MAEP
User's manual v.0

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Electrical analysis and planning - MAEP

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1. **Universidad de los Andes**
   - PhD Ángela Cadena.
     Associate Professor in the Department of Electrical and Electronic Engineering.
     Research Group in Environment and Economy.
   - PhD Nicanor Quijano.
     Titular Professor in the Department of Electrical and Electronic Engineering.
     Research Group in Production Automation.
   - Team:
     - PhD Candidate, José Morillo.
     - MSc. Angélica Pedraza.
     - Ing. David Piñeros.
     - Ing. Santiago Blanco.
2. **Universidad del Rosario**: Faculty of Natural Sciences and Mathematics.
   - PhD. Juan Fernando Pérez.
     Associate Professor in the Department of Applied Mathematics and Computer Science.
3. **Cornell University**: Department of Biological and Environmental Engineering.
   - PhD. C. Lindsay Anderson.
     Associated professor, Department of Biological and Environmental Engineering. Anderson-Lab Research Group.
4. **Laurentian University**: Department of Finance and Operations.
   - PhD. Luckny Zéphyr.
     Assistant Professor in the Department of Finance and Operations.
5. **ISAGEN**: Specific agreement No. 2. Interinstitutional framework agreement No. 47/353.
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Table of contents

1. First steps **4**
1.1. System requirements . . . 4
1.2. Installation . . . 4
1.3. Local execution . . . 5
1.4. Online platform . . . 6

2. Data library **7**
2.1. Data base . . . 7

3. Forecasting resources **8**

4. Generation units **9**
4.1. Thermal plants . . . 9
4.2. Hydro plants . . . 10
4.3. Small plants . . . 10
4.4. Wind power plants . . . 11
4.4.1. Practical wind power model . . . 12
4.5. Solar power plants . . . 12
4.5.1. Distributed solar . . . 12
4.5.2. Large scale . . . 12
4.6. Biomass power plants . . . 14
4.7. Storage units . . . 15

5. Power system model **16**
5.1. Electrical areas/buses . . . 16
5.2. Transmission network . . . 16
5.2.1. Optimal power flow . . . 17
5.2.2. Security constraints . . . 17
5.3. Costs . . . 17
5.4. Demand . . . 17
5.4.1. Subperiods . . . 18
5.4.2. Storage systems restrictions . . . 18

6. Running simulations **20**

6.1. Setting options 20

6.2. Basic parameters 20

6.3. Deterministic/Stochastic 21

6.4. Risk aversion 21

6.4.1. Long-term risk aversion 21

6.4.2. Short-term variability 21

7. Accessing the results **22**

7.1. Output files 22

7.2. Graph module 22

1. First steps

1.1. System requirements

MAEP online platform was developed in several layers, which must be installed separately.

- LandingPage (Vue.js)
- Frontend (Vue.js)
- Backend (Laravel)

To install the online version of MAEP you will need:

- PHP 7.1 or higher
- Apache 2.2.9 or higher
- MySQL 5.5 or higher
- Redis 3.0.2 or higher
- Node.js 8.9.1 or higher
- PM2 2.10.1 or higher
- Supervisord 3.3.3 or higher

To use the source code of MAEP you will need:

- Python 3.05 or higher
- Pyomo: open-source optimization modeling language [2]
- Solver: Pyomo supports a variety of third-party such as CPLEX, GUROBI, or GLPK.
- Python packages: csv, datetime, numpy, statistic, openpyxl pickle, progressbar, among others.

1.2. Installation

The latest version of MAEP is available in a Git system, through which the versions control will be done and the user's contribution will be compiled for the further development of MAEP.

Repository: git clone https://github.com/maep-tools

Figure 1 shows the directory structure on the MAEP project repository. It contains three main directories: documentation, web interface and MAEP source code. The web interface directory contains all the necessary files to install a GU web platform for a straightforward model execution.

To work on the source code it is useful to employ an integrated development environment (IDE). It usually comes with the installation of Python. However, there are others IDE options with extensive features that facilitate coding and which are also open source.

Choosing an IDE depends on which of its features are comfortable for programmers and at the same time satisfy their needs. However, an IDE that is quite familiar in the academic community, due to its similarities with MATLAB, is Spyder Python [1]. This open source IDE is suitable for scientific development, written in Python and available under MIT license.

```
dir
├── docs
│   ├── docs_readme.txt
│   ├── manual_usuario_esp
│   └── user_manual_eng
├── Web_interface
└── MAEP_model
    ├── ConsoleMAEP.py
    ├── datasystem
    ├── __pycache__
    ├── pyomo_model.txt
    ├── reports_utils
    ├── results
    ├── savedata
    ├── scripts
    ├── setup
    ├── temp
    ├── templates
    └── utils
```

Fig. 1. Directory structure on the MAEP project repository.

1.3. Local execution

The source code directory allows access to model scripts, practical exercises, simulation results, experimental modules, and data bases. As shown Figure 2, Once MAEP source code is saved in a local directory, the user will find two folders containing the MAEP main body.

```
dir
├── docs
├── Web_interface
└── MAEP_model
    ├── scripts
    │   ├── backward.py
    │   ├── forward.py
    │   ├── __init__.py
    │   ├── main_model.py
    │   ├── optimality.py
    │   ├── __pycache__
    │   ├── readData.py
    │   └── run_model.py
    └── utils
        ├── efunction.py
        ├── file_results.py
        ├── __init__.py
        ├── input_data.py
        ├── input_hydro.py
        ├── input_others.py
        ├── input_wind.py
        ├── objcalculation.py
        ├── opf_data.py
        ├── parameters.py
        ├── paramvalidation.py
        ├── __pycache__
        ├── readWind.py
        ├── readxlxs.py
        ├── saveresults.py
        ├── solvermodule.py
        └── solver.py
```

Fig. 2. Local directory of MAEP

On the one hand, the folder *scripts*, contains the scripts for the problem optimization. On the other hand, the folder *utils* contains the files on the calculation of parameters, the power system model, experimental modules, and the scripts to write and export the simulation results.

1.4. Online platform

The online platform provides the user with a self-guided to become familiar with the tool. The platform has a navigation menu to enter the data of the electrical system, as well as the configuration of parameters for run simulations of individual projects. In addition, it is possible to upload files or templates with the power system information and do simulations without the need to enter manually the data.

The platform allows the administrator to configure different types of roles for new users, these are:

- Administrator: With access to all tool's features. Create and share projects with other users.
- Standard: Create and simulate projects, as well as access to the public library of projects.
- Limited: Restricted access to the tool's features, usually read only.

The forms to enter the system information in MAEP are described below.

2. Data library

The project library contains the stored files of simulated systems and it is the place to store new projects. The new projects can be created in two ways:

Web interface: Create a project from zero, using the forms provided for it. Additionally, the user can modify existing projects to create their own according to their needs

Input file: Create a project through a *input file* that can be loaded into the web platform to run the simulations, or it can be used directly through the IDE.

2.1. Data base

A base of public projects will be available in MAEP. This base can be continuously fed with public projects created by users.

Figure 3 shows the structure of the database in MAEP. MAEP will have at users disposal a set of practical projects with different levels of difficulty. From simple projects that allow to become familiar with the tool til complex projects that take advantage of all the potentialities of the tool.

```
dir
├── docs
├── Web_interface
├── MAEP_model
└── reports_utils
    └── datasystem
        ├── test_model.xlsx
        └── windminutes
```

Fig. 3. Data base directory of MAEP.

Through the web platform, each user can define a project as public or private. When a project is private, no other users can access this information. When the development platform is used, a project is necessarily private, unless it is shared through the public database of the model.

3. Forecasting resources

In MAEP, the stochastic process is represented by a set of possible trajectories (scenarios) of the hydro inflows, of the wind speed, of the solar radiation, and of the stored biomass, for the power plants in the system. These trajectories are stage-wise independent and each one has a probability of occurrence.

The stochastic process is modeled through a periodic auto-regressive model, and its parameters are estimated from historical data. Additionally, the forecast model is intended to consider the possible correlations between the hydro inflows and the wind speeds in some areas of the system.

Table 1
Parameters of the hydro inflows to reservoirs.

Parameters	Units	Description	Implementation
name		streamflow	
stage		determines the data horizon	
scenario		determines the scenarios of the data	
inflow	m^3/s	hydro inflow in the defined stage and scenario	

Table 2
Parameters of wind speeds in the influence area of plants.

Parameters	Units	Description	Implementation
name		measurement station	
stage		determines the data horizon	
scenario		determines the scenarios of the data	
speed	m/s	average wind speed in the defined stage and scenario	

Table 3
Parameters of solar radiation in the influence area of plants.

Parameters	Units	Description	Implementation
name		measurement station	
stage		determines the data horizon	
scenario		determines the scenarios of the data	
radiation	Wh/m^2	solar radiation in the defined stage and scenario	

Table 4
Parameters of the stored biomass volume for each storage silo.

Parameters	Units	Description	Implementation
name		silo or deposit	
stage		determines the data horizon	
scenario		determines the scenarios of the data	
biomass	Ton	volume collected and stored in the defined stage and scenario	

Note: In the input file, the hydro inflows are entered in the tab ***Inflow***, the wind speeds are entered in the tab ***InflowWind***, the solar radiation is entered in the tab ***InflowSolar***, and the stored biomass is entered in the tab ***Mass_Inflow***. By using the forecasting model through the web interface, the tabs ***Inflow*** and ***InflowWind*** are self-completed.

4. Generation units

Users can model 8 types of generation units in MAEP: thermal, hydroelectric with a reservoir and run-of-river, small power plants, wind power plants, distributed and large-scale solar power plants, and storage systems. Each unit is modeled through techno-economic parameters. Each of them is described below.

All the parameters of plants are implemented in MAEP unless otherwise stated. In addition, since it is assumed that technical parameters are defined for each plant from the year of entry into operation, to simulate the expansion of the system the parameters of each plant can be modified at any stage of the planning horizon, and it is possible to introduce new plants in the system.

4.1. Thermal plants

The thermal plants model has two main components: the techno-economic features of plants and the fuel that they use in the generation process.

Table 5 indicates the techno-economic parameters of thermal plants. The column*modification* indicates the modifiable parameters of those plants for which their capacity is increased or decreased along the planning horizon. For all modified parameters it is required to indicate the stage when the changes occur.

Table 5
Techno-economics parameters of thermal plants.

Parameters	Units	Description	Modification	Implementation
name		name of plant		
capacity	MW	installed capacity	Yes	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)		
fuel type		type of fuel use for electricity generation		
area/node		location of the power plant		
fuel		select a type of fuel among the available options		
dual		operation with two types of fuel		No
gen_min	MW	minimum operating capacity	Yes	
gen_max	MW	maximum operating capacity	Yes	
forced_unav	%	forced or programmed unavailability		No
historical_unav	%	historical unavailability	Yes	
variable cost	$/MWh	variable costs and/or transportation costs		
heat rate	MBTU/MWh	efficiency in fuel consumption		
Emissions_fuel	Ton/MBTU	CO_2 emitted in the fuel consumption process		
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production		

La Tabla 6 indicates the parameters for fuel alternatives for thermal plants.

Table 6
Fuel parameters

Parameters	Units	Description	Implementation
name		fuel name	
stage		determines the data horizon	
cost	$/MBTU	fuel cost consumption	

Note: In the input file, the technical parameters are entered in the tab ***Thermal_config***, the expansion/modification of plants are entered in the tab ***Thermal_expn***, and the fuel data is entered in the tab ***FuelCost***.

4.2. Hydro plants

The hydro plants model has three main components: the techno-economic features of plants, the topology of the generation chains, and the hydro inflows as indicated in the Table 1.

Table 7 indicates the techno-economic parameters of hydro plants. The column*modification* indicates the modifiable parameters of those plants for which their capacity is increased or decreased along the planning horizon. For all modified parameters it is required to indicate the stage when the changes occur.

Table 7
Techno-economics parameters of hydro plants.

Parameters	Units	Description	Modification	Implementation
name		name of plant		
initial_storage	Hm3	stored water at the beginning of the planning horizon		
min_storage	Hm3	minimum volume for the reservoir at any stage		
max_storage	Hm3	maximum volume for the reservoir at any stage	Yes	
capacity	MW	installed capacity	Yes	
prod_coefficient	$MW/m^3/s$	transformation coefficient	Yes	
outflow	m^3/s	maximum volume for turbines	Yes	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)		
storage stage		stage in which the water storage process starts (new plants)		
variable cost	$/MWh	variable costs		
t-downstream		downstream plant that will receive the outflow in its reservoir		
s-downstream		downstream plant that will receive the spilled water in its reservoir		
area/node		location of the power plant		
type		type of reservoir: regulation, diversion or storage		
forced_unav	%	forced or programmed unavailability		No
historical_unav	%	historical unavailability	Yes	
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production		

The figure **??** illustrates the role of a plant within a generation chain. For those plants that are part of a generation chain, the topology information of the entire chain must be entered. This information is entered for each plant, as shown in Table 7.

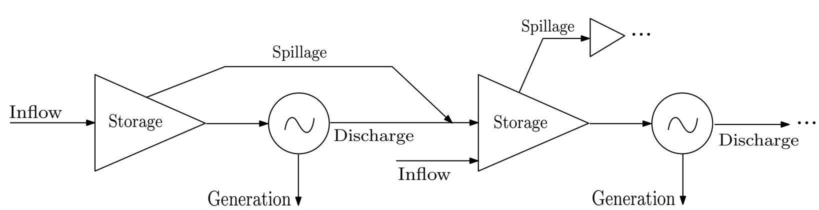

Fig. 4. Hydrochain configuration

Note: In the input file, the technical parameters are entered in the tab ***Hydro_config***, and the expansion/modification of plants are entered in the tab ***Hydro_expn***.

4.3. Small plants

The main component of small plants model is the techno-economic features of plants, as indicated in Table 8. The column*modification* indicates the modifiable parameters of those plants for which their capacity is increased or decreased along the planning horizon. For all modified parameters it is required to indicate the stage when the changes occur.

Table 8
Techno-economics parameters of small plants

Parameters	Units	Description	Modification	Implementation
name		name of plant		
capacity	MW	Installed capacity	Yes	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)		
type		type of plant: thermal or hydro		
area/node		location of the power plant		
gen_min	MW	minimum operating capacity		
gen_max	MW	maximum operating capacity	Yes	
forced_unav	%	forced or programmed unavailability		No
historical_unav	%	historical unavailability	Yes	
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production		

Note: In the input file, the technical parameters are entered in the tab ***Small_config***, and the expansion/modification of plants are entered in the tab ***Small_expn***.

4.4. Wind power plants

The wind power plants model has three main components: the techno-economic features of plants, the wind speed as indicated in the Table 2, and and the estimated short-term variability over wind speed forecasts.

Table 9 indicates the techno-economic parameters of wind power plants. The column*modification* indicates the modifiable parameters of those plants for which their capacity is increased or decreased along the planning horizon. For all modified parameters it is required to indicate the stage when the changes occur.

Table 9
Techno-economics parameters of wind power plants.

Parameters	Units	Description	Modification	Implementation
name		name of plant		
capacity	MW	Installed capacity	Yes	
efficiency_trans	min: 0, max: 1	Efficiency of energy transformation	Yes	
density	Kg/m^3	air density		
efficiency_turb	min: 0, max: 1	Efficiency of turbine	Yes	
diameter	m	rotor diameter of turbines		
nominal speed	m/s	nominal wind speed of turbine		
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date (NE)		
storage stage		stage in which the water storage process starts (batteries)		
area/node		location of the power plant		
forced_unav	%	forced or programmed unavailability		No
historical_unav	%	historical unavailability	Yes	
variability	%	expected wind speed variability		
speed in	m/s	minimum turbine security speed		
speed out	m/s	maximum turbine security speed		
Betz limit	min: 0, max: 1	limit of transformation of kinetic energy of wind into mechanical energy		
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production		No
variable cost	$/MWh	variable costs		No

In order to consider the short-term variability of the wind speed into the model, it is necessary to enter the factors that relate the monthly average wind speed forecasted with the speeds intensity for each hour of each month of the year. Table 10 indicates the parameters of the wind speed intensity in each of the subperiods in which a stage is divided with respect to the monthly average wind speed.

Table 10
Parameters of short-term wind speed in the influence area of plants.

Parameters	Units	Description	Implementation
name		measurement station	
month		reference year	
subperiod		defined at each month	
intensity		factor of intensity of wind speed at each subperiod	

Note: In the input file, the technical parameters are entered in the tab ***Wind_config***, and the wind speed intensities are entered in the tab ***SpeedIndices***.

4.4.1. Practical wind power model

The experimental model of wind power generation designed to support real information of a wind farm project. It requires information on the installed wind turbines, specifically the power curve and the thrust coefficient. In Table 11 the parameters of plants are defined according to the model.

Table 11
Techno-economics parameters of wind power plants - Practical model.

Parameters	Units	Description	Implementation
name		name of plant	
capacity	MW	Installed capacity	
efficiency_trans	min: 0, max: 1	Efficiency of energy transformation	
speed in	m/s	minimum turbine security speed	
speed out	m/s	maximum turbine security speed	
resolution	m/s	wind speed band to which the power curve and thrust coefficient are specified	
measures height	m	height of the measuring station	
bushing	m	bushing height of turbine	
height factor		height correction factor of wind speed measurements	
density	Kg/m^3	air density	
distance	m	distance between the rows of turbines in the wind farm	
diameter	m	rotor diameter of turbines	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date (NE)	
area/node		location of the power plant	
file		file that contains the ten-minute wind speed data	
rows		number of rows of turbines	

4.5. Solar power plants

4.5.1. Distributed solar

The distributed solar generation model has two main components: the techno-economic features of the distributed PV panels, and the solar radiation as indicated in the Table 3.

Table 12 indicates the techno-economic parameters of distributed solar generation.

Note: In the input file, the technical parameters are entered in the tab ***SolarD_config***.

4.5.2. Large scale

The large scale solar plants model has three main components: the techno-economic features of plants, the solar radiation as indicated in the Table 3, and the estimated short-term variability over solar radiation forecasts.

Table 12
Techno-economics parameters of distributed solar generation.

Parameters	Units	Description	Implementation
name		name of plant	
resource		geographical location of the distributed panels	
efficiency_trans	min: 0, max: 1	solar panel yield	
extension	m^2	solar panel area	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)	
area/node		location of the distributed panels in the system	
inverter_loss	%	inverter losses	
temp_loss	%	temperature losses	
dc_loss	%	DC cables losses	
ac_loss	%	AC cables losses	
shadow_loss	%	shadings losses	
dust_loss	%	dust losses	
growth rate	%	anual growth rate of the solar panel area	
variable cost	$/MWh	variable costs	No
variability	%	expected solar radiation variability	
forced_unav	%	forced or programmed unavailability	No
historical_unav	%	historical unavailability	No
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production	No

Table 13 indicates the techno-economic parameters of large scale solar plants, and Table 14 indicates the predicted temperature ambient necessary to estimating the potential of solar power generation.

Table 13
Techno-economics parameters of large scale solar plants.

Parameters	Units	Description	Implementation
name		name of plant	
resource		geographical location of the distributed panels	
Pmmp	W	maximum power of PV panels	
n_ac	min: 0, max: 1	inverter efficiency	
n_mmp	min: 0, max: 1	MPP efficiency	
n_pv	min: 0, max: 1	aggregated efficiency after losses	
n_pv	min: 0, max: 1	aggregated efficiency after losses	
coef_tmpp	%/ °C	power temperature coefficient at the MPP	
tnoct	°C	module temperature at nominal operating conditions	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)	
area/node		location of the power plant	
variability	%	expected solar radiation variability	
serie		number of PV arrays in series	
parallel		number of PV arrays in parallel	
forced_unav	%	forced or programmed unavailability	No
historical_unav	%	historical unavailability	No
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production	No

Table 14
Parameters of the predicted temperature ambient.

Parameters	Units	Description	Implementation
name		fuel name	
month		reference year	
temperature	°C	average monthly temperature	

In order to consider the short-term variability of the solar radiation into the model, it is necessary to enter the factors that relate the monthly average solar radiation forecasted with the radiation intensity for each hour of each month of the year. Table 15 indicates the parameters of the radiation intensity in each of the subperiods in which a stage is divided with respect to the monthly average solar radiation.

Table 15
Parameters of short-term solar radiation in the influence area of plants.

Parameters	Units	Description	Implementation
name		measurement station	
month		reference year	
subperiod		defined at each month	
intensity		factor of intensity of radiation at each subperiod	

Note: In the input file, the technical parameters are entered in the tab ***SolarL_config***, the ambient temperature data is entered in the tab ***TemperatureCell***, and the radiation intensities are entered in the tab ***RadiationIndices***.

4.6. Biomass power plants

The biomass energy generation model has three main components: the techno-economic features of plants, the volume of biomass as indicated in the Table 4, and the biomass costs that they use in the generation process.

Table 16 indicates the techno-economic parameters of wind power plants, and Table 17 indicates the parameters for the biomass alternatives and their costs.

Table 16
Techno-economics parameters of thermal plants.

Parameters	Units	Description	Modification	Implementation
name		name of plant		
initial_storage	Ton	volume in silo or deposit		
min_storage	Ton	minimum volume in silo or deposit		
max_storage	Ton	maximum volume in silo or deposit	Yes	
gen_min	MW	minimum operating capacity		
gen_max	MW	maximum operating capacity		
capacity	MW	installed capacity		
rate	Ton/h	maximum volume for biomass consumption per hour		
prod_coefficient	MBTU/Ton	transformation coefficient		
efficiency	min: 0, max: 1	Efficiency of plant	Yes	
heat rate	MBTU/MWh	efficiency in biomass consumption		
silo		select a silo or deposit among the available options		
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)		
variable cost	$/MWh	variable costs and/or transportation costs		
area/node		location of the power plant		
forced_unav	%	forced or programmed unavailability		No
historical_unav	%	historical unavailability	Yes	
Emissions_fuel	Ton/MBTU	CO_2 emitted in the fuel consumption process		No
Emissions_plant	Ton/MWh	CO_2 emitted in the energy production		No

Table 17
Biomass costs parameters.

Parameters	Units	Description	Implementation
name		silo or deposit	
stage		determines the data horizon	
cost	$/Ton	biomass cost	

Note: In the input file, the technical parameters are entered in the tab ***Biomass_config***, and the biomass costs entered in the tab ***MassCost***.

4.7. Storage units

The storage systems model has two main components: the techno-economic features of plants, and the users' defined operation restrictions. The latter are defined in the section 5.4.2.

Table 18 indicates the techno-economic parameters of storage systems. The column *modification* indicates the modifiable parameters of those plants for which their capacity is increased or decreased along the planning horizon. For all modified parameters it is required to indicate the stage when the changes occur.

Table 18
Techno-economics parameters of storage systems.

Parameters	Units	Description	Modification	Implementation
name		name of plant		
initial storage	min: 0, max: 1	stored energy level at the beginning of the planning horizon		
min storage	min: 0, max: 1	minimum level of energy storage		
max storage	min: 0, max: 1	maximum level of energy storage		
capacity	MW	Installed capacity	Yes	
power_rate	MWh	storage capacity		
efficiency	min: 0, max: 1	charge/discharge efficiency factor	Yes	
outflow	MWh/s	discharge capacity of the storage system	Yes	
entrance		to indicate if the unit exists (E), it has a defined entrance date (month-year), or without a defined entrance date(NE)		
link		joint operation of several storage systems		No
portfolio		indicates whether it belongs to a generation portfolio		No
area/node		location of the power plant		
forced_unav	%	forced or programmed unavailability		No
historical_unav	%	historical unavailability	Yes	

Note: In the input file, the technical parameters are entered in the tab ***Storage_config***.

5. Power system model

The modeling parameters described below determine the main features of the power system and the temporal resolution used in the operation planning model.

5.1. Electrical areas/buses

MAEP supports unimodal, multi-area or multi-modal power system simulation. By defining the type of system, it is determined whether or not the transmission network is included in the analysis.

> Note: In the input file, the type of system entered in the tab ***Areas***.

5.2. Transmission network

If more than one area or bus is defined, it is necessary to define also the electrical connection links. Table 19 indicates the technical parameters of the transmission network. The column*modification* indicates the modifiable parameters for the transmission network expansion analysis. For all modified parameters it is required to indicate the stage when the changes occur.

Table 19
Parameters of the transmission network.

Parameters	Units	Description	Modification	Implementation
initial bus		initial bus for a connection line	Yes	
final bus		final bus for a connection line	Yes	
i_to_f	MW	limit capacity of a connection line considering the flow direction, from i_bus to f_to	Yes	
f_to_i	MW	limit capacity of a connection line considering the flow direction, from f_bus to i_bus	Yes	
efficiency		transfer energy efficiency	Yes	
resistance	%	parameter of the line in p.u	Yes	
reactance	%	parameter of the line in p.u	Yes	

In a multi-area system there are two alternatives: use an transfer energy model or an equivalent network model. In the transfer energy model, it is necessary to determine the capacity of energy transfer between the interconnected subsystems. This capacity can be directional, such that if necessary, different transfer limits can be established depending on the direction of the power flow.

In the equivalent network model, the parameters of resistance and reactance of the interconnection between subsystems must be defined, for an optimal power flow analysis. Such parameters must be entered in *perunit*, defined as the relationship between their value and the base power of the system. Energy losses due to the transfer are included through a constant factor of efficiency.

On the other hand, to simulate a multi-modal system, all parameters in Table 19 must be entered. In large systems, the multi-modal simulation imposes a large number of constraints to the optimization problem, therefore, greatly increasing the computacional burden.

> Note: In the input file, the transmission network is entered in the tab ***Lines***, and the expansion/modification of the network is entered in the tab ***Lines_expn***.

5.2.1. Optimal power flow

MAEP includes a linearized power flow model in which the energy balance for each bus is evaluated (Kirchhoff's first law), the tensions follow Kirchhoff's second law, and limits on the flows of the circuits are hold. All constraints are linearized to include them in the formulation of the optimization problem.

5.2.2. Security constraints

MAEP allows considering security constraint for the system operation. This is by means the restriction on the sum of power flow in selected lines or nodes, considering the power flow direction, due to exogenous technical operation decisions for the safety network operation. Table **??** indicates parameters required to enter this restriction.

Table 20
Security constraint on the power flow limits.

Parameters	Units	Description	Implementation
id		identification number of restriction	
line		number of lines involved in the restriction	
limit	MW	aggregated transfer limit of power flow for lines in a restriction	
initial stage		initial stage for network operation with a restriction	
final stage		final stage for network operation with a restriction	
NI_l		input bus for a connection line in a restriction	
NF_l		output bus for a connection line in a restriction	

The input and output buses definition has the intention of determining which is the direction of the flow to be restricted. In MAEP it is possible to define any number of restrictions, however, the number of lines involved in each restriction is limited to six.

Note: In the input file, the restrictions are entered in the tab ***FlowGates***.

5.3. Costs

Two costs parameters are required for the system simulation. The rationing cost which determines the costs of not meeting the energy demand and the costs of the CO_2 emissions due to the energy generation. Table 21 indicates the parameters required to enter this costs.

Table 21
Parameters of rationing and CO_2 emissions.

Parameters	Units	Description	Implementation
stage		determines the data horizon	
cost_R	\$/MWh	rationing costs per subsystems	
cost_E	\$/TonCO_2	emission costs	

Note: In the input file, the rationing costs are entered in the tab ***RationingCosts***, and the emissions costs are entered in the tab ***EmissionsCosts***.

5.4. Demand

Whether with a unimodal, multi-area or multi-modal system, the system model requires the user to enter the total load demand of the system. If the system is unimodal, this demand will correspond to the total demand in a single bus. Otherwise, it is required to enter the participation factors of the subsystems in the total demand. Demand determines the planning horizon and its temporal resolution. Table 21 indicates the parameters required to enter the load demand.

Table 22
Parameters of load demand.

Parameters	Units	Description	Implementation
stage		determines the data horizon	
total load	MW	total load of the system	
load factor		load factor per subsystem	

Note: In the input file, the demand is entered in the tab ***Demand***.

5.4.1. Subperiods

Subperiods represent the stage short-term resolution of the operation model. A greater number of blocks allows to increase the level of detail in the operation, However, it makes the complexity of problem and computational burden increase. MAEP allows entering any number of blocks from 1 to 24. In this way, the user can work with hourly resolutions within a long-term model.

In addition, since the demand at the stage is represented by the peak demand, to represent the demand at each subperiod it requires the load curve information for each subsystem.

Table 23 indicates the parameters required to enter the short-term resolution.

Table 23
Parameters of short-term resolution.

Parameters	Units	Description	Implementation
subperiod		subperiods per stage	
duration		duration of each subperiod within each stage	
load curve		factor of the peak demand in a subperiond on the stage peak demand	

Note: In the input file, the subperiods and the load curve information are entered in the tab ***Blocks***.

5.4.2. Storage systems restrictions

MAEP allows to establish operation restrictions on the storage systems, such that the storage units operate in specific subperiods within a stage. This function allows to simulate a forced operation of charge and/or discharge following a determined behavior defined by the user. Table 23 indicates the parameters required to enter the storage operation restrictions.

Table 24
Parameters of storage operation restrictions.

Parameters	Units	Description	Implementation
subperiod		subperiods per stage	
restriction	0,1	binary variable for the operation of storage systems. 0 = Does not operate in the subperiod. 1 = operates in the subperiod	

Note: In the input file, the storage restrictions are entered in the tab ***Blocks***.

6. Running simulations

The execution parameters are those that give the user control over the type of analysis that he wants to perform. Through these parameters are selected the modules of MAEP that will be used, it is defined the problem dimension, and the system data pieces to be used for the model execution.

These parameters are entered/selected through the web interface. When the source code is used within a development environment or a Python terminal, the execution parameters are entered through the main console script.

6.1. Setting options

Modularity is one of the most important features of MAEP. This is because of it makes possible to expand and exploit the potentialities of the tool.

Each module is developed to fit the structure of the main model, such that it adds functionalities but ata the same time it can be unppluged from the main structure if its execution is not necessary or if it fails. Table 25 shows the adjustable parameters of MAEP that allow activating or deactivating model components and adjusting the simulation of the system operation to what is required by the user.

Table 25
Parameters to setting model components.

Parameters	Units	Description	Implemented
Optimization			
policy	True - False	calculates the operation policy of the system	
simulation	True - False	executes the simulation of system operation using a previously calculated operating policy	
parallel	True - False	parallel execution to optimize computational resources	No
Data			
read data	True - False	read and format the system's input information	
parameters	True - False	calculates the parameters of the model from the input information	
Analyses			
eólico_PM	True - False	introduces the practical model of wind plants in the model	No
opf_gates	True - False	introduces the network security restriction in the model	
dist_free	True - False	uses a free distribution method to address the penetration of variable renewables	
emissions	True - False	modify the objective function to consider the CO_2 emissions costs	
sens_dem		correction factor of demand	
Results			
print	True - False	generate output files with the main results	
curves	True - False	generate output files and graphics for selected variables	

6.2. Basic parameters

Table 26 indicates the basic parameters for simulation, useful for both the main modules and the auxiliary ones.

The input file that contains all the system information. In a project already simulated, the reading module can be deactivated as long as the input file does not have any change. The execution of this module increases the run times, depending on the size of the system. The second set of parameters has to do with the execution configuration of the SDDP algorithm and the analysis horizon.

Table 26
basic parameters of simulation

Parameters	Units	Description	Implementation
input file		path or name of the input file	
iteration		maximum number of iterations	
stage		determines the planning horizon	
boundary		extra stages to avoid the boundary effects of the algorithm	
s_Backward		scenarios of the random process considered in the backward stage of the algorithm	
s_Forward		scenarios of the random process considered in the forward stage of the algorithm	

6.3. Deterministic/Stochastic

The number of backward and forward scenarios in Table 26 determine the type of model used. If the number of backward stages is equal to one, then the operation policy is calculated by means a deterministic model. The same happens with the simulation of the operation if the number of forward scenarios is equal to one. Therefore, the deterministic and the stochastic models can be combined in a single exceution of the model depending on the preferences of the user.

6.4. Risk aversion

By default, MAEP solves a risk-neutral version of the power planning problem. It seeks for an operation plan that minimizes the total expected cost. MAEP also supports two risk-averse reformulations of the problem in order to account for potential extreme scenarios of resource availability.

6.4.1. Long-term risk aversion

This approach aims to achieve an operation policy with an adequate trade-off between minimizing the expected cost of operation on all scenarios and a level of protection to the operation of the system against the occurrence of critical scenarios of resource availability. Table 27 indicates the parameters required to assess this risk.

Table 27
Parameters of the long-term risk evaluation.

Parameters	Units	Description	Implementation
eps_risk	min: 0.5, max: 1	confidence level on the risk evaluation	
commit	min: 0, max: 1	trade-off parameter between the minimization of the expected and the conditional value at risk (CVAR)	

6.4.2. Short-term variability

For each realization of the stochastic process, it is possible to increase the level of confidence in the short-term balance between supply and demand considering the variability of renewable sources. The level of confidence is established in the energy balance constraint, such that it is hold with a high level of probability. Table 28 indicates the parameters required to assess this risk.

Table 28
Parameters of the short-term risk evaluation.

Parameters	Units	Description	Implementation
eps_area	min: 0.5, max: 1	confidence level on the satisfaction of the demand at each subperiod per area/node.	
eps_all	min: 0.5, max: 1	confidence level on the satisfaction of the demand at each subperiod for the whole system	

7. Accessing the results

Either through the web platform or the IDE, MAEP will deliver a output file with the main results according to the user's settings.

7.1. Output files

Through the web platform users can download .csv and .xlmx files with all the simulation results. Through the development platform it is possible to obtain partial results with a Python variable visualizer. In addition, users will have access to the same output files that are obtained through the web platform. Figure 5 shows the structure of the source code directory to find the output files.

```
dir
├── docs
├── Web_interface
└── MAEP_model
    ├── results
    │   ├── areasdispatch_report.html
    │   ├── csv_variables
    │   ├── General_results.xlsx
    │   └── report_variables
    └── templates
        ├── areasdispatch_report.html
        └── marginalcost_report.html
```

Fig. 5. Output files directory of MAEP.

7.2. Graph module

The results of the basic variables will be presented graphically through the web platform. However, MAEP also offers an experimental plotter of variables through the development platform.

MAEP has test scripts that can be customized to graph selected variables. These modules can be integrated into the main structure of model in a modular way. Figure 6 shows the directory of these scripts in the source code.

```
dir
├── docs
├── Web_interface
├── MAEP_model
└── reports_utils
        ├── curves_report.py
        ├── dispatch.py
        ├── __init__.py
        └── __pycache__
```

Fig. 6. Reports directory of MAEP.

Referencias

[1] Spyder - scientific python development enviroment.

[2] William E. Hart, Carl D. Laird, Jean-Paul Watson, David L. Woodruff, Gabriel A. Hackebeil, Bethany L. Nicholson, and John D. Siirola. *Pyomo–optimization modeling in python*, volume 67. Springer Science & Business Media, second edition, 2017.