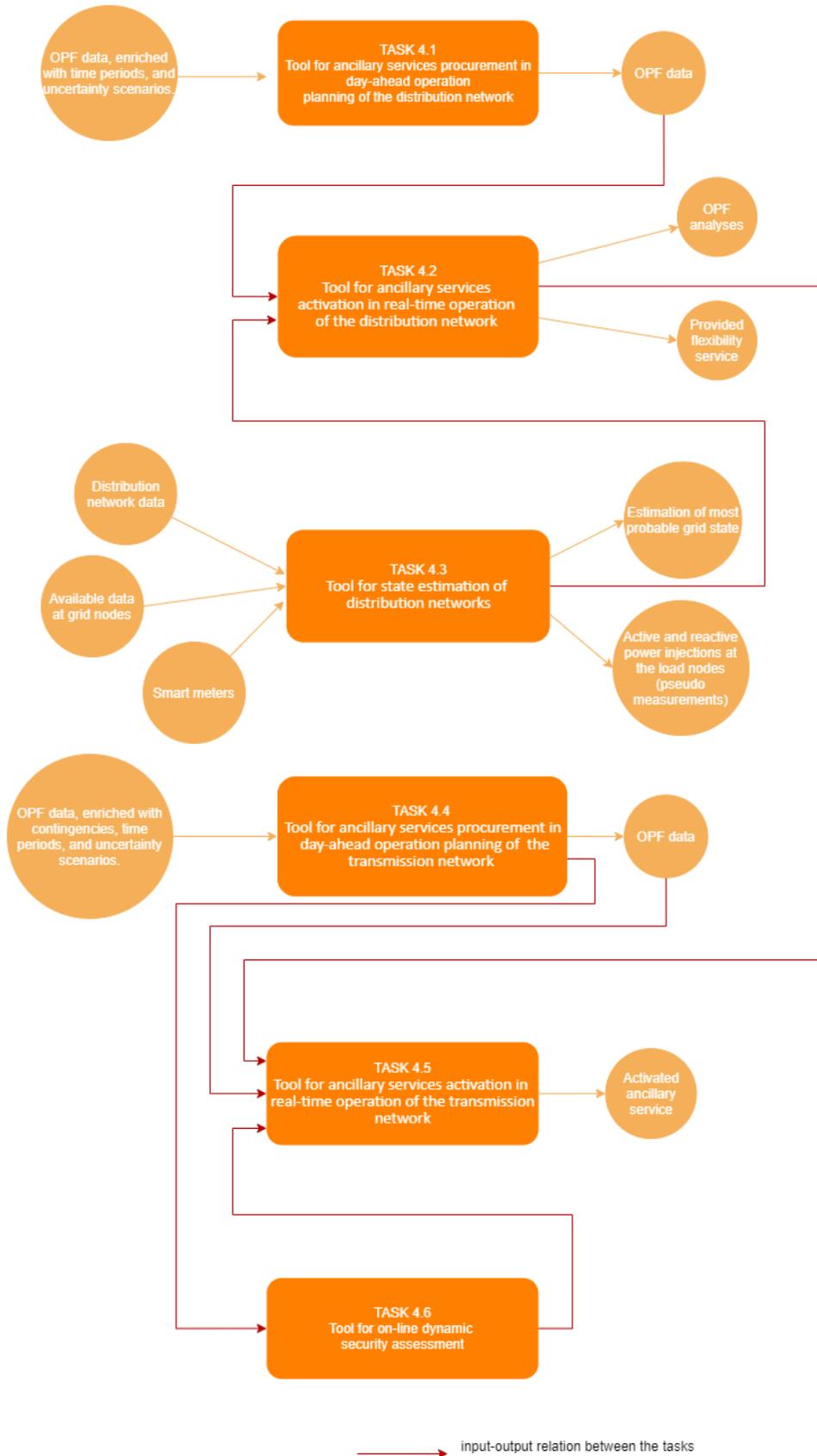


Figure 2.4: Operation Module Tools relationships

### 2.2.1. Tool for ancillary services procurement in day-ahead operation planning of the distribution network (Task 4.1)

The tool solves a problem of optimal power flow (OPF) including multiple time periods and renewable generation forecast uncertainties.

#### 2.2.1.1. Test cases

Test cases defined by WP2 (T2.3) and datasets from Croatian DSO (HEP ODS) provided in WP7.

#### 2.2.1.2. Expected dependencies from other ATTEST tools

The input data of this tool are the test cases defined in T2.3 and the ancillary services bids offered by flexibility providers defined in T2.6 (Market simulator, see subsection 3.3). This tool interacts with the tool developed for TSO in T4.4 (subsection 2.2.4), according to the TSO/DSO coordination mechanism defined in T2.4 (subsection 3.1).

#### 2.2.1.3. Inputs

- Distribution network data (from T2.3)
- Load and generation profiles corresponding to sampled uncertainty scenarios per time period (from T2.3)
- TSO specific requests (issued from T4.4) for ancillary services in terms of active and/or reactive power setpoints at the substation interfacing TSO and DSO
- Sources of flexibility (bids in terms of cost of activation cost provided by T2.6) and from asset and non-asset-based solutions (e.g. ancillary services)

Basically, the problem inputs are typical data needed for optimal power flow problems: network data enriched with time periods and uncertainty scenarios (developed and used only within this task).

#### 2.2.1.4. Input data format

The MATPOWER format will be used to represent network data; however, it needs to be further enriched to fit the needs of this task. An example of an alternative, specific, proprietary, data format for security-constrained optimal power flow (SCOPF) that can be also used is reported in Annex II. This format fits also the input of the tool in task 4.4.

#### 2.2.1.5. Input data size

For a system of 100 buses (typical system size that will be used in ATTEST) a very rough figure would be around 2,500 floating point numbers in double-precision (estimating 2.5-3 times floating point numbers per bus).

#### 2.2.1.6. Outputs

- Same format as the input for OPF data (i.e. either enriched MATPOWER- or enriched SCOPF-).

Optimal re-adjustments of flexible assets corresponding to various ancillary services and the overall cost of service procurement.

#### 2.2.1.7. Output data format

A data format exists and corresponds to the above-mentioned input data format.

### 2.2.1.8. Output data size

Same as input data

### 2.2.1.9. DSO data source

HEP ODS can provide network data:

- Offline: GE Smallworld platform-based GIS data, ABB network manager SCADA (so called “Historical database” is an oracle database). Some data sets can be provided in nearly DA.
- Real time data: ABB network manager SCADA

The data size depends on the format. The 35-kV voltage level is relatively small (up to several MB), 10 kV network is larger, but should not require more than 10 MB

SCADA real time measurements are updated every 10 seconds and aggregated (1 min to 1 hour).

## 2.2.2. Tool for ancillary services activation in real-time operation of the distribution network (Task 4.2)

This tool computes real-time optimal flexibility activation for ancillary services procurement by DSO. A multi-temporal stochastic/deterministic OPF will include flexibility (aggregated at MV/LV transformer interface), RES, storage and the action of active network management controllers of MV grid in order to remove violation of operational constraints (under/over voltages or overloading). Detailed network description is needed: voltage level, topology, power lines, wires and transformer characteristics, connected consumers and generation profiles, plans for future network investments.

### 2.2.2.1. Expected dependencies from other ATTEST tools:

Some dependencies and interactions are expected for the Tool for ancillary services activation in real-time operation of the distribution network.

1. Results from T4.3 (subsection 2.2.3, state estimation of distribution networks)
2. Coordination with T4.1 (subsection 2.2.1) “Tool for ancillary services procurement in day-ahead operation planning of the distribution network” and T 4.5 (subsection 2.2.5, “Tool for ancillary services activation in real-time operation of the transmission network”).
3. Results from T4.1 (Tool for ancillary services procurement in day-ahead operation planning of the distribution network)

### 2.2.2.2. Inputs

1. Consumption and generation profile at least for 2019/2020/2021 (historical data, see subsection 2.2.2.2.1) for each node in the observed area (resolution: 1 min, 5 min, 15 min or 1 hour)
2. Current state of the network test case:
  - Detailed network description (voltage level, connected devices)
  - Transmission power line characteristics (parameters R, X, B, C, length, topology)
  - Transformers characteristics (nominal voltages, rated power, earthing, short-circuit voltage)
  - Detailed description of connected consumers (residential, industrial, commercial) and distributed generations (type, size, location)

- Data communicated between flexibility providers and system operators (cost of peak power, DA load profiles, price for reserve and service activation, penalty for not providing the service)
3. Description of SG technologies (OLTC, storage, demand response), price and volume, OLTC transformer's capabilities
  4. Results from T4.1 (results from DA optimization)
  5. Results from WP4.3 (state estimation of distribution networks for 2030, 2040, 2050):
    1. Pseudo-measurements: Load data (load calibration)
    2. Topology estimation
      - Detailed network description (voltage level, connected devices)
      - Transmission line characteristics (parameters R, X, B, C, length, topology)
      - Transformers characteristics (nominal voltages, rated power, earthing, short-circuit voltage)
      - Detail description of flexibility providers at distribution level (location, size)

#### 2.2.2.2.1. Real time and historical data

An Excel/CSV document can be used as a format to represent the required historical data and real-time SCADA measurements. In the example below, a sheet for each relevant object is reported ("Nodes", "Transformer", "Branch", "Active Power", "Reactive Power", "Activated flexibility", "Price").

There is no need to specify detail description of connected consumers, only aggregated load and generation profile for each node. A sheet 'Price' could describe price for reserve and activation of balancing energy taken from ENTSOE transparency platform. This will differ among countries and type of service. Moreover, the same Excel could be used for pseudo-measurements of load data for 2030/2040/2050 and possible network topology changes reflected through changes in "Nodes" and "Branch" sheets.

#### Sheet 1 – Nodes

- Column A: Node name
- Column B: Node type (MATPOWER description field)
- Column C: RES installed? Yes/no?
- Column D: Installed capacity of RES
- Column E: Is there any flexibility provider? Yes/no
- Column F: Type of flexibility provider
- Column G: Capacity of flexibility provider
- Column H: Maximum duration of activation
- Column I: Time between activations
- Column J: Max number of activations

In Croatia, columns H, I, J are defined in the contract for providing ancillary service. These can differ among countries and different flexibility providers

Table 2.9: Nodes

Node	Type	RES	Installed capacity in MW	flexibility	Type	capacity in MW	maximum duration of activation	time between of activations	max number of activations
ND06	1	no	0	yes	battery	1 MW			
ND07	1	no	0	no		0			
ND15	1	yes	2	yes	battery	1 MW			
ND18	1	no	0	no		0			
ND19	1	no	0	yes	aggregated consumers	LV 2 MW			
ND20	1	yes	3	no		0			

## Sheet 2 – Transformer

- Column A: Name
- Column B: Starting node
- Column C: Ending node
- Column D: Primary voltage U1 [kV]
- Column E: Secondary voltage U2 [kV]
- Column F: short-circuit voltage Uk%
- Column G: OLTC capabilities

Table 2.10: Transformers

Transformer	From node	To node	U1 [kV]	U2 [kV]	Rated power MVA	Uk %
T1	ND00	ND01	110	10	40	18,5

## Sheet 3 – Branch

- Column A: Line name
- Column B: starting node
- Column C: ending node
- Column D: r in Ohm/km
- Column E: X in Ohm/km
- Column F: max rated current IrMax in A

Table 2.11: Branches

Line	Node From	Node To	Length [km]	R [Ohm/km]	X [Ohm/km]	IrMax [A]
LN02	ND01	ND02	0,120	0,130	0,110	496
LN03	ND02	ND03	1,302	0,160	0,270	470

Note: If future network reinforcement is planned, topology changes can be explained in a single Excel.

### Sheet 4 – Active Power (P)

- Column A: Timestamp (dd/mm/yyyy hh:MM:ss)
- Column B-number of nodes: active power in MW – separate load and generation measurements for each node

Table 2.12: P

Timestamp	LD01_P[MW]	LD02_P[MW]	LD03_P[MW]	LD04_P[MW]	LD05_P[MW]
27/03/2019 00:00:00	0,00002855	0,00018675	0,00057279	0,000	0,000
27/03/2019 00:15:00	0,00002764	0,00017905	0,00054584	0,000	0,000
27/03/2019 00:30:00	0,00002692	0,00017178	0,00052008	0,000	0,000

Note: The resolution in this example is 15 minutes. For HEP ODS, any time resolution ranging from 1 minute to an hour is appropriate. Time resolution must be agreed upon and kept consistent throughout the project.

### Sheet 5 – Reactive Power (Q)

- Column A: Timestamp (dd/mm/yyyy hh:MM:ss)
- Column B-number of nodes: reactive power in MVar – separate load and generation measurements for each node

Table 2.13: Q

Timestamp	LD01_Q[MVar]	LD02_Q[MVar]	LD03_Q[MVar]	LD04_Q[MVar]	LD05_Q[MVar]
27/03/2019 00:00:00	2,855E-09	1,8675E-08	5,7279E-08	0,000	0,000
27/03/2019 00:15:00	2,764E-09	1,7905E-08	5,4584E-08	0,000	0,000
27/03/2019 00:30:00	2,692E-09	1,7178E-08	5,2008E-08	0,000	0,000

### Sheet 6 – Activated flexibility

- Column A: Timestamp (dd/mm/yyyy hh:MM:ss)
- Column B, C, etc.: Provided flexibility in MW for each node

Table 2.14: Flexibility

Timestamp	ND06	ND15	ND19
27/03/2019 00:00:00	0		
27/03/2019 00:15:00	0		
27/03/2019 00:30:00	0		

### Sheet 7 – Price

- Column A: Timestamp (dd/mm/yyyy hh:MM:ss)

- Column B: DA prices [EUR/MWh]
- Column C: Price of Reserved Balancing Reserves [EUR/MW]
- Column D: Prices of Activated Balancing Energy up [EUR/MWh]
- Column E: Prices of Activated Balancing Energy down [EUR/MWh]

Table 2.15: Prices

Timestamp	DA prices	Price of Reserved Balancing Reserves	Prices of Activated Balancing Energy up	Prices of Activated Balancing Energy down
27/03/2019 00:00:00	27,13	7,29	41,41	3,129
27/03/2019 00:15:00	23,77	7,29	38,55	11,5
27/03/2019 00:30:00	22,78	6,6	38,8	41,4

Note: Since ancillary services are awarded differently among the countries and the prices differ, each country will provide its own Prices information.

#### 2.2.2.3. Input data formats:

Input data format will be in CSV, JSON, excel formats.

#### 2.2.2.4. Input data size:

Input data size is estimated to be several MB.

#### 2.2.2.5. Outputs:

1. Results of OPF analysis
2. Provided flexibility service (resource and the volume, cost for service activation)
3. Resolved violated operation constraints (nodes with under/over voltages or line overloading)

#### 2.2.2.6. Output data formats:

Output data format will be in CSV, JSON, excel formats.

#### 2.2.2.7. Output data size:

Output data size is estimated to be several MB.

### 2.2.3. Tool for state estimation of distribution networks (Task 4.3)

Even for the 2030 distribution systems, where we can expect the communication technologies to be much more developed and communication-enabled devices prominent, failures may still occur, preventing an accurate definition of the network operating state due to stale or missing data. This tool will allow estimating the operating state of the network with minimal available information (by estimating the net load in each node of the grid) and thus enable usage all the tools developed for networks operation even when there is lack of data and/or inconsistent data redundancy. The distribution system state estimation (DSSE) task is the process of detecting the system's state variables using a limited number of measurement data from certain locations in the modelled distribution system.

The principal difference between the state estimation in transmission and distribution systems is related to much lower observability of the distribution systems, lower X/R values of the network, possibility of unbalanced operation and the absence of topology (network configuration) data. The inclusion of renewable generation in the distribution network makes the problem even more complex. To take on these issues, the distribution state estimation tool must take advantage of the maximum available data and also widen the scope, e.g. towards data read from smart meters or even phasor measurement units from the grid.

#### *2.2.3.1. Input data*

The network data set is quite similar to the one required in subsection 2.2.1: basically, all the operational network data available for the current state of the network test case:

- Detailed network description (voltage level, connected devices)
- Detailed distribution line characteristics to the extent of availability (parameters R, X, B, C, length, topology)
- Transformers characteristics (nominal voltages, rated power, earthing, short-circuit voltage)
- Detailed description of connected consumers (residential, industrial, commercial) and distributed generations (type, size, location)
- Eventual further data communicated between flexibility providers and system operators
- Available measurement data from the SCADA system (real time and historical)

However, in a typical DSSE problem this dataset does not ensure the observability of the system, therefore the input measurement set needs to be augmented artificially with a set of generated pseudo measurements – artificial data points compensating for the missing measurement data, as well as corrected (to remove erroneous data from the existing measurements). Diverse data-driven approaches exist, and for the distribution networks the principal source to generate pseudo measurements are

- Metering readouts and/or node load profiles from the relevant grid, coming from the smart metering system, mapped to the nodes in the grid
- Possibly: relevant meteorological and other data (e.g. current temperature readouts) that could be used to correctly scale the node load profiles

We are aware of the implications of using the meter readout data as well as the challenges in integrating with the meter readout systems that should provide the data. Furthermore, we are aware of privacy issues – for the state estimation one needs the meter readouts and load profiles mapped to the grid node instead to a single customer. The typical existing typical automated meter readout and metering data management systems are principally designed for periodic readouts, targeting the periodic billing operation instead of real-time system operation. For this reason, it is expected this tool will use a snapshot of the available metering data, i.e. the integration with live metering system will be simulated and tested at several levels.

#### *2.2.3.2. Output data*

Estimated most probable grid state variables (voltage angle and magnitude at each node, and active and reactive power injections as pseudo measurements)

### *2.2.3.3. Input data formats:*

MATPOWER format (for the network data to be consistent with the other tools) or another suitable format carrying the network data, CSV or JSON for the metering data time series

### *2.2.3.4. Input data size:*

Several MB

### *2.2.3.5. Output data formats:*

Same as the input data

### *2.2.3.6. Output data size:*

Several MB

## **2.2.4. Tool for ancillary services procurement in day-ahead operation planning of the transmission network (Task 4.4)**

Generally speaking, the tool solves a problem of security-constrained optimal power flow including multiple time periods and forecast uncertainties. Specifically, the tool optimizes the day-ahead procurement of ancillary services for congestion management and voltage.

### *2.2.4.1. Test Cases*

The tool will test cases produced by WP2 (T2.3) and datasets from HOPS provided in WP7.

### *2.2.4.2. Expected dependencies from other ATTEST tools*

The input data of this tool are the test cases developed in T2.3 and the ancillary services bids offered by flexibility providers defined in T2.6. (Market simulator, 3.3) This tool interacts with the tool developed for DSO in T4.1 (subsection 2.2.1), according to the TSO/DSO coordination mechanism defined in T2.4 (3.1). This tool provides inputs to and receives constraints from the tool in T4.6 (subsection 2.2.6).

### *2.2.4.3. Inputs*

Basically, data needed for security-constrained optimal power flow problems, enriched with contingencies, time periods, and uncertainty scenarios.

The MATPOWER or the SCOPF data format, briefly described for T4.1 (subsection 2.2.1), need to also describe contingencies. A contingency consists in the loss of one or several elements (power line, transformer, generator) and contains these fields:

1. the keyword "contingency:"
2. contingency name (character)
3. mode (binary): 0 (resp. 1) contingency is addressed in preventive (resp. corrective) mode. Actually, this is used only if the SCOPF is solved with some contingencies in preventive mode and others in corrective mode. Otherwise, i.e. if the SCOPF is solved in either preventive or corrective mode the value of this field is ignored.
4. the keyword "bt" or "gt" corresponding to branch tripping and generator tripping
5. the name of the lost element
6. the keyword "end contingency".

#### *2.2.4.4. Input data formats*

A sample data format is described in T4.1 section (subsection 2.2.1.3) or MATPOWER format enriched with specific additional files and particularly flexibility providers bids (cost and volume) generated by T2.6.

#### *2.2.4.5. Input data size*

For a system of 1000 buses (typical maximum system size that will be used in ATTEST) a very rough figure would be around 25,000 floating point numbers in double-precision

#### *2.2.4.6. Outputs*

- Typical optimal power flow data (likewise with the input data)
- Optimal re-adjustments of flexible assets corresponding to various ancillary services and the overall cost of service procurement
- Specific requests for DSOs to maintain a specified active and/or reactive power flow according to the TSO-DSO cooperation mechanism

#### *2.2.4.7. Output data formats*

A data format exists and corresponds to the above-mentioned input data, i.e. MATPOWER format enriched with additional specific files. MATPOWER format is non-readable for HOPS. In case MATPOWER format is not readable by partners, needed format converters will be developed.

#### *2.2.4.8. Output data size*

A sample data format is described in T4.1 section (subsection 2.2.1.3) or MATPOWER format enriched with specific additional files and particularly flexibility providers bids (cost and volume) generated by T2.6.

#### *2.2.4.9. TSO data source*

NetVision DAM is an EMS system used by HOPS for real time security analysis, post-mortem analysis, congestion forecast and preparation of data that is exchanged for different purposes, such as coordinated capacity calculation and security analysis.

Data formats are CIM (CGMES), UCTE DEF, PSSE RAW and the data sizes are roughly estimated as 2 MB (CIM-CGMES), 50 KB (UCTE DEF), 150 KB (PSSE RAW). These data formats will require developing a data converter from PSSE RAW format to MATPOWER format.

### **2.2.5. Tool for ancillary services activation in real-time operation of the transmission network (Task 4.5)**

This tool computes TSO-initiated activation of ancillary services as real-time remedial actions to enhance grid security. These remedial actions include classical control means as well as new features such as: flexibility at TSO-DSO interfaces, storage, and flexibility at multi-energy hubs in transmission network

#### *2.2.5.1. Expected dependencies from other ATTEST tools*

- Results from T4.2 (subsection 2.2.2 ancillary services activation in real-time operation of the distribution network)
- Results from T4.6 (subsection 2.2.6 on-line dynamic security assessment) which will determine the ancillary service necessary for maintaining the system security

- Results from T4.4. (Tool for ancillary services procurement in day-ahead operation planning of the transmission network)

## 2.2.5.2. Inputs

1. Detail network description (topology, voltage level, connected devices)
2. Load data (type, size and location) – continuous historical measurements (resolution: 1 min, 5 min, 15 min, 1 hour)
3. Generation data (type, size and location) – continuous historical measurements (resolution: 1 min, 5 min, 15 min, 1 hour)
4. Detail description of flexibility providers at transmission and distribution level (location, size, frequency of activation, price, activated volumes)
5. Results from T4.2 (subsection 2.2.2 ancillary services activation in real-time operation of the distribution network) due to TSO-DSO coordination
6. Results from T4.6 (subsection 2.2.6, on-line dynamic security assessment)
7. Results from T4.4. (the results of DA operation)

### 2.2.5.2.1. Input data formats

CSV, JSON, excel formats

### 2.2.5.2.2. Input data size

Several MB

## 2.2.5.3. Outputs

Activated ancillary service for congestion management, voltage control, frequency in order to satisfy grid security:

1. type of ancillary service provided
2. cost of provided service
3. provided volume
4. impact on the transmission network: voltage, frequency, line and transformer loading
5. impact on the distribution network

### 2.2.5.4. Output data formats

CSV, JSON, excel formats

### 2.2.5.5. Output data size

Several MB

### 2.2.5.6. Input details

Ref. T4.2 section (subsection 2.2.2), for the details; In T4.5, only Sheets Nodes, Branch, P, Q are relevant when considering providing the flexibility from distributed sources.

### 2.2.5.7. TSO data source

The following data can be provided by HOPS:

1. Detail network description data (excel format)
2. Ten Year Network Development Plan
3. Energy Development Strategy of the Republic of Croatia until 2030 with an Outlook to 2050

4. Transmission line characteristics data in excel format
5. Transformers characteristics data in excel format
6. Generation data for transmission connected generation units (excel format)
7. Detail description of flexibility providers at transmission and distribution level **data (excel format)**

There is no direct data base access and web service for providing data.

## 2.2.6. Tool for on-line dynamic security assessment (Task 4.6)

This tool is aimed for on-line dynamic security assessment in future power systems is specially oriented to the prevailing threat of frequency stability due to the increasing large shares of power electronic grid interfaced RES in scenarios close to 100 % of instantaneous renewables penetration. This tool aims to integrate, for this specific purpose, frequency security constraints in the SCOPF formulation of T4.4 (subsection 2.2.4) aiming to guarantee that each dispatch solution meets the necessary volume of inertia (synthetic or synchronous) capable of limiting the rate of change of frequency as well as the minimum primary frequency control power reserve that must be available to cope with postulated contingencies. These constraints will be derived using a machine learning approach that will exploit functional knowledge obtained using an off-line full dynamic simulation toll of the electric power system taking into account a set of critical constraints to be identified and covering all the foreseen operating scenarios.

### 2.2.6.1. Inputs

To be used in the off-line full dynamic simulation:

- Network single line diagram and expected development plans (ex: TYNDP);
- Future scenarios for generation portfolio development;
- Steady state and dynamic model of the grid including the complete parameterization of the generator dynamic models for typical operational scenarios (peak and valley scenarios, seasonal scenarios, etc...)

To be used during on-line security assessment:

- Network state obtained from SCADA/EMS system

### 2.2.6.2. Input data formats

CSV, JSON, excel formats

### 2.2.6.3. Input data size

Several Mb

### 2.2.6.4. Outputs

- Identification of potential instability threats caused by critical disturbances
- Selection of relevant remedial actions (both preventive and remedial)
- Operation constraints for T4.4 (subsection 2.2.4) and T4.5 (subsection 2.2.5)

### 2.2.6.5. Output data formats

CSV, JSON, excel formats

### 2.2.6.6. Output data size

Several Mb

### 2.2.6.7. TSO data source

HOPS can provide dynamic data (Siemens PSS/E) and SCADA real time data.

Format for dynamic data: Dyr

## 2.3. Asset management module

The asset management module of the open source toolbox will incorporate three distinct aspects to observe the asset condition that will contribute to improve and help the asset management of distribution and transmission networks, offering information about their remaining useful life for changing operation conditions. This module will embed the tools described below in a unique framework:

- Tool for the characterization of the condition of assets.
- Tool for the definition of condition indicators based on heterogeneous information sources
- Tool for the definition of smart asset management strategies

The relationship between three asset management module tools can be described in the diagram below.

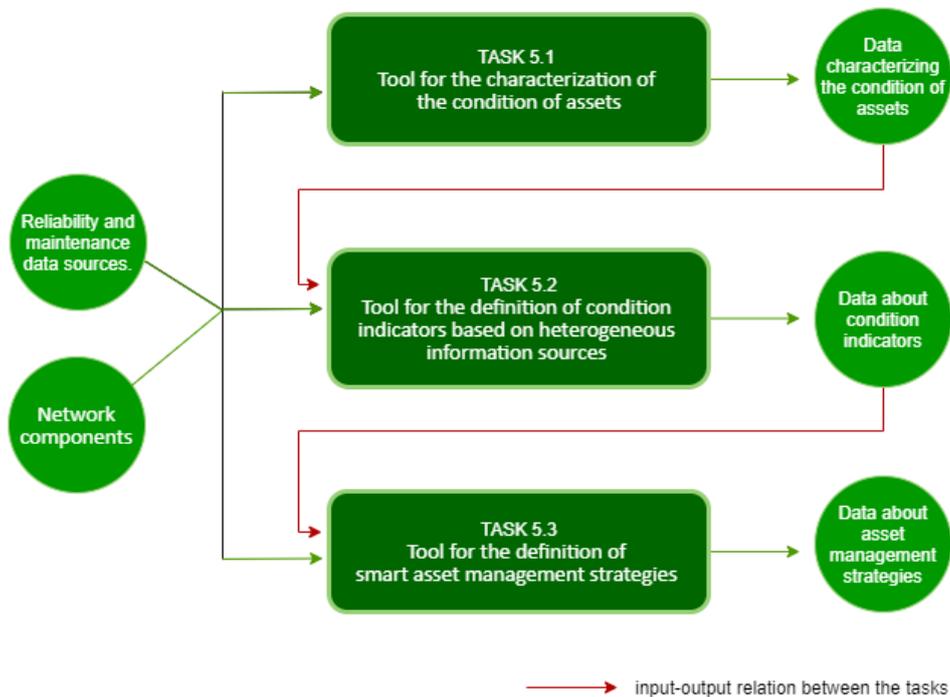


Figure 2.5: Asset Management Tools Relationships

### 2.3.1. Tool for the characterization of the condition of assets (Task 5.1)

This tool will characterize and model the life of important network asset components, such as power transformers, exploring techniques that include the characterization of the reliability using fault history and the characterization of the mean time to repair based on the history of

maintenance actions, while also taking into account patterns for component behaviour and *condition collected from sensors and utilization rates*.

### 2.3.1.1. Test cases

Transmission and/or distribution network with less than 1000 buses and network components at a first approach.

### 2.3.1.2. Expected dependencies from other ATTEST tools

Some dependencies and interactions are expected for the Tool for the characterization of the condition of assets. The expected dependencies are from T2.3, T2.6, T4.2, T4.5.

### 2.3.1.3. Inputs

Most part of the data required for asset management, and in particular in power systems, is not registered under a common format. Usually the data required for asset management in an electrical company is dispersed through several data management systems normally focused on the operation and maintenance in separate ways.

The data used in asset management can be classified in these four categories:

- A. Component data.
- B. Reliability data. Fault historical information.
- C. Maintenance data.
- D. Continuous monitoring behaviour data.

In power systems the data of types A, B and C are stored in different sources and formats. Data in category D are not too extended yet.

#### 2.3.1.3.1. Component data

The information required here is related to the topology of the power network, which is basically the names of the components and their interconnections.

An example of a component record is shown below.

Table 2.16: Component data

Component ID	Component type	Component characteristics	Where is it located? (i.e. substation, feeder...)	In service date	Expected operation	Rating	Maintenance scheduled
Miscellaneous N/A	Alphabetic type	Miscellaneous	Miscellaneous	Date type	Numeric	Numeric	Miscellaneous N/A

The description of the items is the following (OPTIONAL means convenient but not mandatory):

- Component ID. Internal code used in the company for the unique identification of this component.
- Component type. Type of component.
- Component characteristics. Several fields can be used for this definition, depending on component type.
- Where it is located. E.g. in a substation, in a feeder, indoor/outdoor, GPS coordinates, region, city, etc.
- In service date. This is used to know the age of the component.
- Expected operation. E.g. full load, medium load, normally open, normally closed etc.
- Rating. This is the rating (load, voltage, current) expected, if this is applicable.

- Maintenance scheduled. Usually expressed over a period of time as for example 3 years, or a number of manoeuvres or switching operations as for example 1500 switching operations.

Example supplied by HEP ODS - Power Transformers

Table 2.17: Power Transformer

Component ID	Component characteristics	Component characteristics	Component type	Where is located? (i.e. substation, feeder...)	Expected operation	In service date	Rating
Substation ID	Voltage Ratio	Insulation Medium	Transformer Type	Indoor/Outdoor	Annual Maximum Loading (kVA)	Age	kVA Rating
2	10(20)/0.42 kV	OIL	8EuTBN 400-24x/A,24/0.4,400	INDOOR	114	22	400
5	10(20)/0.42 kV	OIL	8EuTBN 830-24x/A,24/0.4,830	INDOOR	170	11	830

Example supplied by HEO ODS - UG cables

Table 2.18: Underground cables

Where is located? (i.e. substation, feeder...)	Component ID	Component characteristics	In service date	Component characteristics	Expected operation	Rating	Component characteristics	Component characteristics					
Section Label	Circuit ID	Conductor Cross Sectional	Sheath Material	Design Voltage	Operating Voltage	Insulation Type / Sheath	Conductor Material	Age	Length of Cable Section (m)	Maximum Section Loading (A)	Section Rating	Type	Number of cores
1KV17/9	230248113	95	LEAD	12 kV	10 kV	Impregnated p	Cu	48	202	11.5	255	IPO 13 3x95	3
1KV17/1	230248113	150	NOT APPLICA	24 kV	10 kV	XLPE/PE	Al	3	1042	32.0	319	XHE 49-A 3x1	1

Observe that the item maintenance scheduled is not present in the example supplied, but it is expected to have this as this is key data.

2.3.1.3.2. Reliability data. Fault historical information

Definitions below are extracted from IEEE standard 493-2007 - IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.

- Component: A piece of electrical or mechanical equipment viewed as an entity for the purpose of reliability evaluation.
- Failure (f): The termination of the ability of a component or system to perform a required function.
- Failure rate ( $\lambda$ ): The mean (arithmetic average) is the number of failures of a component and/or system per unit exposure time. The most common unit in reliability analyses is hours (h) or years (y). Therefore, the failure rate is expressed in failures per hour (f/h) or failures per year (f/y).
- Mean time to failure (MTTF): The mean exposure time between consecutive repairs (or installations) of a component and the next failure of that component. MTTF is commonly found for non-repairable items.
- Mean time between failures (MTBF): The mean exposure time between consecutive failures of a component.
- Reliability: The ability of a component or system to perform required functions under stated conditions for a stated period of time.

In regards the availability of data the following two possible scenarios are considered.

Scenario 1. A failure rate is already available either for each component or for each component and per failure mode. If this is the case and the failure rate is considered constant, then it is only possible to develop an exponential life model.

Scenario 2. There are no kinds of failure rates available, but there are records about fault cases of components. In this case the failure rate can be estimated from this data under the hypothesis of a constant average value (used in exponential life models) or under the hypothesis of a dynamic failure rate. This scenario allows for more flexibility in the creation of life models for components and more accuracy of their lives.

Reliability data for scenario 1

Failure rate is denoted by the Greek letter  $\lambda$  (lambda). In power systems the typical unit is failures per year. In electronics and power systems the failure rate is considered constant for a type of component and is obtained as an average value of the failure rates of all the particular components of the same type. If the failure rate  $\lambda$  is constant the Mean Time Between Failures (MTBF) is  $1/\lambda$ .

The data considered for this case could be the following:

Table 2.19: Demand profile transmission data

Component ID	Component type	Failure rate	Failure mode	Failure rate per failure mode	MTTF	MTBF	Costs	Effects
Miscellaneous N/A	Alphabetic type	Numeric	string type	Numeric	Numeric	Numeric	numeric	Miscellaneous

The description of the items is the following (OPTIONAL means convenient but not mandatory):

- Component ID. Internal code for the unique identification of this component.
- Component type. Type of component
- Failure rate. Mean number of failures of a component per unit exposure time. Units: failures/year
- Failure mode (OPTIONAL). As an example, a power transformer can fail due to an internal short circuit or a problem in the magnetic core or a problem in the isolation. There should be three different failures modes.
- Failure rate per failure mode (OPTIONAL). Unit failure/year.
- MTTF (OPTIONAL). Mean exposure time between consecutive repairs (or installations) of a component and the next failure of that component. MTTF is commonly found for non-repairable items. Unit: years
- MTBF (OPTIONAL). Mean exposure time between consecutive failures of a component. If the failure rate is considered constant, this data is not needed. Unit: years.
- Costs. Costs associated to this fault. Unit: monetary unit used.
- Effects (OPTIONAL). Any additional comment describing the consequences or effects of the fault of this component.

Reliability data for scenario 2

This is the scenario when no failure rate is available, but it is possible to estimate it from records of failures. In this case more work has to be carried out in order to reach the scenario 1 which is the target. However, in this case more accurate life models can be designed and implemented.

The data considered for this case could be the following:

Table 2.20: Reliability data for scenario 2

Event ID	Starting date	End date	Component type	Failure mode	Costs	Effects
numeric type/ (alphabetic)	date type	date type	Alphabetic type	string type	numeric	Miscellaneous

The description of the items is the following (OPTIONAL means convenient but not mandatory):

- Event ID (also it could be fault ID). Internal code for the unique identification of this fault.
- Starting date. Date when the failure was detected.
- End date. Date when the failure was removed.
- Component type. Type of component
- Failure mode (OPTIONAL). As an example, a power transformer can fail due to an internal short circuit or a problem in the magnetic core or a problem in the isolation. There should be three different failures modes. If they are known the life of the component can be better characterized.
- Costs of the failure. Costs associated to this fault. Unit: monetary unit used.
- Effects (OPTIONAL). Any additional comment in free style describing the consequences or effects of the fault of this component.

HEP ODS Example - Case of power transformers

Table 2.21: Power transformers case of HEP ODS example

ID	Transformer Type	Age	Cost of failure [€]
2	8EuTBN 400-24x/A,24/0.4,400,	22	4916
5	8EuTBN 630-24x/A,24/0.4,630,	11	6014

Under some adaptation it could be associated to scenario 1. If the hypothesis of failure rate constant is assumed for this particular case, it is required to find a failure rate from the manufacturer of the power transformer or from public information about failure rates of this type of power transformer. Once this is obtained and using the item “Age” in the data, a life model for each power transformer can be obtained as an approximation. Note that “failure rate” is required but a reasonable approximation combining “Age” and a generic failure rate for these power transformers could be obtained.

“Costs” could be associated to “Cost of failure [€]”

HEP ODS Example - Case of underground cables

Table 2.22: Underground cables case of HEP ODS example

Section Label	Circuit ID	Age	Network Performance Cost of Failure	Fault History
1KV17/9	230248113	48	34,083 €	0
1KV17/1	230248113	3	34,083 €	0

If the hypothesis of failure rate constant is assumed, it is required to find a failure rate that in this case can be supported by the item “Fault history” combined with information coming from the cable manufacturer or from public information about failure rate of this type of cable. Once this is obtained and using the item “Age” in the data, a life model for each underground cable can be obtained, as an approximation. Note that we required “failure rate” but we could obtain a reasonable approximation combining “Fault history”, “Age” and a generic failure rate for these cables.

“Costs” could be associated to “Network Performance Cost of Failure [€]”

### 2.3.1.3.3. Maintenance data

Definitions below are extracted from IEEE standard 493-2007 - IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.

- Maintenance downtime (Mdt): The total downtime for scheduled maintenance (including logistics time, spare parts availability, crew availability, etc.) for a given time period (Tp) (hours).
- Mean downtime (MDT): The average downtime caused by scheduled and unscheduled maintenance, including any logistics time.
- Mean time to maintain (MTTM): The average time it takes to maintain a component, including logistics time. MTTM is primarily a measure of the preventative maintenance frequency and durations.
- Mean time to repair (MTTR or simply r): The mean time to replace or repair a failed component. Logistics time associated with the repair, such as parts acquisitions, crew mobilization, are not included. It can be estimated by dividing the summation of repair times by the number of repairs and, therefore, is practically the average repair time. The most common unit in reliability analyses is hours (h/f).
- Total maintenance actions (Tma): The total number of scheduled maintenance actions during the Tp.

The data considered for this case could be the following:

Table 2.23: Maintenance Data

Component ID	Component type	Maintenance action ID	Starting date	End date	Maintenance type	Maintenance code	Effectivity expected	Cost	Resources required: work hours, materials...
Miscellaneous N/A	Alphabetic type	numeric type/ (a	date type	date type	string type	string type	numeric	numeric	Miscellaneous

The description of the items is as follows (OPTIONAL means convenient but not mandatory):

- Component ID. Internal code for the unique identification of this component.
- Component type. Type of component
- Maintenance action ID (also it could be work order ID). Internal code for the unique identification of a maintenance work order.
- Maintenance type. The most used maintenance categories: scheduled (preventive maintenance), corrective (corrective maintenance) and inspection (preventive maintenance). However other deep codes are used for example in the scheduled category in order to distinguish between scheduled maintenance based on time or events (i.e. number of manoeuvres).
- Maintenance code. Internal of the maintenance action (i.e. change oil in the power transformer)

- Effectivity expected (OPTIONAL). Estimate effect that this maintenance work has for restoring the best condition of the component. Unit: percentage with respect to the best condition of the component.
- Costs. Costs associated to this maintenance order. Unit: monetary unit used.
- Resources required (OPTIONAL) Maintenance-hours required, spares needed, ...

Using these items, the Mean downtime (MDT) and Mean Time To Repair (MTTR) can be estimated.

HEP ODS example - Case of power transformers

Table 2.24: Power transformers case of HEP ODS example

Substation ID	Transformer Type	Transformer External Condition
2	8EuTBN 400-24x/A,24/0.4,400,	GOOD
5	8EuTBN 630-24x/A,24/0.4,630,	GOOD

HEP ODS example - Case of underground cables

Table 2.25: Underground cables case of HEP ODS example

Section Label	Circuit ID	Repair time (h)
1KV17/9	230248113	6
1KV17/1	230248113	4

“Repair time (h)” corresponds to MTTR which is a key maintenance parameter.

#### 2.3.1.3.4. Other data

There is other data that can be useful to complement the previous information, such as the importance of a component from an asset management point of view

Table 2.26: Complementary data for Asset management

Component ID	Component type	ENS (Energy Not Supplied)	Clients affected
Miscellaneous N/A	Alphabetic type	Numeric	Numeric

HEP ODS example - Case of power transformers

Table 2.27: Power transformers case of HEP ODS example

Substation ID	Transformer Type	Annual Maximum Loading (kVA)	Number of Connected Customers	Number of Sensitive Customers	Backup Supply
2	8EuTBN 400-24x/A,24/0.4,400	114	188	5	NO
5	8EuTBN 630-24x/A,24/0.4,630	170	230	11	NO

- ENS. This can be expressed in terms of losses of energy units. This data is not available at this moment but a rough value could be obtained from the annual maximum loading and customers connected.
- Clients affected. Number of clients affected for a fault of this component. “Clients affected” could be associated to a “Number of Connected Customers”. Additionally, a very important item included in the HEP data is the “Number of Sensitive Customers”. This can be used as another factor of the importance of this component. In the same way the item “Backup Supply” can be considered.

HEP ODS example - Case of underground cables

Table 2.28: Underground cables case of HEP ODS example

Section Label	Circuit ID	Number of Connected Customers on Feeder	Number of Connected Sensitive Customers on Feeder
1KV17/9	230248113	1731	23
1KV17/1	230248113	1731	23

- ENS (Energy Not Supplied). This can be expressed in terms of losses of energy units. If this data is not available a rough value could be obtained from the annual maximum loading and customers connected.
- Clients affected. Number of clients affected for a fault of this component. “Clients affected” could be associated to a “Number of Connected Customers on Feeder”. Additionally, a very important item included in the HEP data is the “Number of Connected Sensitive Customers on Feeder”. This can be used as another factor of the importance of this component.

2.3.1.3.5. Elaborated Data

Formulation is required for building impact factors in the asset management:

- Type of life models applied to the component: model type, parameters, ...
- Maintenance models applied to the component: type of model, parameters, reference date

Other data sources continuous or discrete that are monitoring important characteristics of components could be considered in this WP, such as current or temperatures in power

transformers or other network components. In this case, the amount of information to be managed would be much higher

#### *2.3.1.4. Input data format*

Xlsx/CSV tables or other digital formats of data storage

#### *2.3.1.5. Input data size*

<100 MB (estimated)

#### *2.3.1.6. Outputs*

- Data characterizing the condition of assets based on life models
- Data about condition indicators based on combination of life and maintenance models and effectiveness of the application of preventive maintenance
- Data about asset management strategies based on ranking of condition indicators observed in the components

#### *2.3.1.7. Output data format*

Text or JSON files

#### *2.3.1.8. 2.3.1.8. Output data size*

<30MB (estimated)

#### *2.3.1.9. 2.3.1.9. DSO data source*

COMILLAS can provide three Spanish distribution networks, including:

- An urban medium voltage network (20kV).
- A high voltage network (66 / 132 kV)
- A synthetic medium voltage network (20 kV)

The medium voltage network will also include the low voltage network (0.4kV), but from the point of view of the analysis to be carried out in the project, the aggregated demand in the distribution transformer can be considered as sufficient.

Main elements of the networks:

- Consumers
- Power lines
- Distribution transformers
- Substations
- Switching devices

The synthetic distribution network will be fully available. The model that will be used to build the network will not be available.

The format of the network is MATLAB/MATPOWER format (bus and branch matrixes .m) and GIS files (.dbf, .shp, shx).

Data size is about 5-20MB total for all three networks together.

### 2.3.2. Tool for the definition of condition indicators based on heterogeneous information sources (Task 5.2)

This tool will incorporate an innovative approach to translate the results obtained from the previous tool into a set of harmonised, easily measurable and comparable life indicators for different types of assets, which will allow determining the remaining useful life and the underlying sensitivities against different operation conditions.

#### 2.3.2.1. Inputs

The inputs for this task are the outputs of T5.1.

#### 2.3.2.2. Outputs

- Common life indicators for heterogeneous assets in JSON format

### 2.3.3. Tool for the definition of smart asset management strategies (Task 5.3)

This tool will define common approaches to evaluate the assets under different perspectives (operation, maintenance, cost, impact) resulting in asset priority lists. Smart strategies for asset management based on the previous asset evaluation and common life indicators will also be developed. Finally, the outputs of this tool will be embedded in the grid planning and operation tools available in the toolbox to allow optimized decisions taking into account not only CAPEX but also OPEX costs.

#### 2.3.3.1. Inputs

The inputs for this task are the outputs of T5.2.

#### 2.3.3.2. Outputs

- Prioritized lists of assets according to predefined management strategies in JSON format

### 3. Support tools and data for operationalization

Some support tools will be developed to generate test cases to test the tools from the different modules of the open source toolbox as well as a set of data to operate the ICT platform is required.

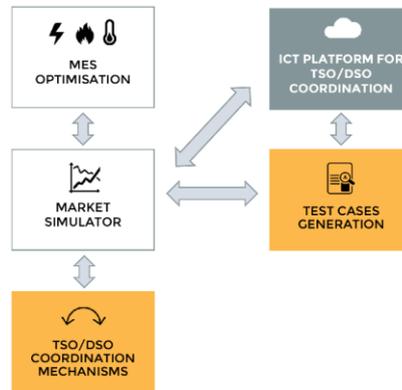


Figure 3.1: Support tools and data for the ICT platform

In order to run the proposed tools, a set of test cases will be generated to feed the three classes of tools (for network operation, asset management and network planning). These test cases include identification of the electricity networks at the different voltage levels, as well as integration scenarios of smart grid technologies and corresponding prices, load and generation scenarios, electricity market data, more relevant assets to consider, etc.

To this end, a set of networks, both at the transmission and at the distribution level considering several voltage levels, will be identified from different European countries including Portugal, Spain, UK and Croatia. This includes network topology and characteristics from the different assets (lines, cables, transformers, consumers, DG, etc.) from real networks that will be provided in an anonymised way.

#### 3.1. TSO/DSO coordination mechanisms (Task 2.4)

The planning and operation tools will be developed taking into account TSO/DSO coordination mechanisms to foster more cost-efficient and reliable utilization of the resources available in both transmission and distribution systems. At planning level, the TSO/DSO coordination mechanisms will reduce CAPEX of the planning strategies and optimize the utilization of the smart grid technologies located in both transmission and distribution networks. At operation level, the TSO/DSO coordination mechanisms will optimize the interactions between TSO and DSO during the acquisition and delivery of ancillary services at both local and cross-border levels.

The TSO/DSO coordination mechanisms will include innovative electricity market architectures, rules and codes to support a joint TSO/DSO strategy to plan and operate the future energy system. These new coordination mechanisms will extend the roles of the TSO and DSO. From the DSO perspective, the coordination mechanisms will enable the DSO to participate in the technical validation and procurement of ancillary services traded in the electricity markets. From the TSO perspective, the coordination mechanisms will enable the TSO to procure and activate ancillary services provided by smart grid technologies located in both transmission and distribution networks.

## 3.2. Day-ahead and real-time optimization tools to support MES aggregators (Task 2.5)

This task aims at developing optimization tools to support the participation of MES aggregators in energy and ancillary services markets. The optimization tools are divided into day-ahead and real-time approaches. The day-ahead optimization tool defines bids for the energy and ancillary services markets. The real-time management algorithm dispatches the operation of the MES and ensures the reliable delivery of the energy and ancillary services traded by the aggregator in the day-ahead markets. Both day-ahead and real time approaches will include steady state modelling of the electricity, district heating and gas networks so that day-ahead bids and actual realizations are technically feasible. This task will feed the electricity market simulation platform (described in T2.6) with day-ahead and real-time market behaviours of MES aggregators.

### 3.2.1. Test cases

The test case to be used is the microgrid of the University of Manchester. It has 39 buildings, an electricity network, a gas network and a district heating. In the following figure it is presented the diagram of these networks:

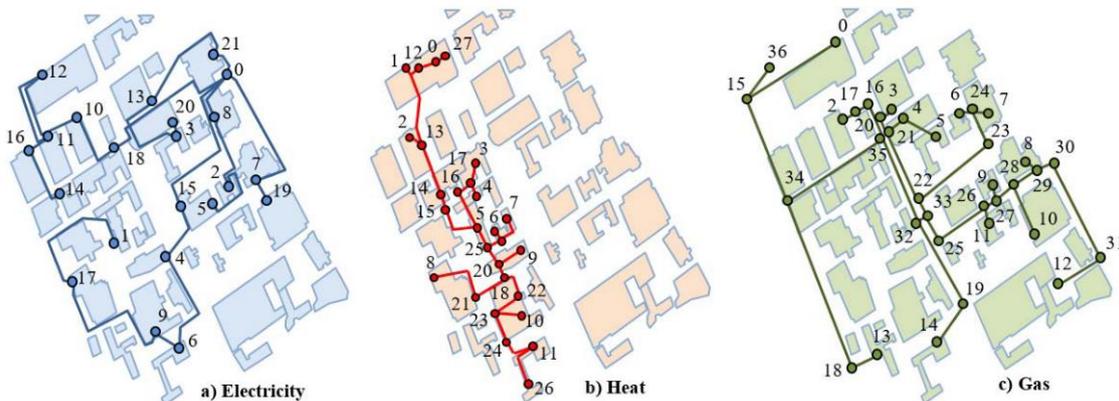


Figure 3.2: Diagram of the UoM microgrid

### 3.2.2. Expected dependencies from other ATTEST tools

There are no expected dependencies from the other ATTEST tools.

### 3.2.3. Inputs

The data used by the aggregator to perform the optimization are costs and weather forecasts:

1. Costs
  - 1.1. Electricity buying
  - 1.2. Gas buying
  - 1.3. Electricity sold to the network
  - 1.4. Demand response programs
2. Weather forecasts
  - 2.1. PV generation
  - 2.2. Outside temperature

The data needed to characterize electricity networks operated by the electricity DSO are the following:

1. Branches
  - 1.1. Node connections
  - 1.2.  $R_{ij}$  [ $\Omega$ ]
  - 1.3.  $X_{ij}$  [ $\Omega$ ]
  - 1.4. Maximum limits [kW]
2. Generators
  - 2.1. Location
  - 2.2. Maximum and minimum limits [kW]
3. Loads
  - 3.1. Location
  - 3.2. Power [kW]

The data needed to characterize gas networks operated by the gas DSO are the following:

1. Pipelines
  - 1.1. Node connections
  - 1.2. Length (m)
  - 1.3. Diameter (mm)
  - 1.4. Maximum and minimum pressure limits (Pa)
  - 1.5. Maximum and minimum flow limits ( $\text{m}^3/\text{s}$ )
2. Generators
  - 2.1. Location
  - 2.2. Maximum and minimum limits [kW]
3. Loads
  - 3.1. Location
  - 3.2. Power [kW]

The data needed to characterize district heating networks operated by the heat DSO are the following:

1. Pipelines
  - 1.1. Node connections
  - 1.2. Length (m)
  - 1.3. Diameter (mm)
  - 1.4. Heat transfer coefficient ( $\text{W}/^\circ\text{C}$ )
  - 1.5. Maximum and minimum pressure limits (Pa)
  - 1.6. Maximum and minimum flow limits ( $\text{kg}/\text{s}$ )
  - 1.7. Maximum and minimum temperature limits ( $^\circ\text{C}$ )
2. Generators
  - 2.1. Location
  - 2.2. Maximum and minimum limits [kW]
3. Loads
  - 3.1. Location
  - 3.2. Power [kW]

The data needed to characterize each energy hub operated by the aggregator is the following:

1. Location of each energy hub in the network
2. Number of rooms
3. Parameters of each room and energy system necessary for the thermal model
  - 3.1. Thermal constant
  - 3.2. Thermal resistance [ $^{\circ}\text{C}/\text{kW}$ ]
  - 3.3. Thickness of the walls [m]
  - 3.4. Thermal conductivity of the material [ $\text{kW}/\text{m}\cdot^{\circ}\text{C}$ ]
  - 3.5. Area [ $\text{m}^2$ ]
  - 3.6. Volumetric heat capacity [ $\text{kJ}/\text{m}^3\cdot^{\circ}\text{C}$ ]
  - 3.7. Volume [ $\text{m}^3$ ]
  - 3.8. Thermal capacitance [ $\text{kWh}/^{\circ}\text{C}$ ]
  - 3.9. Specific heat capacity [ $\text{J}/\text{g}\cdot^{\circ}\text{C}$ ]
  - 3.10. Density of the materials of the walls [ $\text{g}/\text{m}^3$ ]
  - 3.11. Efficiency of coils [%]
  - 3.12. Coefficient of performance of coil
  - 3.13. Coefficient of performance of refrigeration systems
  - 3.14. Insulation [ $\text{kWh}/^{\circ}\text{C}$ ]
4. Inflexible loads profiles
  - 4.1. Electrical equipment [kWh]
  - 4.2. Cooking [kWh]
5. Flexible loads – requisites for each consumer:
  - 5.1. Spaces temperature set points and flexibility bands [ $^{\circ}\text{C}$ ];
  - 5.2. Hot water temperature and flexibility band [ $^{\circ}\text{C}$ ];
  - 5.3. Refrigeration systems temperatures and flexibility bands [ $^{\circ}\text{C}$ ];
  - 5.4. EVs connection and disconnection hours;
  - 5.5. Final SOC of the EVs [kWh].
6. Energy resources limits (electric boilers, gas heaters, CHP, ...)
  - 6.1. Maximum capacity [kWh]
7. EVs limits
  - 7.1. Charging and discharging limits [kWh]
  - 7.2. Maximum and minimum capacity [kWh]
8. PV limits
  - 8.1. Installed power[kW]

### 3.2.4. Input Data formats

Text, CSV or numpy files.

### 3.2.5. Input Data size

Less than 100 MB.

### 3.2.6. Outputs

The outputs of this tool are the bids and energy needs from the aggregator:

1. Electricity energy bids per hour
2. Upward and downward electricity reserve bids

3. Gas consumed in each hour
4. Heat consumed at each hour

### 3.2.7. Data format

Text, CSV or numpy files.

### 3.2.8. Data size

Less than 100 MB.

## 3.3. Market simulator (Task 2.6)

A market simulator will be developed since future energy systems operation and assets utilization will be highly influenced by electricity markets functioning. The consideration of the market outputs in the network management tools development assures that they will be easily integrated in TSOs/DSOs everyday tasks and seamlessly applicable to future networks. The market simulator purpose is to emulate future EU-wide energy and ancillary services markets, so that the open source toolbox performance can be evaluated in a realistic manner that takes into account the economic influence of the market on the network's operation and assets utilization. Furthermore, the market simulator will allow defining network operating states for future scenarios of grid development, which enable a more effective network planning taking into account the foreseen existence of DER flexibility and its optimal utilization.

In order to ensure an effective interaction between TSOs/DSOs, the market simulator will be designed to extend the current roles of DSOs in the electricity market, enabling the participation of DSOs in energy and ancillary services markets for technical validation and procurement of ancillary services for congestion management and voltage control at distribution level.

To avoid that TSOs and DSOs procure conflicting ancillary services (e.g. buy flexibility in opposite directions in the same network region), several TSO/DSO coordination mechanisms will be developed in the project and incorporated in the market simulator.

The sequential market operations from day-ahead to real-time are described in Figure 2.8. The market operations require different tools. The steps of the process (1, 2, ...) and the role of each tool in each step are reported in the figure and explained below.

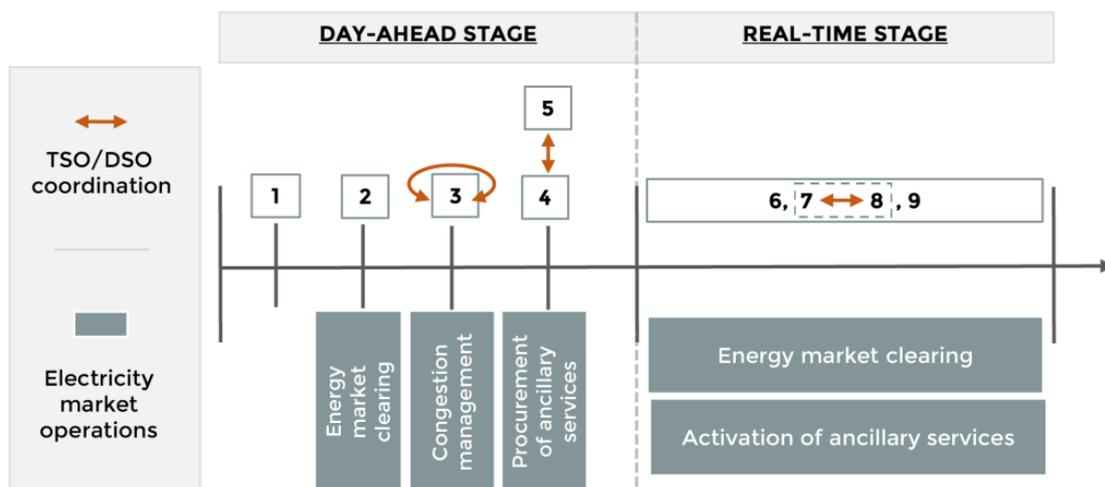


Figure 3.3: Proposed electricity market operations

1. **Day-ahead bidding optimization tool to support MES aggregators:** defines energy and ancillary service bids through the optimization of MES;
2. **Market simulator:** performs the clearing of the day-ahead energy market;
3. **Market simulator:** performs congestion management to generate viable daily schedules, based on the results of the energy market clearing. TSO and DSOs participate in this market operation through a strong coordination;
4. Tool for ancillary services procurement in day-ahead operation planning of the distribution network:  
  
DSO procures ancillary services for voltage control and congestion management in the day-ahead ancillary services markets;
5. Tool for ancillary services procurement in day-ahead operation planning of the transmission network:  
  
TSO procures ancillary services for frequency control, voltage control and congestion management in the day-ahead ancillary services markets. This tool considers TSO/DSO coordination mechanisms;
6. **Market simulator:** performs the clearing of the intra-day energy market in continuous mode. It includes also the technical validation of the updated energy offers;
7. **Tool for ancillary services activation in real-time operation of the distribution network:** DSO optimizes the activation of flexibility, provided by both DSO assets and ancillary services procured by the DSO in the day-ahead markets;
8. **Tool for ancillary services activation in real-time operation of the transmission network:** TSO optimizes the activation of flexibility, provided by both TSO assets and ancillary services procured by the TSO in the day-ahead markets. This tool considers TSO/DSO coordination mechanisms;
9. **Real-time optimization tool to support MES aggregators:** dispatches the operation of the MES to ensure that the energy and ancillary services traded in the day-ahead markets, and activated by the TSO and DSOs are delivered.

## 4. Technical requirements

In Annex III, some tool characteristics, collected from the developers of the tools are summarized. Some preliminary technology-related requirements (e.g. languages, software dependencies, etc.) are also included, to be finalized and detailed in the specific tools and ICT platform development deliverables.

## 5. Conclusions

This document reports the main requirements collected from the developers of the tools and reflects the current status of the research in tools specification. Consequently, these requirements will be better specified in the course of the ATTEST project: this deliverable should be considered as a living document, that will be amended and completed during the first phases of tools development.

Nonetheless, the current work in requirement specification allows to set some important guidelines, that define a common framework for tools and ICT platform development.

### 5.1. Data model

---

The main classes of data that will be modelled in the project are summarized in the following diagram

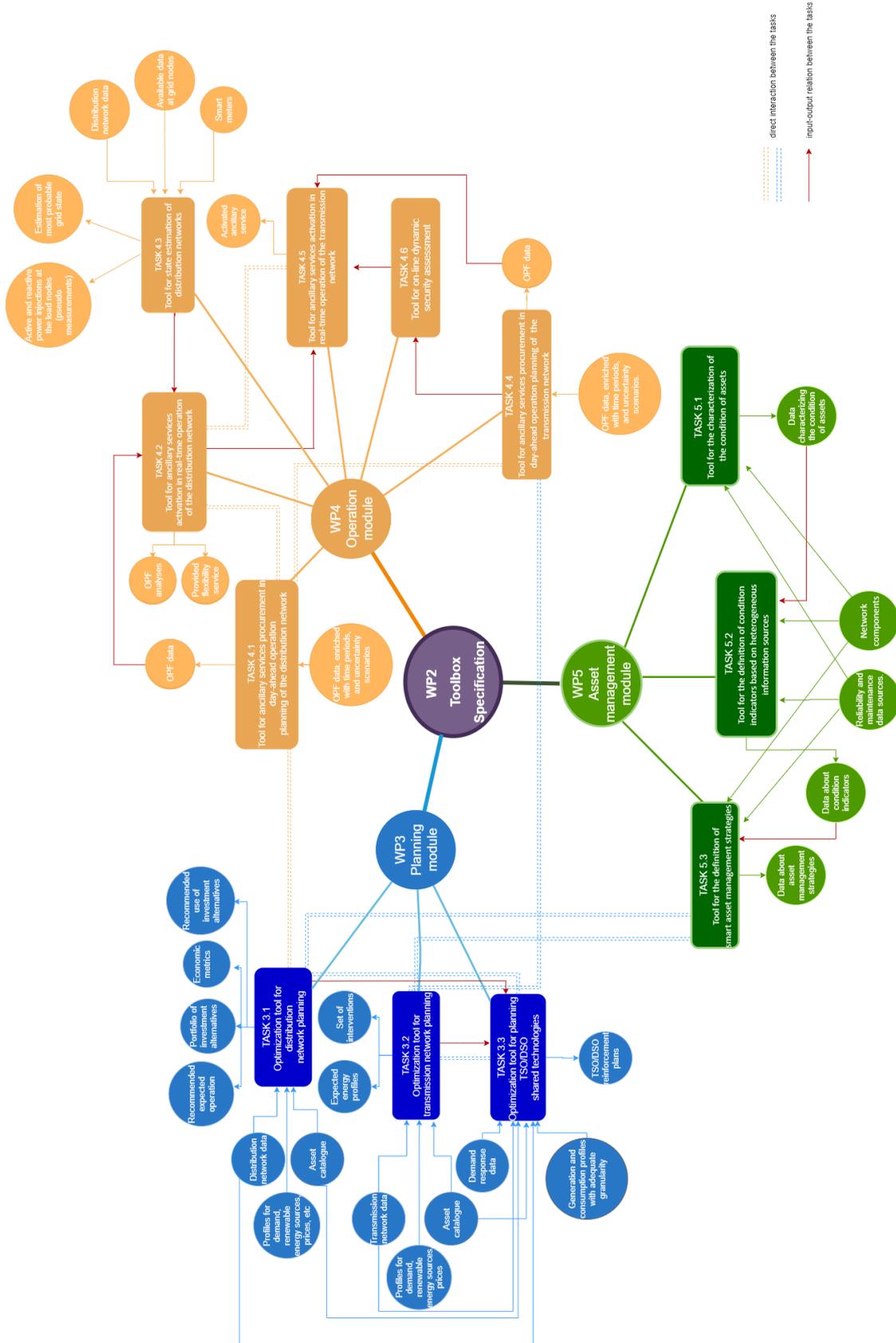


Figure 5.1: Inputs, outputs and interactions among the tools

## 5.2. Network data formats for transmission and distribution data

---

While collecting the requirements, it emerged that the level of detail provided by the CIM model is overwhelming for the needs of ATTEST tools. Importantly, the use of the node-breaker representation in CIM is convenient for real-time but is more complicated for planning and operation, the major tools to be developed in ATTEST.

It has been decided, therefore, to focus more on facilitating the development of the algorithmic tools by using the MATPOWER format model (even if is rarely used in practice by the operators), while leaving the support for actual formats (e.g. CIM) in the actual DSOs/TSOs, for the integration stage.

The MATPOWER format model, which is able to represent a bus branch network topology, should be rich enough to be used as the internal toolbox format for both transmission and distribution networks ATTEST needs – provided that it is ‘extended’ to capture new data sets envisioned for the power systems of the future:

- to allow alphanumeric IDs, to identify the network components
- to include component attributes that are not in the official format, e.g. lines length, load losses in transformers, list of points for power lines
- time series of generation and load profiles
- scenarios sampled from uncertainties

Of course, it is needed to track and document the semantics of each extension: data types, etc.

It also emerged that the excel file format is adequate to encode the networks models. HDF5 format could be thought as an alternative to excel.

## 5.3. Asset Catalog

---

There will be an effort to unify in a single catalogue the list of assets required for WP3 and WP5.

In WP5, asset data is split into three categories: “component data”, “reliability fault historical data” and “maintenance data”.

Data about costs used in WP3 and WP5 should also be put into relationship. For example, in WP3 there are variables linked to costs: “cost”, “maintenance cost” and “investment cost”, whereas in WP5 costs are split into two categories: reliability (Costs of the failure; cost associated to “Network Performance Cost of Failure”) and maintenance (Costs associated to a maintenance order).

## 5.4. Technologies related requirements

---

### 5.4.1. Programming languages

According to the information collected from the developers of the open source toolbox, Python (<https://www.python.org/>) seems to be the most common programming language choice. Some tools could also use C++ (<https://isocpp.org/>) and Julia (<https://julialang.org/>). Some tools will likely depend on external software (e.g. optimization solvers like CPLEX, Gurobi, GAMS) and possible further constraints and requirements to be verified for each third-party component (e.g., in terms of their availability for a specific OS and the integration APIs).

#### 5.4.2. Licenses and third-party software

The source code for the tools in the toolbox, will be available as open-source (license model to be discussed). Some tools could depend on and integrate some non-open source proprietary software. The developers for a tool will be responsible to verify possible licenses conflicts between what is expected from the tool and its required third-party software.

#### 5.4.3. Memory requirements

Memory requirements for the tools are not easy to estimate at this stage of the project. For some tools a rough, initial, estimate is, at least, 16 GB.

#### 5.4.4. Storage requirements

Not easy to estimate at this stage of the projects. It depends largely on the size of the input data.

#### 5.4.5. Processing power

The execution time for the tools generally depends on the test case. The execution time could take several hours and up to a day for T3.1 and T3.2, less than three hours for the tools in WP5 (but it depends on the number of the components). It could vary between few minutes and one or two hours for T4.4, T4.6. It is to be investigated if and to what extend the tools can exploit forms of parallel computation, to cover cases where a computation is expected at a regular cadence (e.g. every hour, each 15 minutes, etc.)

### 5.5. Time series data resolution

---

The resolution requirements for the time series data will vary for different countries. The most typical will be 1h and 0.5h. However, there will be cases where 5min or 1min resolutions may be required.

### 5.6. Tools interactions

---

The "Phase #2" box, in the ATTEST workflow figure below from the proposal, shows the expected interactions among the tools.

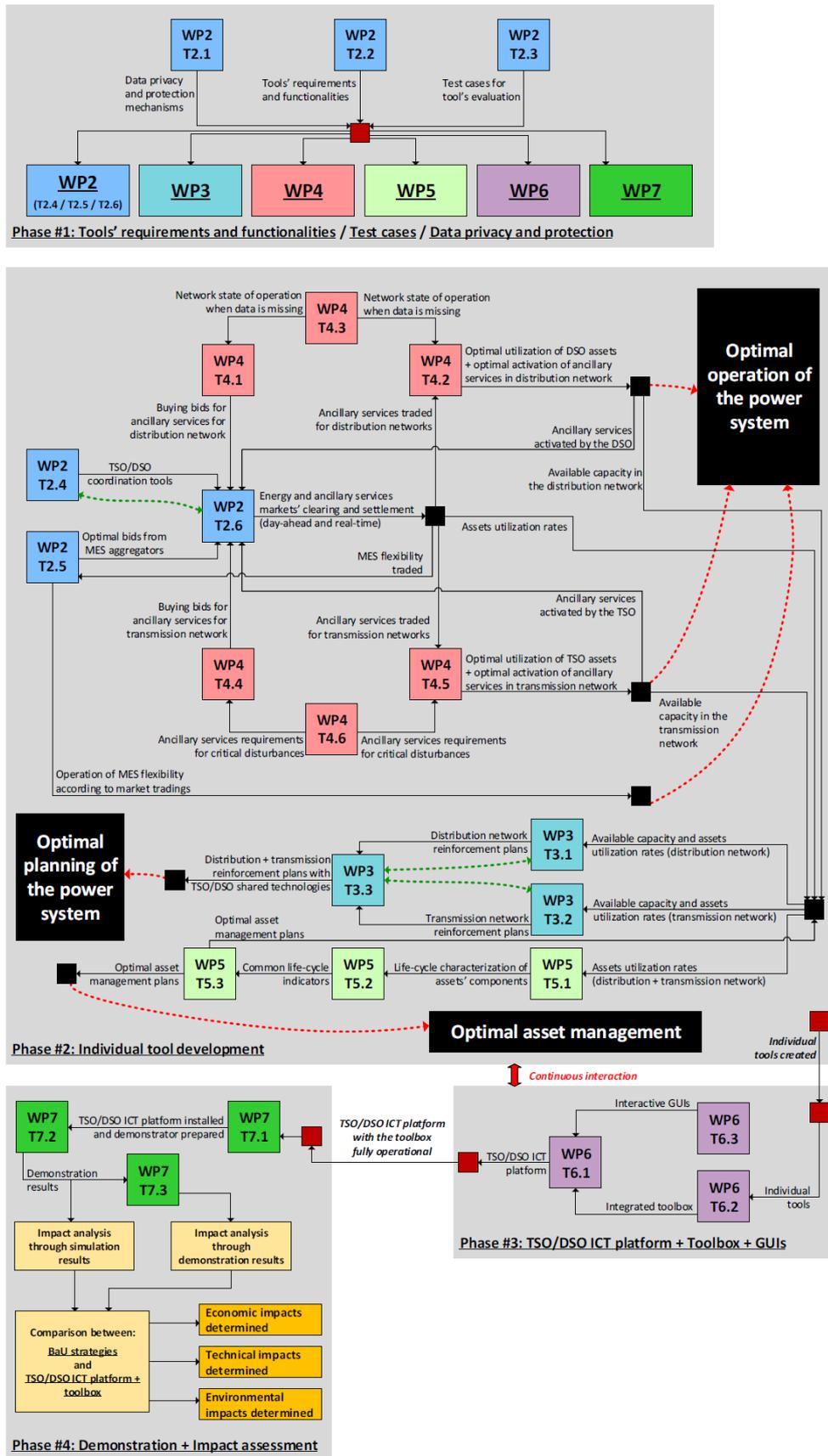


Figure 5.2: ATTEST workflow

## 5.7. Interface between the toolbox and the ICT platform

---

The open source toolbox will be embedded into an ICT platform that will provide the following services to the tools:

- A common data access layer that will enable data integration with a set of connectors that will allow each tool to retrieve the required input and to store the output in a common data model.
- A set of converters in charge of handling the data conversions among different formats.
- An orchestration layer that will allow to coordinate the tools so that their execution will happen in the correct order for a specific task.
- An interface layer that will provide a set of interactive visualization tools (graphical user interfaces)

At the first stage the following converters will be developed

- CIM → MATPOWER
- Comma separated/Excel → MATPOWER

Other converters will be likely developed in the following stages of the project.

The visualization requirements for the tools will be clarified in a later stage of the project.

## ANNEX I | MATPOWER FORMAT

MATPOWER ( <https://matpower.org> ) is an open-source (BSD license) power system simulation package, based on MATLAB, that provides a set of power flow, optimal power flow (OPF), and other tools targeted toward researchers, educators, and students. The data files used by MATPOWER are MATLAB M-files (accessible with any text processing software) which define and return a single MATLAB struct (MPC). The fields of the struct are 'base MVA', 'bus', 'branch', 'gen' and optionally 'gencost', where 'base MVA' is a scalar and the rest are matrices. In the matrices, each row corresponds to a single bus, branch, or generator. The columns are similar to the columns in the standard IEEE CDF and PTI formats. Additional fields will be added to the files based on the different applications in ATTEST.

The details of the MATPOWER case format are given in the tables below.

This information is extracted from the MATPOWER manual (<https://matpower.org/docs/manual.pdf>).

### Bus Data

1. BUS\_I: bus number (positive integer)
2. BUS\_TYPE: bus type (1 = PQ, 2 = PV, 3 = ref, 4 = isolated)
3. PD: real power demand (MW)
4. QD: reactive power demand (MVA<sub>r</sub>)
5. GS: shunt conductance (MW demanded at V= 1.0 p.u.)
6. BS: shunt susceptance (MVA<sub>r</sub> injected at V= 1.0 p.u.)
7. BUS\_AREA: area number (positive integer)
8. VM: voltage magnitude (p.u.)
9. VA: voltage angle (degrees)
10. BASE\_KV: base voltage (kV)
11. ZONE: loss zone (positive integer)
12. VMAX: maximum voltage magnitude (p.u.)
13. VMIN: minimum voltage magnitude (p.u.)
14. LAM\_P: Lagrange multiplier on real power mismatch (u/MW)
15. LAM\_Q: Lagrange multiplier on reactive power mismatch (u/MVA<sub>r</sub>)
16. MU\_VMAX: Kuhn-Tucker multiplier on upper voltage limit (u/p.u.)
17. MU\_VMIN: Kuhn-Tucker multiplier on lower voltage limit (u/p.u.)

### Generator Data

1. GENBUS: bus number
2. PG: real power output (MW)
3. QG: reactive power output (MVA<sub>r</sub>)
4. QMAX: maximum reactive power output (MVA<sub>r</sub>)
5. QMIN: minimum reactive power output (MVA<sub>r</sub>)
6. VG: voltage magnitude setpoint (p.u.)
7. MBASE: total MVA base of machine, defaults to base MVA
8. GEN\_STATUS: machine status, >0 = machine in-service ≤0 = machine out-of-service
9. PMAX: maximum real power output (MW)
10. PMIN: minimum real power output (MW)
11. PC1: lower real power output of PQ capability curve (MW)
12. PC2: upper real power output of PQ capability curve (MW)

13. QC1MIN: minimum reactive power output atPC1(MVAr)
14. QC1MAX: maximum reactive power output atPC1(MVAr)
15. QC2MIN: minimum reactive power output atPC2(MVAr)
16. QC2MAX: maximum reactive power output atPC2(MVAr)
17. RAMPAGC: ramp rate for load following/AGC (MW/min)
18. RAMP\_10: ramp rate for 10-minute reserves (MW)
19. RAMP\_30: ramp rate for 30-minute reserves (MW)
20. RAMP\_Q: ramp rate for reactive power (2 sec timescale) (MVAr/min)
21. APF: area participation factor
22. MUP\_MAX: Kuhn-Tucker multiplier on upper Pg limit (u/MW)
23. MUP\_MIN: Kuhn-Tucker multiplier on lower Pg limit (u/MW)
24. MUQ\_MAX: Kuhn-Tucker multiplier on upper Qg limit (u/MVAr)
25. MUQ\_MIN: Kuhn-Tucker multiplier on lower Qg limit (u/MVAr)

## Branch Data

1. FBUS: "from" bus number
2. TBUS: "to" bus number
3. BR\_R: resistance (p.u.)
4. BR\_X: reactance (p.u.)
5. BR\_B: total line charging susceptance (p.u.)
6. RATE\_A: MVA rating A (long term rating), set to 0 for unlimited
7. RATE\_B: MVA rating B (short term rating), set to 0 for unlimited
8. RATE\_C: MVA rating C (emergency rating), set to 0 for unlimited
9. TAP: transformer off nominal turns ratio, if non-zero (taps at "from" bus, impedance at "to" bus, i.e. if  $r=x=b=0$ ,  $\text{tap} = |V_f|/|V_t|$ ; tap= 0 used to indicate transmission line rather than transformer, i.e. mathematically equivalent to transformer with tap= 1)
10. SHIFT: transformer phase shift angle (degrees), positive  $\Rightarrow$  delay
11. BR\_STATUS: initial branch status, 1 = in-service, 0 = out-of-service
12. ANGMIN: minimum angle difference,  $\theta_f - \theta_t$  (degrees)
13. ANGMAX: maximum angle difference,  $\theta_f - \theta_t$  (degrees)
14. PF: real power injected at "from" bus end (MW)
15. QF: reactive power injected at "from" bus end (MVAr)
16. PT: real power injected at "to" bus end (MW)
17. QT: reactive power injected at "to" bus end (MVAr)
18. MU\_SF: Kuhn-Tucker multiplier on MVA limit at "from" bus (u/MVA)
19. MU\_ST: Kuhn-Tucker multiplier on MVA limit at "to" bus (u/MVA)
20. MU\_ANGMIN: Kuhn-Tucker multiplier lower angle difference limit (u/degree)
21. MU\_ANGMAX: Kuhn-Tucker multiplier upper angle difference limit (u/degree)

## Generator Cost Data

1. MODEL: cost model, 1 = piecewise linear, 2 = polynomial
2. STARTUP: startup cost in US dollars\*
3. SHUTDOWN: shutdown cost in US dollars\*
4. NCOST: number  $N=n+1$  of data points defining an n-segment piecewise linear cost function, or of coefficients defining an n-th order polynomial cost function
5. COST: parameters defining total cost function  $f(p)$  begin in this column, units of  $f$  and  $p$  are \$/hr and MW (or MVAr), respectively.

## ANNEX II | SCOPF FORMAT

SCOPF is a data format developed at the University of Liege for solving security-constrained optimal power flow problems for a given forecasted system (steady) state. In this format, network data is represented as a collection of records which start with predefined names. Each name identifies a specific network component type (BUS\_OPF is a bus, LOAD\_OPF is a load, TRFO\_OPF is a transformer GEN\_OPF is a generator, etc.) and determines the specific record data. Records are separated by a ";" character and record fields are separated by the space character.

### BUS OPF

1. NAME (maximum 19 characters): name of the bus (must not contain any blank).
2. ZONE (maximum 19 characters): name of the zone of which the bus belongs (must not contain any blank).
3. Vnom (kV): the nominal voltage at this bus.
4. Vmin (kV): the lower voltage limit at this bus.
5. Vmax (kV): the upper voltage limit at this bus.

### LOAD OPF

1. NAME LOAD (maximum 19 characters): name of the load, generally having the first letter "L" (must not contain any blank).
2. NAME BUS (maximum 19 characters): name of the bus where the load is connected (must not contain any blank).
3. P (MW): the load active power demand.
4. Q (Mvar): the load reactive power demand.
5. FRAC (positive real): represents the fraction of the total load which is allowed to be shed when load shedding is considered as control variable. FRAC belongs to the interval [0;1], where 0 corresponds to no load shedding and 1 to the curtailment of the whole load.
6. FRACmin (positive real): is the minimal fraction of load shedding allowed at this bus (it is generally equal to 0).
7. FRACmax (positive real): is the maximal fraction of load shedding allowed at this bus (practically it should not be greater than 0.2).
8. ALLOWsh (binary): is a decision variable to cope with some "fictious" loads which may produce active and/or reactive power. If ALLOWsh=0 the load cannot be taken as control variable while if ALLOWsh=1, it can be taken as control variable.

### LINE OPF

1. NAME (maximum 19 characters): name of the line (must not contain any blank).
2. ORIGIN (maximum 9 characters): name of the origin bus of the line (must not contain any blank).
3. END (maximum 9 characters): name of the ending bus of the line (must not contain any blank).
4. R (ohm): the power line resistance.
5. X (ohm): the power line reactance.
6. G/2 ( $\mu$ S): the half line conductance (it is generally equal to 0).
7. wC/2 ( $\mu$ S): the half of the line susceptance.
8. Snom (MVA): the apparent power of the line (in the OPF computation it corresponds to the maximal apparent power limit).

9. STATUS (binary): status of the line breaker (equal to 1 if it is connected and 0 if it is disconnected).

## TRFO OPF

1. NAME (maximum 19 characters): name of the transformer (must not contain any blank).
2. ORIGIN (maximum 9 characters): name of the origin bus of the transformer (must not contain any blank).
3. END (maximum 9 characters): name of the ending bus of the transformer (must not contain any blank).
4. R (% p.u.): transformer resistance on the base Vb1 (ORIGIN bus voltage) and Snom.
5. X (% p.u.): transformer reactance on the base Vb1 (ORIGIN bus voltage) and Snom.
6. G (% p.u.): transformer conductance on the base Vb1 (ORIGIN bus voltage) and Snom (it is generally equal to 0).
7. B (% p.u.): transformer susceptance on the base Vb1 and Snom (it is generally equal to 0).
8. r (%): transformer tap ratio.
9. ang (degrees): transformer angle (is equal to 0 if it does not correspond to a phase shifter).
10. Snom (MVA): the apparent power of the transformer (in the OPF computation it corresponds to the maximal apparent power limit).
11. STATUS (binary): status on/off of the of the transformer breaker (equal to 1 if it is connected and 0 if it is disconnected).

## GEN OPF

1. NAME GENERATOR (maximum 9 characters): name of the generator, generally having the first letter "G" (must not contain any blank).
2. NAME BUS (maximum 9 characters): name of the bus where the generator is connected (must not contain any blank).
3. NAME CONTROLLED BUS (maximum 9 characters): name of the bus whose voltage is controlled (must not contain any blank).
4. P (MW): the active power generated.
5. Q (Mvar): the reactive power generated.
6. Vo (p.u.): the terminal voltage setpoint (if Vo=0. the generator is treated as having a constant reactive power output).
7. Snom (MVA): the generator apparent power.
8. Pmin (MW): the generator lower active power limit.
9. Pmax (MW): the generator upper active power limit.
10. Qmin (Mvar): the generator lower reactive power limit.
11. Qmax (Mvar): the generator upper reactive power limit.
12. STATUS (binary): the status of the generator' breaker (equal to 1 if connected and 0 if disconnected).

ANNEX III | TECHNICAL REQUIREMENTS TABLE

	INESC-TEC	UniMan (distribution)	UniMan (transmission)	INESC-TEC	LIST	ICENT	KONCAR-KET	LIST	ICENT	INESC-TEC , HOPS	IIT- COMILLAS
Tools	WP2, Task 2.5 Day-ahead and real-time optimization tools to support MES aggregators	WP3, Task 3.1 Optimization tool for distribution network planning	WP3, Task 3.2 Optimization tool for transmission network planning	WP3 Task 3.3 Optimisation Tool for Planning TSO/DSO Shared Technologies	WP4, Task 4.1 Tool for ancillary services procurement in day-ahead operation planning of distribution network	WP4, Task 4.2 Tool for ancillary services activation in real-time operation of the distribution network	WP4, Task 4.3 Tool for state estimation of distribution networks	WP4, Task 4.4 Tool for ancillary services procurement in day-ahead operation planning of the transmission network	WP4, Task 4.5 Tool for ancillary services activation in real-time operation of the transmission network	WP4, Task 4.6 Tool for on-line dynamic security assessment	WP5, Tasks 5.1, 5.2, 5.3 Set of tools for a smart environment for asset management in power grids
Technology: Language / OS	Python 3.x or MS Windows	Python	Python Possible optimization solvers (e.g. Knitro)	TBD (possibly Python or C++) OS: Windows	Julia/JuMP as programming environment and under Windows. Likely optimization solvers are IPOPT or CPLEX but TBD. GAMS and IPOPT solver for nonlinear programming	Python	TBD	Julia/JuMP as programming environment and under Windows. Likely optimization solvers are IPOPT or CPLEX but TBD. GAMS and IPOPT solver for nonlinear programming	Python	Python 3.x / Kernel Linux based OS (open source) or MS Windows (proprietary but commonly used)	Python
License(s)	None	Open source	Open source (if all the work is done in python)	TBD	Open Source (possibly 100%)	Gurobi, GAMS, CPLEX	TBD	Open Source (possibly 100%)	Gurobi, GAMS, CPLEX	GNU GPL MIT licence	Open source
Memory requirements	16 GB at least	Typically low	Typically low	TBD	Not easy to estimate	TBD	TBD	Not easy to estimate	TBD	16 GB at least	<16GB at a first approximation
Storage requirements (specify size of disk or database)	256 GB SSD at least for better writing/reading speed 1 TB HDD for storage (historic data, etc) (Multicore processor is preferable – 8 cores at minimum, for parallel processing)	The model itself is relatively small (<1Mb) but, the processed inputs and outputs can reach several Mb	The model itself is relatively small (<1Mb) but, the processed inputs and outputs can reach several Mb	TBD	Input/output data files, for which it is not considered such requirements could be an issue.	TBD	TBD	Input/output data files, for which it is not considered such requirements could be an issue.	TBD	256 GB SSD at least for better writing/reading speed, 1 TB HDD for storage (historic data, etc) (Multicore processor is preferable – 8 cores at minimum, for parallel processing)	300 MB (but it's difficult to estimate at this moment)
<b>INPUT</b>											
Data format	TBD	Network models in OpenDSS (*.txt), MATPOWER (*.m) formats. Other inputs in MATLAB (*.mat), csv, json and excel formats.	Network models in MATPOWER (*.m) format. Other inputs in MATLAB (*.mat), json, csv and excel formats.	TBD	The needs for data sets in tasks 4.1, 4.2, 4.4, 4.5 are more or less the same except the differences between data sets for transmission and distribution system.	CSV, json, excel formats (REF GRID.xls)	MATPOWER or another suitable format carrying the network data, CSV or json for the metering data time series	TBD	CSV, json, excel formats (REF GRID.xls)	CSV, json, excel formats	xlsx/csv tables or other digital formats of data storage
Data size	<100 MB	Depends on the size of the network (or level of detail). Each system will take a couple of Mb (~10Mb). This can become large if we store data from multiple networks	Depends on the size of the network (and level of detail). Each system will take a couple of Mb (~20Mb)	TBD	For a system of 100 buses (typical maximum system size that will be used in ATTEST) a rough figure would be around 1,000 floats in double-precision	Several Mb	Several Mb	For a system of 100 buses (typical maximum system size that will be used in ATTEST) a rough figure would be around 1,000 floats in double-precision	Several Mb	Several Mb	<100 MB (It's an estimation)
<b>OUTPUT</b>											
Data format	TBD	HDF5 and json, but other formats (e.g., CSV) can also be used	HDF5 and json, but other formats (e.g., CSV) can also be used	TBD	TBD	CSV, json, excel formats	MATPOWER, CSV or json	TBD	CSV, json, excel formats	CSV, json, excel formats	Text or html files
Data size	TBD	A couple of Mb (e.g., ~15 Mb) per network, but it can grow substantially (~1Gb)	A couple of Mb (e.g., ~20 Mb) per network, but it can grow substantially (~1Gb)	TBD	Same as input data	Several Mb	Several Mb	Same as input data	Several Mb	Several Mb	<30MB