Deliverable 3.1.
Description of workflow coordination

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Chapter 1

Introduction

This document describes the workflow and data management of the tools developed in Work Package 3 (WP3) of the PlaMES project. Since WP3 mainly comprises the tools dealing with mathematical optimization problems (described in Deliverable 2.2), this is also the focus of this deliverable. The final PlaMES tool architecture will consist of a range of additional tools and submodules which are in development or will be developed at later stages. Nevertheless, provided information may be useful with later developments, e.g. external data exchange interfaces, additional tool integration, or as an inspiration for developments outside the projects' context.

The presented tools can actually be run in various orders. To reach the targets that have been defined in Deliverable 2.1, it is required to use the tools within certain workflows. We describe these workflows to handle the data management between tools and different data versions along the proposed use cases in chapter 2. Although the intended tool workflows are mostly consecutive, they require extensive preparation and exchange of data and results. Thereby, multiple versions of data might occur due to calculating different sensitivities, regions or scenario years. Central to the data management is a database, which serves as a data hub for all the tools used. Therefore, chapter 3 introduces *scenario management*: means of managing tools, data and version workflows. Furthermore, we explain required and exchanged data to run each tool and how this setup can be exploited in the future. For better understanding in the actual application, exchanged data formats are explained in chapter 4. Lastly, current conclusions and possible next steps are outlined in chapter 5.

Chapter 2

Tool workflow and scenario definition

To receive results from an integrated energy system planning, as it is intended with PlaMES, certain tools and processes have to be accessed in a certain order. Although the order is partially restricted, there are several unique orders in which the tools can be called, as shown in Figure 2.1. However, the shown tools only demonstrate the central application of developed tools, whereby the preparation of input data also requires work and precaution. The requirements for a scenario preparation are explained in section 2.1. Then, the general workflow for both use cases is explained in detail. This allows detecting requirements for and defining interfaces and data formats in the following chapters.

A summary of the workflow along two use cases is described in section 2.2. In the first use case, the target is to plan a central energy system by planning the multi- energy generation expansion combined with an electric transmission network expansion for large energy system such as Europe. The second use case focuses on disaggregating the technological multi-energy generation expansion capacities of the central energy system planning, operationally dispatching the technology and determining the necessary electric distribution grid expansion of a Distribution System Operators (DSOs).

2.1 Preparation for a scenario run

In order to start the PlaMES tool with a specific scenario run, users have to define their objective or research question. In regards to this question, the required tools might differ. Therefore, the user identifies the essential tools for the scenario run as well as analysing the required data to answer the research question. Besides tool specific input data, the user prepares common input scenario data for the scenario run. Based on the defined parameters and input data for the scenario the user makes assumptions of the expected results. With these assumptions in mind the user starts the identified tools and analyses the results of the tools against the assumptions.

If the results and expectations complied with each other the user would validate the results through a comparison with other studies and visualise the results. If the results and the assumptions did not match, the user would have to check the data and re-run certain tools. In the worst case the user would need to evaluate the proposed research question and start from the beginning.

2.2 Description of the tool workflow in PlaMES' showcase application

This description of workflow is focusing on the models and the interfaces between the models developed in PlaMES. An overview of the models to be developed was initially shown in Deliverable 2.2 and is shown in the following Figure 2.1.

The PlaMES-tool can be used to calculate results for multiple use cases. Within PlaMES, we are going to focus on two specific use cases, one central and one decentral. Some tools (Central Energy System (CES), Decentral Energy System Aggregation (DESA)) can be required to be used for both. Other tools (Transmission Expansion Planning (TEP), Decentral Energy System Disaggregation (DESD), Decentral Energy System Operation (DESOP), Distribution Network Expansion Planning (DNEP)) are just used for one use case. The following subsections describe both workflows.

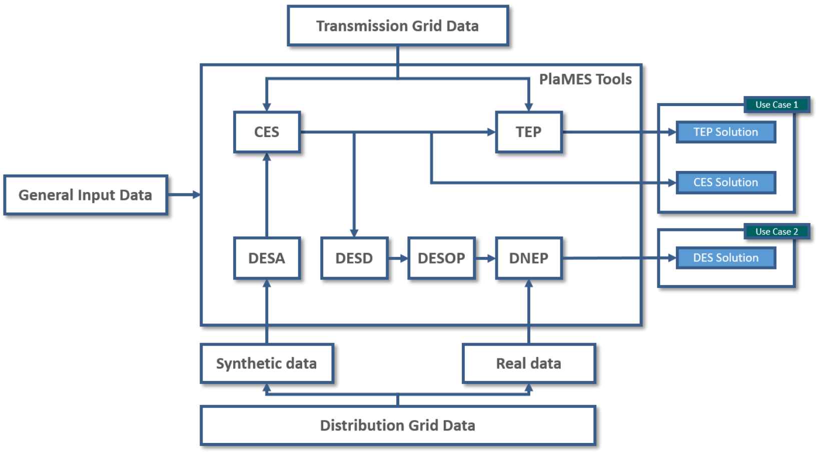

Figure 2.1: Overview over different models within PlaMES.

2.2.1 Use Case 1 - Central Use Case

Use Case 1 contains the expansion of the central multi-energy system on transmission network level as well as an extensive transmission grid expansion planning for a specific future scenario year. Thereby, the expected distribution network expansion costs are considered.

The focus of the central use case lies on the integrated expansion planning in CES. A generation expansion planning is performed considering multiple modalities, transmission network expansion costs and distribution network expansion costs. The transmission network expansion costs will be minimized with the actual transmission network model in an integrated optimization. The distribution network expansion will be considered through preliminary determined cost factors.

These cost factors will be provided by DESA. Thereby, distribution network expansion costs are determined for each node in the transmission system for different penetration scenarios of renewable energy sources. This proceeding allows considering distribution network expansion costs within the generation expansion planning.

CES uses a simplified approach to determine the grid expansion measures of the transmission grid. However, the central use case addresses among others Transmission System Operators (TSOs), hence an extensive transmission grid expansion planning is inevitable. The TEP tool uses the same transmission grid model as the CES tool as the starting topology for the grid expansion planning.

In the process of the grid expansion planning, the power flows over the existing lines have to be evaluated in regards to the specific transmission capacity. In the process of determining the power flow of one grid utilisation snapshot the supply and demand of each node need to be known. The electric supply and demand time series can be derived from the input to and result of the CES tool.

The TEP tool uses a defined catalogue of expansion measures. Besides reinforcing existing lines by building new parallel lines, conducting voltage upgrades or rebuilding the transmission lines as High Temperature Low Sag (HTLS) conductors, the TEP model considers power flow control measures e.g. Phase Shifting Transformers (PSTs), Thyristor Controlled Series Compensators (TCSCs) or High Voltage Direct Current (HVDC) lines. Furthermore, the construction of new lines is considered.

The solution of the generation expansion planning in CES and the detailed transmission network expansion planning in TEP concludes the overall results for the central use case, which is an integrated expansion planning of central energy systems for e.g. regulators or TSOs.

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2.2.2 Use Case 2 - Decentral Use Case

Target of the use case 2 is to determine the operational planning and necessary distribution network expansion for decentral energy systems based on given generation expansions.

The scenario is defined as a given multi-energy generation expansion within a distribution network area. The scenario input for the second use case can thus be either generated within calculating the first use case – the result of the CES model – or defined by the end-users future expansion expectations.

The scenario input for the decentral use case consists of expansion capacity targets of each technology to be installed within the distribution grid up to the scenario year. This can be renewable energy sources such as PV-systems and Wind Power Plants (WPPs), heating technologies (i.e. heat pumps, Combined Heat and Powers (CHPs)) or flexibilities (electric vehicles, battery storage systems etc.). Further required input is information about the buildings in the network, potential areas for large scale technologies and a status quo grid model.

To perform a distribution network expansion planning, the location of these assets within the distribution network need to be known. The model DESD disaggregates technologies based on a heuristic approach within the distribution network onto building level or distribution transformer level depending on the available data. Technologies which can not be assigned to buildings (WPPs, large scale CHPs) are assigned to the next grid node [1].

Knowing the planned location of each asset within the distribution network, the operation of all assets can be determined. To do so, the model DESOP performs a operational planning of each generation and load asset within the distribution network. This model is based on a linear program [1].

Once the disaggregation and operational planning is concluded, for each grid node in the distribution grid model an aggregated electric time-series is assigned. The DNEP model run then determines a cost-optimized distribution network expansion and concludes the results of the decentral use case.

1. Compare PlaMES deliverable 2.2

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Chapter 3

Interfaces

As described in chapter 2, PlaMES consists of several tools which can be used sequentially. However, if aiming to receive results for the presented use cases 1 and 2, certain results and inputs have to be transferred between the tools. Furthermore, certain scenario inputs such as the scenario year or weather time series are general input for multiple tools.

To ensure the consistency of the tools within PlaMES, interfaces have to be defined allowing to transfer data between tools while guaranteeing that data can't be accessed or edited wrong.

In this chapter, the interfaces within PlaMES are described. Since the exchange between the tools and the consistency of multiple scenario needs to be managed, we propose a data system for energy system studies. This data handling considers an overall database structure. To ensure the security of versions and scenarios, we furthermore propose a scenario handling methodology within the database. Subsequently, the interfaces between certain tools are described.

3.1 Data Handling

Out of several means to exchange data between the tools, PlaMES has chosen a database-driven approach. The database simultaneously functions as a data handling and exchange platform. Although it requires more effort to define exchange formats in advance, it enables faster integration of shared data points in multiple tools. To tackle the challenges of handling data concerning different energy types, different infrastructure levels in a multi-energy, multi-tool approach, a database ensures consistency in data preprocessing and data exchange between the tools in PlaMES. Depending on the chosen technology, a relational-database management system comes with methods to checks the integrity or ensure the compatibility of handled data. Furthermore, add-ons help with an improved data-handling.

3.1.1 Database Management System

Our data is managed within databases in the free and open-source relational database management system PostgreSQL[1]. Among several available management systems, PostgreSQL has been chosen for its available add-ons and the resulting flexibility. The relational database has been chosen for its ability of defining relationships between several objects and therefore one resulting uniform data structure. The database integration is an ongoing process, but to this date PostgreSQL has performed up to expectations.

3.1.2 Spatial data

A substantial share of data includes spatial information. PlaMES uses the PostgreSQL add-on PostGIS[2], which adds and handles geographic objects (points and polygons). An exemplary use of these properties would be that PostGIS allows to request data entries based on geographical information, such as *return all entries in an area / a polygon*.

1. https://www.postgresql.org/
2. https://postgis.net/

3.1.3 Time-series data

The largest amount of data is related to time series. Such time-series data can be stored without add-ons, but related tables can get large very quickly and decrease the performance of requests. As a method of prevention, the add-on TimescaleDB[3] can be integrated into tables. TimescaleDB operates in the background and can be integrated at any stage of the development, if database performance becomes an issue.

3.2 Handling scenario data

Typical use cases within PlaMES require to deal with different data sets at a time and more importantly with different versions of each data set. We understand a collection of different data sets and their respective versions as "scenario data", as these typically contain assumptions about future developments. When several tools are required for a scenario calculation, not every data set is required at a time. To keep the overview we

- define available data sets upfront,
- define available tools upfront and
- define which data sets are required to run a certain tool (read or write).

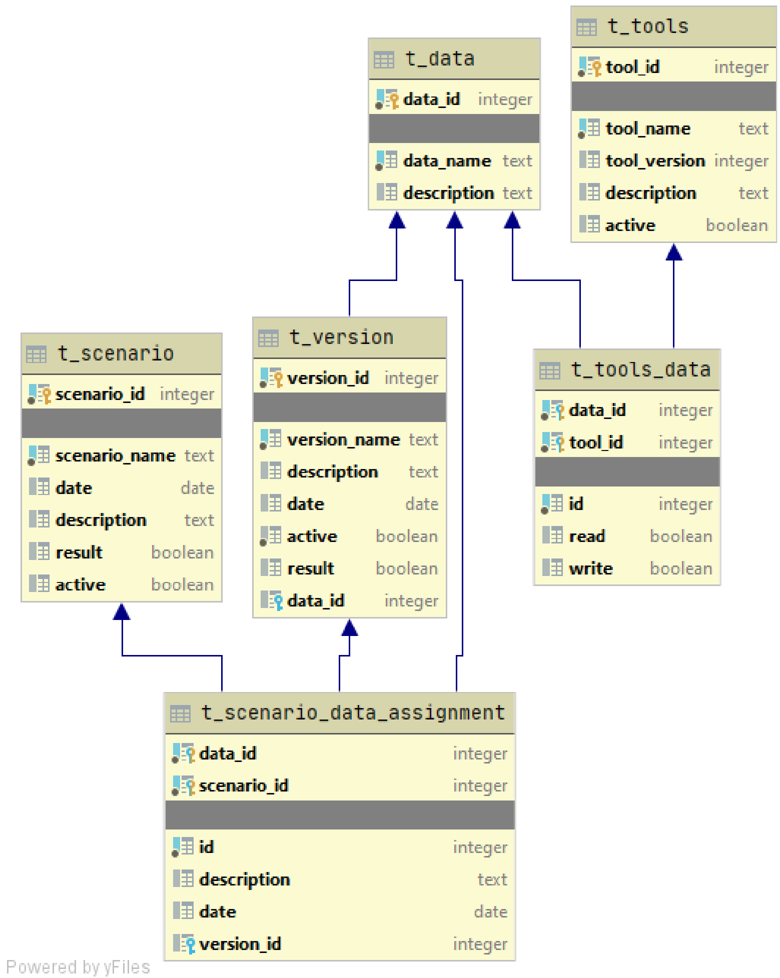

Figure 3.1: Scenario management tables as described in 3.2. The configuration is preliminary, but depicts the current progress.

3. https://www.timescale.com/

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3.2.1 Data versioning

Every data set can be stored in different versions. Each version of a data set receives a unique version number. First of all, a table stores each version per data set. The data version table tracks not only whether a version has been set up, but also whether required data is available or outdated. Furthermore, each entry in a data set table stores the version number it belongs to. Therefore, an extra column *version id* is added to actual data tables that stores the version numbers (comp. Figure 3.2).

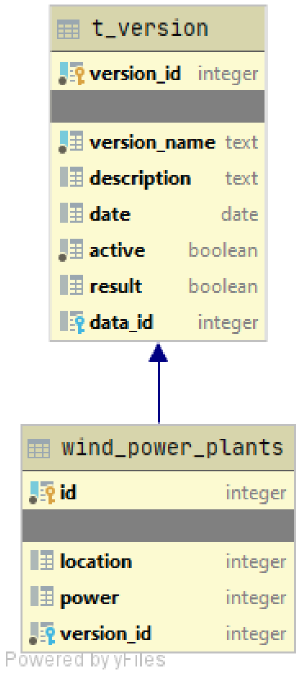

Figure 3.2: Exemplary dataset table with column *version_id*

3.2.2 Scenario management

In addition, a table is required that contains all available scenarios. Further tables contain all data sets and versions that belong to a certain scenario. To minimize the amount of required data, that information can also be inter-sectioned with the information about which data is required to run a certain tool. Furthermore, one can check if all required data is provided to run the tools which have been defined in the scenario.

3.2.3 Workflow tracking and checks

Cross-combining aforementioned tables enables workflow tracking. Using the information of required data versions and their availability, tools and their read and write output, one can determine which tools need to be run to gain certain results.

3.3 Model Interfaces

Each tool within PlaMES can be run on its own to reach a certain target, but multiple tools need to be run sequentially to gain the results of the defined use cases. To ensure a successful performance of the overall PlaMES-tool, we define model interfaces between respective models. In these interfaces, we identify the common data which is being used as an input by both tools or which is output of one and input of the other tool.

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3.3.1 DESA/CES

To enable the consideration of necessary distribution grid expansion in the CES model, DESA provides a cost factor for discrete generation expansion technology combinations. The cost factor includes the predicted costs for distribution network expansion which are necessary to integrate the intended generation capacity into the electric distribution grid, whereas the distribution grid corresponds to an overlaying CES node.

3.3.2 CES/TEP

The CES tool determines the supply potential at the different nodes, for this the CES tool receives all the data required for the calculation from the PlaMES database. The CES tool applies an extensive planning of the potential energy supply in the respected use case. Besides the potentials of electrical supply, the CES tool provides the supply for other integrated sectors as well. The result contains the potential for supply at each node in the system and is stored in the PlaMES database.

Aftwards an extensive transmission grid expansion planning is based on the results of the CES tool. The TEP tool uses a defined catalogue of measures for grid expansion and the power flow results from a specific feed-in and withdrawal of electrical energy at the nodes of the transmission grid. As shown in Figure 2.1, the transmission grid model is the same input data for the CES as for the TEP tool. The TEP tool performs the extensive grid expansion planning only for the electrical grid, hence requires only data about electrical energy transmission. The TEP tool transforms the potential supply into time specific feed-in for the power flow calculation.

3.3.3 CES/DESD

As mentioned before, if the second use case is calculated for a certain distribution network area, the future supply structure needs to be known. This supply structure originates in the asset park of decentral energy systems. This input can be received as a part of the result of CES. If the first use case is not calculated, this information can also be a scenario assumption. The input needs to contain shell targets for each technology that will be placed within the distribution grid.

3.3.4 DESD/DESOP

The interface between DESD and DESOP is defined by the distributed technologies. This means, that information of the location of each asset in the distribution network will be transferred from DESD to DESOP. Thereby, the information also contains the installed size (power, capacity) of the asset and further restrictions (efficiencies, costs). If the available data allows it, the location of each asset will be defined on building level for building related technologies or on LV-bus level for large-scale technologies. If there is no sufficient data in high granularity, the data can also be transferred per distribution transformer.

3.3.5 DESOP/DNEP

DNEP uses the planned operational time series from DESOP as input parameter for the network expansion planning. Therefore, the time series of each asset is aggregated onto electrical node level. If further actions by the grid operator such as curtailment, cos phi controls or QU controls should be allowed by the grid operator, the time series would have to be assigned to assets and their technology. Thereby, DNEP may decide which asset will be controlled specifically.

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Chapter 4

Data formats

To allow exchange of input and output data between our models, we use a database in PlaMES. Within, each data format has to be defined before adding the data. This allows for detecting false inserts during the execution of our tools. In addition, a well defined data format allows for prepraring the interface between the tools and the database. In the following chapter, we define the most important data formats for our tools.

4.1 Graph Data

Graph data describes a type of data structure which comprises of nodes (vertices) and edges (lines). In PlaMES the energy flows are determined through the modelling of networks on different levels. We divide these network models between the transmission and distribution network model, since they are used in seperate tools. The transmission network model is used in the tools calculating transmission network expansion (CES and TEP). The distribution network model is used in the tools calculating distribution network expansion (DESA, DNEP). Since different standards have emerged for both applications we use different model types for the transmission and distribution network model. To model the energy demand and generation for each node, the supply task data format will also be explained in detail in the following sections.

4.1.1 Transmission Network Model

The European transmission grid model pays attention to the high voltage grid level. The data format used for the transmission grid is oriented at the MatPower[1] format. The CES as well as the TEP tool are implemented in Matlab[2], hence the grid model is stored in this format.

Simplified, the transmission grid model consists of edges connecting nodes. However, the CES and TEP tool require more detailed data. In the context of the PlaMES project, the TEP and CES solely exploit the electrical transmission grid model. One can also refer to nodes as buses and edges are referred to as lines.

Figure 4.1 shows the structure of the data format of the transmission grid model. All tables contain the variable “version-id” which belongs to the database scenario management, described in chapter 3. In this context, the “version-id” refers to the buses and lines to a specific grid in a certain scenario.

On the one hand, the table of the buses contains geographic data of the bus in form of coordinates and geographic areas. On the other hand, every bus has a bus id, an electrical bus type and a base voltage. The lines require information regarding which two buses each line connects and what amount of power can be transmitted via this line. In regards to different grid utilisation snapshots, not all lines may be activated all the time, therefore, this information is stored as well. Furthermore, the TEP and CES tool use a DC power flow calculation to determine the power flow in the transmission grid; this requires

1. https://matpower.org/
2. https://de.mathworks.com/products/matlab.html

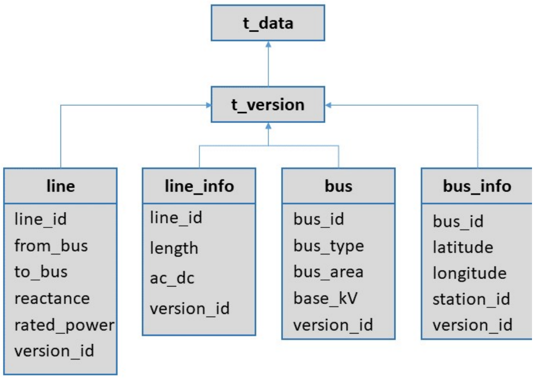

Figure 4.1: Exemplary overview of the data format of the transmission grid model.

the information about the reactance of each line. With all this information, it is possible to calculate the TEP and the CES tool within the PlaMES tool.

4.1.2 Distribution Network Model

To handle the networks on the decentral network level we use the pandapower[3] network format. The network model enables the power flow calculations in the DNEP and DESA tools. Different voltage levels and asset types must clearly be defined to depict the physical boundaries of electric distribution networks. Since distribution network models of DSOs exist in multiple types and detail we decided on defining this network model as the decentral network standard in our modelling approach. An exemplary overview over the data format is given in Figure 4.2.

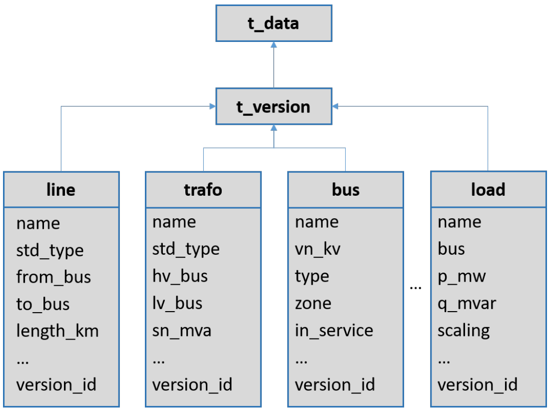

Figure 4.2: Exemplary overview of the data format of the decentral grid model.

4.1.3 Supply Task Model

The nodes of each network model contain a modelling of the energy supply task. The supply task data format is based on a building-oriented database structure. Thereby, for each building, necessary information is stored. The overall structure of the data format can be seen in Figure 4.3.

The central information of the supply task database is the buildings table. This table stores basic information about each building such as the location (which references onto the 'Regional Information' table) or information about the physical object of the building.

3. L. Thurner et al., "pandapower — An Open-Source Python Tool for Convenient Modeling, Analysis, and Optimization of Electric Power Systems," *IEEE Transactions on Power Systems* 33, no. 6 (November 2018): 6510–6521, ISSN: 0885-8950, https://doi.org/10.1109/TPWRS.2018.2829021

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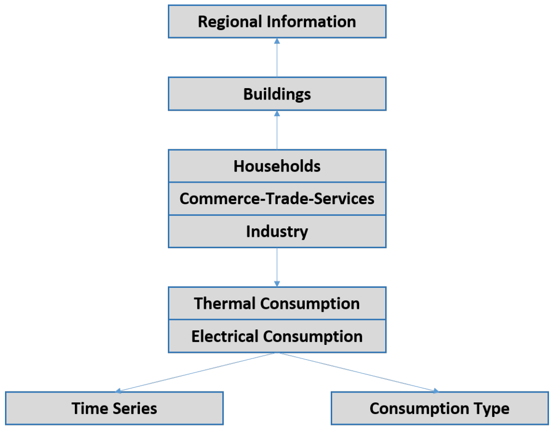

Figure 4.3: Exemplary overview over the supply task database.

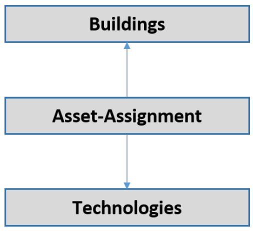

Figure 4.4: Exemplary overview over the asset assignment tables.

The tables Households, Commerce, Trade and Service (CTS) and Industry store information about the objects which are located in each building and points on the Buildings-table. Thereby, each building contains at least one object in the tables Households, CTS and Industry. These tables then contain certain information about the object, too. Each of the tables contain information about the thermal and electrical consumption of the object by pointing onto the tables 'thermal consumption' and 'electrical consumption'.

In the tables thermal and electrical consumption, information about the amount of consumption (heat, electrical) and the load profile is stored for each object (household, CTS, industry) and each consumption type. Thereby, it can be distinguished between several consumption types in the electrical and heat consumption which are stored in the table consumption types. To have access to time series, the tables 'thermal consumption' and 'electrical consumption' reference onto time series tables (see section 4.2).

The assets that have been assigned to buildings in DESD will be stored in assets tables. The framework of these tables can be seen in Figure 4.4.

The table 'asset assignment' stores information about the assignment of assets to buildings. Therefore, it references onto the buildings table. Each asset-to-building assignment can then be stored with information about the installed power or capacity. The 'asset assignment' furthermore references onto the technology table. In this table, information about the technologies which can be assigned as assets can be stored. This could be efficiencies or minimal / maximal installed power.

4.2 Temporal Data

Temporal data or time series are sequences of values which are ordered in time. Each quantity is observed at regular time intervals (unix time stamp with time zone). Typical data could be:

- quarter hourly electricity demand at network node,
- hourly solar irradiation or

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- monthly average wind speed.

4.3 Spatial Data

Spatial Data is representing data with geographic information. Geoinformation is defined as information about objects and circumstances with a reference to the earth [4]. Thus, data with geoinformation are data sets that have at least one assignment to a location on earth. The data of state, federal state, city names, postal code areas and addresses are examples of geoinformation. Since some information about the energy system is available in a wide range of geographic and temporal resolutions, geographic data transfer between data sets are required to ensure consistent use. For the management and organization of geographic data in PlaMES, standard layer sets are defined, to ensure consistency in assigning information to the respective model nodes and branches. The database development enables the use of geometry objects as a data type to explicitly relate information between different objects.

4.3.1 Vector Data

Vector data contains geometry objects such as points, lines, polygons or any combination of these three objects. In most cases, vector data has less storage overhead than other Geographic information system (GIS) formats because its structure is based on a text data type. Vector data resolution allows high geographic accuracy but is not suitable for mapping continuous data. Typical data used are:

- OpenStreetMap[5]
- Administrative areas (e.g. NUTS)

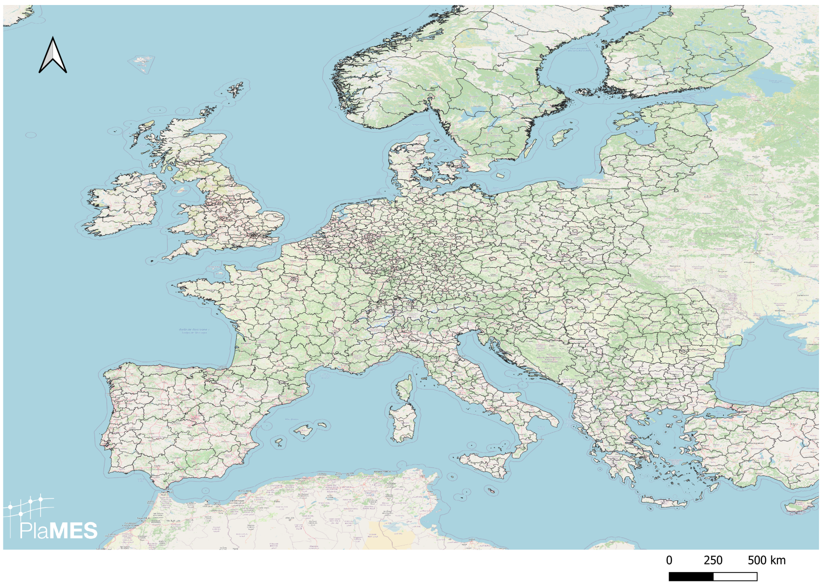

Figure 4.5: NUTS Regions on OpenStreetMap Layer.

4.3.2 Raster Data

Raster data are constructed in pixel-matrix-like format. In contrast to vector data, continuous data are mapped more extensively. A raster represents a quadrilateral grid divided into many smaller quadrilaterals. However, spatial analysis cannot be easily performed on raster data. To be more specific, typical data types are:

- Census data

4. *Geographic information - Reference model*, Standard, 19101, 2014
5. OpenStreetMap contributors, *Planet dump retrieved from https://planet.osm.org*, https://www.openstreetmap.org, 2017

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- Weather data (e.g. ERA5)

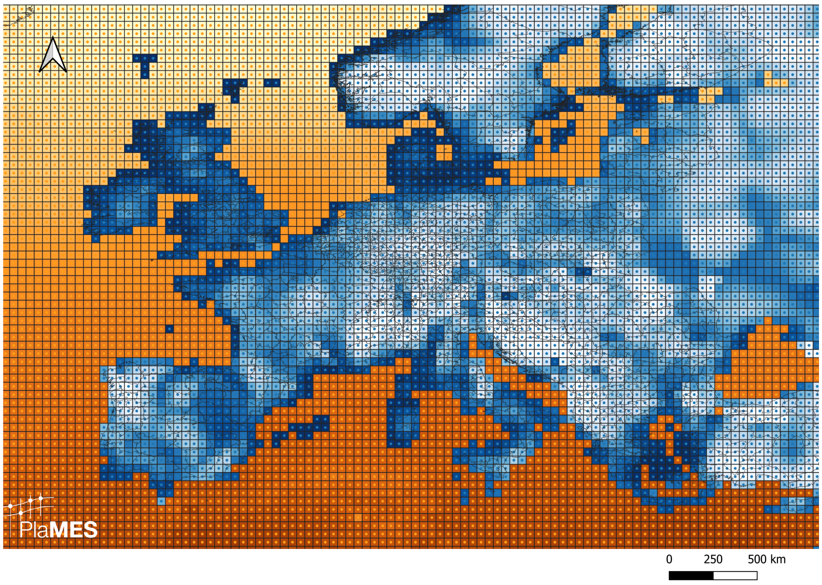

Figure 4.6: Exemplary weather data in processed raster format.

4.3.3 Geometryless Data

Data without geometry contains geoinformation that is based on a geographic reference layer. Data containing references to a geographic location without an geometry object are linked to spatial data layers which enable the processing of spatial functionalities, e.g.:

- Lists of statistical data referenced to e.g. a postal code area

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Chapter 5

Conclusion and next steps

In this document, we have explained the overall workflow as well as data handling within PlaMES. The developed mathematical models can be run seperately or in several consecutive orders. To solve the central and decentral use case as we intend to, the order of the tools is defined. Thereby, data exchange is required between the tools. This exchange can be common scenario input data or results of one tool and input for another tool. Thereby, tracking different scenarios and versions is inevitable to avoid confusing data. To deal with this data exchange we propose a database system based on a PostgreSQL-database. In this database, we keep all input, exchange and result data. Defining the tables in this database upfront allows ensuring upload of complete data sets. To deal with versions and scenario, we propose a scenario handling tool. Thereby, the rights for each tool to access data (read and write only) can be defined. Thereby, accidental access of false data can be avoided.

In this deliverable, we define each interface between the tools that need to be called consecutively to solve our use cases. Furthermore, we define the data format for the most important data sets that are used in multiple models. With these defined data formats, the consistency of all tools can be made sure.

In the following development phases of PlaMES in workpackage 5, a Decision Support System (DSS) will be implemented. This DSS will function as the finale PlaMES tool frame and will enable the user entering scenario data, selecting the use case and extracting the results as visual animations. Therefore, in the PlaMES database a section will be set up to enable the development of the interface between the by the DSS required data and the different PlaMES tools (CES, TEP, DESA, DESD, DESOP and DNEP).

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Abbreviations

CES	Central Energy System
CHP	Combined Heat and Power
CTS	Commerce, Trade and Service
DESA	Decentral Energy System Aggregation
DESD	Decentral Energy System Disaggregation
DESOP	Decentral Energy System Operation
DNEP	Distribution Network Expansion Planning
DSO	Distribution System Operator
DSS	Decision Support System
GIS	Geographic information system
HTLS	High Temperature Low Sag
HVDC	High Voltage Direct Current
PlaMES	Integrated Planning of Multi Energy Systems
PST	Phase Shifting Transformer
TCSC	Thyristor Controlled Series Compensator
TEP	Transmission Expansion Planning
TSO	Transmission System Operator
WPP	Wind Power Plant

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