Multi-Vector Simulator (MVS)

Release 1.1.1

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May 03, 2024

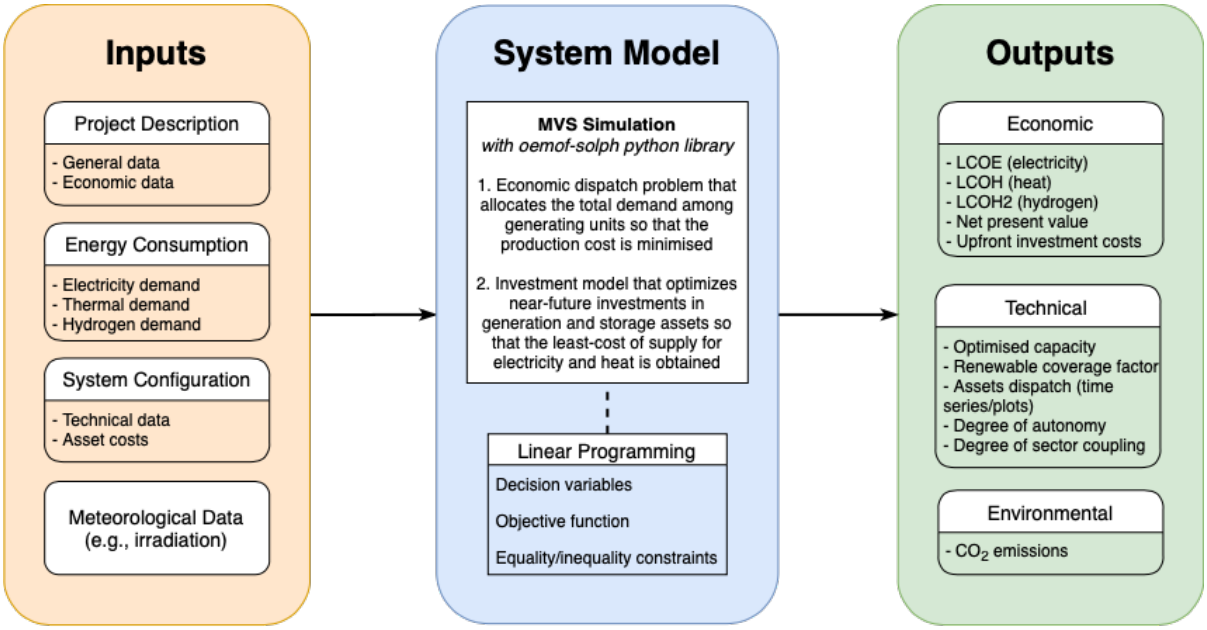
GETTING STARTED

The Multi-Vector Simulator (hereafter MVS) is an oemof -based Python package which aims at facilitating the modelling of multi-energy carriers energy systems in island or grid connected mode.

The main goals of the MVS are

1. to minimize the production costs by determining the generating units' optimal output, which meets the total demand
2. to optimize near-future investments in generation and storage assets with the least possible cost of energy.

The MVS graphical model is divided into three connected blocks that trace the logic sequence: inputs, system model, and outputs. This is a typical representation of a simulation model:



The user is asked to provide the required data via a collection of csv files or a unique json file with particular format. The input data is split into the following categories:

- **Project description**, which entails the general information regarding the project (country, coordinates, etc.), as well as the economic data such as the discount factor, project duration, or tax
- **Energy consumption**, which is expressed as times series based on the type of energy (in this case: electrical and thermal)
- **System configuration**, in which the user specifies the technical and financial data of each asset
- **Meteorological data**, which is related to the components that generate electricity by harnessing an existing source of energy that is weather- and time-dependent (e.g., solar and wind power)

This set of input data is then translated to a linear programming problem, also known as a constrained optimization problem. The MVS is based on the oemof-solph python library that describes the problem by specifying an objective function to minimize the annual energy supply costs, the decision variables and the bounds and constraints.

The simulation outputs are also separated into categories:

- Economic results used for the financial evaluation, such as the levelized cost of electricity/heat or the net present value of the projected investments
- Technical results that include the optimized capacities and dispatch of each asset
- Environmental results assessing the system's environmental contribution in terms of CO2 emissions.

Additionally, different vizualizations of the results can be provided, eg. as pie charts, plots of asset dispatch and an automatic summary report.

CHAPTER

ONE

MAINTAINERS

The multi-vector simulator is currently maintained by staff from Reiner Lemoine Institute.

The MVS is developed as a work package in the European Union's Horizon 2020 Research E-LAND project

Acknowledgement

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 824388.

CHAPTER

TWO

GETTING STARTED

2.1 Installation

2.1.1 Setup

To set up the MVS, follow the steps below:

- If python3 is not pre-installed: Install miniconda (for python 3.7: https://docs.conda.io/en/latest/miniconda.html)
- WINDOWS USERS: Using an Anaconda virtual environment is highly recommended for being able to fully utilize the tool. Venv environtments works only for running the optimization tool (mvs_tool). For this, updating Pandas to at least version 1.3.5 and installing the package pygraphviz as indicated in this link https://pygraphviz.github.io/documentation/stable/install.html is necessary. However, it is not possible to run the interactive report (mvs_report) with venv, as it gives an error. Therefore, it is best to use conda environments.
- Open Anaconda prompt (or other software as Pycharm) to create and activate a virtual environment

  `conda create -n [your_env_name] python=3.6 activate [your env_name]`

- Install the latest MVS release:

  `pip install multi-vector-simulator`

- Download the cbc-solver into your system from https://ampl.com/dl/open/cbc/ and integrate it in your system, ie. unzip, place into chosen path, add path to your system variables (Windows: "System Properties" –>"Advanced"–> "Environment Variables", requires admin-rights).

  You can also follow the steps from the oemof setup instructions

- Test if that the cbc solver is properly installed by typing

  `oemof_installation_test`

  You should at least get a confirmation that the cbc solver is working

```
******************************
Solver installed with oemof:

cbc: working
glpk: not working
gurobi: not working
cplex: not working

******************************
oemof successfully installed.
******************************
```

- Test if the MVS installation was successful by executing

  `mvs_tool`

This should create a folder `MVS_outputs` with the example simulation's results

You can always check which version you installed with the following command

```
mvs_tool --version
```

2.1.2 Using the MVS

To run the MVS with custom inputs you have several options:

Use the command line

Edit the json input file (or csv files) and run

```
mvs_tool -i path_input_folder -ext json -o path_output_folder
```

With `path_input_folder`: path to folder with input data,

`ext`: json for using a json file and csv for using csv files

and `path_output_folder`: path of the folder where simulation results should be stored.

For more information about the possible command lines options

```
mvs_tool -h
```

Use the `main()` function

You can also execute the mvs within a script, for this you need to import

```
from multi_vector_simulator.cli import main
```

The possible arguments to this functions are:

- `overwrite` (bool): Determines whether to replace existing results in `path_output_folder` with the results of the current simulation (True) or not (False) (Command line "-f"). Default: `False`.
- `input_type` (str): Defines whether the input is taken from the `mvs_config.json` file ("json") or from csv files ('csv') located within /csv_elements/ (Command line "-ext"). Default: `json`.
- `path_input_folder` (str): The path to the directory where the input CSVs/JSON files are located. Default: `inputs/` (Command line "-i").
- `path_output_folder` (str): The path to the directory where the results of the simulation such as the plots, time series, results JSON files are saved by MVS (Command line "-o"). Default: `MVS_outputs/`.
- `display_output` (str): Sets the level of displayed logging messages. Options: "debug", "info", "warning", "error". Default: "info".
- `lp_file_output` (bool): Specifies whether linear equation system generated is saved as lp file. Default: False.
- `pdf_report` (bool): Specify whether pdf report of the simulation's results is generated or not (Command line "-pdf"). Default: False.

- `save_png` (bool): Specify whether png figures with the simulation's results are generated or not (Command line "-png"). Default: False.

Edit the csv files (or, for devs, the json file) and run the `main()` function. The following `kwargs` are possible:

Default settings

If you execute the `mvs_tool` command in a path where there is a folder named `inputs` (you can use the folder `input_template` for inspiration) this folder will be taken as default input folder and you can simply run

```
mvs_tool
```

A default output folder will be created, if you run the same simulation several time you would have to either overwrite the existing output file with

```
mvs_tool -f
```

Or provide another output folder's path

```
mvs_tool -o <path_to_other_output_folder>
```

Generate pdf report or an app in your browser to visualise the results of the simulation

To use the report feature you need to install extra dependencies first

```
pip install multi-vector-simulator[report]
```

If you are using zsh terminals and recieve the error message "no matches found", you might need to run

```
pip install 'multi-vector-simulator[report]'
```

Use the option `-pdf` in the command line `mvs_tool` to generate a pdf report in a simulation's output folder (by default in `MVS_outputs/report/simulation_report.pdf`):

```
mvs_tool -pdf
```

Use the option `-png` in the command line `mvs_tool` to generate png figures of the results in the simulation's output folder (by default in `MVS_outputs/`):

```
mvs_tool -png
```

To generate a report of the simulation's results, run the following command **after** a simulation generated an output folder:

```
mvs_report -i path_simulation_output_folder -o path_pdf_report
```

where `path_simulation_output_folder` should link to the folder of your simulation's output, or directly to a json file (default `MVS_outputs/json_input_processed.json`) and `path_pdf_report` is the path where the report should be saved as a pdf file.

The report should appear in your browser (at http://127.0.0.1:8050) as an interactive Plotly Dash app.

You can then print the report via your browser print functionality (ctrl+p), however the layout of the pdf report is only well optimized for chrome or chromium browser.

It is also possible to automatically save the report as pdf by using the option `-pdf`

```
mvs_report -i path_simulation_output_folder -pdf
```

By default, it will save the report in a `report` folder within your simulation's output folder default (`MVS_outputs/report/`). See `mvs_report -h` for more information about possible options. The css and images used to make the report pretty should be located under `report/assets`.

2.1.3 Contributing and additional information for developers

If you want to contribute to this project, please read CONTRIBUTING.md. For less experienced github users, we propose a workflow.

For advanced programmers: please checkout the *dev* branch that includes the latest updates and changes. You can find out about the latest changes in the CHANGELOG.md file.

2.2 Simulating with the MVS

The MVS can perform capacity as well as dispatch optimisations of a specific energy system. This means that both the needed additional capacity to be installed is optimised as well as the respective asset's operation. To perform an energy system simulation, a multitude of input parameters is needed. They are described in details in the *input parameters* section. They include economic parameters, technological parameters and project settings. Together they define all aspects of the energy system to be simulated and optimised. With these parameters, the MVS builds an energy system model which is translated to a system of linear equations. The MVS tries to find an optimal solution which minimizes the annual costs of demand supply.

In this section, we want to provide you with all information needed to design your own energy system and run your own optimisations. First we will explain the two possible ways to provide the input parameters to the MVS. Then how to draft an energy system model out of a real local energy system configuration.

2.2.1 Input files

All input files need to be within a folder with the following structure.

```
input_folder
    ├── csv_elements
        ├── constraints.csv
        ├── economic_data.csv
        ├── energyBusses.csv
        ├── energyConsumption.csv
        ├── energyConversion.csv
        ├── energyProduction.csv
        ├── energyProviders.csv
        ├── energyStorage.csv
        ├── fixcost.csv
        ├── project_data.csv
        ├── simulation_settings.csv
        └── storage_01.csv
    ├── time_series
        └── blank
```

└── mvs_config.json

The name and location of the `input_folder` is up to the user. The underlying structure and file names within this folder should not be altered (with the exception of `storage_01.csv` which is only required to match a filename provided in `energyStorage.csv`.

There are two allowed formats to provide input data to the MVS: Json or CSV (comma separated values).

The folder `time_series` is always required, it should contain the timeseries for energy demand, energy production and potentially other time-dependent parameters. To provide the inputs using the Json format, only the `file mvs_config.json` is required, whereas for the CSV format only the folder `csv_elements` is required.

The CSV format is more user-friendly to design a local energy system model and the Json format is more compact (the whole model is contained in only one file).

Csv files: csv_elements folder

To use the CSV format, each of the following files have to be present in the folder `csv_elements`.

Files containting enumeration of energy system's assets (or components):

- energyConsumption.csv - Energy demands and paths to their time series as csv
- energyConversion.csv - Conversion/transformer objects, eg. transformers, generators, heat pumps
- energyProduction.csv - Act as energy "sources", ie. PV or wind plants, with paths to their generation time series as csv
- energyProviders.csv - Specifics of energy providers, eg. DSOs that are connected to the local energy system, including energy prices and feed-in tariffs
- energyStorage.csv - List of energy storages of the energy system
- storage_01.csv - Technical parameters of each energy system
- energyBusses.csv - Energy busses of the energy system to be simulated

Files containing enumeration of energy system's global parameters:

- fixcost.csv - fix project development/maintenance costs (should not be used currently)
- simulation_settings.csv - Simulation settings, including start date and duration
- project_data.csv - some generic project information
- constraints.csv - Constraints on the energy system
- economic_data.csv - Major economic parameters of the project

The detailed description of the content of those files is available in the *input parameters* section. Moreover, an input folder template is available here.

You can conveniently create a copy of this folder in your local path with the command (after having followed *the installation steps*) .. code:

```
mvs_create_input_template
```

A simple example system is setup with this input folder.

Note: Currently only one of `,`, `;` or `&` is allowed as value separation for the CSV files (each file should make a coherent use of a unique separator, otherwise leading to parsing problems).

For developers: the allowed separators for csv files are located in `src/constants.py` under the `CSV_SEPARATORS` variable.

Note: The name (or label) of each assets needs to be unique and used coherently across the various csv files.

Note: If the user used the CSV format to simulate a local energy system, the MVS will automatically create a Json file (`mvs_csv_config.json`) from the provided input data. The user could rename this file `mvs_config.json` and use it as input for the simulation.

Json file: mvs_config.json

The structure of the Json file matches the one described by the `csv_elements` folder. The Json format is intended for easier exchange: via http requests for online services such as EPA for example.

Use of Json file is recommended for advanced users only.

There can only be a single Json file in your input folder and it must be named `mvs_config.json`.

An example of a Json file structure is available from the default scenario of the MVS.

Time series: time_series folder

In the CSV and Json files, the value of the parameter *file_name* are filenames. Those filenames correspond to files which must be present in the folder `time_series` in your input folder, formatted as CSV. As an example, if one asset listed in *energy production* has `generation_pv.csv` as value for the *file_name*. The file `generation_pv.csv` containing a value of the pv generation for each timestep of the simulation should be present in the `time_series` folder.

Note: When a time series describes a non-dispatchable demand or an otherwise scalar value of a parameter (eg. energy price), the values of the time series can have any positive value.

Note: For non-dispatchable sources, eg. the generation of a PV plant, you need to provide a specific time series (unit: kWh/kWp, etc.). For the latter, make sure that its values are between zero and one (`[0, 1]`).

2.2.2 Defining an energy system

To define your energy system you have to fill out the CSV sheets that are provided in the folder `csv_elements`. For each asset you want to add, you have to add a new column to a file. If you do not have an asset of a specific type, simply leave the columns empty (but leave the columns with the parameter names and units).

The unit columns can indicate you what is the type of the parameter which is required from you (string, boolean, number) if it is not a physical unit. In case of doubts, also consider having a look in the *parameter list*.

Warning: Do not delete any of the rows of the CSV´s – each parameter is needed for the simulation. There will also be warnings if a parameters is missing or misspelled.

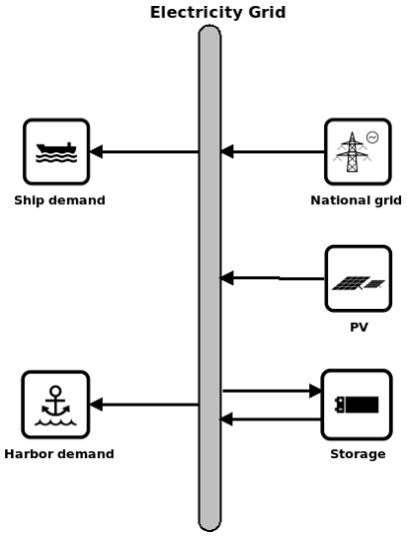
Example of simple energy systems

Please refer to the *Examples* section

Building a model from assets and energy flows

Simulating an energy system with the MVS requires a certain level of abstraction. In general, as it is based on the programming framework oemof, it will depict the energy system only as linearized model. This allows for the quick computation of the optimal system sizing and approximate dispatch, but does not replace operational management.

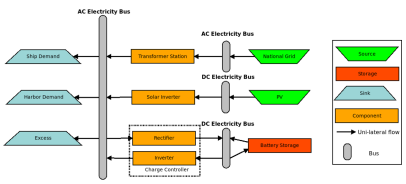
The level of abstraction and system detail needed for an MVS simulation will be explained based on an exemplary local energy system. Let's assume that we want to simulate an industrial site with some electrical demand, the grid connection, a battery as well as a PV plant. A schematic of such a system is shown below.



We can see that we have an electricity bus, to which all other components are connected, specifically demand external electricity supply and the local assets (battery and PV). However even though all those components belong to the same sector, their interconnection with the electricity bus or here the electricity grid could be detailed in the deeper manner.

As such, in reality, the battery may be on an own DC electricity bus, which is either the separate from or identical to the DC bus of the PV plant. Both DC busses would have to be interconnected with the main electricity bus (AC) through an inverter, or in case of bi-directional flow for the battery with an rectifier as well.

Just like so, the DSO could either be only providing electricity also allowing feed in, or the demand may be split up into multiple demand profiles. This granularity of information would be something that the MVS model requires to properly depict the system behaviour and resulted optimal capacities and dispatch. The information fed into the MVS via the CSV's would therefore define following components:



Ideally you sketch down the energy system you want to simulate with the above-mentioned granularity and only using sources, sinks, transformers and buses (meaning the oemof components). When interconnecting different assets make sure that you use the correct bus name in each of the CSV input files. The bus names are defined with `input_direction` and `output_direction`. If you interconnect your assets or buses incorrectly the system will still

be built but the simulation terminated. When executing a simulation, the MVS will generate a rough graphic visualisation of your energy system if you use the option `-png`.

There, all components and buses should be part of a single system (i.e. linked to each other) - otherwise you misconfigured your energy system.

Warning: You need to be aware that you yourself have to make sure that the units you assign to your assets and energy flows make sense. The MVS does neither perform a logical check, nor does it transform units, eg. from MWh to kWh.

2.3 Example of PV + Battery + Grid

Input files of simple benchmarks (PV + battery + grid) scenarios can be found here

2.4 Adding a timeseries for a parameter

Sometimes you may want to define a parameter not as a scalar value but as a time series. This can for example happen for efficiencies (heat pump COP during the seasons), energy prices (currently only hourly resolution), or the state of charge (for example if you want to achieve a certain stage of charge of an FCEV at a certain point of time).

You can define a scalar as a time series in the csv input files (not applicable for `energyConsumption.csv`), by replacing the scalar value with following dictionary:

{'file_name': 'your_file_name.csv', 'header': 'your_header', 'unit': 'your_unit'}

The feature was tested for following parameters:

- energy_price
- feedin_tariff
- dispatch_price
- efficiency

You can see an implemented example here, where the heat pump has a time-dependent efficiency:

Table 1: Example for defining a scalar parameter as a time series

	unit	heat_pump
age_installed	year	0
development_costs	currency	0
specific_costs	currency/kW	7000
efficiency	factor	{'file_name': 'cops_eers_test.csv', 'header': 'no_unit', 'unit': 'NA'}
inflow_direction	str	Electricity
installedCap	kW	0
label	str	Heat pump
lifetime	year	20
specific_costs_om	currency/kW/year	0
dispatch_price	currency/kWh	0
optimizeCap	bool	True
outflow_direction	str	Heat
energyVector	str	Electricity
type_oemof	str	transformer
unit	str	kW

The feature is tested with benchmark test `test_benchmark_feature_parameters_as_timeseries()`.

Example input files, where at least one parameter is defined as a time series, can be found here:

- First example: Defines the `energy_price` (file) of an energy provider as a time series
- Second example: Defines the `energy_price` (file) of an energy provider and the efficiency of a diesel generator (file) as a time series.

2.5 Using multiple in- or output busses

Sometimes, you may also want to have multiple input or output busses connected to a component. This is for example the case if you want to model an electrolyzer with a transformer, and want to track water consumption at the same time as you want to track electricity consumption.

You can define this, again, in the csv´s. First you should provide the input, or output, busses as a list for the *energyConversion.csv* parameter of *inflow_direction* or *outflow_direction* resp.:

> "[h2o_bus, electricity_bus]"

Then you need to provide the *efficiencies* and *dispatch prices* respective to each bus, for example:

> "[0.99, 0.98]"

You can also provide a timeseries for one or both values. To do so, you can simply use the notation introduced in *Adding a timeseries for a parameter*:

> "[0.99, {'value': {'file_name': 'your_file_name.csv', 'header': 'your_header'}, 'unit': 'your_unit'}]"

You can see an example here, with an electrolyzer :

Table 2: Example for defining a component with multiple inputs/outputs

	unit	electrolyser
age_installed	year	3
development_costs	currency	0
specific_costs	currency/kW	1500
efficiency	factor	"[0.01923,0.28845]"
inflow_direction	str	"[MicroGrid,Water]"
installedCap	kW	0
label	str	Electrolyser
lifetime	year	20
specific_costs_om	currency/kW/year	75
dispatch_price	currency/kWh	"[0,0.0038]"
optimizeCap	bool	True
outflow_direction	str	Local H2 grid
energyVector	str	Electricity
type_oemof	str	transformer
unit	str	kW

The features were integrated with Pull Request #63 and Pull Request #949.

For more information, you might also reference following issues:

- Parameters can now be a list of values, eg. efficiencies for two busses or multiple input/output vectors(Issue #52)
- Parameters can now be defined as a list as well as as a timeseries (Issue #52, Issue #82)

2.6 Tips & Tricks

2.6.1 Including sunk costs for previous investments into specific assets

Usually, the investments into existing capacities are neglected and assumed to be sunk costs of the system. The existing capacity `installedCap` as well as the age of the installed asset `age_installed` are only used to calculate when necessary re-investments take place, and how high the *replacements costs* are. But there is no option if one wants to optimize a system with pre-existing capacities of certain assets and still account for the installation costs that happened before the first time step of the simulation.

When optimizing a system with pre-existing capacities of certain assets, it can be usefull for the user to implement the installation costs of these assets in the economic evaluation. This trick triggers the replacement of those assets, thus accounting for investments costs of pre-existing assets in the scenario.

With the trick presented here, it is possible to optimize a system with a specific or a specific minimal capacity of a certain asset and still account for installation costs of the asset at the beginning of the project (in the idea of a greenfield / brownfield optimization). The presented trick works for energy production assets as well as energy conversion assets.

To apply this trick, the following manipulations must be applied to the input parameters of the asset in question:

- `optimizeCap` to False
- `installedCap` to the specific existing capacity
- `aged_installed` to the lifetime of the asset

Previous investment costs into now pre-existing asset capacities are now taken into account in the economic evaluation of a scenario.

CHAPTER

THREE

MODEL REFERENCE

- **How the energy system is modelled**: *Assumption behind the model* | *Available components for modelling* | *Setting constraints on model or components* | *Scope and limitation of the model*
- **Description of parameters**: *Input parameters* | *Output variables and KPIs*
- **Validation of the model**: *Validation methodology*

3.1 Assumptions

The MVS uses the programming framework `oemof-solph` at its core and builds an energy system model based upon its nomenclature. As such, the energy system model can be described with a linear equation system. The most important aspects of a linear equation system are described below in a generalized way, and additionally explained through the use of an example. This will enable the clear comparision to other energy system models.

3.1.1 Economic Dispatch

Linear programming is a mathematical modelling and optimization technique for a system of a linear objective function subject to linear constraints. The goal of a linear programming problem is to find the optimal value for the objective function, be it a maximum or a minimum. The MVS is based on `oemof-solph`, which in turn uses `Pyomo` to create a linear problem. The economic dispatch problem in the MVS has the objective of minimizing the production cost by allocating the total demand among the generating units at each time step. The equation is the following:

$$minZ = \sum_{i} a_i \cdot CAP_i + \sum_{i} \sum_{t} c_{var,i} \cdot E_i(t)$$

$CAP_i \geq 0$

$E_i(t) \geq 0 \qquad \forall t$

i: asset

a_i: asset annuity [currency/kWp/year, currency/kW/year, currency/kWh/year]

CAP_i: asset capacity [kWp, kW, kWh]

$c_{var,i}$: variable operational or dispatch cost [currency/kWh, currency/L]

$E_i(t)$: asset dispatch [kWh]

The annual cost function of each asset includes the capital expenditure (investment cost) and residual value, as well as the operating expenses of each asset. It is expressed as follows:

$$a_i = \left(capex_i + \sum_{k=1}^{n} \frac{capex_i}{(1+d)^{k \cdot t_a}} - c_{res,i} \right) \cdot CRF(T) + opex_i$$

$$CRF(T) = \frac{d \cdot (1+d)^T}{(1+d)^T - 1}$$

$capex_i$: specific investment costs [currency/unit]
n: number of replacements of an asset within project lifetime T
t_a: asset lifetime [years]
CRF: capital recovery factor
$c_{res,i}$: residual value of asset i at the end of project lifetime T [currency/unit]
$opex_i$: annual operational and management costs [currency/unit/year]
d: discount factor
T: project lifetime [years]

The CRF is a ratio used to calculate the present value of the annuity. The discount factor can be replaced by the weighted average cost of capital (WACC), calculated by the user.

The lifetime of the asset t_a and the lifetime of the project T can be different from each other; as a result, the number of replacements n is estimated using the equation below:

$$n = round\left(\frac{T}{t_a} + 0.5\right) - 1$$

The residual value is also known as the salvage value and it represents an estimate of the monetary value of an asset at the end of the project lifetime T. The MVS considers a linear depreciation over T and accounts for the time value of money through the use of the following equation:

$$c_{res,i} = \frac{capex_i}{(1+d)^{n \cdot t_a}} \cdot \frac{1}{T} \cdot \frac{(n+1) \cdot t_a - T}{(1+d)^T}$$

3.1.2 Energy Balance Equation

One main constraint that the optimization model is subject to is the energy balance equation, which specifically maintains equality between the total incoming and outgoing energy of a bus. This balancing equation is applicable to all bus types, be it electrical, thermal, hydrogen or any other energy carrier.

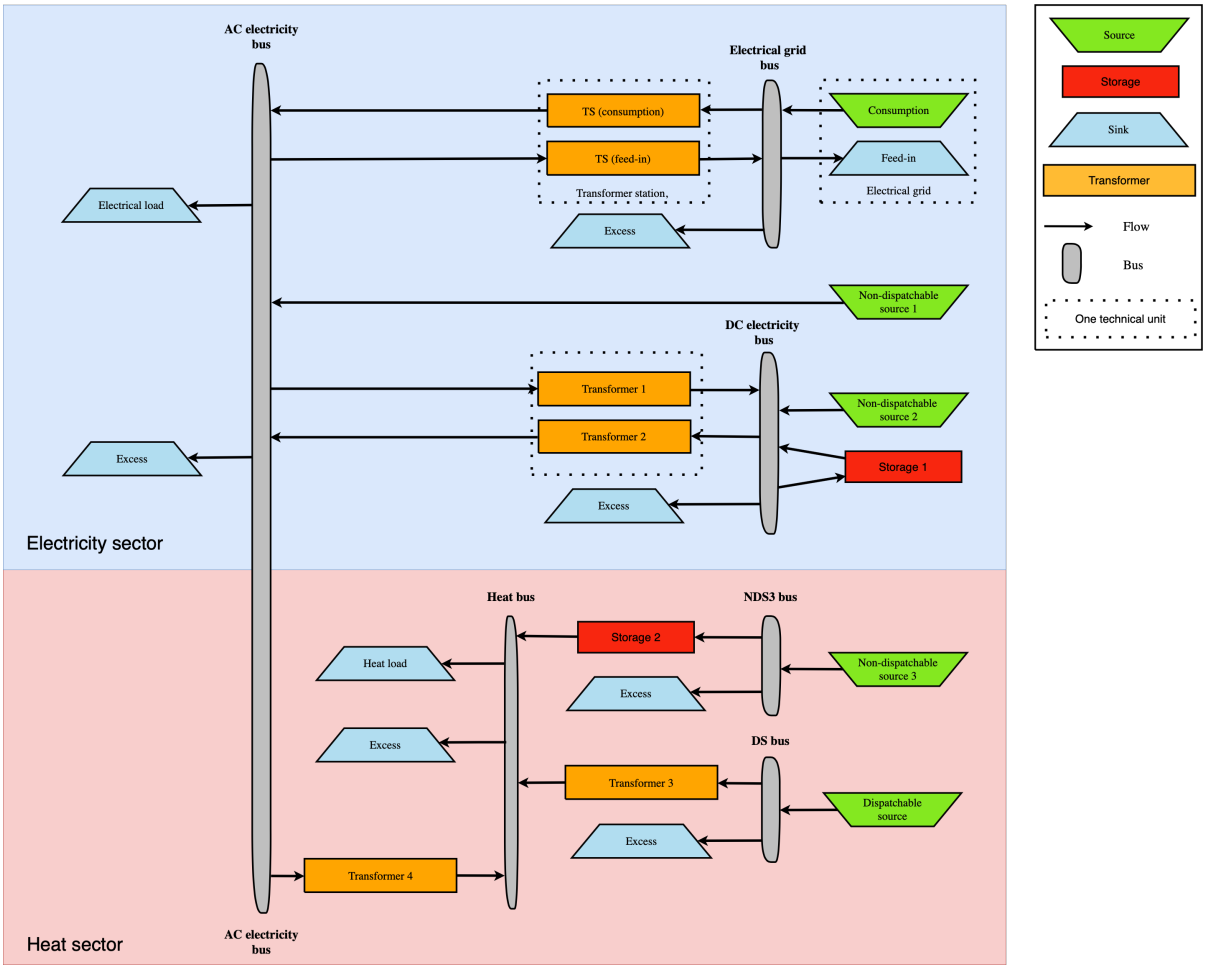
$$\sum E_{in,i}(t) - \sum E_{out,j}(t) = 0 \qquad \forall t$$

$E_{in,i}$: energy flowing from asset i to the bus
$E_{out,j}$: energy flowing from the bus to asset j

It is very important to note that assets i and j can be the same asset (e.g. a battery with an electrical inflow/outflow). *Oemof-solph* allows both E_{in} and E_{out} to be larger than zero in the same time step t (see *Infeasible bi-directional flow in one timestep*).

3.1.3 Example: Sector Coupled Energy System

In order to understand the component models, a generic sector coupled energy system example is shown in the figure below. It brings together the electricity and heat sector through a transformer (Transformer 4) which connects the two sector buses.



For the sake of simplicity, the following table gives an example for each asset type with an abbreviation to be used in the energy balance and component equations.

Table 1: Asset Types and Examples

Asset Type	Asset Example	Abbreviation	Unit
Non-dispatchable source 1	Wind turbine	wind	kW
Non-dispatchable source 2	Photovoltaic panels	pv	kWp
Storage 1	Battery energy storage	bat	kWh
Transformer 1	Rectifier	rec	kW
Transformer 2	Solar inverter	inv	kW
Non-dispatchable source 3	Solar thermal collector	stc	kWth
Storage 2	Thermal energy storage	tes	kWth
Dispatchable source	Heat source (e.g., biogas)	heat	L
Transformer 3	Turbine	turb	kWth
Transformer 4	Heat pump	hp	kWth

All grid and dispatchable source asset types are assumed to be available 100% of the time with no consumption limits. For each bus in the system, the MVS automatically includes a sink component for excess energy related to the bus, which is denoted E_{ex} in the equations. This excess sink accounts for the extra energy in the system that has to be dumped.

Electricity Grid Equation

The electricity grid is modeled through a feed-in and a consumption node. Transformers limit the peak flow into or from the local electricity line, and electricity sold to the grid experiences losses in the transformer (ts, f).

$$E_{grid,c}(t) - E_{grid,f}(t) + E_{ts,f}(t) \cdot \eta_{ts,f} - E_{ts,c}(t) = 0 \qquad \forall t$$

$E_{grid,c}$: energy consumed from the electricity grid
$E_{grid,f}$: energy fed into the electricity grid
$E_{grid,c}$: transformer station feed-in
$\eta_{ts,f}$: transformer station efficiency
$E_{grid,c}$: transformer station consumption

Non-Dispatchable Source Equations

Non-dispatchable sources in the sector coupled energy system example are wind, PV and solar thermal power. Their generation is determined by the provided timeseries of instantaneous generation, providing α, β, γ in relation to wind, PV and solar thermal power respectively.

$$E_{wind}(t) = CAP_{wind} \cdot \alpha_{wind}(t) \qquad \forall t$$
$$E_{pv}(t) = CAP_{pv} \cdot \beta_{pv}(t) \qquad \forall t$$
$$E_{stc}(t) = CAP_{stc} \cdot \gamma_{stc}(t) \qquad \forall t$$

E_{wind}: energy generated from the wind turbine
CAP_{wind}: wind turbine capacity [kW]
α_{wind}: instantaneous wind turbine performance metric [kWh/kW]
E_{pv}: energy generated from the PV panels
CAP_{pv}: PV panel capacity [kWp]
β_{pv}: instantaneous PV specific yield [kWh/kWp]
E_{stc}: energy generated from the solar thermal collector
CAP_{stc}: Solar thermal collector capacity [kWth]
γ_{stc}: instantaneous collector's production [kWh/kWth]

Storage Model

There are two storages in the defined example system: An electrical energy storage (Storage 1, bat) and a thermal energy storage (Storage 2, tes). Below, the equations for Storage 1 are provided, but Storage 2 follows analogous equations for charge, discharge and bounds.

$$E_{bat}(t) = E_{bat}(t-1) + E_{bat,in}(t) \cdot \eta_{bat,in} - \frac{E_{bat,out}}{\eta_{bat,out}} - E_{bat}(t-1) \cdot \epsilon \qquad \forall t$$

$$\begin{aligned} CAP_{bat} \cdot SOC_{min} \leq E_{bat}(t) \leq CAP_{bat} \cdot SOC_{max} \qquad & \forall t \\ 0 \leq E_{bat}(t) - E_{bat}(t-1) \leq CAP_{bat} \cdot C_{rate,in} \qquad & \forall t \\ 0 \leq E_{bat}(t-1) - E_{bat}(t) \leq CAP_{bat} \cdot C_{rate,out} \qquad & \forall t \end{aligned}$$

E_{bat}: energy stored in the battery at time t
$E_{bat,in}$: battery charging energy
$\eta_{bat,in}$: battery charging efficiency
$E_{bat,out}$: battery discharging energy
$\eta_{bat,out}$: battery discharging efficiency
ϵ: decay per time step
CAP_{bat}: battery capacity [kWh]
SOC_{min}: minimum state of charge
SOC_{max}: maximum state of charge
$C_{rate,in}$: battery charging rate
$C_{rate,in}$: battery discharging rate

DC Electricity Bus Equation

The following equation illustrates an example of a DC bus with a battery, PV and a bi-directional inverter.

$$E_{pv}(t) + E_{bat,out}(t) \cdot \eta_{bat,out} + E_{rec}(t) \cdot \eta_{rec} - E_{inv}(t) - E_{bat,in} - E_{ex}(t) = 0 \qquad \forall t$$

E_{rec}: rectifier energy
η_{rec}: rectifier efficiency
E_{inv}: inverter energy

AC Electricity Bus Equation

This equation describes the local electricity grid and all connected assets:

$$E_{ts,c}(t) \cdot \eta_{ts,c} + E_{wind}(t) + E_{inv}(t) \cdot \eta_{inv} - E_{ts,c}(t) - E_{rec}(t) - E_{hp}(t) - E_{el}(t) - E_{ex}(t) = 0 \qquad \forall t$$

$\eta_{ts,c}$: transformer station efficiency
η_{inv}: inverter efficiency
E_{hp}: heat pump electrical consumption
E_{el}: electrical load

Heat Bus Equation

This equation describes the heat bus and all connected assets:

$$E_{tes}(t) \cdot \eta_{tes} + E_{turb}(t) \cdot \eta_{turb} + E_{hp}(t) \cdot COP - E_{th}(t) - E_{ex}(t) = 0$$

η_{tes}: thermal storage efficiency
η_{turb}: turbine efficiency
COP: heat pump coefficient of performance
E_{th}: heat load

NDS3 Bus Equation

The NDS3 Bus is an example of a bus which does not serve both as the input and output of a storage system. Instead, the thermal storage is charged from the NDS3 bus, but discharges into the heat bus.

$$E_{stc}(t) - E_{tes}(t) - E_{ex}(t) = 0$$

E_{tes}: thermal energy storage

DS Bus Equation

The DS Bus shows an example of a fuel source providing an energy carrier (biogas) to a transformer (turbine).

$$E_{heat}(t) - E_{turb}(t) - E_{ex}(t) = 0$$

E_{heat}: thermal energy (biogas) production
E_{turb}: turbine (biogas turbine) energy

3.1.4 Cost calculations

The optimization of the MVS is mainly based on costs. There is, however, the possibility of introducing additional constraints which will impact the optimization results e.g. implementing a maximum installable capacity limit (comp. *maximumCap*) or adding constraints for certain key performance indicators (see *Constraints*). In order to optimize the energy systems properly, the economic data provided with the input data has to be pre-processed (also see *Economic Dispatch*) and then also post-processed when evaluating the results. The following assumptions are therefore important:

- *Project lifetime*: The simulation has a defined project lifetime, for which continuous operation is assumed - which means that the first year of operation is considered to be the same as the last year of operation. Existing and optimized assets have to be replaced (if their lifetime preceeds the system lifetime) to make this possible.
- *Simulation duration*: It is advisable to simulate the whole year to find the most suitable combination of energy assets for your system. Sometimes however you might want to look at specific seasons to see their effect - this is possible in the MVS by choosing a specific start date and simulation duration.
- ***Asset costs*: Each asset can have development costs, specific investment costs, specific operation and management costs as well as dispatch costs.**
  - *Replacement costs* are calculated based on the lifetime of the assets, and residual values are paid at the end of the project.
  - *Development costs* are costs that will occurr regardless of the installed capacity of an asset - even if it is not installed at all. It stands for system planning and licensing costs. If you have optimized your energy system and see that an asset might not be favourable (zero optimized capacities), you might want to run the simulation again and remove the asset, or remove the development costs of the asset.
  - *Specific investment costs* and *specific operation and maintenance costs* are used to calculate the annual expenditures that an asset has per year, in the process also adding the replacement costs.
  - *Dispatch price* can often be set to zero, but are supposed to cover instances where utilization of an asset requires increased operation and maintenance or leads to wear.
- ***Pre-existing capacities*: It is possible to add assets that already exist in your energy system with their capacity and age.**
  - *Replacements* - To ensure that the energy system operates continously, the existing assets are replaced with the same capacities when they reached their end of life within the project lifetime.
  - *Replacement costs* are calculated based on the lifetime of the asset in general and the age of the pre-existing capacities
- **Fix project costs: It is possible to define fix costs of the project - this is important if you want to compare different project locations with each other. You can define…**
  - *Development costs*, which could for example stand for the cost of licenses of the whole energy system
  - *(Specific) investment costs*, which could be an investment into land or buildings at the project site. When you define a lifetime for the investment, the MVS will also consider replacements and reimbursements.
  - *(Specific) operation and management costs*, which can cover eg. the salaries of at the project site

3.1.5 Weighting of energy carriers

To be able to calculate sector-wide key performance indicators, it is necessary to assign weights to the energy carriers based on their usable potential. In the conference paper handed in to the CIRED workshop, we have proposed a methodology comparable to Gasoline Gallon Equivalents.

After thorough consideration, it has been decided to base the equivalence in tonnes of oil equivalent (TOE). Electricity has been chosen as a baseline energy carrier, as our pilot sites mainly revolve around it and also because we believe that this energy carrier will play a larger role in the future. For converting the results into a more conventional unit, we choose crude oil as a secondary baseline energy carrier. This also enables comparisons with crude oil price developments in the market. For most KPIs, the baseline energy carrier used is of no relevance as the result is not dependent on it. This is the case for KPIs such as the share of renewables at the project location or its self-sufficiency. The choice of the baseline energy carrier is relevant only for the levelized cost of energy (LCOE), as it will either provide a system-wide supply cost in Euro per kWh electrical or per kg crude oil.

First, the conversion factors to kg crude oil equivalent [1] were determined (see *Conversion factors: kg crude oil equivalent (kgoe) per unit of a fuel* below). These are equivalent to the energy carrier weighting factors with baseline energy carrier crude oil.

Following conversion factors and energy carriers are defined:

Table 2: Conversion factors: kg crude oil equivalent (kgoe) per unit of a fuel

Energy carrier	Unit	Value
H2 [3]	kgoe/kgH2	2.87804
LNG	kgoe/kg	1.0913364
Crude oil	kgoe/kg	1
Gas oil/diesel	kgoe/litre	0.81513008
Kerosene	kgoe/litre	0.0859814
Gasoline	kgoe/litre	0.75111238
LPG	kgoe/litre	0.55654228
Ethane	kgoe/litre	0.44278427
Electricity	kgoe/kWh(el)	0.0859814
Biodiesel	kgoe/litre	0.00540881
Ethanol	kgoe/litre	0.0036478
Natural gas	kgoe/litre	0.00080244
Heat	kgoe/kWh(therm)	0.086
Heat	kgoe/kcal	0.0001
Heat	kgoe/BTU	0.000025

The values of ethanol and biodiesel seem comparably low in [1] and [2] and do not seem to be representative of the net heating value (or lower heating value) that was expected to be used here.

From this, the energy weighting factors are calculated using the electricity content for crude oil as baseline (see *Electricity equivalent conversion per unit of a fuel* below).

Table 3: Electricity equivalent conversion per unit of a fuel

Energy carrier	Unit	Value
LNG	kWh(eleq)/kg	12.6927
Crude oil	kWh(eleq)/kg	11.6304
Diesel	kWh(eleq)/litre	9.4803
Kerosene	kWh(eleq)/litre	8.9080
Gasoline	kWh(eleq)/litre	8.7358
LPG	kWh(eleq)/litre	6.4728
Ethane	kWh(eleq)/litre	5.1498
H2	kWh(eleq)/kgH2	33.4728
Electricity	kWh(eleq)/kWh(el)	1
Biodiesel	kWh(eleq)/litre	0.0629
Ethanol	kWh(eleq)/litre	0.0424
Natural gas	kWh(eleq)/litre	0.009
Heat	kWh(eleq)/kWh(therm)	1.0002
Heat	kWh(eleq)/kcal	0.0011
Heat	kWh(eleq)/BTU	0.0003

With this, the equivalent potential of an energy carrier $E_{\{eleq,i\}}$, compared to electricity, can be calculated with its

conversion factor w_i as:

$$E_{eleq,i} = E_i \cdot w_i$$

As it can be noticed, the conversion factor between heat (kWh(therm)) and electricity (kWh(el)) is almost 1. The deviation stems from the data available in source [1] and [2]. The equivalency of heat and electricity can be a source of discussion, as from an exergy point of view these energy carriers can not be considered equivalent. When combined, say with a heat pump, the equivalency can also result in ripple effects in combination with the minimal renewable factor or the minimal degree of autonomy, which need to be evaluated during the pilot simulations.

For the most part, the energy carrier weighting factors are similar to the lower heating value of the fuel in question. A stark deviation is noticable for ethanol and biodiesel. This deviation should be investigated further. In the future, it should be discussed whether it would be better to directly use the lower heating values of a fuel as its energy carrier weighting factor, as this would be more intuitive.

Note: The `energy_vector` of each of the assets and busses must be identical in spelling to one of the energy carriers defined in the above table. Spaces should be translated to underscores (ie. Crude oil as an energy carrier is defined as `Crude_oil` in the input files). Other energy carriers can not be parsed and will raise a warning. Please note that *Heat* currently has to be measured in kWh(thermal).

Code

Currently, the energy carrier conversion factors are defined in `constants.py` with `DEFAULT_WEIGHTS_ENERGY_CARRIERS`. New energy carriers should be added to its list when needed. Unknown carriers raise an `UnknownEnergyVectorError` error.

Comment

Please note that the energy carrier weighting factor is not applied dependent on the LABEL of the energy asset, but based on its energy vector. Let us consider an example:

In our system, we have a dispatchable *diesel fuel source*, with dispatch carrying the unit *l Diesel*. The energy vector needs to be defined as *Diesel* for the energy carrier weighting to be applied, ie. the energy vector of *diesel fuel source* needs to be *Diesel*. This will also have implications for the KPI: For example, the *degree of sector coupling* will reach its maximum, when the system only has heat demand and all of it is provided by processing diesel fuel. If you want to portrait diesel as something inherent to heat supply, you will need to make the diesel source a heat source, and set its *dispatch costs* to currency/kWh, ie. divide the diesel costs by the heating value of the fuel.

Comment

In the MVS, there is no distinction between energy carriers and energy vector. For *Electricity* of the *Electricity* vector this may be self-explanatory. However, the energy carriers of the *Heat* vector can have different technical characteristics: A fluid on different temperature levels. As the MVS measures the energy content of a flow in kWh(thermal) however, this distinction is only relevant for the end user to be aware of, as two assets that have different energy carriers as an output should not be connected to one and the same bus if a detailed analysis is expected. An example of this would be, that a system where the output of the diesel boiler as well as the output of a solar thermal panel are connected to the same bus, eventhough they can not both supply the same kind of heat demands (radiator vs. floor heating). This, however, is something that the end-user has to be aware of themselves, eg. by defining self-explanatory labels.

3.1.6 Emission factors

In order to optimise the energy system with minimum emissions, it is important to calculate emission per unit of fuel consumption.

In table *Emission factors: Kg of CO2 equivalent per unit of fuel consumption* the emission factors for energy carriers are defined. These values are based on direct emissions during stationary consumption of the mentioned fuels.

Table 4: Emission factors: Kg of CO2 equivalent per unit of fuel consumption

Energy carrier	Unit	Value	Source
Diesel	kgCO2eq/litre	2.7	[4] Page No. 26
Gasoline	kgCO2eq/litre	2.3	[4] Page No. 26
Kerosene	kgCO2eq/litre	2.5	[4] Page No. 26
Natural gas	kgCO2eq/m3	1.9	[4] Page No. 26
LPG	kgCO2eq/litre	1.6	[4] Page No. 26
Biodiesel	kgCO2eq/litre	0.000125	[5] Page No. 6
Bioethanol	kgCO2eq/litre	0.0000807	[5] Page No. 6
Biogas	kgCO2eq/m3	0.12	[6] Page No. 1

In table *CO2 Emission factors: grams of CO2 equivalent per kWh of electricity consumption* the CO2 emissions for Germany and the four pilot sites (Norway, Spain, Romania, India) are defined:

Table 5: CO2 Emission factors: grams of CO2 equivalent per kWh of electricity consumption

Country	Unit	Value	Source
Germany	gCO2eq/kWh	338	[7] Fig. 2
Norway	gCO2eq/kWh	19	[7] Fig. 2
Spain	gCO2eq/kWh	207	[7] Fig. 2
Romania	gCO2eq/kWh	293	[7] Fig. 2
India	gCO2eq/kWh	708	[8] Page No. 7

The values mentioned in the table above account for emissions during the complete life cycle. This includes emissions during energy production, energy conversion, energy storage and energy transmission.

3.1.7 Input verification

The inputs for a simulation with the MVS are subjected to a couple of verification tests to make sure that the inputs result in valid oemof simulations. This should ensure:

- Uniqueness of labels (`C1.check_for_label_duplicates`): This function checks if any LABEL provided for the energy system model in dict_values is a duplicate. This is not allowed, as oemof can not build a model with identical labels.
- No levelized costs of generation lower than feed-in tariff of same energy vector in case of investment optimization (`optimizeCap` is `True`) (`C1.check_feedin_tariff_vs_levelized_cost_of_generation_of_providers`): Raises error if feed-in tariff > levelized costs of generation if `maximumCap` is `None` for energy asset in `ENERGY_PRODUCTION`. This is not allowed, as oemof otherwise may be subjected to an unbound problem, ie. a business case in which an asset should be installed with infinite capacities to maximize revenue. If maximumCap is not `None` a `logging.warning` is shown as the maximum capacity of the asset will be installed.

- No feed-in tariff higher then energy price from an energy provider (`C1.check_feedin_tariff_vs_energy_price`): Raises error if feed-in tariff > energy price of any asset in `energyProvider.csv`. This is not allowed, as oemof otherwise is subjected to an unbound and unrealistic problem, eg. one where the owner should consume electricity to feed it directly back into the grid for its revenue.
- Assets have well-defined energy vectors and belong to an existing bus (`C1.check_if_energy_vector_of_all_assets_is_valid`): Validates for all assets, whether `energyVector` is defined within `DEFAULT_WEIGHTS_ENERGY_CARRIERS` and within the `energyBusses`.
- Energy carriers used in the simulation have defined factors for the electricity equivalency weighting (`C1.check_if_energy_vector_is_defined_in_DEFAULT_WEIGHTS_ENERGY_CARRIERS`): Raises an error message if an energy vector is unknown. It then needs to be added to the `DEFAULT_WEIGHTS_ENERGY_CARRIERS` in `constants.py`
- An energy bus is always connected to one inflow and one outflow (`C1.check_for_sufficient_assets_on_busses`): Validating model regarding busses - each bus has to have more then two assets connected to it, exluding energy excess sinks
- Time series of energyProduction assets that are to be optimized have specific generation profiles (`C1.check_non_dispatchable_source_time_series`, `C1.check_time_series_values_between_0_and_1`): Raises error if time series of non-dispatchable sources are not between [0, 1].
- Provided timeseries are checked for `NaN` values, which are replaced by zeroes (`C0.replace_nans_in_timeseries_with_0`).
- Asset capacities connected to each bus are sized sufficiently to fulfill the maximum demand (`C1.check_energy_system_can_fulfill_max_demand`): Logs a logging.warning message if the aggregated installed capacity and maximum capacity (if applicable) of all conversion, generation and storage assets connected to one bus is smaller than the maximum demand. The check is applied to each bus of the energy system. Check passes when the potential peak supply is larger then or equal to the peak demand on the bus, or if the maximum capacity of an asset is set to `None` when optimizing.

3.2 Component models

The component models of the MVS result from the used python-library `oemof-solph` for energy modeling.

It requires component models to be simplified and linearized. This is the reason why the MVS can provide a prefeasibility study of a specific system setup, but not the final sizing and system design. The types of assets are presented below.

3.2.1 Energy consumption

Demands within the MVS are added as energy consumption assets in *energyConsumption.csv*. Most importantly, they are defined by a timeseries, representing the demand profile, and their energy vector. A number of demand profiles can be defined for one energy system, both of the same and different energy vectors. The main optimization goal for the MVS is to supply the defined demand withouth fail for all of the timesteps in the simulation with the least cost of supply (comp. *Economic Dispatch*).

3.2.2 Energy production

Non-dispatchable sources of generation

Examples:

- PV plants
- Wind plants
- Run-of-the-river hydro power plants
- Solar thermal collectors

Variable renewable energy (VRE) sources, like wind and PV, are non-dispatchable due to their fluctuations in supply. They are added as sources in *energyProduction.csv*.

The fluctuating nature of non-dispatchable sources is represented by generation time series that show the respective production for each time step of the simulated period. In energy system modelling it is common to use hourly time series. The name of the file containing the time series is added to *energyProduction.csv* with the parameter *file_name*. For further requirements concerning the time series see section *Time series: time_series folder*.

If you cannot provide time series for your VRE assets you can consider to calculate them by using models for generating feed-in time series from weather data. The following is a list of examples, which is not exhaustive:

- PV: pvlib , Renewables Ninja (download capacity factors), altlite
- Wind: windpowerlib, Renewables Ninja (download capacity factors), altlite
- Hydro power (run-of-the-river): hydropowerlib
- Solar thermal: flat plate collectors of oemof.thermal

Dispatchable sources of generation

Examples:

- Fuel sources
- Deep-ground geothermal plant (ground assumed to allow unlimited extraction of heat, not depending on season)

Fuel sources are added as dispatchable sources, which can have development, investment, operational and dispatch costs. They are added to *energyProduction.csv*, while setting *file_name* to `None`.

Fuel sources are for example needed as source for a diesel generator (diesel), biogas plant (gas) or a condensing power plant (gas, coal, ...), see *Energy conversion*.

Energy providers, even though also dispatchable sources of generation, should be added via *energyProviders.csv*, as there are some additional features available then, see *Energy providers*.

Both energy providers and the additional fuel sources are limited to the options of energy carriers provided in the table of *Electricity equivalent conversion per unit of a fuel*, as the default weighting factors to translate the energy carrier into electricity equivalent need to be defined.

3.2.3 Energy conversion

Examples:

- Electric transformers (rectifiers, inverters, transformer stations, charge controllers)
- HVAC and Heat pumps (as heater and/or chiller)
- Combined heat and power (CHP) and other condensing power plants
- Diesel generators
- Electrolyzers
- Biogas power plants

Conversion assets are added as transformers and are defined in *energyConversion.csv*.

The parameters *dispatch_price*, *efficiency* and *installedCap* of transformers are assigned to their output flows. This means that these parameters need to be provided for the output of the asset and that the costs of the input, (e.g. cost of fuel) are not included in its *dispatch_price* but in the *dispatch_price* of the fuel source, see *Dispatchable sources of generation*.

Conversion assets can be defined with multiple inputs or multiple outputs, but one asset currently cannot have both, multiple inputs and multiple outputs. Note that multiple inputs/output is possible but this feature is not currently tested.

Electric transformers

Electric rectifiers and inverters that are transforming electricity in one direction only, are simply added as transformers. Bidirectional converters and transformer stations are defined by two transformers that are optimized independently from each other, if optimized. The same accounts for charge controllers for a *Battery energy storage system (BESS)* that are defined by two transformers, one for charging and one for discharging. The parameters *dispatch_price*, *efficiency* and *installedCap* need to be given for the electrical output power of the electric transformers.

Note: When using two conversion objects to emulate a bidirectional conversion asset, their capacity should be inter-dependent. This is currently not the case, see *Infeasible bi-directional flow in one timestep*.

Heating, Ventilation, and Air Conditioning (HVAC)

Like other conversion assets, devices for heating, ventilation and air conditioning (HVAC) are added as transformers. As the parameters *dispatch_price*, *efficiency* and *installedCap* are assigned to the output flows they need to be given for the nominal heat output of the HVAC.

Different types of HVAC can be modelled. Except for an air source device with ambient temperature as heat reservoir, the device could be modelled with two inputs (electricity and heat) in case the user is interested in the heat reservoir. This has not been tested yet. Also note that currently efficiencies are assigned to the output flows the see issue #799. Theoretically, a HVAC device can be modelled with multiple outputs (heat, cooling, ...); this has not been tested yet.

The efficiency of HVAC systems is defined by the coefficient of performance (COP), which is strongly dependent on the temperature. In order to take account of this, the efficiency can be defined as time series, see section *Adding a timeseries for a parameter*. If you do not provide your own COP time series you can calculate them with oemof.thermal, see documentation on compression heat pumps and chillers and documentation on absorption chillers.

Electrolyzers

Electrolyzers are added as transformers with a constant or time dependent but in any case pre-defined efficiency. The parameters *dispatch_price*, *efficiency* and *installedCap* need to be given for the output of the electrolyzers (hydrogen).

Currently, electrolyzers are modelled with only one input flow (electricity), not taking into account the costs of water; see issue #799. The minimal operation level and consumption in standby mode are not taken into account, yet, see issue #50.

Condensing power plants and Combined heat and power (CHP)

Condensing power plants are added as transformers with one input (fuel) and one output (electricity), while CHP plants are defined with two outputs (electricity and heat). The parameters *dispatch_price*, *efficiency* and *installedCap* need to be given for the electrical output power (and nominal heat output) of the power plant, while fuel costs need to be included in the *dispatch_price* of the fuel source.

The ratio between the heat and electricity output of a CHP is currently simulated as fix values. This might be changed in the future by using the ExtractionTurbineCHP or the GenericCHP component of oemof, see issue #803

Note that multiple inputs/output have not been tested yet.

Other fuel powered plants

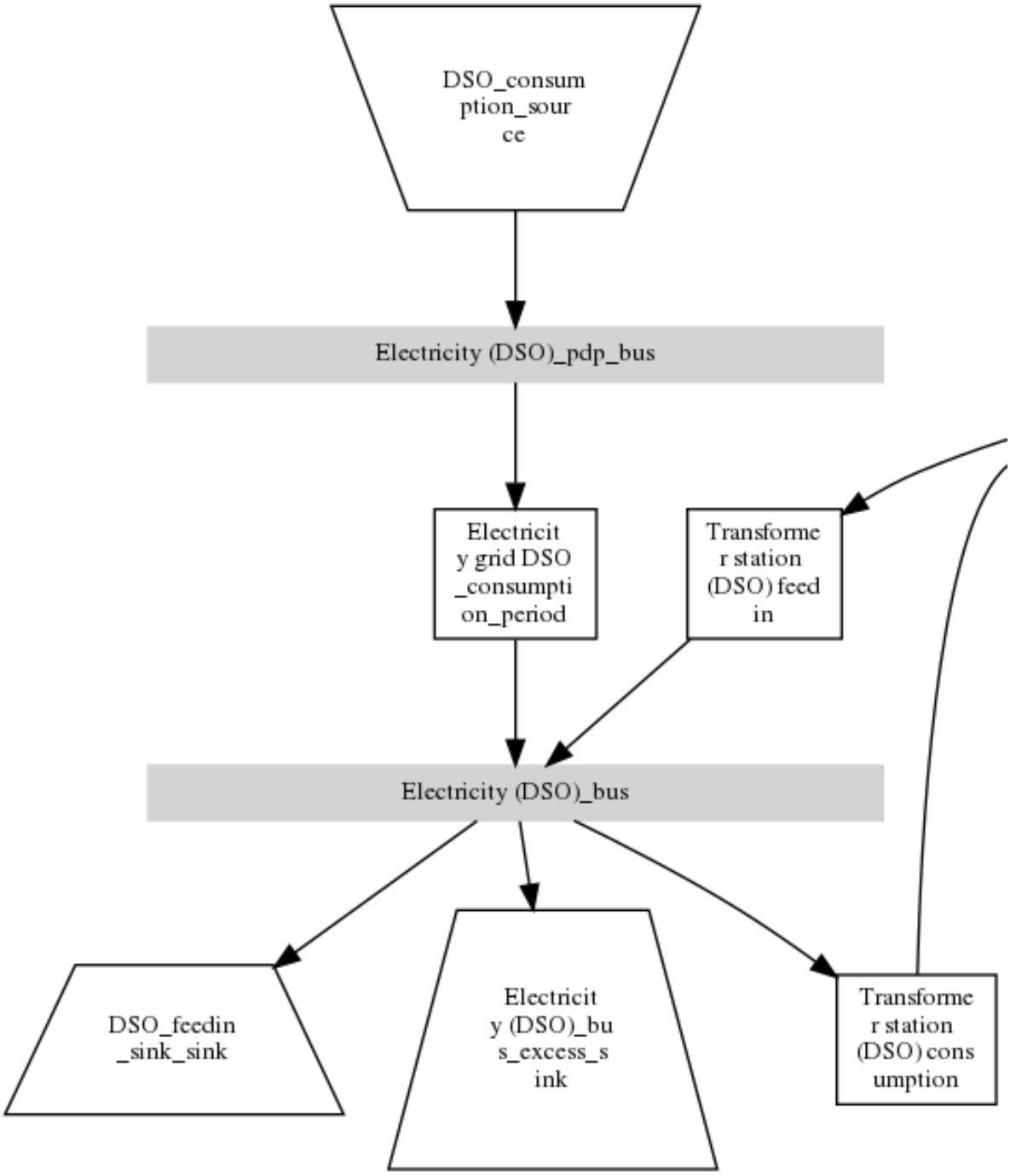
Fuel powered conversion assets, such as diesel generators and biogas power plants, are added as transformers. The parameters *dispatch_price*, *efficiency* and *installedCap* need to be given for the electrical output power of the diesel generator or biogas power plant. As described above, the costs for diesel and gas need to be included in the *dispatch_price* of the fuel source.

3.2.4 Energy providers

The energy providers are the most complex assets in the MVS model. They are composed of a number of sub-assets

- Energy consumption source, providing the energy required from the system with a certain price
- Energy peak demand pricing "transformers", which represent the costs induced due to peak demand
- Bus connecting energy consumption source and energy peak demand pricing transformers
- Energy feed-in sink, able to take in generation that is provided to the energy provider for revenue
- Optionally: Transformer Station connecting the energy provider bus to the energy bus of the LES

With all these components, the energy provider can be visualized as follows:


DSO_consum
ption_sour
ce
Electricity (DSO)_pdp_bus
Electricit
y grid DSO
_consumpti
on_period
Transforme
r station
(DSO) feed
in
Electricity (DSO)_bus
DSO_feedin
_sink_sink
Electricit
y (DSO)_bu
s_excess_s
ink
Transforme
r station
(DSO) cons
umption

Variable energy consumption prices (time-series)

Energy consumption prices can be added as values that vary over time. See section *Time series: time_series folder* or more information.

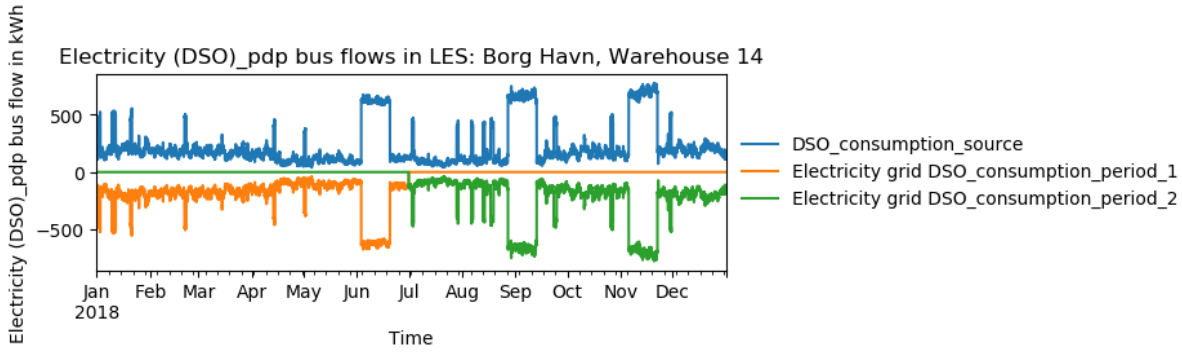
Peak demand pricing

A peak demand pricing scheme is based on an electricity tariff, that requires the consumer not only to pay for the aggregated energy consumption in a time period (eg. kWh electricity), but also for the maximum peak demand (load, eg. kW power) towards the grid of the energy provider within a specific pricing period.

In the MVS, this information is gathered in `energyProviders` assets with:

- `multi_vector_simulator.utils.constants_json_strings.PEAK_DEMAND_PRICING_PERIOD` as the period used in peak demand pricing. Possible values are 1 (yearly), 2 (half-yearly), 3 (each trimester), 4 (quaterly), 6 (every 2 months) and 12 (each month). If you have a *simulation_duration* < 365 days, the periods will still be set up assuming a year! This means, that if you are simulating 14 days, you will never be able to have more than one peak demand pricing period in place.
- `multi_vector_simulator.utils.constants_json_strings.PEAK_DEMAND_PRICING` as the costs per peak load unit, eg. kW

To represent the peak demand pricing, the MVS adds a "transformer" that is optimized with specific operation and maintenance costs per year equal to the PEAK_DEMAND_PRICING for each of the pricing periods. For two peak demand pricing periods, the resulting dispatch could look as following:



3.2.5 Energy storage

Energy storages such as battery storages, thermal storages or H2 storages are modelled with the `GenericStorage` component of `oemof.solph`. They are designed for one input and one output and are defined within the files *energyStorage.csv* and *storage_*.csv*.

The state of charge of a storage at the first and last time step of an optimization are equal. Charge and discharge of the whole capacity of the energy storage are possible within one time step in case the capacity of the storage is not optimized. In case of capacity optimization charge and discharge is limited by the *c-rate*.

Battery energy storage system (BESS)

BESS are modelled as `GenericStorage` like described above. The BESS can either be connected directly to the electricity bus of the LES or via a charge controller that manages the BESS. When choosing the second option, the capacity of the charge controller can be optimized individually, which takes its specific costs and lifetime into consideration. If you do not want to optimize the charge controller's capacity you can take its costs and efficiency into account when defining the storage's input and output power, see *storage_*.csv*. A charge controller is defined by two transformers, see section *Energy conversion* above.

Note that capacity reduction over the lifetime of a BESS that may occur due to different effects during aging cannot be taken into consideration in MVS. A possible workaround for this could be to manipulate the lifetime.

Hydrogen storage (H2)

Hydrogen storages are modelled as all storage types in MVS with as `GenericStorage` like described above.

The most common hydrogen storages store H2 as liquid under temperatures lower than -253 °C or under high pressures. The energy needed to provide these requirements cannot be modelled via the storage component as another energy sector such as cooling or electricity is needed. It could therefore, be modelled as an additional demand of the energy system, see issue #811

Thermal energy storage

Thermal energy storages of the type sensible heat storage (SHS) are modelled as `GenericStorage` like described above. The implementation of a specific type of SHS, the stratified thermal energy storage, is described in section *Stratified thermal energy storage*. The modelling of latent-heat (or Phase-change) and chemical storages have not been tested with MVS, but might be achieved by precalculations.

Stratified thermal energy storage

Stratified thermal energy storage is defined by the two optional parameters *fixed_thermal_losses_relative* and *fixed_thermal_losses_absolute*. If they are not included in *storage_*.csv* or are equal to zero, then a normal generic storage is simulated instead. These two parameters are used to take into account temperature dependent losses of a thermal storage. To model a thermal energy storage without stratification, the two parameters are not set. The default values of *fixed_thermal_losses_relative* and *fixed_thermal_losses_absolute* are zero. Except for these two additional parameters the stratified thermal storage is implemented in the same way as other storage components.

Precalculations of the *installedCap*, *efficiency*, *fixed_thermal_losses_relative* and *fixed_thermal_losses_absolute* can be done orientating on the stratified thermal storage component of oemof.thermal. The parameters `U-value`, `volume` and `surface` of the storage, which are required to calculate *installedCap*, can be precalculated as well.

The efficiency η of the storage is calculated as follows:

$$\eta = 1 - loss\_rate$$

This example shows how to do precalculations using stratified thermal storage specific input data:

```
from oemof.thermal.stratified_thermal_storage import (
calculate_storage_u_value,
calculate_storage_dimensions,
calculate_capacities,
calculate_losses,
)
```

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```
# Precalculation
u_value = calculate_storage_u_value(
    input_data['s_iso'],
    input_data['lamb_iso'],
    input_data['alpha_inside'],
    input_data['alpha_outside'])

volume, surface = calculate_storage_dimensions(
    input_data['height'],
    input_data['diameter']
)

nominal_storage_capacity = calculate_capacities(
    volume,
    input_data['temp_h'],
    input_data['temp_c'])

loss_rate, fixed_losses_relative, fixed_losses_absolute = calculate_losses(
    u_value,
    input_data['diameter'],
    input_data['temp_h'],
    input_data['temp_c'],
    input_data['temp_env'])
```

Please see the *oemof.thermal* examples and the documentation for further information.

For an investment optimization the height of the storage should be left open in the precalculations and *installedCap* should be set to 0 or NaN.

An implementation of the stratified thermal storage component has been done in pvcompare. You can find the precalculations of the stratified thermal energy storage made in *pvcompare* here.

3.2.6 Energy excess

Note: Energy excess components are implemented **automatically** by MVS! You do not need to define them yourself.

An energy excess sink is placed on each of the LES energy busses, and therefore energy excess is allowed to take place on each bus of the LES. This means that there are assumed to be sufficient vents (heat) or resistors (electricity) to dump excess (waste) generation. Excess generation can only take place when a non-dispatchable source is present or if an asset is allowed to supply energy without any fuel or dispatch costs.

In case of excessive excess energy, a warning is issued that it seems to be cheaper to have high excess generation than investing into more capacities. High excess energy can for example result into an optimized inverter capacity that is smaller than the peak generation of installed PV. The model becomes unrealistic when the excess is very high.

3.3 Constraints

Constraints are controlled via the file *constraints.csv*.

3.3.1 Minimal renewable factor constraint

The minimal renewable factor constraint requires the capacity and dispatch optimization of the MVS to reach at least the minimal renewable factor defined within the constraint. The renewable share of the optimized energy system may also be higher than the minimal renewable factor.

The minimal renewable factor is applied to the minimal renewable factor of the whole, sector-coupled energy system, but not to specific sectors. As such, energy carrier weighting plays a role and may lead to unexpected results. The constraint reads as follows:

$$minimalrenewablefactor <= \frac{\sum renewablegeneration \cdot weightingfactor}{\sum renewablegeneration \cdot weightingfactor + \sum non-renewablegeneration \cdot weightingfacto}$$

Please be aware that the minimal renewable factor constraint defines bounds for the *Renewable factor (renewable_factor)* of the system, ie. taking into account both local generation as well as renewable supply from the energy providers. The constraint explicitly does not aim to reach a certain *Renewable share of local generation (renewable_share_of_local_generation)* on-site.

Deactivating the constraint

The minimal renewable factor constraint is deactivated by inserting the following row in *constraints.csv* as follows:

```
`minimal_renewable_factor,factor,0`
```

Activating the constraint

The constraint is enabled when the value of the minimal renewable factor factor is above 0 in *constraints.csv*:

```
`minimal_renewable_factor,factor,0.3`
```

Depending on the energy system, especially when working with assets which are not to be capacity-optimized, it is possible that the minimal renewable factor criterion cannot be met. The simulation terminates in that case. If you are not sure if your energy system can meet the constraint, set all `optimize_Cap` parameters of your optimizable assets to `True`, and then investigate further.

Also, if you are aiming at very high minimal renewable factors, the simulation time can increase drastically. If you do not get a result after an execessive simulation time (e.g. 10 times the simulation without constraints), you should consider terminating the simulation and trying with a lower minimum renewable share.

The minimum renewable share is introduced to the energy system by *D2. constraint_minimal_renewable_share()* and a validation test is performed with *E4. minimal_constraint_test()*.

3.3.2 Minimal degree of autonomy constraint

The minimal degree of autonomy constraint requires the capacity and dispatch optimization of the MVS to reach at least the minimal degree of autonomy defined within the constraint. The degree of autonomy of the optimized energy system may also be higher than the minimal degree of autonomy. For more details, refer to the definition of *degree of autonomy*

The minimal degree of autonomy is applied to the whole, sector-coupled energy system, but not to specific sectors. As such, energy carrier weighting plays a role and may lead to unexpected results.

The constraint reads as follows:

$$minimal\ degree\ of\ autonomy <= DA = \frac{\sum E_{demand,i} \cdot w_i - \sum E_{consumption,provider,j} \cdot w_j}{\sum E_{demand,i} \cdot w_i}$$

Deactivating the constraint

The minimal degree of autonomy constraint is deactivated by inserting the following row in *constraints.csv* as follows:

```
`minimal_degree_of_autonomy,factor,0`
```

Activating the constraint

The constraint is enabled when the value of the minimal degree of autonomy is above 0 in *constraints.csv*:

```
`minimal_degree_of_autonomy,factor,0.3`
```

Depending on the energy system, especially when working with assets which are not subject to the optimization of their capacities, it is possible that the minimal degree of autonomy criterion cannot be met. The simulation terminates in that case. If you are not sure if your energy system can meet the constraint, set all *optimizeCap* parameters of your optimizable assets to `True`, and then investigate further.

The minimum degree of autonomy is introduced to the energy system by *D2.constraint_minimal_degree_of_autonomy()* and a validation test is performed with *E4.minimal_constraint_test()*.

3.3.3 Maximum emission constraint

The maximum emission constraint limits the maximum amount of total emissions per year of the energy system. It allows the capacity and dispatch optimization of the MVS to result into a maximum amount of emissions defined by the maximum emission constraint. The yearly emissions of the optimized energy system may also be lower than the maximum emission constraint.

Note: The maximum emissions constraint currently does not take into consideration life cycle emissions, also see *Total GHG emissions (total_emissions)* section for an explanation.

Activating the constraint

The maximum emissions constraint is enabled by inserting the following row in *constraints.csv* as follows:

```
`maximum_emissions,kgCO2eq/a,800000`
```

Deactivating the constraint

The constraint is deactivated by setting the value in *constraints.csv* to `None`:

```
`maximum_emissions,kgCO2eq/a,None`
```

The unit of the constraint is *kgCO2eq/a*. To pick a realistic value for this constraint you can e.g.:

- Firstly, optimize your system without the constraint to get an idea about the scale of the emissions and then, secondly, set the constraint and lower the emissions step by step until you reach an unbound problem (which then represents the non-achievable minimum of emissions for your energy system)
- Check the emissions targets of your region/country and disaggregate the number

The maximum emissions constraint is introduced to the energy system by *D2.constraint_maximum_emissions()* and a validation test is performed with *E4.maximum_emissions_test()*.

3.3.4 Net zero energy (NZE) constraint

The net zero energy (NZE) constraint requires the capacity and dispatch optimization of the MVS to result into a net zero system, but can also result in a plus energy system. The degree of NZE of the optimized energy system may be higher than 1, in case of a plus energy system. Please find the definition of net zero energy (NZE) and the KPI here: *Degree of Net Zero Energy (degree_of_nze)*.

Some definitions of NZE systems in literature allow the energy system's demand solely be provided by locally generated renewable energy. In MVS this is not the case - all locally generated energy is taken into consideration. To enlarge the share of renewables in the energy system you can use the *Minimal renewable factor constraint*.

The NZE constraint is applied to the whole, sector-coupled energy system, but not to specific sectors. As such, energy carrier weighting plays a role and may lead to unexpected results. The constraint reads as follows:

$$\sum_i E_{feedin,provider}(i) \cdot w_i - E_{consumption,provider}(i) \cdot w_i >= 0$$

Deactivating the constraint

The NZE constraint is deactivated by inserting the following row in *constraints.csv* as follows:

`net_zero_energy,bool,False`

Activating the constraint

The constraint is enabled when the value of the NZE constraint is set to `True` in *constraints.csv*:

`net_zero_energy,bool,True`

Depending on the energy system, especially when working with assets which are not subject to the optimization of their capacities, it is possible that the NZE criterion cannot be met. The simulation terminates in that case. If you are not sure whether your energy system can meet the constraint, set all *optimizeCap* parameters of your optimizable assets to `True`, and then investigate further.

The net zero energy constraint is introduced to the energy system by *D2.constraint_net_zero_energy()* and a validation test is performed with *E4.net_zero_energy_test()*.

3.4 Limitations

When running simulations with the MVS, there are certain peculiarities to be aware of. The peculiarities can be considered as limitations, some of which are merely model assumptions and others are drawbacks of the model. A number of those are inherited due to the nature of the MVS and its underlying modules. The following table (*Limitations*) lists the MVS limitations based on their type.

Table 6: Limitations

Inherited	Can be addressed
Infeasible bi-directional flow in one timestep	*Need to model one technical unit with two transformer assets*
Simplified linear component models	*Random excess energy distribution*
No degradation of efficiencies over a component lifetime	*Renewable energy share definition relative to energy carriers*
Perfect foresight	*Energy carrier weighting*
	Events of energy shortage or grid interruption cannot be modelled

3.4.1 Infeasible bi-directional flow in one timestep

Limitation

It is not possible to model two flows in opposite directions during the same time step.

Reason

The MVS is based on the python library `oemof-solph`. Its generic components are used to set up the energy system. As a ground rule, the components of `oemof-solph` are unidirectional. This means that for an asset that is bidirectional two transformer objects have to be used. Examples for this are:

- Physical bi-directional assets, eg. inverters
- Logical bi-directional assets, eg. consumption from the grid and feed-in to the grid

To achieve the real-life constraint one flow has to be zero when the other is larger zero, one would have to implement following relation:

$$E_{in} \cdot E_{out} = 0$$

However, this relation creates a non-linear problem and can not be implemented in `oemof-solph`.

Implications

This limitation means that the MVS might result in infeasible dispatch of assets. For instance, a bus might be supplied by a rectifier and itself supplying an inverter at the same time step t, which cannot logically happen if these assets are part of one physical bi-directional inverter. Another case that could occur is feeding the grid and consuming from it at the same time t.

Under certain conditions, including excess generation as well as dispatch costs of zero, the infeasible dispatch can also be observed for batteries and result in a parallel charge and discharge of the battery. If this occurs, a solution may be to set a marginal dispatch cost of battery charge.

3.4.2 Simplified linear component models

Limitation

The MVS simplifies the component model of some assets.

- Generators have an efficiency that is not load-dependent
- Storage have a charging efficiency that is not SOC-dependent
- Turbines are implemented without ramp rates

Reason

The MVS is based `oemof-solph` python library and uses its generic components to set up an energy system. Transformers and storages cannot have variable efficiencies, because otherwise the system of equation to solve would not be linear.

Implications

Simplifying the implementation of some component specifications can be beneficial for the ease of the model, however, it contributes to the lack of realism and might result in less accurate values. The MVS trades off the decreased level of detail for a quick evaluation of its scenarios, which are often only used for a pre-feasibility analysis.

3.4.3 No degradation of efficiencies over a component lifetime

Limitation

The MVS does not degrade the efficiencies of assets over the lifetime of the project, eg. in the case of production assets like PV panels.

Reason

The simulation of the MVS is only based on a single reference year, and it is not possible to take into account multi-year degradation of asset efficiency.

Implications

This results in an overestimation of the energy generated by the asset, which implies that the calculation of some other results might also be overestimated (e.g. overestimation of feed-in energy). The user can circumvent this by applying a degradation factor manually to the generation time series used as an input for the MVS.

3.4.4 Perfect foresight

Limitation

The optimal solution of the energy system is based on perfect foresight.

Reason

As the MVS and thus `oemof-solph`, which is handling the energy system model, know the generation and demand profiles for the whole simulation time and solve the optimization problem based on a linear equation system, the solver knows their dispatch for certain, whereas in reality the generation and demand could only be forecasted.

Implications

The perfect foresight can lead to suspicious dispatch of assets, for example charging of a battery right before a (in real-life) random blackout occurs. The systems optimized with the MVS therefore, represent their optimal potential, which in reality could not be reached. The MVS has thus a tendency to underestimate the needed battery capacity or the minimal state of charge for backup purposes, and also designs the PV system and backup power according to perfect forecasts. In reality, operational margins would need to be considered.

3.4.5 Optimization precision

Limitation

Marginal capacities and flows below a threshold of 10^-6 are rounded to zero.

Reason

The MVS makes use of the open energy modelling framework (oemof) by using `oemof-solph`. For the MVS, we use the `cbc-solver` with a `ratioGap=0.03`. This influences the precision of the optimized decision variables, ie. the optimized capacities as well as the dispatch of the assets. In some cases the dispatch and capacities vary around 0 with fluctuations of the order of floating point precision (well below <10e-6), thus resulting sometimes in marginal fluctuations dispatch or capacities around 0. When calculating KPI from these decision variables, the results can be nonsensical, for example leading to SoC curves with negative values or values far above the viable value 1. As the reason for these inconsistencies is known, the MVS enforces the capacities and dispatch of to be above 10e-6, ie. all capacities or flows smaller than that are automatically set to zero. This is applied to absolute values, so that irregular (and incorrect) values for decision variables can still be detected.

Implications

If your energy system has demand or resource profiles that include marginal values below the threshold of 10^-6, the MVS will not result in appropriate results. For example, that means that if you have an energy system with usually is measured in *MW* but one demand is in the *W* range, the dispatch of assets serving this minor demand is not displayed correctly. Please consider using *kW* or even *W* as a base unit then.

3.4.6 Extension of KPIs necessary

Limitation

Some important KPIs usually required by developers are currently not implemented within the MVS:

- Internal rate of return (IRR)
- Payback period
- Return on equity (ROE),

Reason

The MVS tool is a work in progress and this can still be addressed in the future.

Implications

The absence of such indicators might affect decision-making.

3.4.7 Random excess energy distribution

Limitation

There is random excess distribution between the feed-in sink and the excess sink when no feed-in-tariff is assumed in the system.

Reason

Since there is no feed-in-tariff to benefit from, the MVS randomly distributes the excess energy between the feed-in and excess sinks. As such, the distribution of excess energy changes when running several simulations for the same input files.

Implications

On the first glance, the distribution of excess energy onto both feed-in sink and excess sink may seem off to the end-user. Other than these inconveniences, there are no real implications that affect the capacity and dispatch optimization. When a degree of self-supply and self-consumption is defined, the limitation might tarnish these results.

3.4.8 Renewable energy share definition relative to energy carriers

Limitation

The current renewable energy share depends on the share of renewable energy production assets directly feeding the load. The equation to calculate the share also includes the energy carrier rating as described here below:

$$RES = \frac{\sum_i E_{RE,generation}(i) \cdot w_i}{\sum_i E_{RE,generation}(i) \cdot w_i + \sum_k E_{nonRE,generation}(k) \cdot w_k}$$

with i: renewable energy asset

k: non-renewable energy asset

Reason

The MVS tool is a work in progress and this can still be addressed in the future.

Implications

This might result in different values when comparing them to other models. Another way to calculate it is by considering the share of energy consumption supplied from renewable sources.

3.4.9 Energy carrier weighting

Limitation

The MVS assumes a usable energy content rating for every energy carrier. The current version assumes that 1 kWh thermal is equivalent to 1 kWh electricity.

Reason

This is an approach that the MVS currently uses.

Implications

By weighing the energy carriers according to their energy content (Gasoline Gallon Equivalent (GGE)), the MVS might result in values that can't be directly assessed. Those ratings affect the calculation of the levelized cost of the energy carriers, but also the minimum renewable energy share constraint.

3.4.10 Events of energy shortage or grid interruption cannot be modelled

Limitation

The MVS assumes no shortage or grid interruption in the system.

Reason

The aim of the MVS does not cover this scenario.

Implications

Electricity shortages due to power cuts might happen in real life and the MVS currently omits this scenario. If a system is self-sufficient but relies on grid-connected PV systems, the latter stop feeding the load if any power cuts occur and the battery storage systems might not be enough to serve the load thus resulting energy shortage.

3.4.11 Need to model one technical unit with two transformer assets

Limitation

Two transformer objects representing one technical unit in real life are currently unlinked in terms of capacity and attributed costs.

Reason

The MVS uses `oemof-solph`'s generic components which are unidirectional so for a bidirectional asset, two transformer objects have to be used.

Implications

Since only one input is allowed, such technical units are modelled as two separate transformers that are currently unlinked in the MVS (e.g., hybrid inverter, heat pump, distribution transformer, etc.). This raises a difficulty to define costs in the input data. It also results in two optimized capacities for one logical unit.

This limitation can be addressed with a constraint which links both capacities of one logical unit, and therefore solves both the problem to attribute costs and the previously differing capacities.

3.5 Input parameters

3.5.1 Parameters in each category/CSV file

Important note: Each asset and bus needs to have an unique label. In the `csv` input files, these are defined by the column headers. The input parameters are gathered under the following categories. These categories reflect the structure of the `csv` input files or the firsts keys of the `json` input file.

constraints.csv

The file *constraints.csv* includes the following parameter(s):

- *maximum_emissions*
- *minimal_degree_of_autonomy*
- *minimal_renewable_factor*
- *net_zero_energy*

economic_data.csv

The file *economic_data.csv* includes all economic data that the simulation will use. This includes the following parameters:

- *currency*
- *discount_factor*
- *project_duration*
- *tax*

energyBusses.csv

The file *energyBusses.csv* defines all busses required to build the energy system. It includes following parameters:

- *energyVector*

energyConsumption.csv

The file *energyConsumption.csv* defines all energy demands that should be included in the energy system. It includes the following parameters:

- *energyVector*
- *file_name*
- *inflow_direction*
- *outflow_direction*
- *type_oemof*
- *unit*

energyConversion.csv

The file *energyConversion.csv* defines the assets that convert one energy carrier into another one, eg. inverters or generators. Following parameters define them:

- *age_installed*
- *development_costs*
- *dispatch_price*
- *efficiency*
- *energyVector*
- *inflow_direction*
- *installedCap*
- *lifetime*
- *optimizeCap*
- *outflow_direction*
- *specific_costs*
- *specific_costs_om*
- *type_oemof*
- *unit*
- *beta*

energyProduction.csv

The file *energyProduction.csv* defines the assets that serve as energy sources, eg. fuel sources or PV plants. They include the following parameters:

- *age_installed*
- *development_costs*
- *dispatch_price*
- *emission_factor*
- *energyVector*
- *file_name*
- *installedCap*
- *lifetime*
- *maximumCap*
- *optimizeCap*
- *renewableAsset*
- *specific_costs*
- *specific_costs_om*
- *type_oemof*

- *unit*

energyProviders.csv

The file *energyProviders.csv* defines the energy providers of the energy system. They include the following parameters:

- *emission_factor*
- *energy_price*
- *energyVector*
- *feedin_tariff*
- *inflow_direction*
- *optimizeCap*
- *outflow_direction*
- *peak_demand_pricing*
- *peak_demand_pricing_period*
- *renewable_share*
- *type_oemof*
- *unit*

energyStorage.csv

The file *energyStorage.csv* defines the storage assets included in the energy system. It does not hold all needed parameters, but requires *storage_xx.csv* to be defined as well. The file *energyStorage.csv* includes the following parameters:

- *energyVector*
- *file_name*
- *inflow_direction*
- *optimizeCap*
- *outflow_direction*
- *storage_filename*
- *type_oemof*

fixcost.csv

The parameters must be filled for all three columns/components namely: *distribution_grid*, *engineering* and *operation*. The file *fixcost.csv* includes the following parameters:

- *development_costs*
- *dispatch_price*
- *label*
- *lifetime*
- *specific_costs*

- *specific_costs_om*

project_data.csv

The file *project_data.csv* includes the following parameters:

- *country*
- *latitude*
- *longitude*
- *project_id*
- *project_name*
- *scenario_description*
- *scenario_id*
- *scenario_name*

simulation_settings.csv

The file *simulation_settings.csv* includes the following parameters:

- *evaluated_period*
- *output_lp_file*
- *start_date*
- *timestep*

storage_*.csv

The * in the storage filename is the number identifying the storage. It depends on the number of storage components (such as batteries, etc.) present in the system. For e.g., there should be two storage files named storage_01.csv and storage_02.csv if the system contains two storage components.The file *storage_xx.csv* contains the following parameters:

- *c-rate*
- *development_costs*
- *dispatch_price*
- *efficiency*
- *fixed_thermal_losses_absolute*
- *fixed_thermal_losses_relative*
- *installedCap*
- *lifetime*
- *soc_initial*
- *soc_max*
- *soc_min*
- *specific_costs*

- *specific_costs_om*
- *unit*

3.5.2 Table of parameters

The input parameters are gathered in the table below. Each parameter is provided with unit, type and example values. For more information about one parameter, please click on it.

Table 7: Parameters summary

Parameter	Type	Unit	Default
age_installed	numeric	Year	0
c-rate	numeric	Factor	1
country	str		
currency	str		EUR
development_costs	numeric	currency	0
discount_factor	numeric	Factor	0
dispatch_price	numeric	currency/kWh	0
efficiency	numeric	Factor	1
emission_factor	numeric	kgCO2eq/asset unit	0
energy_price	numeric	currency/energy carrier unit	0
energyVector	str		Electricity
evaluated_period	numeric	Day	365
feedin_tariff	numeric	currency/kWh	0
file_name	str		
fixed_thermal_losses_absolute	numeric	factor	0
fixed_thermal_losses_relative	numeric	factor	0
inflow_direction	str		
installedCap	numeric	kWp	0
label	str		
latitude	numeric		
lifetime	numeric	Year	20
longitude	numeric		
maximum_emissions	numeric	kgCO2eq/a	
maximumCap	numeric	kWp	
minimal_degree_of_autonomy	numeric	factor	0
minimal_renewable_factor	numeric	factor	0
net_zero_energy	boolean		False
optimizeCap	boolean		False
outflow_direction	str		
output_lp_file	boolean		False
peak_demand_pricing	numeric	currency/kW	0
peak_demand_pricing_period	numeric	times per year (1,2,3,4,6,12)	1
project_duration	numeric	Years	20
project_id	str		
project_name	str		
renewable_share	numeric	Factor	0
renewableAsset	boolean		False
scenario_description	str		
scenario_id	str		
scenario_name	str		

continues on next page

Table 7 – continued from previous page

Parameter	Type	Unit	Default
soc_initial	numeric	None or factor	
soc_max	numeric	Factor	1
soc_min	numeric	Factor	0
specific_costs	numeric	currency/unit	0
specific_costs_om	numeric	currency/unit/year	0
start_date	str		
storage_filename	str		
tax	numeric	Factor	0
timestep	numeric	Minutes	60
type_oemof	str		
unit	str		
beta	numeric	factor	0

3.5.3 List of parameters

Below is the list of all the parameters of MVS, sorted in alphabetical order. Each of the parameters has the following properties

Definition
parameter's definition, could also contain potential use cases of the parameter

Type
str (text), numeric (integer or double precision number), boolean (True or False)

Unit
physical unit

Example
an example of parameter's value

Restrictions
specific restrictions on the parameter's value (e.g., "positive integer number", "must be an even number", "must be one of ['val1', 'val2']"

Default
default parameter's value

age_installed

Definition
The number of years the asset has already been in operation.

Type
numeric

Unit
Year

Example
10

Restrictions
Natural number

Default
0

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*

c-rate

Definition
C-rate is the rate at which the storage can charge or discharge relative to the nominal capacity of the storage. A c-rate of 1 implies that the battery can discharge or charge completely in a single timestep.

Type
numeric

Unit
Factor

Example
storage capacity: NaN, *input power*: 1, *output power*: 1

Restrictions
Real number between 0 and 1. Only the columns "input power" and "output power" require a value, in column "storage capacity" c_rate should be set to NaN.

Default
1

This parameter is used within the following categories: *storage_*.csv*

country

Definition
Name of the country where the project is being deployed

Type
str

Unit
nan

Example
Norway

Restrictions
nan

Default
nan

This parameter is used within the following categories: *project_data.csv*

currency

Definition
The currency of the country where the project is implemented.

Type
str

Unit
nan

Example
EUR

Restrictions
nan

Default
EUR

This parameter is used within the following categories: *economic_data.csv*

development_costs

Definition
A fixed cost to implement the asset, eg. planning costs which do not depend on the (optimized) asset capacity.

Type
numeric

Unit
currency

Example
10000

Restrictions
Positive real number

Default
0

This parameter is used within the following categories: *energyConversion.csv*, *storage_*.csv*, *energyProduction.csv*, *fixcost.csv*

discount_factor

Definition
Discount factor is the factor which accounts for the depreciation in the value of money in the future, compared to the current value of the same money. The common method is to calculate the weighted average cost of capital (WACC) and use it as the discount rate.

Type
numeric

Unit
Factor

Example
0.06

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *economic_data.csv*

dispatch_price

Definition
Variable cost associated with a flow through/from the asset (eg. Euro/kWh).

Type
numeric

Unit
currency/kWh

Example
0.64 or "[0.3, 0.26]" for multiple input or output busses

Restrictions
In "storage_xx.csv" only the columns "input power" and "output power" require a value, in column "storage capacity" dispatch_price should be set to NaN. In conversion assets, there should be different dispatch prices provided for each input or output busses. For two output busses (for example a heat pump), then write "[0.1, 0.4]"

Default
0

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*, *storage_*.csv*, *fixcost.csv*

efficiency

Definition
Ratio of energy output/energy input. The battery efficiency is the ratio of the energy taken out from the battery, to the energy put into the battery. It means that it is not possible to retrieve as much energy as provided to the battery due to the discharge losses. The efficiency of the "input power" and "ouput power" columns should be set equal to the charge and dischage efficiencies respectively, while the "storage capacity" efficiency should be equal to the storage's efficiency/ability to hold charge over time (= *1 - self-discharge/decay*), which is usually in the range of 0.95 to 1 for electrical storages.

Type
numeric

Unit
Factor

Example
0.95 or "[0.91, 0.98]" for multiple input or output busses

Restrictions
Between 0 and 1

Default
1

This parameter is used within the following categories: *energyConversion.csv*, *storage_*.csv*

emission_factor

Definition
Emissions per unit dispatch of an asset.

Type
numeric

Unit
kgCO2eq/asset unit

Example
14.4

Restrictions
Positive real number

Default
0

This parameter is used within the following categories: *energyProviders.csv*, *energyProduction.csv*

energy_price

Definition
Price of energy carrier sourced from the utility grid.

Type
numeric

Unit
currency/energy carrier unit

Example
0.1

Restrictions
nan

Default
0

This parameter is used within the following categories: *energyProviders.csv*

energyVector

Definition
Energy vector/commodity. Convention: For an energy conversion asset define energyVector of the output. For a sink define based on inflow. For a source define based on output flow. For a storage, define based on stored energy carrier.

Type
str

Unit
nan

Example
Electricity

Restrictions
One of "Electricity", "Gas", "Bio-Gas", "Diesel", "Heat", "H2"

Default
Electricity

This parameter is used within the following categories: *energyBusses.csv*, *energyConsumption.csv*, *energyProduction.csv*, *energyStorage.csv*, *energyProviders.csv*, *energyConversion.csv*

evaluated_period

Definition
The number of days simulated with the energy system model.

Type
numeric

Unit
Day

Example
365

Restrictions
Natural number

Default
365

This parameter is used within the following categories: *simulation_settings.csv*

feedin_tariff

Definition
Price received for feeding electricity into the grid.

Type
numeric

Unit
currency/kWh

Example
0.7

Restrictions
Real number between 0 and 1

Default
0

This parameter is used within the following categories: *energyProviders.csv*

file_name

Definition
Name of a csv file containing the input generation or demand timeseries.

Type
str

Unit
nan

Example
demand_harbor.csv

Restrictions
This file must be placed in a folder named "time_series" inside your input folder.

Default
nan

This parameter is used within the following categories: *energyConsumption.csv*, *energyProduction.csv*, *energyStorage.csv*

fixed_thermal_losses_absolute

Definition
Thermal losses of storage independent of state of charge and independent of nominal storage capacity between two consecutive timesteps.

Type
numeric

Unit
factor

Example
0.0003

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *storage_*.csv*

fixed_thermal_losses_relative

Definition
Thermal losses of storage independent of state of charge between two consecutive timesteps relative to nominal storage capacity.

Type
numeric

Unit
factor

Example
0.0016

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *storage_*.csv*

inflow_direction

Definition
The label of the bus/component from which the energyVector is arriving into the asset.

Type
str

Unit
nan

Example
Electricity or "[Electricity, Heat]" for multiple input busses

Restrictions
nan

Default
nan

This parameter is used within the following categories: *energyConsumption.csv*, *energyConversion.csv*, *energyProviders.csv*, *energyStorage.csv*

installedCap

Definition
The already existing installed capacity in-place. If the project lasts longer than its remaining lifetime, its replacement costs will be taken into account.

Type
numeric

Unit
kWp

Example
50

Restrictions
Each component in the "energy production" category must have a value.

Default
0

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*, *storage_*.csv*

label

Definition
Name of the asset for display purposes

Type
str

Unit
nan

Example
pv_plant_01

Restrictions
Input the names in a computer friendly format, preferably with underscores instead of spaces, and avoiding special characters

Default
nan

This parameter is used within the following categories: *fixcost.csv*

latitude

Definition
Latitude coordinate of the project's geographical location.

Type
numeric

Unit
nan

Example
45.641603

Restrictions
Should follow geographical convention

Default
nan

This parameter is used within the following categories: *project_data.csv*

lifetime

Definition
Number of operational years of the asset until it has to be replaced.

Type
numeric

Unit
Year

Example
30

Restrictions
Natural number

Default
20

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*, *storage_*.csv*, *fixcost.csv*

longitude

Definition
Longitude coordinate of the project's geographical location.

Type
numeric

Unit
nan

Example
10.95787

Restrictions
Should follow geographical convention

Default
nan

This parameter is used within the following categories: *project_data.csv*

maximum_emissions

Definition
The maximum amount of total emissions in the optimized energy system.

Type
numeric

Unit
kgCO2eq/a

Example
100000

Restrictions
Acceptable values are either a positive real number or None

Default
nan

This parameter is used within the following categories: *constraints.csv*

maximumCap

Definition
The maximum total capacity of an asset that can be installed at the project site. This includes the installed and the also the maximum additional capacity possible. An example would be that a roof can only carry 50 kWp PV (maximumCap), whereas the installed capacity is already 10 kWp. The optimization would only be allowed to add 40 kWp PV at maximum.

Type
numeric

Unit
kWp

Example
1050

Restrictions
Acceptable values are either a positive real number or None

Default
nan

This parameter is used within the following categories: *energyProduction.csv*

minimal_degree_of_autonomy

Definition
The minimal degree of autonomy that needs to be met by the optimization.

Type
numeric

Unit
factor

Example
0.3

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *constraints.csv*

minimal_renewable_factor

Definition
The minimum share of energy supplied by renewable generation in the optimized energy system. Insert the value 0 to deactivate this constraint.

Type
numeric

Unit
factor

Example
0.7

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *constraints.csv*

net_zero_energy

Definition
Specifies whether optimization needs to result into a net zero energy system (True) or not (False).

Type
boolean

Unit
nan

Example
True

Restrictions
Acceptable values are either True or False.

Default
False

This parameter is used within the following categories: *constraints.csv*

optimizeCap

Definition
Allow the user to perform capacity optimization for an asset.

Type
boolean

Unit
nan

Example
True

Restrictions
Permissible values are either True or False

Default
False

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*, *energyProviders.csv*, *energyStorage.csv*

outflow_direction

Definition
The label of bus/component towards which the energyVector is leaving from the asset.

Type
str

Unit
nan

Example
Electricity or "[Electricity, Heat]" for multiple output busses

Restrictions
nan

Default
nan

This parameter is used within the following categories: *energyConsumption.csv*, *energyConversion.csv*, *energyProviders.csv*, *energyStorage.csv*

output_lp_file

Definition
Enable the generation of a file with the linear equation system describing the simulation, ie., with the objective function and all the constraints. This lp file enables the user look at the underlying equations of the optimization.

Type
boolean

Unit
nan

Example
False

Restrictions
Acceptable values are either True or False

Default
False

This parameter is used within the following categories: *simulation_settings.csv*

peak_demand_pricing

Definition
Price to be paid additionally for energy-consumption based on the peak demand of a given period.

Type
numeric

Unit
currency/kW

Example
60

Restrictions
nan

Default
0

This parameter is used within the following categories: *energyProviders.csv*

See also: *peak_demand_pricing_period*

peak_demand_pricing_period

Definition
Number of reference periods in one year for the peak demand pricing.

Type
numeric

Unit
times per year (1,2,3,4,6,12)

Example
2

Restrictions
Only one of the following are acceptable values: 1 (yearly), 2, 3 ,4, 6, 12 (monthly)

Default
1

This parameter is used within the following categories: *energyProviders.csv*

See also: *peak_demand_pricing*

project_duration

Definition
The number of years the project is intended to be operational. The project duration also sets the installation time of the assets used in the simulation. After the project ends these assets are 'sold' and the refund is charged against the initial investment costs.

Type
numeric

Unit
Years

Example
30

Restrictions
Natural number

Default
20

This parameter is used within the following categories: *economic_data.csv*

project_id

Definition
Users can assign a project ID as per their preference.

Type
str

Unit
nan

Example
1

Restrictions
Cannot be the same as an already existing project

Default
nan

This parameter is used within the following categories: *project_data.csv*

project_name

Definition
Users can assign a project name as per their preference.

Type
str

Unit
nan

Example
Borg Havn

Restrictions
nan

Default
nan

This parameter is used within the following categories: *project_data.csv*

renewable_share

Definition
The share of renewables in the generation mix of the energy supplied by the DSO (utility).

Type
numeric

Unit
Factor

Example
0.1

Restrictions
Real number between 0 and 1

Default
0

This parameter is used within the following categories: *energyProviders.csv*

renewableAsset

Definition
Allow the user to tag as asset as renewable.

Type
boolean

Unit
nan

Example
True

Restrictions
Acceptable values are either True or False

Default
False

This parameter is used within the following categories: *energyProduction.csv*

scenario_description

Definition
Brief description of the scenario being simulated.

Type
str

Unit
nan

Example
This scenario simulates a sector-coupled energy system

Restrictions
nan

Default
nan

This parameter is used within the following categories: *project_data.csv*

scenario_id

Definition
Users can assign a scenario id as per their preference.

Type
str

Unit
nan

Example
1

Restrictions
Cannot be the same as an already existing scenario within the project

Default
nan

This parameter is used within the following categories: *project_data.csv*

scenario_name

Definition
Users can assign a scenario name as per their preference.

Type
str

Unit
nan

Example
Warehouse 14

Restrictions
nan

Default
nan

This parameter is used within the following categories: *project_data.csv*

soc_initial

Definition
The level of charge (as a factor of the actual capacity) in the storage in the initial (0) time-step.

Type
numeric

Unit
None or factor

Example
`storage capacity`: None, `input power`: NaN, `output power`: NaN

Restrictions
Acceptable values are either None or the factor. Only the column `storage capacity` requires a value, in column `input power` and `output power` `soc_initial` should be set to NaN. The `soc_initial` has to be within the [0,1] interval.

Default
nan

This parameter is used within the following categories: *storage_*.csv*

soc_max

Definition
The maximum permissible level of charge in the battery (generally, it is when the battery is filled to its nominal capacity), represented by the value 1.0. Users can also specify a certain value as a factor of the actual capacity.

Type
numeric

Unit
Factor

Example
`storage capacity`: 1, `input power`: NaN, `output power`: NaN

Restrictions
Only the column `storage capacity` requires a value, in column `input power` and `output power` `soc_max` should be set to NaN. The `soc_max` has to be in the [0,1] interval.

Default
1

This parameter is used within the following categories: *storage_*.csv*

soc_min

Definition
The minimum permissible level of charge in the battery as a factor of the nominal capacity of the battery.

Type
numeric

Unit
Factor

Example
`storage capacity`:0.2, `input power`: NaN, `output power`: NaN

Restrictions
Only the column `storage capacity` requires a value, in column `input power` and `output power` `soc_min` should be set to NaN. The soc_min has to be in the [0,1] interval.

Default
0

This parameter is used within the following categories: *storage_*.csv*

specific_costs

Definition
Actual CAPEX of an asset, i.e., specific investment costs

Type
numeric

Unit
currency/unit

Example
4000

Restrictions
nan

Default
0

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*, *storage_*.csv*, *fixcost.csv*

specific_costs_om

Definition
Actual OPEX of an asset, i.e., specific operational and maintenance costs.

Type
numeric

Unit
currency/unit/year

Example
120

Restrictions
nan

Default
0

This parameter is used within the following categories: *energyConversion.csv*, *energyProduction.csv*, *storage_*.csv*, *fixcost.csv*

start_date

Definition
The date and time on which the simulation starts at the first step.

Type
str

Unit
nan

Example
2018-01-01 00:00:00

Restrictions
Acceptable format is YYYY-MM-DD HH:MM:SS

Default
nan

This parameter is used within the following categories: *simulation_settings.csv*

storage_filename

Definition
Name of a csv file containing the properties of a storage component

Type
str

Unit
nan

Example
storage_01.csv

Restrictions
Follows the convention of 'storage_xx.csv' where 'xx' is a number. This file must be placed in a folder named "csv_elements" inside your input folder.

Default
nan

This parameter is used within the following categories: *energyStorage.csv*

tax

Definition
Tax factor.

Type
numeric

Unit
Factor

Example
0

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *economic_data.csv*

timestep

Definition
Length of the time-steps.

Type
numeric

Unit
Minutes

Example
60

Restrictions
Can only be 60 at the moment

Default
60

This parameter is used within the following categories: *simulation_settings.csv*

type_oemof

Definition
Input the type of OEMOF component. For example, a PV plant would be a source, a solar inverter would be a transformer, etc. The *type_oemof* will later on be determined through the EPA.

Type
str

Unit
nan

Example
sink

Restrictions
sink or *source* or one of the other component classes of OEMOF.

Default
nan

This parameter is used within the following categories: *energyConsumption.csv*, *energyConversion.csv*, *energyProduction.csv*, *energyProviders.csv*, *energyStorage.csv*

unit

Definition
Unit associated with the capacity of the component.

Type
str

Unit
nan

Example
Storage could have units like kW or kWh, transformer station could have kVA, and so on.

Restrictions
Appropriate scientific unit

Default
nan

This parameter is used within the following categories: *energyConsumption.csv*, *energyConversion.csv*, *energyProduction.csv*, *energyProviders.csv*, *storage_*.csv*

beta

Definition
Power loss index for CHPs

Type
numeric

Unit
factor

Example
0.6

Restrictions
Between 0 and 1

Default
0

This parameter is used within the following categories: *energyConversion.csv*

3.6 Outputs of a simulation

After optimization of an energy system, the MVS evaluates the simulation output. It evaluates the flows, costs and performance of the system. As a result, it calculates a number of *key performance indicators (KPI)*, namely *economic*, *technical* and *environmental* KPI. Depending on the simulation settings, it can also generate different *output files and figures* of the results, including an *automatic report* in `pdf` or `html` format.

3.6.1 Overview of Key Performance Indicators

Technical KPI are calculated to assess the performance of a simulated energy system, ie. represent the technical system configuration and operation. They are calculated based on the asset capacities and asset dispatch. They should allow the comparision of different energy system topologies and different project sites with each other. These are the calculated technical KPI:

- *Aggregated flow*
- *Average flow*
- *Degree of Autonomy*
- *Degree of Net Zero Energy*
- *Dispatch of an asset*
- *Onsite energy fraction*
- *Onsite energy matching*
- *Optimal additional capacity*
- *Peak flow*
- *Renewable factor*
- *Renewable share of local generation*
- *Energy import*
- *Energy demand*
- *Energy excess*
- *Energy export*
- *Total local generation*
- *Total non-renewable local generation*
- *Total renewable local generation*
- *Total non-renewable energy use*
- *Total renewable energy use*

Economic KPI are calculated to assess the costs of a simulated energy system. They include the costs per asset as well as the system's overall costs. Relative values like the levelized costs of supply allow a comparision to other investment options. These are the calculated economic KPI:

- *Annual operation, maintenance and dispatch expenses*
- *Annuity*
- *Costs attributed to a specific sector*
- *Operation and maintenance costs*

- *Dispatch costs*
- *Investment costs*
- *Operation, maintenance and dispatch costs*
- *Net Present Costs (NPC)*
- *Upfront investment costs*
- *Levelized cost of throughput*
- *Levelized costs of electricity equivalent*
- *Replacement costs*

Environmental KPI are calculated to assess the impact of a simulated energy system on the environment. These are the calculated environmental KPI:

- *Specific GHG per electricity equivalent*
- *Total GHG emissions*

Additionally to the KPI, the MVS can also generate a number of output files, which can be shared with other partners and used to vizualize the system's behaviour and performance. These are the calculated files KPI:

- *Simulation report*
- *Bar chart of optimal capacities*
- *Excel file with all KPI*
- *Excel file with dispatch timeseries*
- *Simulation data after pre-processing (JSON)*
- *Simulation data and results (JSON)*
- *MVS logfile*
- *Energy system model visualization*
- *Pie charts of cost parameters*
- *Dispatch of all assets on a bus*
- *Input timeseries*

In the sections *economic*, *technical* and *environmental* KPI, these indicators are further defined and in *Files* the possible exportable figures and files are presented. This takes place with the following structure:

Definition
: Definition of the defined KPI, can be used as tooltips.

Type
: One of Numeric, Figure, Excel File, JSON, Time series, Logfile or html/pdf

Unit
: Unit of the KPI, multiple units possible if KPI can be applied to individual sectors (see also: *Suffixes of KPI*).

Valid Interval
: Expected valid range of the KPI. Exceptions are possible under certain conditions.

Related indicators
: List of indicators that are related to the described KPI, either because they are part of its calculation or can be compared to it.

Besides these parameters attributes, the underlying equation of a specific KPI may be presented and explained, or further hints might be provided for the parameter evaluation or for special cases.

3.6.2 Suffixes of KPI

The KPI of the MVS can be calculated per asset, for each sector or for the overall system.

KPI calculated per asset are not included in the scalar results of the automatic report or in the stored Excel file, but are displayed separately. They do not need suffixes, as they are always displayed in tables next to the respective asset.

KPI calculated for each vector are specifically these KPI that aggregate the dispatch and costs of multiple assets. For cost-related KPI, such aggregating KPI have the energy vector they are describing as a suffix. An example would be the `attributed_costs` of each energy vector - the attributed costs of the electricity and H2 sector would be called `attributed_costs_electricity` and `attributed_costs_H2` respectively. For technical KPI, this suffix also applies, but additionally, due to the *energy carrier weighting*, they also feature the suffix `electricity equivalent` when the weighting has been applied. The energy demand of the system is an example: the demand per sector would be `total_demand_electricity` and `total_demand_H2`. To be able to aggregate these cost into an overall KPI for the system, the electricity equivalents of both values are calculated. They then are named `total_demand_electricity_electricity_equivalent` and `total_demand_H2_electricity_equivalent`.

KPI that describe the costs of the overall energy system do not have suffixes. Technical KPI often have the suffix `electricity_equivalent` to underline the energy carrier that the parameter is relative to.

3.6.3 Economic KPI

All the KPI related to costs described below are provided in net present value.

Net Present Costs (NPC) (costs_total)

Definition
Net present costs of the system for the whole project duration, includes all operation, maintainance and dispatch costs as well as the investment costs (including replacements). Applied to a single asset, the costs can also be called present costs of the asset.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Operation and maintenance costs (costs_cost_om) | *Dispatch costs (costs_dispatch)* | *Investment costs (costs_investment_over_lifetime)* | *Operation, maintenance and dispatch costs (costs_om_total)* | *Upfront investment costs (costs_upfront_in_year_zero)*

The Net present costs (NPC) is the present value of all the costs associated with installation, operation, maintenance and replacement of energy assets within the optimized multi-vector energy system over the whole project lifetime, deducting the present value of the residual value of asset at project end and as well as all the revenues that it earns over the project lifetime. The capital recovery factor (CRF) is used to calculate the present value of the cash flows.

$$NPC = \sum_i \left(c_{specific} + c_{replacement} + c_{residual}\right) \cdot CAP_i + \sum_i \sum_t E_i(t) \cdot p_{dispatch}$$

Operation and maintenance costs (costs_cost_om)

Definition
Costs for fix annual operation and maintenance costs over the whole project lifetime, which do not depend on the assets dispatch but solely on installed capacity. An example would be the maintenance costs for cleaning the installed PV capacity.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Dispatch costs (costs_dispatch) | *Investment costs (costs_investment_over_lifetime)* | *Operation, maintenance and dispatch costs (costs_om_total)* | *Net Present Costs (NPC) (costs_total)* | *Upfront investment costs (costs_upfront_in_year_zero)*

Operation, maintenance and dispatch costs (costs_om_total)

Definition
Costs for annual operation and maintenance costs as well as dispatch of all assets of the energy system, for the whole project duration.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Operation and maintenance costs (costs_cost_om) | *Dispatch costs (costs_dispatch)* | *Investment costs (costs_investment_over_lifetime)* | *Net Present Costs (NPC) (costs_total)* | *Upfront investment costs (costs_upfront_in_year_zero)*

Dispatch costs (costs_dispatch)

Definition
Dispatch costs over the whole project lifetime including all expenditures that depend on the dispatch of assets (e.g. fuel costs, electricity consumption from the external grid, costs for operation and maintainance that depend on the throughput of an asset)

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Operation and maintenance costs (costs_cost_om) | *Investment costs (costs_investment_over_lifetime)* | *Operation, maintenance and dispatch costs (costs_om_total)* | *Net Present Costs (NPC) (costs_total)* | *Upfront investment costs (costs_upfront_in_year_zero)*

Investment costs (costs_investment_over_lifetime)

Definition
Investment costs over the whole project lifetime, including all replacement costs.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Operation and maintenance costs (costs_cost_om) | *Dispatch costs (costs_dispatch)* | *Operation, maintenance and dispatch costs (costs_om_total)* | *Net Present Costs (NPC) (costs_total)* | *Upfront investment costs (costs_upfront_in_year_zero)* | *Replacement costs (replacement_costs_during_project_lifetime)*

Upfront investment costs (costs_upfront_in_year_zero)

Definition
The costs which will have to be paid upfront when project begins, ie. In year 0. These are the investment and fix project costs into the chosen configuration.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Operation and maintenance costs (costs_cost_om) | *Dispatch costs (costs_dispatch)* | *Investment costs (costs_investment_over_lifetime)* | *Operation, maintenance and dispatch costs (costs_om_total)* | *Net Present Costs (NPC) (costs_total)*

Replacement costs (replacement_costs_during_project_lifetime)

Definition
Costs for replacement of assets which occur over the project lifetime.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Investment costs (costs_investment_over_lifetime)

Costs attributed to a specific sector (attributed_costs)

Definition
Costs attributed to supplying the demand of a specific sector, based on the *net present costs (NPC)* of the energy system and the share of the sector demand compared to the overall system demand.

Type
Numeric

Unit
currency

Valid Interval
>=0

Related indicators
Net Present Costs (NPC) (costs_total)

A multi-vector energy system connects energy vectors into a joined energy system and the system is then designed to have an optimial, joined operation. With other systems, the costs associated to each individual energy vector would be used to calculate the costs to supply the individual sector. With the multi-vector system, this could lead to distorted costs - for example if there is a lot of PV (electricity sector), which in the end is only supplying an electrolyzer (H2 sector). The investment and operational costs of the electricity sector assets would thus turn out to be very high, which could be considered unfair as the electricity from PV is solely used to provide the H2 demand. Therefore, we define the *attributed costs of each energy vector*, to determine how much of the overall system costs should be attributed to one sector, depending on the energy demand it has compared to the other sectors. To be able to compare the demands of different energy carriers, *energy carrier weighting* is applied.

Annuity (annuity_total)

Definition
Annuity of the assets costs over the project lifetime or the energy system's *net present costs (NPC)* .

Type
Numeric

Unit
currency/a

Valid Interval
>=0

Related indicators
Annual operation, maintenance and dispatch expenses (annuity_om) | *Net Present Costs (NPC) (costs_total)*

Annual operation, maintenance and dispatch expenses (annuity_om)

Definition
Annuity of the operation, maintenance and dispatch costs of the asset or energy system, i.e. ballpark number of the annual expenses for asset or system operation.

Type
Numeric

Unit
currency/a

Valid Interval
>=0

Related indicators
Annuity (annuity_total) | *Operation, maintenance and dispatch costs (costs_om_total)*

Levelized costs of electricity equivalent (levelized_costs_of_electricity_equivalent)

Definition
Levelized cost of energy of the sector-coupled energy system, calculated from the systems annuity and the total system demand in electricity equivalent.

Type
Numeric

Unit
currency/kWheleq

Valid Interval
>=0

Related indicators
Net Present Costs (NPC) (costs_total) | *Energy demand (total_demand)*

Specific electricity supply costs, eg. levelized costs of electricity are commonly used to compare the supply costs of different investment decisions or also energy provider prices to local generation costs. However, the a multi-vector energy system connects energy vectors into a joined energy system and the optimization objective of the MVS then is to minimize the overall energy costs, without distinguising between the different sectors. This sector-coupled energy system is then designed to have an optimial, joined operation. With other systems, the costs associated to each individual energy vector would be used to calculate the levelized costs of energy (LCOEnergy). With the multi-vector system, this could lead to distorted costs - for example if there is a lot of PV (electricity sector), which in the end is only supplying an electrolyzer (H2 sector). The LCOE of electricity would thus turn out to be very high, which could be considered unfair as the electricity from PV is solely used to provide the H2 demand. Therefore, we define the *attributed costs of each energy vector*, to determine how much of the overall system costs should be attributed to one sector, depending on the energy demand it has compared to the other sectors. To be able to compare the demands of different energy carriers, *energy carrier weighting* is applied.

Therefore the levelized costs of energy (LCOEnergy) for energy carrier i are defined based on the annuity of the attributed costs, the CRF and the demand of one energy sector $E_{dem,i}$:

$$LCOEnergy_i = \frac{Attributed\ costs \cdot CRF}{\sum_t E_{dem,i}(t)}$$

The LCOEnergy are are calculated for each sector (resulting in the levelized costs of electricity, heat, H2...), but also for the overall energy system. For the overall energy system, the levelized costs of electricity equivalent are calculated, as this system may supply different energy vectors.

Levelized cost of throughput (levelized_cost_of_energy_of_asset)

Definition
Cost per kWh throughput through an asset, based on the assets costs during the project lifetime as well as the total throughput through the asset in the project lifetime. For generation assets, equivalent to the levelized cost of generation.

Type
Numeric

Unit
currency/kWh

Valid Interval
>=0

Related indicators
Annuity (annuity_total) | *Aggregated flow (annual_total_flow)*

This KPI measures the cost of generating 1 kWh for each asset in the system. It can be used to assess and compare the available alternative methods of energy production. The levelized cost of energy of an asset ($LCOE\ ASSET_i$) is usually obtained by looking at the lifetime costs of building and operating the asset per unit of total energy throughput of an asset over the assumed lifetime [currency/kWh].

Since not all assets are production assets, the MVS distinguishes between the type of assets. For assets in energyConversion and energyProduction the MVS calculates the $LCOE\ ASSET_i$ by dividing the total annuity a_i of the asset i by the total flow $\sum_t E_i(t)$.

$$LCOE\ ASSET_i = \frac{a_i}{\sum_t E_i(t)}$$

For assets in `energyStorage`, the MVS sums the annuity for `storage capacity` $a_{i,sc}$, `input power` $a_{i,ip}$ and `output power` $a_{i,op}$ and divides it by the `output power` total flow $\sum tE_{i,op}(t)$.

$$LCOE\ ASSET_i = \frac{a_{i,sc} + a_{i,ip} + a_{i,op}}{\sum_t E_{i,op}(t)}$$

If the total flow is 0 in any of the previous cases, then the $LCOE\ ASSET$ is set to `None`.

$$LCOE\ ASSET_i = None$$

For assets in *energyConsumption*, the MVS outputs 0 for the $LCOE\ ASSET_i$.

$$LCOE\ ASSET_i = 0$$

3.6.4 Technical KPI

Optimal additional capacity (optimizedAddCap)

Definition
Capacity added to installed capacity for optimal economic system performance.

Type
Numeric

Unit
kW, kWh, kWp, ...

Valid Interval
>=0

Related indicators
Peak flow (peak_flow)

Dispatch of an asset (flow)

Definition
Optimized dispatch of an asset in the optimized energy system, ie. its generation or thoughput.

Type
Time series (with time stamps and values)

Unit
kW,kgH2,...

Valid Interval
nan

Related indicators
Dispatch of all assets on a bus | *Peak flow (peak_flow)* | *Aggregated flow (annual_total_flow)* | *Average flow (average_flow)*

Peak flow (peak_flow)

Definition
Peak of the dispatch of an asset.

Type
Numeric

Unit
kW

Valid Interval
>=0

Related indicators
Average flow (average_flow) | *Aggregated flow (annual_total_flow)*

Average flow (average_flow)

Definition
Average value of the assets dispatch. The ratio of average dispatch to peak dispatch indicates how much the asset is used in comparison to its actual installed capacity.

Type
Numeric

Unit
kWh

Valid Interval
>=0

Related indicators
Aggregated flow (annual_total_flow) | *Peak flow (peak_flow)*

Aggregated flow (annual_total_flow)

Definition
Dispatch of the asset over a year, aggregated generation, demand or throughput.

Type
Numeric

Unit
kWh

Valid Interval
>=0

Related indicators
Average flow (average_flow) | *Peak flow (peak_flow)*

Energy demand (total_demand)

Definition
Demand of energy in local energy system over a the project lifetime.

Type
Numeric

Unit
kWh, kWheleq, ...

Valid Interval
>=0

Related indicators
None

Energy export (total_feedin)

Definition
Feed-in of energy into external grid.

Type
Numeric

Unit
kWh, kWheleq, ...

Valid Interval
>=0

Related indicators
Onsite energy fraction (onsite_energy_fraction)

Energy import (total_consumption_from_energy_provider)

Definition
Aggregated energy imports into the local energy system from the provider.

Type
Numeric

Unit
kWh, kWheleq, ...

Valid Interval
>=0

Related indicators
None

Total non-renewable local generation (total_internal_non-renewable_generation)

Definition
Aggregated amount of non-renewable energy generated within the energy system.

Type
Numeric

Unit
kWheleq

Valid Interval
>=0

Related indicators
Total local generation (total_internal_generation) | *Total renewable local generation (total_internal_renewable_generation)*

Total renewable local generation (total_internal_renewable_generation)

Definition
Aggregated amount of renewable energy generated within the energy system.

Type
Numeric

Unit
kWheleq

Valid Interval
>=0

Related indicators
Total local generation (total_internal_generation) | *Total non-renewable local generation (total_internal_non-renewable_generation)*

Total local generation (total_internal_generation)

Definition
Aggregated amount of energy generated within the energy system.

Type
Numeric

Unit
kWheleq

Valid Interval
>=0

Related indicators
Total non-renewable local generation (total_internal_non-renewable_generation) | *Total renewable local generation (total_internal_renewable_generation)*

Energy excess (total_excess)

Definition
Excess of energy, ie. unused energy in local energy system.

Type
Numeric

Unit
kWh, kWheleq, ...

Valid Interval
>=0

Related indicators
None

Total renewable energy use (total_renewable_energy_use)

Definition
Aggregated amount of renewable energy used within the energy system (ie. Including local generation and external supply).

Type
Numeric

Unit
kWheleq

Valid Interval
>=0

Related indicators
Total non-renewable energy use (total_non-renewable_energy_use)

Total non-renewable energy use (total_non-renewable_energy_use)

Definition
Aggregated amount of non-renewable energy used within the energy system (ie. Including local generation and external supply).

Type
Numeric

Unit
kWheleq

Valid Interval
>=0

Related indicators
Total renewable energy use (total_renewable_energy_use)

Renewable share of local generation (renewable_share_of_local_generation)

Definition
The renewable share of local generation describes how much of the energy generated locally is produced from renewable sources. It does not take into account the consumption from energy providers.

Type
Numeric

Unit
Factor

Valid Interval
[0,1]

Related indicators
Renewable factor (renewable_factor)

The renewable share of local generation describes how much of the energy generated locally is produced from renewable sources. It does not take into account the consumption from energy providers.

The renewable share of local generation for each sector does not utilize energy carrier weighting but has a limited, single-vector view:

$$REGen_v = \frac{\sum_i E_{rgen,i}}{\sum_j E_{gen,j}}$$

with v: Energy vector
$rgen$: Renewable generation
gen: Renewable and non-renewable generation
i, j: Asset 1,2,...

For the system-wide share of local renewable generation, energy carrier weighting is used:

$$REGen = \frac{\sum_i E_{rgen,i} \cdot w_i}{\sum_j E_{gen,j} \cdot w_j}$$

with $rgen$: Renewable generation
gen: Renewable and non-renewable generation
i, j: Assets 1,2,...
w_i, w_j: Energy carrier weighting factor for output of asset i/j

Example

An energy system is composed of a heat and an electricity side. Following are the energy flows:

- 100 kWh from a local PV plant
- 0 kWh local generation for the heat side

This results in:

- A single-vector renewable share of local generation of 0% for the heat sector.
- A single-vector renewable share of local generation of 100% for the electricity sector.
- A system-wide renewable share of local generation of 100%.

Renewable factor (renewable_factor)

Definition
Describes the share of the energy influx to the local energy system that is provided from renewable sources. This includes both local generation as well as consumption from energy providers.

Type
Numeric

Unit
Factor

Valid Interval
[0,1]

Related indicators
Renewable share of local generation (renewable_share_of_local_generation) | *Onsite energy fraction (onsite_energy_fraction)* | *Onsite energy matching (onsite_energy_matching)*

Describes the share of the energy influx to the local energy system that is provided from renewable sources. This includes both local generation as well as consumption from energy providers.

$$RF = \frac{\sum_i E_{rgen,i} \cdot w_i + RES \cdot E_{grid}}{\sum_j E_{gen,j} \cdot w_j + \sum_k E_{grid}(k) \cdot w_k}$$

with $rgen$: Renewable generation

gen: Renewable and non-renewable generation

i, j: Assets 1,2,...

RES: Renewable energy share of energy provider

k: Energy provider 1,2...

w_i, w_j, w_k: Energy carrier weighting factor for output of asset i/j/k

Example

An energy system is composed of a heat and an electricity side. Following are the energy flows:

- 100 kWh from a local PV plant
- 0 kWh local generation for the heat side
- 100 kWh consumption from the electricity provider, who has a renewable factor of 50%

Again, the heat sector would have a renewable factor of 0% when considered separately, and the electricity side would have an renewable factor of 75%. This results in a system-wide renewable share of:

$$RF = \frac{100kWh(el) \cdot \frac{kWh(eleq)}{kWh(el)} + 50kWh(el) \cdot \frac{kWh(eleq)}{kWh(el)}}{200kWh(el) \cdot \frac{kWh(eleq)}{kWh(el)}} = 3/4 = 75\ \%$$

The renewable factor, just like the *Renewable share of local generation (renewable_share_of_local_generation)*, cannot indicate how much renewable energy is used in each of the sectors. In the future, it might be possible to get a clearer picture of the flows between the sectors with the proposed *degree of sector-coupling*.

Degree of sector-coupling (DSC)

To assess how much an optimized multi-vector energy system makes use of the potential of sector-coupling, it is planned to introduce the degree of sector-coupling in the future. This level of interconnection is to be calculated with the ratio of energy flows in between the sectors (ie. those, where energy carriers are converted to another energy carrier) to the energy demand supplied:

$$DSC = \frac{\sum_{i,j} E_{conversion}(i,j) \cdot w_i}{\sum_i E_{demand}(i) \cdot w_i}$$

with i, j: Electricity,H2...

Note: This feature is currently not implemented.

Onsite energy fraction (onsite_energy_fraction)

Definition
Onsite energy fraction is also referred to as self-consumption. It describes the fraction of all locally generated energy that is consumed by the system itself.

Type
Numeric

Unit
Factor

Valid Interval
[0,1]

Related indicators
Onsite energy matching (onsite_energy_matching)

Onsite energy fraction is also referred to as "self-consumption". It describes the fraction of all locally generated energy that is consumed by the system itself. (see [1] and [2]).

An OEF close to zero shows that only a very small amount of locally generated energy is consumed by the system itself. It is at the same time an indicator that a large amount is fed into the grid instead. A OEF close to one shows that almost all locally produced energy is consumed by the system itself.

$$OEF = \frac{\sum_i (E_{generation}(i) - E_{gridfeedin}(i)) \cdot w_i}{\sum_i E_{generation}(i) \cdot w_i}$$

$OEF \epsilon [0,1]$

Onsite energy matching (onsite_energy_matching)

Definition
The onsite energy matching is also referred to as self-sufficiency. It describes the fraction of the total demand that can be covered by the locally generated energy.

Type
Numeric

Unit
Factor

Valid Interval
[0,1]

Related indicators
Onsite energy fraction (onsite_energy_fraction) | *Energy export (total_feedin)*

The onsite energy matching is also referred to as "self-sufficiency". It describes the fraction of the total demand that can be covered by the locally generated energy (see [1] and [2]).

An OEM close to zero shows that very little of the demand can be covered by locally produced energy. Am OEM close to one shows that almost all of the demand can be covered with locally generated energy. Per definition OEM cannot be greater than 1 because the excess generated energy would automatically be fed into the grid or an excess sink.

$$OEM = \frac{\sum_i \left(E_{generation}(i) - E_{gridfeedin}(i) - E_{excess}(i)\right) \cdot w_i}{\sum_i E_{demand}(i) \cdot w_i}$$

$$OEM \epsilon [0,1]$$

Note: The feed into the grid should only be positive.

Degree of Autonomy (degree_of_autonomy)

Definition
A degree of autonomy close to zero shows high dependence on the energy provider, while a degree of autonomy of 1 represents an autonomous or net-energy system and a degree of autonomy higher 1 a surplus-energy system.

Type
Numeric

Unit
Factor

Valid Interval
[0,1]

Related indicators
Energy demand (total_demand)

The degree of autonomy describes the overall energy consumed minus the energy consumed from the grid divided by the overall energy consumed. Adapted from this definition [3].

A degree of autonomy close to zero shows high dependence on the grid operator, while a degree of autonomy of one represents an autonomous system. Note that this key parameter indicator does not take into account the outflow from the system to the grid operator (also called feedin). As above, we apply a weighting based on Electricity Equivalent.

$$Degree of Autonomy = \frac{\sum_i E_{demand,i} \cdot w_i - \sum_j E_{consumption,provider,j} \cdot w_j}{\sum_i E_{demand,i} \cdot w_i}$$

Degree of Net Zero Energy (degree_of_nze)

Definition
The degree of net zero energy describes the ability of an energy system to provide its aggregated annual demand through local sources.

Type
Numeric

Unit
Factor

Valid Interval
>=0

Related indicators
Energy export (total_feedin) | *Energy import (total_consumption_from_energy_provider)*

The degree of net zero energy describes the ability of an energy system to provide its aggregated annual demand though local sources. For that, the balance between local generation as well as consumption from and feed-in towards the energy provider is compared. In a net zero energy system, demand can be supplied by energy import, but then local energy generation must provide an equally high energy export of energy in the course of the year. In a plus energy system, the export exceeds the import, while local generation can supply all demand (from an aggregated perspective). To calculate the degree of NZE, the margin between grid feed-in and grid consumption is compared to the overall demand.

Some definitions of NZE systems require that the local demand is solely covered by locally generated renewable energy. In MVS this is not the case - all locally generated energy is taken into consideration. For information about the share of renewables in the local energy system checkout *Renewable share of local generation (renewable_share_of_local_generation)*.

A degree of NZE lower than 1 shows that the energy system can not reach a net zero balance, and indicates by how much it fails to do so, while a degree of NZE of 1 represents a net zero energy system and a degree of NZE higher 1 a plus-energy system.

As above, we apply a weighting based on Electricity Equivalent.

$$Degree of NZE = 1 + \frac{\sum_i \left(E_{gridfeedin}(i) - E_{gridconsumption}(i)\right) \cdot w_i}{\sum_i E_{demand,i} \cdot w_i}$$

3.6.5 Environmental KPI

Total GHG emissions (total_emissions)

Definition
Total greenhouse gas emissions in kg.

Type
Numeric

Unit
kg GHGeq

Valid Interval
>=0

Related indicators
Renewable factor (renewable_factor) | *Specific GHG per electricity equivalent (specific_emissions_per_electricity_equivalent)*

The total emissions of the MES in question are calculated with all aggregated energy flows from the generation assets including energy providers and their subsequent emission factor:

$$Total\_emissions = \sum_i E_{gen}(i) \cdot emission\_factor(i)$$

with i: generation assets 1,2,...

The emissions of each generation asset and provider are also calculated and displayed separately in the outputs of MVS.

Specific GHG per electricity equivalent (specific_emissions_per_electricity_equivalent)

Definition
Specific GHG emissions per supplied electricity equivalent.

Type
Numeric

Unit
kg GHGeq/kWh

Valid Interval
>=0

Related indicators
Total GHG emissions (total_emissions)

The specific emissions per electricity equivalent of the MES are calculated in kg/kWh$_{eleq}$:

$$Specific\_emissions = \frac{Total\_emissions}{total\_demand_{eleq}}$$

Emissions can be of different nature: CO2 emissions, CO2 equivalents, greenhouse gases, ...

Currently the emissions do not include life cycle emissions of energy conversion or storage assets, nor are they calculated separately for the energy sectors. For the latter, the problem of the assignment of assets to sectors arises e.g. emissions caused by an electrolyser would be counted to the electricity sector although you might want to count it for the H2 sector, as the purpose of the electrolyser is to feed the H2 sector. Therefore, we will have to verify whether or not we can apply the energy carrier weighting also for this KPI.

3.6.6 Files

Bar chart of optimal capacities

Definition
A bar chart to compare the optimized additional capacities for each asset to be installed in the energy system. Please be aware that the units of the capacities may different.

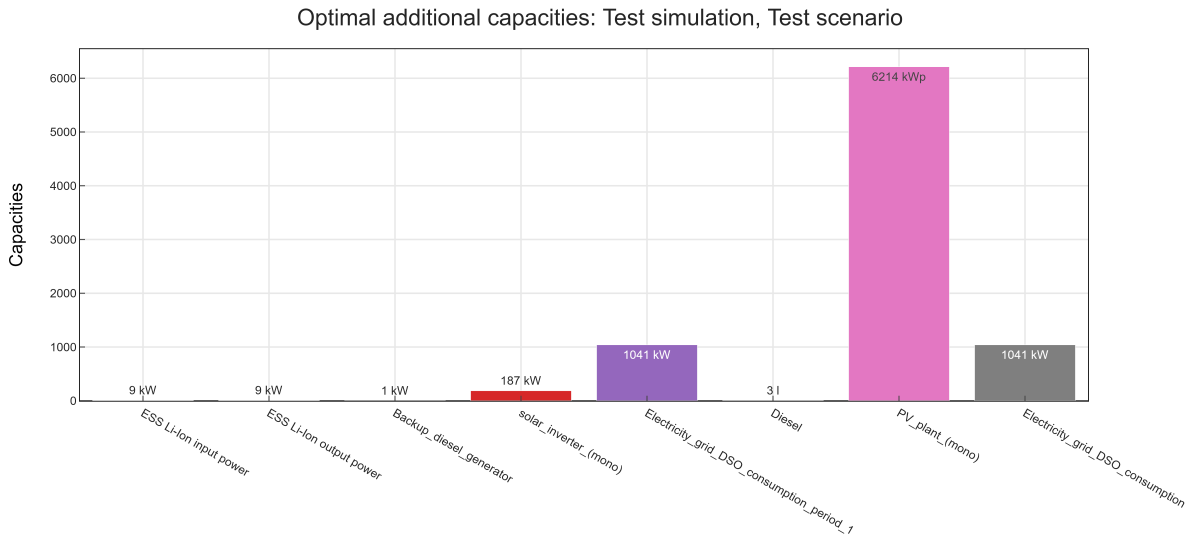
Type
Figure

Unit
kWh, kWp, kW, ...

Valid Interval
nan

Related indicators
Optimal additional capacity (optimizedAddCap)

An example of a bar chart of recommended additional asset capacities is shown below. Note that currently kWp are displayed on the same scale as kW (or kWh or gkH2), which is not ideal.



Pie charts of cost parameters

Definition
Displays the share of individual asset costs on different economical parameters of the overall system

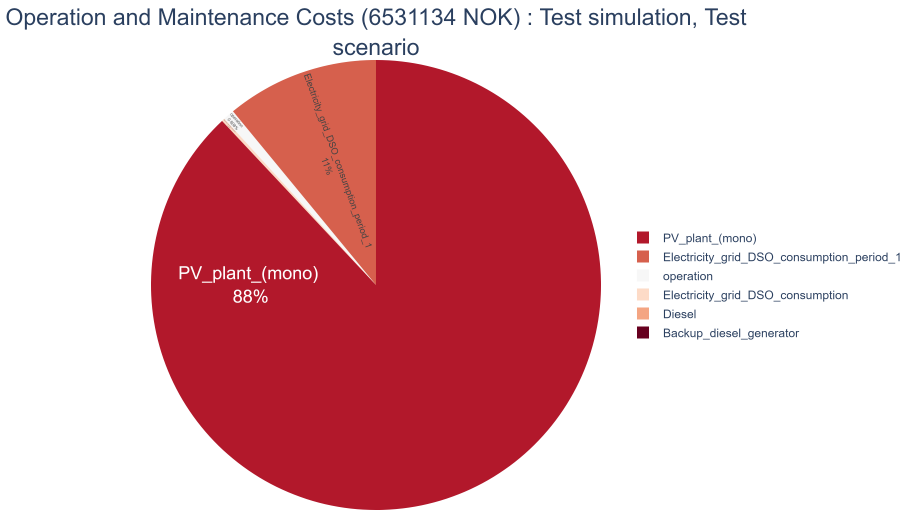
Type
Figure

Unit
Percentages

Valid Interval
nan

Related indicators
Net Present Costs (NPC) (costs_total) | *Operation, maintenance and dispatch costs (costs_om_total)* | *Annuity (annuity_total)*

An examplary pie chart is displayed below, in this case for the operation and management costs of an energy system.



Input timeseries

Definition
Vizualization of timeseries provided as input data, eg. PV generation timeseries.

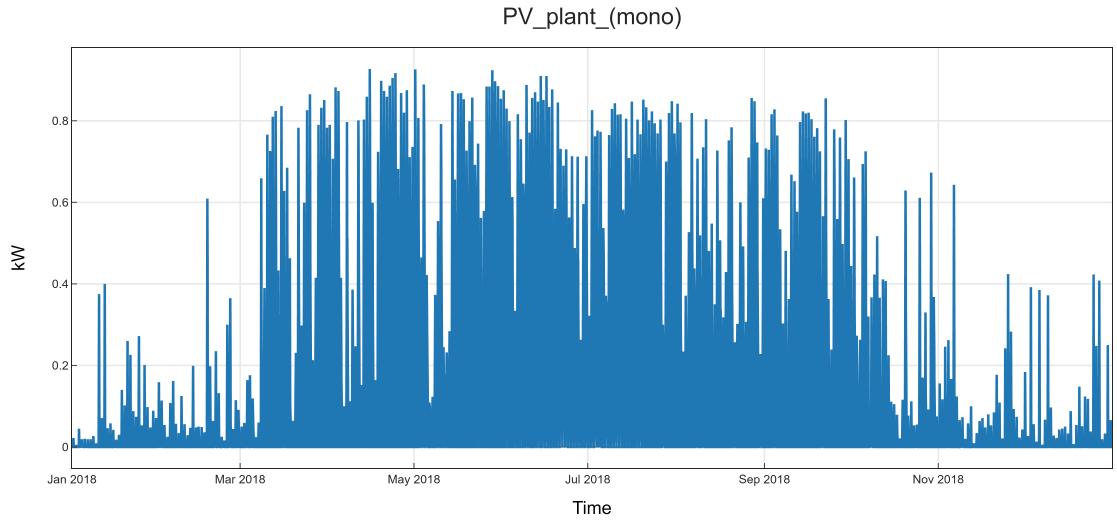
Type
Figure

Unit
kW, kgH2, ...

Valid Interval
nan

Related indicators
None

An example of the graph created from the timeseries, eg. specific generation timeseries, provided by the input files is shown below.



Dispatch of all assets on a bus

Definition
Visualization of the dispatch of all assets of a specific energy bus, ie. all inflows and outflows of a specific bus. Generated for every single energy bus in the energy system. If relevant, a plot of the state of charge is also displayed.

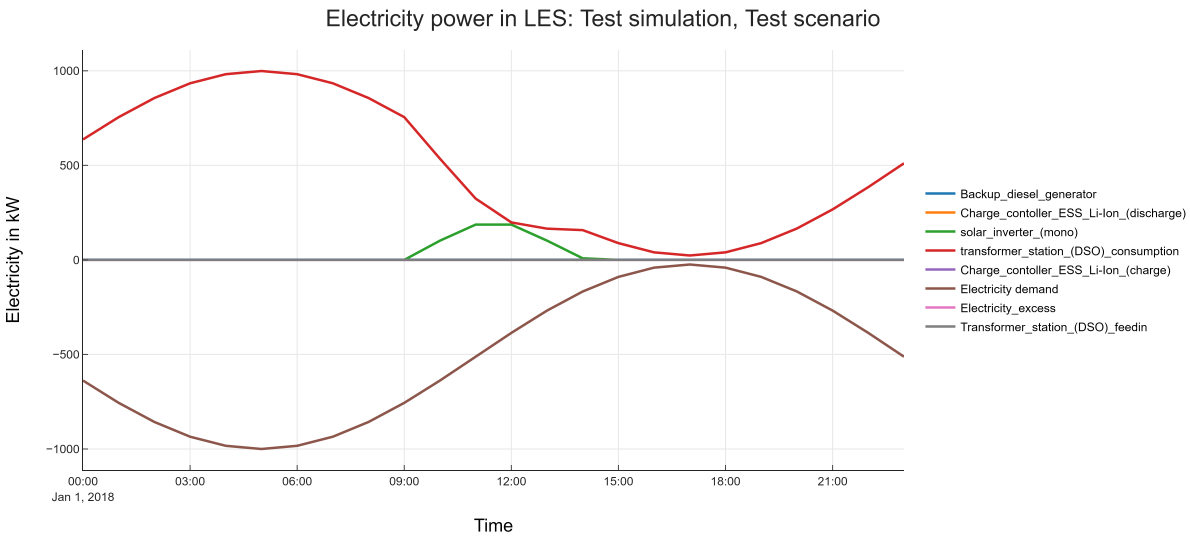
Type
Figure

Unit
kW, kgH2, ...

Valid Interval
nan

Related indicators
Dispatch of an asset (flow)

An example of the graph displaying the asset dispatch on a specific bus is shown below.



Energy system model visualization

Definition
Plot of the energy system model in oemof-solph topology. This graph also includes the automatically generated components, ie. the sub-assets of energy providers and an energy excess sink on each energy bus. The model therefore appears different than in the Energy Planning Application (EPA).

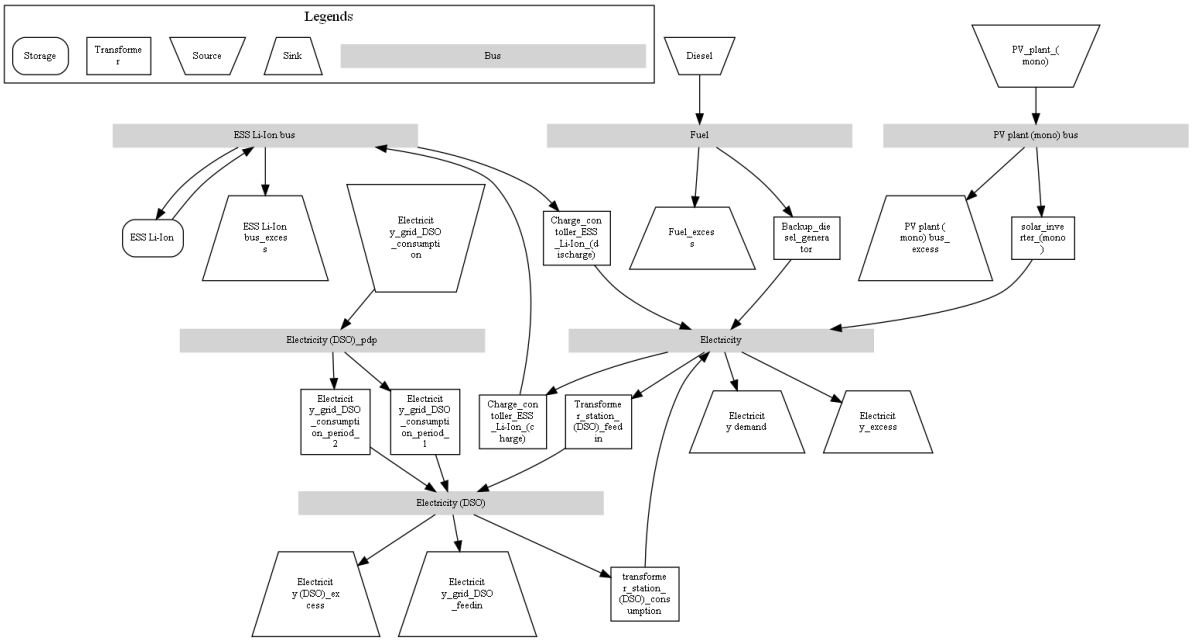
Type
Figure

Unit
nan

Valid Interval
nan

Related indicators
None

An example of the created energy system model graphs is shown below.



Excel file with all KPI

Definition
Excel sheet with all calculated KPI, both for the individual assets, the sectors and the overall energy system.

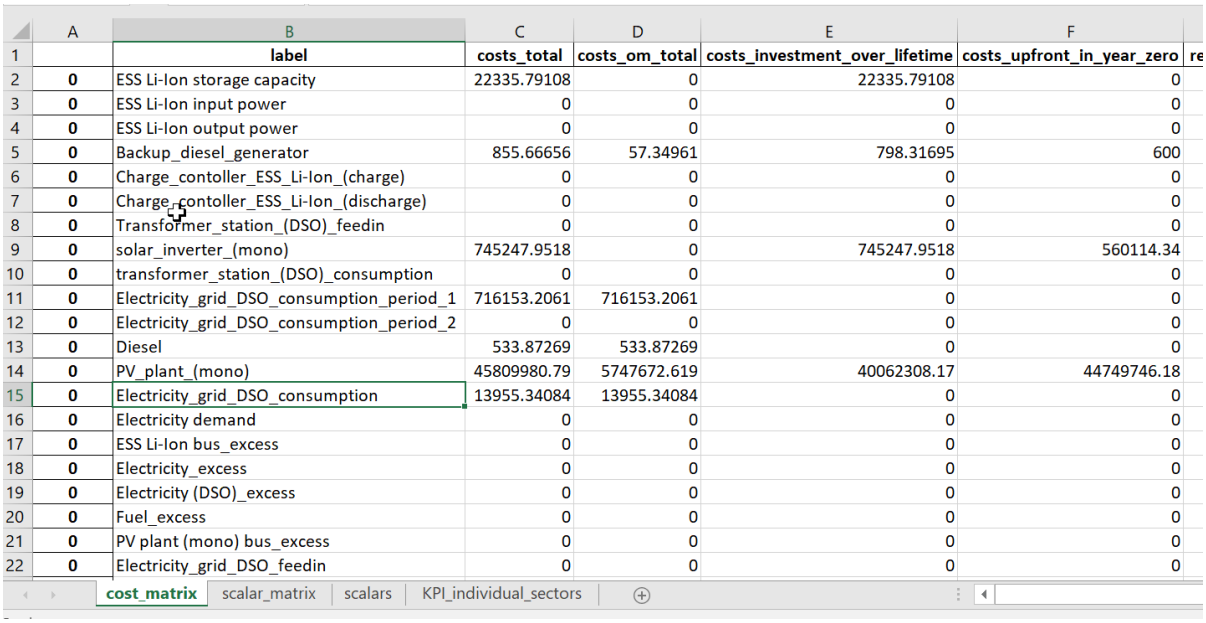
Type
Excel file

Unit
nan

Valid Interval
nan

Related indicators
None

The file is named `scalars.xlsx`. An example is shown below.



	A	B	C	D	E	F
1		label	costs_total	costs_om_total	costs_investment_over_lifetime	costs_upfront_in_year_zero
2	0	ESS Li-Ion storage capacity	22335.79108	0	22335.79108	0
3	0	ESS Li-Ion input power	0	0	0	0
4	0	ESS Li-Ion output power	0	0	0	0
5	0	Backup_diesel_generator	855.66656	57.34961	798.31695	600
6	0	Charge_contoller_ESS_Li-Ion_(charge)	0	0	0	0
7	0	Charge_contoller_ESS_Li-Ion_(discharge)	0	0	0	0
8	0	Transformer_station_(DSO)_feedin	0	0	0	0
9	0	solar_inverter_(mono)	745247.9518	0	745247.9518	560114.34
10	0	transformer_station_(DSO)_consumption	0	0	0	0
11	0	Electricity_grid_DSO_consumption_period_1	716153.2061	716153.2061	0	0
12	0	Electricity_grid_DSO_consumption_period_2	0	0	0	0
13	0	Diesel	533.87269	533.87269	0	0
14	0	PV_plant_(mono)	45809980.79	5747672.619	40062308.17	44749746.18
15	0	Electricity_grid_DSO_consumption	13955.34084	13955.34084	0	0
16	0	Electricity demand	0	0	0	0
17	0	ESS Li-Ion bus_excess	0	0	0	0
18	0	Electricity_excess	0	0	0	0
19	0	Electricity (DSO)_excess	0	0	0	0
20	0	Fuel_excess	0	0	0	0
21	0	PV plant (mono) bus_excess	0	0	0	0
22	0	Electricity_grid_DSO_feedin	0	0	0	0

cost_matrix | scalar_matrix | scalars | KPI_individual_sectors

Excel file with dispatch timeseries

Definition
Excel sheet with the dispatch of all assets of the energy system. Each tab represents one energy bus.

Type
Excel file

Unit
nan

Valid Interval
nan

Related indicators
Dispatch of an asset (flow) | *Dispatch of all assets on a bus*

The file is named `timeseries_all_busses.xlsx`. An example is shown below.

	A	B	C	D	E	F	G	H	I
1		Backup_diesel_generator	Charge_contoller_ESS_Li-Ion_(discharge)	solar_inverter_(mono)	transformer_station_(DSO)_consumption	Charge_contoller_ESS_Li-Ion_(charge)	Electricity demand	Electricity_excess	Transformer_station_(DSO)_feedin
2	2018-01-01 00:00:00	1	0	0	637	0	-638	0	0
3	2018-01-01 01:00:00	1	0	0	755	0	-756	0	0
4	2018-01-01 02:00:00	1	0	0	856	0	-857	0	0
5	2018-01-01 03:00:00	1	0	0	934	0	-935	0	0
6	2018-01-01 04:00:00	1	0	0	982	0	-983	0	0
7	2018-01-01 05:00:00	1	0	0	999	0	-1000	0	0
8	2018-01-01 06:00:00	1	0	0	982	0	-983	0	0
9	2018-01-01 07:00:00	1	0	0	934	0	-935	0	0
10	2018-01-01 08:00:00	1	0	0	856	0	-857	0	0
11	2018-01-01 09:00:00	1	0	0	755	0	-756	0	0
12	2018-01-01 10:00:00	1	0	101.83897	535.16103	0	-638	0	0
13	2018-01-01 11:00:00	1	0	186.70478	324.29522	0	-512	0	0
14	2018-01-01 12:00:00	1	0	186.70478	198.29522	0	-386	0	0
15	2018-01-01 13:00:00	1	0	101.83897	165.16103	0	-268	0	0
16	2018-01-01 14:00:00	1	0	8.4865809	157.51342	0	-167	0	0
17	2018-01-01 15:00:00	1	0	0	88.7	0	-89.7	0	0
18	2018-01-01 16:00:00	1	0	0	40	0	-41	0	0
19	2018-01-01 17:00:00	1	0	0	23.4	0	-24.4	0	0
20	2018-01-01 18:00:00	1	0	0	40	0	-41	0	0

ESS Li-Ion bus | Electricity | Electricity (DSO) | Fuel | PV plant (mono) bus | Electricity (DSO)_pdp ...

MVS logfile

Definition
Logfile of the MVS simulation including a number of log entries: Debug, information, warning and error messages. Helpful to debug the energy system simulation.

Type
Logfile

Unit
nan

Valid Interval
nan

Related indicators
None

The file is named `mvs_logfile.log`. An example is shown below.

mvs_logfile.log

```
**************************************************
2021-04-28 15:16:01,053 - INFO - logger - Path for logging: D:\PycharmProjects\mvs_eland\MVS_outputs\mvs_logfile.log
2021-04-28 15:16:01,053 - INFO - A0_initialization -

 Multi-Vector Simulation Tool (MVS) V0.5.6dev
 Version: 2021-03-04
 Part of the toolbox of H2020 project "E-LAND", Integrated multi-vector management system for Energy isLANDs
 Coded at: Reiner Lemoine Institute (Berlin)
 Reference: https://zenodo.org/record/4610237


2021-04-28 15:16:01,054 - DEBUG - cli - Accessing script: A1_csv_to_json
2021-04-28 15:16:01,054 - INFO - A1_csv_to_json - loading and converting all csv's from tests/inputs\csv_elements into one json
2021-04-28 15:16:01,054 - DEBUG - A1_csv_to_json - Loading input data from csv: constraints
2021-04-28 15:16:01,059 - DEBUG - A1_csv_to_json - From file constraints following assets are added to the energy system:
2021-04-28 15:16:01,059 - DEBUG - A1_csv_to_json - Loading input data from csv: economic_data
2021-04-28 15:16:01,062 - DEBUG - A1_csv_to_json - From file economic_data following assets are added to the energy system:
2021-04-28 15:16:01,062 - DEBUG - A1_csv_to_json - Loading input data from csv: energyBusses
2021-04-28 15:16:01,066 - DEBUG - A1_csv_to_json - From file energyBusses following assets are added to the energy system:
2021-04-28 15:16:01,066 - DEBUG - A1_csv_to_json - Loading input data from csv: energyConsumption
2021-04-28 15:16:01,068 - WARNING - A1_csv_to_json - The parameter type_asset in the file tests/inputs\csv_elements\energyConsumpt
2021-04-28 15:16:01,070 - DEBUG - A1_csv_to_json - From file energyConsumption following assets are added to the energy system:
```

Simulation report

Definition
Automatically generated simulation report, including the most important input data as well as all output data. The *html* can be browsed interactively, while the *pdf* can be shared with partners.

Type
html or pdf

Unit
nan

Valid Interval
nan

Related indicators
None

MVS has a feature to automatically *generate a PDF report* that contains the main elements from the input data as well as the simulation results' data. The report can also be viewed as a web app on the browser, which provides some interactivity.

MVS version number, the branch ID and the simulation date are provided as well in the report, under the MVS logo. A commit hash number is provided at the end of the report in order to prevent the erroneous comparing results from simulations using different versions.

It includes several tables with project data, simulation settings, the various demands supplied by the user, the various components of the system and the optimization results such as the energy flows and the costs. The report also provides several plots which help to visualize the flows and costs.

Please, refer to the *report section* for more information on how to setup and use this feature, or type

```
mvs_report -h
```

in your terminal or command line.

A screenshot of the example report header is displayed below. The full examplary report can be accessed on github in `docs/model/images/example_simulation_report.pdf`.

Information

MVS Release: 0.5.6dev (2021-03-04)

Simulation date: 2021-05-07

Simulation data after pre-processing (JSON)

Definition
This file includes all data that is used to setup the energy system model, including all the pre-processing performed within *the module C0*. It is mostly used by developers.

Type
JSON

Unit
nan

Valid Interval
nan

Related indicators
None

Simulation data and results (JSON)

Definition
This file includes all simulation data and also results of the energy system optimization. With `mvs_report` this file can be used to create a report without re-simulating the energy system. This file is also only used by developers, and also the file used to provide the EPA with the simulation results.

Type
JSON

Unit
nan

Valid Interval
nan

Related indicators
None

3.7 Validation methodology

MVS is validated using three validation methods: conceptual model validation, model verification and operational validity.

Conceptual model validation consists of looking into the underlying theories and assumptions. Therefore, the conceptual validation scheme includes a comprehensive review of the generated equations by the `oemof-solph` python library (see *Economic Dispatch* and *Energy Balance Equation*) and the *components' models*. Next step is to try and adapt them to a sector coupled *example with specific constraints*. Tracing and examining the flowchart is also considered as part of this validation type, which is presented in *Multi-vector simulator*. The aim is to assess the reasonability of the model behavior through pre-requisite knowledge; this technique is known as face validity.

Model validation is related to computer programming and looks into whether the code is a correct representation of the conceptual model. To accomplish this, static testing methods are used to validate the output with respect to an input. Unit tests and integration tests, using proof of correctness techniques, are integrated within the code. Unit tests target a single unit such as an individual component, while integration tests target more general parts such as entire modules. Both test types are implemented using `pytest` for the MVS, their evaluation is automatized and they are executed with each change of the MVS. The unit tests are further described in *Unit and integration tests*.

Operational validity assesses the model's output with respect to the required accuracy. In order to achieve that, several validation techniques are used, namely:

- **Graphical display**, which is the use of model generated or own graphs for result interpretation. Graphs are simultaneously used with other validation techniques to inspect the results. This technique was regularly applied within the MVS developing process, especially with the help of real use cases from the E-LAND pilot sites.
- **Benchmark testing**, through which scenarios are created with different constraints and component combinations, and the output is calculated and compared to the expected one to evaluate the performance of the model. The applied benchmark tests are described in *Benchmark tests*.
- **Extreme scenarios** (e.g., drastic meteorological conditions, very high costs, etc.) are created to make sure the simulation runs through and check if the output behavior is still valid by the use of graphs and qualitative analysis.
- **Comparison to other validated model**, which compares the results of a case study simulated with the model at hand to the results of a validated optimization model in order to identify the similarities and differences in results. Further information are provided in *Comparison to other models*
- **Sensitivity analysis**, through which input-output transformations are studied to show the impact of changing the values of some input parameters. An example is provided in *Sensitivity analysis verification tests*

Additionally to the presented validation tests, a couple of input verification tests are implemented in the pre-processing module `C0` and a number of output verification tests in `E4` (see *Automatic output verification*).

The validation process of the MVS was identified and defined within the master thesis *(El Mir, 2020)*. The evaluation of extreme scenarios and senstivity analysis was conducted for that thesis only, they are not repeated for each MVS release.

3.7.1 Unit and integration tests

To make sure that the MVS works correctly from a programming perspective, its functions need to be tested by unit tests, while its modules should be tested with integration tests. To automatize the testing process, the tests are implemented as `pytest` functions, which also allows to test the test coverage with `coveralls`. They also ensure that the tested existing functionalities do not cease to work properly as new code is introduced in the continuous development of MVS, as each proposed pull request must first pass all existing tests. The unit and integration tests can be found in the folder `tests` of the MVS github repository . Each of the files represent tests for one of the codebase modules (e.g., *A0*, *A1*, *B0*, etc.), and are named respectively: as such, the test file for the codebase module *C2_economic_functions* is named `test_C2_economic_functions`.

As of MVS release 0.5.5, the unit tests covered 74% of the code lines of the MVS. The *benchmark tests*, which also also include integration tests, increase this coverage to 91%.

3.7.2 Benchmark tests

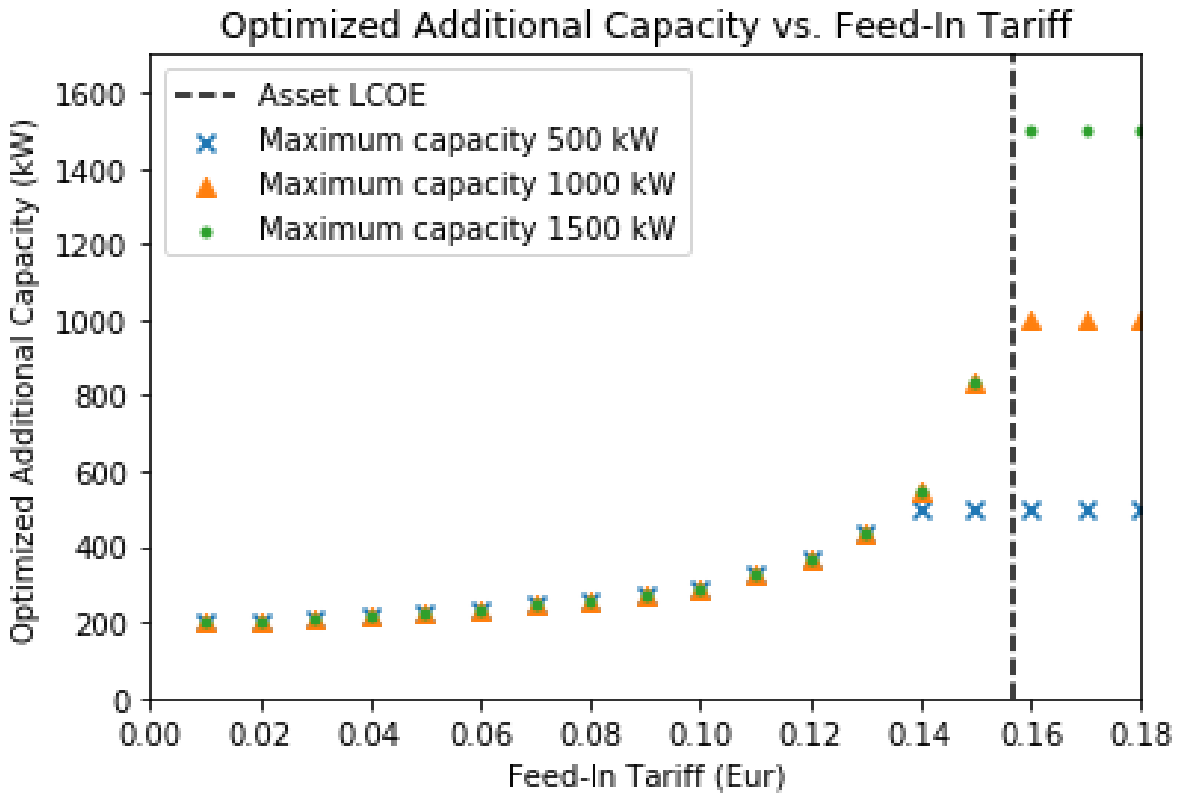
A benchmark is a point of reference against which results are compared to assess the operational validity of a model. Benchmark tests are also automated like unit and integration tests, hence it is necessary to check that they are always passing for any implemented changes in the model. A list of selected benchmark tests, which cover several features and functionalities of the MVS, are listed here below. The list is not exhaustive, some additional tests are provided in `tests`.

- **Electricity Grid + PV** (data/pytest): Maximum use of PV to serve the demand and the rest is compensated from the grid
- **Electricity Grid + PV + Battery** (data/pytest): Reduced excess energy compared to Grid + PV scenario to charge the battery
- **Electricity Grid + Diesel Generator** (data/pytest): The diesel generator is only used if its LCOE is less than the grid price
- **Electricity Grid + Battery** (data/pytest): The grid is only used to feed the load
- **Electricity Grid + Battery + Peak Demand Pricing** (data/pytest): Battery is charged at times of peak demand and used when demand is larger
- **Electricity Grid (Price as Time Series) + Heat Pump + Heat Grid** (data/pytest): Heat pump is used when electricity_price/COP is less than the heat grid price
- **Maximum emissions constraint**: Grid + PV + Diesel Generator (data: set 1, set 2, set 3/pytest): Emissions are limited by constraint, more PV is installed to reduce emissions. For RE share of 100 % in grid, more electricity from the grid is used
- **Parser** converting an energy system model from EPA to MVS (data/pytest)
- **Stratified thermal energy storage** (data/pytest): With fixed thermal losses absolute and relative reduced storage capacity only if these losses apply
- **Net zero energy (NZE) constraint**: Grid + PV and Grid + PV + Heat Pump (data set 1, set 2, set 3, set 4/pytest): Degree of NZE >= 1 when constraint is used and degree of NZE < 1 when constraint is not used.

Note: Benchmark test input data is available in the codebase folders within `tests/benchmark_test_inputs`. It can also be used as simple example cases to get to know the MVS. The benchmark test assertions are provided as `pytests` in a number of files in `tests` with the naming convention `test_benchmark_*`.

3.7.3 Sensitivity analysis verification tests

Sensitivity analysis can determine whether a model behaves as expected regarding changes of the model inputs. For the MVS, a sensitivity analysis was performed in *(El Mir, 2020, p. 54f)* regarding the effect of changing the value of the feed-in tariff (FIT), combined with an energy generation asset with constant marginal costs of generation less then the electricity price. Below graph visualizes the relation of installed PV capacity and FIT, indicating that a FIT larger then the marginal costs of generation leads to an installation of the maximum allowed capacity (`maximumCap`):



The graph underlines the use of the graphical displays validation technique for model verification. It is not an automatized output of the MVS, but indicates that such tests would also be appropriate to translate into benchmark tests.

Other input-output transformations that could be used for sensitivity analysis tests are:

- **Fuel price or generator efficiency variation** around a point where the fuel price or generator efficiency is equal to electricity price or transformer efficiency of the electricity grid.
- **Peak demand price variation** around a point where generator dispatch could avoid consumption from the grid at times of peak demand, thus avoiding peak demand pricing expenditures

3.7.4 Comparison to other models

A comparison of the results of different models regarding an identical reference system is a validation method that is commonly used. However, one model cannot absolutely validate another model or claim that one is better than the other. This is why the focus should rather be on testing the correctness, appropriateness and accuracy of a model vis-à-vis its purpose. Since the MVS is an open source tool, it is important to use a validated model for comparison, but also similar open source tools like urbs and Calliope for instance. The following two articles list some of the models that could be used for comparison to the MVS: *(Ringkjøb, 2018)* and *(Bloess, 2017)*. A thorough comparison to other models able to perform optimizations for sector-coupled energy systems is something that should be performed in the future.

So far, the MVS has been compared to HOMER for a sector coupled energy system combining electricity and hydrogen sectors. This comparison was able to highlight the similarities and differences between the two optimization models. On the electricity side, most of the values are comparable and within the same range. The differences mainly arise on the hydrogen part in terms of investment into electrolyzer capacity, i.e. the component linking the two sectors, as well as related values. The calculation of the levelized cost of a certain energy carrier appear very different, which, however, was expected due to the *energy carrier weighting approach*: Using this, the costs of the energy system are attributed to the different energy sectors based on their respective share of the total electricity equivalent demand (compare *Costs attributed to a specific sector (attributed_costs)*, *Levelized costs of electricity equivalent (levelized_costs_of_electricity_equivalent)*), whereas Homer is likely to assign the costs of the assets based on their output energy carrier. Details regarding the comparison drawn between the two models can be found in *(El Mir, 2020, p. 55ff)*.

3.7.5 Automatic output verification

In addition to the aforementioned validation tests, a couple of verification tests are implemented. They serve as a safeguard against issues that indicate noteworthy misbehaviour of the model, and are tested with each MVS execution. Some of the issues are fatal issues that the users need to be protected against, others indicate possible unrealistic system optimization (and input) results. The tests are provided in the MVS codebase module `E4_verification`.

Following test serves as an alert to the energy system modeler to check their inputs again:

- **Excessive excess generation**: Certain combinations of inputs can lead to excessive excess generation on a bus, for example if PV panels itself are very cheap compared to electricity input, while inverter capacity is very expensive. The test `E4.detect_excessive_excess_generation_in_bus` notifies to user of optimal but overly high excess generation of a bus within the energy system. Excess generation is defined to be excessive, if the ratio of total outflows to total inflows is less than 90%. The test is applied to each bus individually. The user should check the inputs again and potentially define a `maximumCap` for the generation asset at the root of the problem.

Following tests ensure that introduced constraints where applied correctly:

- **Adherence to maximum emissions constraint**: With the *maximum emission constraint* the user can define the maximum allowed emissions in the energy mix of the optimized energy system. The test `E4.maximum_emissions_test` runs a verifies that the constraint is adhered to.
- **Adherence to minimal renewable share constraint**: Test `E4.minimal_renewable_share_test` makes sure that the user-defined constraint of the *minimal share of renewables* in the energy mix of the optimized system is respected.
- **Adherence to net zero energy constraint**: If the user activated the *net zero energy constraint*, the test `E4.net_zero_energy_constraint_test` makes sure that the optimized energy system adheres to it.
- **Adherence to realistic SOC values**: Test `E4.verify_state_of_charge` makes sure that the timeseries of the state of charge (SOC) values for storages in the energy system simulation results are within the valid interval of $[0, 1]$. A SOC value out of bounds is physically not feasible, but can occurr when the optimized storage capacity is so marginal that it is in the range of the *precision limit* of the MVS.

Note: If there is an `ERROR` displayed in the log file (or the automatic report), the user should follow the instructions of the error message. Some will require the user to check and adapt their input data, others will indicate serious misbehaviour. A `WARNING` in the log file (or the automatic report) is important information about the perfomed system optimization which the user should be aware of.

3.8 E-LAND requirements of the MVS

3.8.1 Functional Requirements

FUN-MVS-01 - Solving an energy system optimization model

Description
The MVS shall solve an energy system planning optimization problem and provide the optimal sizing of individual assets.

Rationale
Basic operation of MVS.

Priority
HIGH

Progress
Done

Progress message

The MVS can solve energy system planning optimization problems and identify the optimal additional capacities of chosen assets. In-code validation checks, unit tests and benchmark tests were added to ensure that the simulation runs smoothly and correctly.

Notes

As with all simulation tools, there are always possibilities to improve the tool, specifically to address current limitations (comp. *Limitations*).

FUN-MVS-02 - Automatic setting up of an energy system optimization model

Description
The MVS should accept modelling parameters regarding the LES in a specific format.

Rationale
Currently MVS supports the Oemof model. The rationale is to support external entities or users with no experience in Oemof, by automatically generating the respective Oemof model for the agreed format

Priority
HIGH

Progress
Done

Progress message

The MVS accepts simulation data provided as csv files and automatically sets up an energy system. It also supports the integration into the Energy Planning Application (EPA) by providing a parser for the interfaces of the two tools.

FUN-MVS-03 - Manual setting up an energy system optimization model

Description
The MVS shall support adding specific components/constraints from a set of options to an energy system optimization model.

Rationale
Basic operation of MVS

Priority
LOW

Progress
Done

Progress message

It is possible to add as many components as needed to the energy model that is to be simulated with the MVS. They can be divided into following asset types:

- *Energy providers*
- *Energy production*
- *Energy consumption*
- *Energy conversion*
- *Energy storage*

Details on how to model different assets are included in the model assumptions (see *Component models*).

Notes

Energy excess sinks are automatically added by the MVS to enable energy system optimization and do not have to be added by the energy system planners.

In the future, it may be possible to add energy shortage sources, which would allow energy systems with a defined annual supply shortage. While this mostly will not result in an energy system many operators would require, it would also have benefits for the debugging of energy systems, as infeasible energy systems would be easier to evaluate and specific debug messages could be displayed.

FUN-MVS-04 - Optimisation Results

Description
The MVS shall provide the results of the optimisation process upon completion of calculation in a specific format, which include at least information related to asset costs (CAPEX and OPEX), sizes, as well as aggregated energy flows and overall system performance (autonomy, renewable share, losses).

Rationale
Basic operation of MVS.

Priority
HIGH

Progress
Done

Progress message

The results of the MVS simulation are post-processed, and result in numberous key performance indicators (KPI). Following information is calculated for an economic evaluation of the energy system:

- Capital and operational expenditures (capex, opex) per asset, both as annuities as well as present costs. This includes also the first-time investment costs (FIC), the replacement costs minus residual values, and the costs for asset dispatch (equations compare *Economic Dispatch*).
- *NPC* and annuity of the whole energy system
- *Levelized cost of energy (LCOE)* of the energy system, in electricity equivalent
- *Levelized cost of an energy carrier* in electricity equivalent (LCOEleq) for each energy carrier in the energy system
- *Levelized cost of asset dispatch*, calculated from the annuity of an asset and their throughput

Additionaly, a number of technical parameters are calculated both the energy system and the individual energy vectors:

- Dispatch, *aggregated energy flows* as well as *peak flows* of each asset
- *Renewable share*
- *Renewable share of local generation*
- *Degree of autonomy*
- *Degree of net zero energy*
- *Onsite Energy Matching (OEM)*
- *Onsite Energy Fraction (OEF)*
- Annual excess energy
- *Annual GHGeq emissions* and specific emissions per electricity equivalent

Notes

Currently in discussion is the implementation of a so-called *degree of sector-coupling* (see issue 702). This is a novel key performance indicator and would be integrated in addition to above mentioned parameters.

FUN-MVS-05 - Production Assets

Description
The MVS should consider a diverse type of production assets in the energy model i.e. PV, BESS, CHP, Thermal Storage

Rationale
Enable support of multi-vector production and storage assets.

Priority
HIGH

Progress
In-progress

Progress message

The MVS is able to simulate a wide range of assets:

- *PV plants, wind plants*
- *Battery Electricity Storage Systems (BESS)*, via generic storage object
- *Thermal storages*, via generic or thermal storage object
- *Power plants* as simple generators.
- And many more (see below)

ToDo

A CHP with fix ratio between the heat and electricity output can already be simulated, but has not been tested. For a CHP with a variable ration between those two outputs, we need to add the specific CHP asset to the possible inputs.

FUN-MVS-06 - Assets of Energy Conversion

Description
The MVS should consider assets which convert energy from one vector to another i.e. CHP, geothermal conversion (heat pump)

Rationale
Integration of the multi-vector approach in the MVS.

Priority
LOW

Progress
Done

Progress message

The MVS already covers generic conversion assets. How the generic definition can be applied to the individual assets is explained *here*. This includes

- *Electric transformers*
- *Power plants (Condensing power plants and Combined heat and power)*
- *Heat pumps and Heating, Ventilation, and Air Conditioning (HVAC) assets*
- *Electrolyzers*

ToDo

A CHP with a variable share of heat and electricity output is currently not implemented. It could be added as a new oemof asset type.

When using two conversion objects to emulate a bidirectional conversion assets (eg. charge controllers, bi-directional inverters), their capacity should be interdependent. This is currently not the case, as explained in the *limitations*.

FUN-MVS-07 - Optimisation goal

Description
The optimisation process should take into account: Increasing the degree of autonomy of the LES, system costs minimization, and CO2 emissions reduction. Optional extension of the MVS is to allow for multi-objective optimisation.

Rationale
Different optimisation goal shall be supported for covering the different perspectives of the possible end-users.

Priority
HIGH

Progress
Done

Progress message

In general, the MVS aims to minimize the energy supply cost of the local energy system. Additionally, a number of *constraints* can be activated:

- *Minimal renewable share constraint*
- *Minimal degree of autonomy*
- *Maximum GHG emission constraint*
- *Net zero energy constraint*
- *Limited maximum capacities of assets to be optimized*

FUN-MVS-08 - Electricity cost model

Description
The MVS model shall be provided with data defining electricity grid supply regarding: a) kWh prices (both import and export from/to the grid), b) kWh/h prices (time series of prices), c) Constraints of the interconnection with the main grid (e.g. substation capacity)

Rationale
Information necessary for building the MVS Multi-vector Model.

Priority
HIGH

Progress
Done

Progress message

The different constraints regarding the electricity DSO can be considered:

a) The energy price as well as the feed-in tariff of a DSO can be provided as a time series (see *Time series: time_series folder*)

b) *Peak demand pricing* can be considered

c) The transformer station limitation can, but does not have to, be added.

FUN-MVS-09 - Load profiles

Description
The MVS model shall be provided with annual electric/thermal demand profiles (hourly values) for each load in the LES.

Rationale
Information necessary for building the MVS Multi-vector Model.

Priority
HIGH

Progress
Done

Progress message

The MVS can be provided with a variable number of energy consumption profiles, that can be connected to variable busses. Details on how this works can be found in *these instructions*.

FUN-MVS-10 - DH cost model

Description
For calculations involving district heating, the MVS model shall support data on thermal distribution network supply, concerning: a) kWh prices (both import and export from/to the grid), b) kWh/h prices (time series of prices), c) optional: thermal power cap (e.g. maximum allowable feed-in per day)

Rationale
Information necessary for building the MVS Multi-vector Model.

Priority
HIGH

Progress
Done

Progress message
Same as for *FUN-MVS-08 - Electricity cost model*.

FUN-MVS-11 - PV data

Description
For calculations involving PV assets, the MVS model shall be provided with data on PV assets: a) At minimum: Precise location (latitude and longitude), b) Optionally: performance indicators for new PV systems (efficiency - constant or time series, module technology, performance ratio), historical/tracked data (energy generated by existing PV systems, weather data), Inverter efficiency

Rationale
Information necessary for building the MVS Multi-vector Model.

Priority
HIGH

Progress
Done for option (b), no automization (minimal requirement met)

Progress message

To simulate a PV plant, the MVS model requires following data from the end-user:

- (Historical) Specific PV generation profile (in kWh/kWp)
- Inverter efficiencies can be considered with an additional energyConversion asset

ToDo

To ease the data input for the end-user, more processing could be included here (option a)). For example, the `feedinlib` could be used to fetch the specific PV generation profiles with following data:

- Longitude and latitude
- Module or efficiency
- Performance ratio

This could also be implemented in the EPA.

FUN-MVS-12 - Battery data

Description
For calculations involving battery assets, the MVS model shall be provided with data on Battery Energy Storage Systems (BESS): a) Battery type (e.g. lead-acid, lithium ion) b. Technical parameters: C-rate, max and min state of charge (SOC), max. depth of discharge (DOD), roundtrip efficiency (constant or time series), c. Inverter efficiency (optional), d. historical/tracked data from existing BESS

Rationale
Information necessary for building the MVS Multi-vector Model.

Priority
HIGH

Progress
Done for option (b), no default inputs, no historical data (minimal requirement met)

Progress message

For the MVS, the type of the BESS does not matter. Important are the technical parameters:

- *C-rate*
- *Maximum* and *minimum* state of charge (SOC), whereas the latter is inverse to the maximum depth of discharge (DOD)
- Charge- and discharge (constant or time series, equivalent to roundtrip-efficiency) as well as self-discharge rate (comp. *efficiency*)
- It is possible to define *soc_initial*, the initial storage charge at the beginning of the optimization period, which is most important for short-term optimizations.
- An inverter or charge controller can be defined by defining an additional energyConversion asset

Notes

It may be preferrable for the end-users to have default input values for different battery types (option a)), which is not implemented. This would best be addressed in the EPA with a database of default values, but is currently not being discussed.

Historical dispatch data of batteries is not considered, as the MVS is supposed to determine the optimal dispatch rather then only the performance of a current energy system with determined operational schedules.

FUN-MVS-13 - CHP data

Description
For calculations involving CHP assets, the MVS model shall be provided with efficiency factors (electric/thermal)

Rationale
Information necessary for building the MVS Multi-Vector Model.

Priority
LOW

Progress
In progress (minimal requirement met)

Progress message

A simple CHP model is already included in the MVS (compare *Condensing power plants and Combined heat and power (CHP)*). It considers a fix ratio between thermal and electric output.

ToDo

For a variable ratio between heat and electricity output, a new, specific oemof asset would need to be added to the MVS.

FUN-MVS-14 - Thermal storage data

Description
For calculations involving Thermal Storage assets, the MVS model shall be provided with: a) Charging and discharging efficiencies, b. Max/Min SOC, initial SOC

Rationale
Information necessary for building the MVS Multi-Vector Model.

Priority
LOW

Progress
Done

Progress message

It is possible to simulate thermal storage assets with the MVS. Their model is analogous to the BESS, which fulfills the requirement. They are defined by:

- *C-rate*
- *Maximum* and *minimum* state of charge (SOC)
- Charge- and discharge (constant or time series, equivalent to roundtrip-efficiency) as well as self-discharge rate (comp. *efficiency*)
- It is possible to define *soc_initial*, the initial storage charge at the beginning of the optimization period, which is most immportant for short-term optimizations.

Adding another level of detail, it is possible to model a *Stratified thermal energy storage*, with additional parameters *fixed_thermal_losses_relative* and *fixed_thermal_losses_absolute*.

FUN-MVS-15 - Autonomous operation data

Description
The MVS model shall be provided with information on the autonomous operation of the LES i.e. minimum/maximum time of autonomy for specific time intervals.

Rationale
Information necessary for building the MVS Multi-vector Model

Priority
HIGH

Progress
Done

Progress message

This requirement is addressed by the *degree of autonomy constraint*. It is related to the aggregated demand of the energy system and the required consumption from the grid (comp. *DOA*), and not minimum or maximum time of autonomous operation.

Notes

A constraint of time-related autonomous operation is not possible in the current MVS, as it would introduced a mixed-integer constraint, which would extend simulation times too much. It would be possible in the future to add KPI that quantify the behaviour.

FUN-MVS-16 - Economic data

Description
The MVS model shall be provided with information on economic assumptions per asset: CAPEX/kW and OPEX/kWh (constant or time series), lifetime (years), Weighted Average Cost of Capital (WACC).

Rationale
Information necessary for building the Multi-vector Model.

Priority
HIGH

Progress
Done

Progress message

The MVS receives economic data from the end-user. This includes:

- *Specific investment costs of assets (CAPEX/kW)*
- *Dispatch price of assets*
- *Specific annual operation and management costs (OPEX/kWh, constant or time series))*
- *Currency*
- *Tax*
- *Weighted Average Cost of Capital (WACC)*
- *Lifetime of the project*
- *Liftetime of assets*

FUN-MVS-17 - Constraints

Description
The MVS model shall be provided with constraints of the optimisation problem: a) Operating reserve provided by the battery (i.e. redundancy, availability), b. Sizing constraints, c. Cost constraints

Rationale
Information necessary for building the Multi-vector Model.

Priority
HIGH

Progress
In progress

Progress message

To address the sizing constraint, the attribute `maximumCap` was introduced. This will limit the optimized capacity, even if this results in higher energy supply costs.

A cost constraint is for now disregarded, as always the cheapest supply solution is identified. Limiting the overall NPC would result in infeasible solutions and a termination of the MVS. Cost constraints considering specific technologies can be covered by adapting the `maximumCap`.

ToDo

It was decided at the beginning of the project that the operating reserve constraint may be developed in cooperation with the end-users. This constraint would still need to be defined with the stakeholders.

3.8.2 Non-Functional Requirements

NF-MVS-01 - MVS pre-processing tools for LES optimization model input

Description
The MVS should support Python-Pandas DataFrames as parameterization input for the LES model

Scope
Interface, Usability

Metric
Y/N

Verification and Measurement
The requirement is validated by observing the system under test when an operator attempts to input/modify the model parameters.

Target
User can adjust input parameters without any further support

Progress
Done

Progress message

Internally, the MVS uses dictionaries (*dict*) in combination with pandas (*pd.DataFrame*) to set up the energy system model. However, for data exchange with the end-user the input files, ie. the csv or json file is essential. To be able to use all features of the MVS, the user should consider the terminal-based MVS with csv input files. For a more comfortable and interactive usage, the end user can use the MVS though the user interface of the Energy Planning Application (EPA). Here, the data format becomes irrelevant for the user.

NF-MVS-02 - MVS post-processing tools for LES optimization model output/results

Description
The MVS should provide results aggregation, reports, and plots

Scope
User Interface, Usability

Metric
Y/N

Verification and Measurement
The requirement is validated by observing the system under test when an operator attempts to access the output results.

Target
User can extract the results in a way that can be directly used for the users purpose

Progress
Done

Progress message

The post-processing of results ensures that important KPI can be provided for the energy system optimization. There are three output formats of the MVS:

- For the end-user of the standalone application, an *automatic report* is generated that makes scenario evaluation easy
- For a developer of the standalone application, the results are also provided as excel files and pngs
- For the EPA, the results are provided in a json format to be displayed interactively in their environment

Notes

Improving the outputs is a continuing task. Following improvements can be considered in the future:

- Move all KPI connected to the individual energy vectors into a seperate table and display in the report
- Add-on requested by end-users: Cash flow projections

NF-MVS-03 - Communication interface between MVS and ESB

Description
Communication functionality must be included so that ESB can send requests to MVS and vice versa. This assures that all requests can be coordinated through one platform (e.g. ESB).

Scope
User Interface, Usability

Metric
Y/N

Verification and Measurement
Send a set of different requests from ESB to MVS and count received requests. Do vice versa.

Target
Send/receive requests that can be processed without information loss

Progress
Done

Progress message

After discussion, there is no direct interface of the ESB and the MVS. The MVS is a standalone application that must be usable without the ESB. To ease end-user use, the EPA (Energy Planning Application) is developed. It sends inputs in json format to the MVS, and receives a json file with the results back. Parsers are coded to allow a translation of the different formats of the MVS and the EPA.

Notes

The EPA development is a continuous process, and currently the MVS has more features than the EPA. Mainly, the EPA does not feature:

- Any constraints of the MVS
- GHG emission calculation
- Set of energy assets of different energy vectors (as EPA explicitly names the assets)

NF-MVS-04 - Unit commitment time step restriction

Description
Energy flows between selected components (Unit commitment) are simulated in hourly timesteps.

Scope
Performance

Metric
Timestamps

Verification and Measurement
Subtract 2-time steps.

Target
Timestep width of 1 hour

Progress
Done

Progress message
The MVS can be run for a variable number of days. The time series have to be provided on an hourly basis.

Notes
A wish from the end-users war a finer resolution of eg. 15-minute time steps. This possibility still has to be explored.

NF-MVS-05 - Interface for technical parameters and model

Description
Technical parameters are reflected in component modelling

Scope
Performance

Metric
Technical variable in energy system model object

Verification and Measurement
Technical variable in ESM object being not NAN.

Target
N/A

Progress
Done

Progress message
The MVS uses the input parameters to compile the component models. This is also tested using pytests and benchmark tests.

NF-MVS-06 - Interface for economic parameters and model

Description
Cost parameters are reflected in component modelling

Scope
Interface

Metric
Cost variable in energy system model object

Verification and Measurement
Cost variable in ESM object being not NAN.

Target
N/A

Progress
Done

Progress message

The MVS uses the input parameters to compile the component models. This is also tested using pytests and benchmark tests.

CHAPTER

FOUR

API REFERENCE

- **Documentation**: *Modules and functions*
- **Getting involved**: *Contributing guidelines and protocols*
- **Academic references**: *Publications and Bibliography*
- **Using or modifying MVS**: *License* | *How to cite MVS*
- **Getting help**: *Know issues and workaround* | *Report a bug or issue*

4.1 Code documentation

4.1.1 Util functions

Module data_parser

This module defines all functions to convert formats between EPA and MVS - Define similar parameters mapping between the EPA and MVS in MAP_EPA_MVS and MAP_MVS_EPA - Define which fields are expected in asset list of EPA for various assets' groups in EPA_ASSET_KEYS - Convert MVS to EPA - Convert EPA to MVS

`multi_vector_simulator.utils.data_parser.`**`convert_epa_params_to_mvs`**`(`*epa_dict*`)`

Convert the EPA output parameters to MVS input parameters

Parameters
epa_dict (*dict*) – parameters from EPA user interface

Returns
dict_values – MVS json file, generated from EPA inputs, to be provided as MVS input

Return type
dict

Notes

- **For *simulation_settings*:**
  - parameter *TIMESTEP* is parsed as unit-value pair
  - *OUTPUT_LP_FILE* is set to *False* by default
- For *project_data*: parameter *SCENARIO_DESCRIPTION* is defined as placeholder string.
- *fix_cost* is not required, default value will be set if it is not provided.

- **For missing asset group *CONSTRAINTS* following parameters are added:**
  - MINIMAL_RENEWABLE_FACTOR: 0
  - MAXIMUM_EMISSIONS: None
  - MINIMAL_DEGREE_OF_AUTONOMY: 0
  - NET_ZERO_ENERGY: False
- ***ENERGY_STORAGE* assets:**
  - Optimize cap written to main asset and removed from subassets
  - Units defined automatically (assumed: electricity system)
  - *SOC_INITIAL*: None
  - *THERM_LOSSES_REL*: 0
  - *THERM_LOSSES_ABS*: 0
- If *TIMESERIES* parameter in asset dictionary: Redefine unit, value and label.
- ***ENERGY_PROVIDERS*:**
  - Auto-define unit as kWh(el)
  - *INFLOW_DIRECTION=OUTFLOW_DIRECTION*
  - Default value for *EMISSION_FACTOR* added
- ***ENERGY_CONSUMPTION*:**
  - *DSM* is *False*
  - *DISPATCHABILITY* is FALSE
- ***ENERGY_PRODUCTION*:**
  - Default value for *EMISSION_FACTOR* added
  - *DISPATCHABILITY* is always *False*, as no dispatchable fuel assets possible right now. Must be tackeld by EPA.

multi_vector_simulator.utils.data_parser.**convert_mvs_params_to_epa**(*mvs_dict*, *verbatim=False*)

Convert the MVS output parameters to EPA format

Parameters
mvs_dict (*dict*) – output parameters from MVS

Returns
epa_dict – epa parameters

Return type
dict

Helper functions

Util functions that are useful throughout the MVS

Including: - find_valvue_by_key(): Finds value of a key in a nested dictionary.

multi_vector_simulator.utils.helpers.**find_value_by_key**(*data*, *target*, *result=None*)

Finds value of a key in a nested dictionary.

Parameters

- **data** (*dict*) – Dict to be searched for target key
- **target** (*str*) – Key for which the value should be found in data
- **result** (*None, value or list*) – Only provided if function loops in itself

Returns

- *value if the key is only once in data*
- *list of values if it appears multiple times.*

multi_vector_simulator.utils.helpers.**get_asset_types**(*dict_values*)

Function which returns records of assets in the energy system

multi_vector_simulator.utils.helpers.**get_item_if_list**(*list_or_float*, *index*)

multi_vector_simulator.utils.helpers.**get_length_if_list**(*list_or_float*)

multi_vector_simulator.utils.helpers.**peak_demand_bus_name**(*dso_name: str*, *feedin: bool = False*)

Name for auto created bus related to peak demand pricing period

multi_vector_simulator.utils.helpers.**peak_demand_transformer_name**(*dso_name: str*, *peak_number: int | None = None*, *feedin: bool = False*)

Name for auto created bus related to peak demand pricing period

multi_vector_simulator.utils.helpers.**reducable_demand_name**(*demand_name: str*, *critical: bool = False*)

Name for auto created bus related to peak demand pricing period

multi_vector_simulator.utils.helpers.**translates_epa_strings_to_mvs_readable**(*folder_name*, *file_name*)

This function translates the json file generated by the EPA to a file readable by the MVS. This is necessary as there are some parameter names whose string representative differs in both tools.

Parameters

- **folder_name** (*path*) – Path to the folder with the json file
- **file_name** (*json file name with extension*) – Json to be converted

Returns

- *Stores converted json file to current dict*
- *Usage – import multi_vector_simulator.utils.helpers as helpers helpers.translates_epa_strings_to_mvs_readable("./epa_benchmark", "epa_benchmark.json-original")*

4.1.2 Initialization

Module A0 - Initialization

Module A0_initialization defines functions to parse user inputs to the MVS simulation.

- Display welcome message with current version number
- Parse command line arguments and set default values for MVS parameters if not provided
- Check that all necessary files and folder exist
- Create output directory
- Define screen logging depth

Usage from root of repository:

```
python mvs_tool.py [-h] [-i [PATH_INPUT_FOLDER]] [-ext [{json,csv}]] [-o [PATH_OUTPUT_
↪FOLDER]]
[-log [{debug,info,error,warning}]] [-f [OVERWRITE]] [-pdf [PDF_REPORT]] [-png [SAVE_
↪PNG]]
```

Usage when multi-vector-simulator is installed as a package:

```
mvs_tool [-h] [-i [PATH_INPUT_FOLDER]] [-ext [{json,csv}]] [-o [PATH_OUTPUT_FOLDER]]
[-log [{debug,info,error,warning}]] [-f [OVERWRITE]] [-pdf [PDF_REPORT]] [-png [SAVE_
↪PNG]]
```

Process MVS arguments

optional arguments:

-h, --help show this help message and exit

-i [PATH_INPUT_FOLDER]
path to the input folder

-ext [{json,csv}]
type (json or csv) of the input files (default: 'json')

-o [PATH_OUTPUT_FOLDER]
path to the output folder for the simulation's results

-log [{debug,info,error,warning}]
level of logging in the console

-f [OVERWRITE]
overwrite the output folder if True (default: False)

-pdf [PDF_REPORT]
generate a pdf report of the simulation if True (default: False)

-png [SAVE_PNG]
generate png figures of the simulation in the output_folder if True (default: False)

multi_vector_simulator.A0_initialization.**check_input_folder**(*path_input_folder*, *input_type*)

Enforces the rules for the input folder and files

There should be a single json file for config (described under JSON_FNAME) in case input_type is equal to JSON_EXT. There should be a folder with csv files (name of folder given by CSV_ELEMENTS) in case input_type is equal to CSV_EXT.

Parameters

- **path_input_folder** – path to input folder
- **input_type** – of of JSON_EXT or CSV_EXT

Returns
the json filename which will be used as input of the simulation

multi_vector_simulator.A0_initialization.**check_output_folder**(*path_input_folder*, *path_output_folder*, *overwrite*)

Enforces the rules for the output folder

An error is raised if the path_output_folder already exists, unless overwrite is set to True. The path_output_folder is created if not existing and the content of path_input_folder is copied in a folder named INPUTS_COPY.

Parameters

- **path_input_folder** – path to input folder
- **path_output_folder** – path to output folder
- **overwrite** – boolean indicating what to do if the output folder exists already

Returns
the path to the folder stored in the output folder as copy of the input folder

multi_vector_simulator.A0_initialization.**mvs_arg_parser**()

Create a command line argument parser for MVS

Usage from root of repository:

```
python mvs_tool.py [-h] [-i [PATH_INPUT_FOLDER]] [-ext [{json,csv}]] [-o [PATH_
↪OUTPUT_FOLDER]]
[-log [{debug,info,error,warning}]] [-f [OVERWRITE]] [-pdf [PDF_REPORT]] [-png␣
↪[SAVE_PNG]]
[--version]
```

Usage when multi-vector-simulator is installed as a package:

```
mvs_tool [-h] [-i [PATH_INPUT_FOLDER]] [-ext [{json,csv}]] [-o [PATH_OUTPUT_FOLDER]]
[-log [{debug,info,error,warning}]] [-f [OVERWRITE]] [-pdf [PDF_REPORT]] [-png␣
↪[SAVE_PNG]]
[--version]
```

Process MVS arguments

optional arguments:

-h, --help show this help message and exit

-i [PATH_INPUT_FOLDER]
path to the input folder

-ext [{json,csv}]
type (json or csv) of the input files (default: 'json')

-o [PATH_OUTPUT_FOLDER]
path to the output folder for the simulation's results

-log [{debug,info,error,warning}]
level of logging in the console

-f [OVERWRITE]
overwrite the output folder if True (default: False)

-pdf [PDF_REPORT]
generate a pdf report of the simulation if True (default: False)

-png [SAVE_PNG]
generate png figures of the simulation in the output_folder if True (default: False)

--version show program's version number and exit

Returns
parser

multi_vector_simulator.A0_initialization.**process_user_arguments**(*path_input_folder=None*, *input_type=None*, *path_output_folder=None*, *overwrite=None*, *pdf_report=None*, *display_output=None*, *save_png=None*, *lp_file_output=False*, *welcome_text=None*)

Process user command from terminal inputs. If inputs provided as arguments of the function, they will overwrite the command line arguments.

Parameters

- **path_input_folder** – Describes path to inputs folder (command line "-i")
- **input_type** – Describes type of input to expect (command line "-ext")
- **path_output_folder** – Describes path to folder to be used for terminal output (command line "-o") Must not exist before
- **overwrite** – (Optional) Can force tool to replace existing output folder (command line "-f")
- **pdf_report** – (Optional) Can generate an automatic pdf report of the simulation's results (Command line "-pdf")
- **save_png** – (Optional) Can generate png figures with the simulation's results (Command line "-png")
- **display_output** – (Optional) Determines which messages are used for terminal output (command line "-log") Allowed values are "debug": All logging messages, "info": All informative messages and warnings (default), "warning": All warnings, "error": Only errors,
- **lp_file_output** – Save linear equation system generated as lp file
- **welcome_text** – Text to be displayed

Returns
a dict with these arguments as keys (except welcome_text which is replaced by label)

multi_vector_simulator.A0_initialization.**report_arg_parser**()

Create a command line argument parser for MVS

Usage when multi-vector-simulator is installed as a package:

```
mvs_report [-h] [-i [PATH_SIM_OUTPUT]] [-o [REPORT_PATH]] [-pdf]
```

Process mvs report command line arguments

optional arguments:

-h, --help show this help message and exit

-pdf [PRINT_REPORT]
print the report as pdf (default: False)

-i [OUTPUT_FOLDER]
path to the simulation result json file 'json_with_results.json'

-o [REPORT_PATH]
path to save the pdf report

Returns
parser

Module A1 - Csv to json

Convert csv files to json file as input for the simulation.

The default input csv files are stored in "/inputs/elements/csv". Otherwise their path is provided by the user.

The user can change parameters of the simulation of of the energy system in the csv files.

Storage: The "energyStorage.csv" contains information about all storages. For each storage there needs to be another file named exactly after each storage-column in the "energyStorage.csv" file. For the default file this is "storage_01", "storage_02" etc. Please stick to this convention.

The function "create_input_json()" reads all csv files that are stored in the given input folder (input_directory) and creates one json input file for mvs_tool.

Functions of this module (that need to be tested) - read all necessary input files (*REQUIRED_CSV_FILES*) from input folder - display error message if *CSV_FNAME* already in input folder - read all parameters in from csv files - parse parameter that is given as a timeseries with input file name and header - parse parameter that is given as a list

- check that parameter that is given as a list results and subsequent other parameters to be given as list e.g. if we have two output flows in conversion assets there should be two efficiencies to operational costs (this is not implemented in code yet)
- only necessary parameters should be transferred to json dict, error message with additonal parameters
- parse data from csv according to intended types - string, boolean, float, int, dict, list!

multi_vector_simulator.A1_csv_to_json.**add_storage_components**(*storage_filename*, *input_directory*, *storage_label*)

Creates json dict from storage csv.

Loads the csv of a the specific storage listed as column in "energyStorage.csv", checks for complete set of parameters, adds a label and creates a json dictionary.

Parameters

- **storage_filename** (*str*) – file name excl. extension, given by the parameter 'file_name` in "energyStorage.csv
- **input_directory** (*str*) – path to the input directory where *storage_filename* is located

- **storage_label** (*str*) – Label of storage

Notes

Tested with: - test_add_storage_components_label_correctly_added()

Returns
dictionary containing the storage parameters

Return type
dict

multi_vector_simulator.A1_csv_to_json.**check_storage_file_is_csv**(*storage_file*)

Checks that the storage file name defined in *energyStorage.csv* has ending *.csv*.

Parameters
storage_file (*str*) – Defined storage file name

Returns

- **If test fails** (*MissingCsvEndingError(ValueError), else:*)
- **storage_file** (*str*) – Storage file name without ending '.csv'

multi_vector_simulator.A1_csv_to_json.**conversion**(*value*, *asset_dict*, *row*, *param*, *asset*, *filename=''*)

This function converts the input given in the csv to the dict used in the MVS.

When using json files, they are already provided parsed like this functions output.

Parameters

- **value** (*Misc.*) – Value to be parsed
- **asset_dict** (*dict*) – Dict of asset that is to be filled with data
- **row**
- **param** (*str*) – Parameter that is currently parsed
- **asset**
- **filename**

multi_vector_simulator.A1_csv_to_json.**create_input_json**(*input_directory*, *pass_back=True*)

Convert csv files to json file as input for the simulation.

Looks at all csv-files in *input_directory* and compile the information they contain into a json file. The json file is then saved within the *input_directory* with the filename *CSV_FNAME*. While reading the csv files, it is checked, whether all required parameters for each component are provided. Missing parameters will return a warning message.

Parameters

- **input_directory** – path of the directory where the input csv files can be found
- **str** – path of the directory where the input csv files can be found
- **pass_back** – if True the final json dict is returned. Otherwise it is only saved
- **bool** – if True the final json dict is returned. Otherwise it is only saved
- **optional** – if True the final json dict is returned. Otherwise it is only saved

Return type
None or dict

multi_vector_simulator.A1_csv_to_json.**create_json_from_csv**(*input_directory*, *filename*, *parameters=None*, *asset_is_a_storage=False*)

One csv file is loaded and it's parameters are checked. The csv file is then converted to a dictionary; the name of the csv file is used as the main key of the dictionary. Exceptions are made for the files ["economic_data", "project", "project_data", "simulation_settings", "constraints"], here no main key is added. Another exception is made for the file "energyStorage". When this file is processed, the according "storage" files (names of the "storage" columns in "energyStorage" are called and added to the energyStorage Dictionary.

Parameters

- **input_directory** (*str*) – path of the directory where the input csv files can be found
- **filename** (*str*) – name of the input file that is transformed into a json, without extension
- **parameters** (*list*) – List of parameters names that are required
- **asset_is_a_storage** (*bool*) – default value is False. If the function is called by add_storage_components() the parameter is set to True

Returns
the converted dictionary

Return type
dict

Notes

Tested with: - test_default_values_storage_without_thermal_losses() - test_default_values_storage_with_thermal_losses()

4.1.3 Data input

Module B0 - Data input json

multi_vector_simulator.B0_data_input_json.**convert_from_json_to_special_types**(*a_dict*, *prev_key=None*, *time_index=None*)

Convert the field values of the mvs result json file which are not simple types.

The function is recursive to explore all nested levels

Parameters

- **a_dict** (*variable*) – In the recursion, this is either a dict (moving down one nesting level) or a field value
- **prev_key** (*str*) – The previous key of the dict in the recursive loop

Returns

- *The original dictionary, with the serialized instances of pandas.Series,*
- *pandas.DatetimeIndex, pandas.DataFrame, numpy.array converted back to their original form*

multi_vector_simulator.B0_data_input_json.**convert_from_special_types_to_json**(*o*)

This converts all data stored in dict_values that is not compatible with the json format to a format that is compatible.

Parameters
o – Any type. Object to be converted to json-storable value.

Returns
json-storable value.

Return type
type

multi_vector_simulator.B0_data_input_json.**load_json**(*path_input_file*, *path_input_folder=None*, *path_output_folder=None*, *move_copy=False*, *flag_missing_values=True*, *set_default_values=False*)

Opens and reads json input file and parses it to dict of input parameters.

Parameters

- **path_input_file** (*str*) – The path to the json file created from csv files
- **path_input_folder** (*str, optional*) – The path to the directory where the input CSVs/JSON files are located. Default: 'inputs/'.
- **path_output_folder** (*str, optional*) – The path to the directory where the results of the simulation such as the plots, time series, results JSON files are saved by MVS E-Lands. Default: 'MVS_outputs/'
- **move_copy** (*bool, optional*) – if this is set to True, the path_input_file will be moved to the path_output_folder Default: False
- **flag_missing_values** (*bool*) – if True, raise MissingParameterError for each missing required parameter
- **set_default_values** (*bool*) – if True, set the default value of a missing required parameter which is listed in KNOWN_EXTRA_PARAMETERS

Return type
dict of all input parameters of the MVS E-Lands simulation

multi_vector_simulator.B0_data_input_json.**retrieve_date_time_info**(*simulation_settings*)

Updates simulation settings by all time-related parameters. - START_DATE - END_DATE - TIME_INDEX - PERIODS

Parameters
simulation_settings (*dict*) – Simulation parameters of the input data

Return type
Update simulation_settings by start date, end date, timeindex, and number of simulation periods

Notes

Function tested with test_retrieve_datetimeindex_for_simulation()

4.1.4 Data pre-processing and validity checks

Module C0 - Data processing

Module C0 prepares the data read from csv or json for simulation, ie. pre-processes it. - Verify input values with C1 - Identify energyVectors and write them to project_data/sectors - Create an excess sink for each bus - Process start_date/simulation_duration to pd.datatimeindex (future: Also consider timesteplenghts) - Add economic parameters to json with C2 - Calculate "simulation annuity" used in oemof model - Add demand sinks to energyVectors (this should actually be changed and demand sinks should be added to bus relative to input_direction, also see issue #179) - Translate input_directions/output_directions to bus names - Add missing cost data to automatically generated objects (eg. DSO transformers) - Read timeseries of assets and store into json (differ between one-column csv, multi-column csv) - Read timeseries for parameter of an asset, eg. efficiency - Parse list of inputs/outputs, eg. for chp - Define dso sinks, sources, transformer stations (this will be changed due to bug #119), also for peak demand pricing - Add a source if a conversion object is connected to a new input_direction (bug #186) - Define all necessary energyBusses and add all assets that are connected to them specifically with asset name and label - Multiply *maximumCap* of non-dispatchable sources by max(timeseries(kWh/kWp)) as the *maximumCap* is limiting the flow but we want to limit the installed capacity (see issue #446)

multi_vector_simulator.C0_data_processing.**add_a_transformer_for_each_peak_demand_pricing_period**(*dict_valu*
dict_dso,
dict_avai

Adds transformers that are supposed to model the peak_demand_pricing periods for each period. This is changed compared to MVS 0.3.0, as there a peak demand pricing period was added by adding a source, not a transformer.

Parameters

- **dict_values** (*dict*) – dict with all simulation parameters
- **dict_dso** (*dict*) – dict with all info on the specific dso at hand
- **dict_availability_timeseries** (*dict*) – dict with all availability timeseries for each period

Returns

- **list_of_dso_energyConversion_assets** (*list*) – List of names of newly added energy conversion assets,
- *Updated dict_values with a transformer for each peak demand pricing period*

Notes

Tested by: - C0.test_add_a_transformer_for_each_peak_demand_pricing_period_1_period - C0.test_add_a_transformer_for_each_peak_demand_pricing_period_2_periods

multi_vector_simulator.C0_data_processing.**add_asset_to_asset_dict_for_each_flow_direction**(*dict_values*,
dict_asset,
asset_key)

Add asset to the asset dict of the busses connected to the INPUT_DIRECTION and OUTPUT_DIRECTION of the asset.

Parameters

- **dict_values** (*dict*) – All simulation information
- **dict_asset** (*dict*) – All information of the current asset
- **asset_key** (*str*) – Key that calls the dict_asset from dict_values[asset_group][key]

Return type
Updated dict_values, with dict_values[ENERGY_BUSSES] now including asset dictionaries for each asset connected to a bus.

Notes

Tested with: - C0.test_add_asset_to_asset_dict_for_each_flow_direction()

multi_vector_simulator.C0_data_processing.**add_asset_to_asset_dict_of_bus**(*bus*, *dict_values*, *asset_key*, *asset_label*)

Adds asset key and label to a bus defined by *energyBusses.csv* Sends an error message if the bus was not included in *energyBusses.csv*

Parameters

- **dict_values** (*dict*) – Dict of all simulation parameters
- **bus** (*str*) – A bus label
- **asset_key** (*str*) – Key with with an dict_asset would be called from dict_values[groups][key]
- **asset_label** (*str*) – Label of the asset

Returns

- Updated dict_values[ENERGY_BUSSES] by adding an asset to the busses` ASSET DICT
- **EnergyBusses now has following keys** (*LABEL, ENERGY_VECTOR, ASSET_DICT*)

Notes

Tested with: - C0.test_add_asset_to_asset_dict_of_bus() - C0.test_add_asset_to_asset_dict_of_bus_ValueError()

multi_vector_simulator.C0_data_processing.**add_assets_to_asset_dict_of_connected_busses**(*dict_values*)

This function adds the assets of the different asset groups to the asset dict of ENERGY_BUSSES. The asset groups are: ENERGY_CONVERSION, ENERGY_PRODUCTION, ENERGY_CONSUMPTION, ENERGY_PROVIDERS, ENERGY_STORAGE

Parameters
dict_values (*dict*) – Dictionary with all simulation information

Return type
Extends dict_values[ENERGY_BUSSES] by an asset_dict that includes all connected assets.

Notes

Tested with: - C0.test_add_assets_to_asset_dict_of_connected_busses()

multi_vector_simulator.C0_data_processing.**add_economic_parameters**(*economic_parameters*)

Update economic parameters with annuity factor and CRF

Parameters
economic_parameters (*dict*) – Economic parameters of the simulation

Return type
Updated economic parameters

Notes

Function tested with test_add_economic_parameters()

multi_vector_simulator.C0_data_processing.**add_version_number_used**(*simulation_settings*)

Add version number to simulation settings

Parameters
simulation_settings (*dict*) – Dict of simulation settings

Returns

- Updated dict simulation_settings with *VERSION_NUM* equal to local version number.
- *This version number will be added to the json output files.*
- The automatic report generated in *F0* references the version number and date on its own accord.

multi_vector_simulator.C0_data_processing.**all**(*dict_values*)

Function executing all pre-processing steps necessary :param dict_values All input data in dict format

:return Pre-processed dictionary with all input parameters

multi_vector_simulator.C0_data_processing.**apply_function_to_single_or_list**(*function*, *parameter*, ***kwargs*)

Applies function to a paramter or to a list of parameters and returns resut

Parameters

- **function** (*func*) – Function to be applied to a parameter
- **parameter** (*float/str/boolean or list*) – Parameter, either float/str/boolean or list to be evaluated
- **kwargs** – Miscellaneous arguments for function to be called

Return type
Processed parameter (single) or list of processed para<meters

multi_vector_simulator.C0_data_processing.**change_sign_of_feedin_tariff**(*dict_feedin_tariff*, *dso*)

Change the sign of the feed-in tariff. Additionally, prints a logging.warning in case of the feed-in tariff is entered as negative value in 'energyProviders.csv'.

Parameters

- **dict_feedin_tariff** (*dict*) – Dict of feedin tariff with Unit-value pair
- **dso** (*str*) – Name of the energy provider

Returns
dict_feedin_tariff – Dict of feedin tariff, to be used as input to C0.define_sink

Return type
dict

Notes

Tested with: - C0.test_change_sign_of_feedin_tariff_positive_value() - C0.test_change_sign_of_feedin_tariff_negative_value() - C0.test_change_sign_of_feedin_tariff_zero()

multi_vector_simulator.C0_data_processing.**compute_timeseries_properties**(*dict_asset*)

Compute peak, aggregation, average and normalize timeseries

Parameters

dict_asset (*dict*) – dict of all asset parameters, must contain TIMESERIES key

Returns

- *None*
- *Add TIMESERIES_PEAK, TIMESERIES_TOTAL, TIMESERIES_AVERAGE and TIMESERIES_NORMALIZED*
- *to dict_asset*

Notes

Function tested with - C0.test_compute_timeseries_properties_TIMESERIES_in_dict_asset() - C0.test_compute_timeseries_properties_TIMESERIES_not_in_dict_asset()

multi_vector_simulator.C0_data_processing.**define_auxiliary_assets_of_energy_providers**(*dict_values*, *dso_name*)

Defines all sinks and sources that need to be added to model the transformer using assets of energyConsumption, energyProduction and energyConversion.

Parameters

- **dict_values** (*dict*) – All simulation parameters
- **dso_name** (*str*) – the name of the energy provider asset

Return type

Updated dict_values

Notes

This function is tested with following pytests: - C0.test_define_auxiliary_assets_of_energy_providers() - C0.test_determine_months_in_a_peak_demand_pricing_period_not_valid() - C0.test_determine_months_in_a_peak_demand_pricing_period_valid() - C0.test_define_availability_of_peak_demand_pricing_a - C0.test_define_availability_of_peak_demand_pricing_assets_monthly() - C0.test_define_availability_of_peak_demand_pricing_ - C0.test_add_a_transformer_for_each_peak_demand_pricing_period_1_period() - C0.test_add_a_transformer_for_each_peak_demand_pricing_period_2_periods() - C0.test_define_transformer_for_peak_demand_pricing() - C0.test_define_source() - C0.test_define_source_exception_unknown_bus() - C0.test_define_source_timeseries_not_None() - C0.test_define_source_price_not_None_but_with_scalar_value() - C0.test_define_sink() -> incomplete - C0.test_change_sign_of_feedin_tariff_positive_value() - C0.test_change_sign_of_feedin_tariff_negative_value() - C0.test_change_sign_of_feedin_tariff_zero()

multi_vector_simulator.C0_data_processing.**define_availability_of_peak_demand_pricing_assets**(*dict_values*, *number_of_pricing*
months_in_a_p

Determined the availability timeseries for the later to be defined dso assets for taking into account the peak demand pricing periods.

Parameters

- **dict_values** (*dict*) – All simulation inputs
- **number_of_pricing_periods** (*int*) – Number of pricing periods in a year. Valid: 1,2,3,4,6,12
- **months_in_a_period** (*int*) – Duration of a period

Returns
dict_availability_timeseries – Dict with all availability timeseries for each period

Return type
dict

multi_vector_simulator.C0_data_processing.**define_energy_vectors_from_busses**(*dict_values*)

Identifies all energyVectors used in the energy system by looking at the defined energyBusses. The EnergyVectors later will be used to distribute costs and KPI amongst the sectors

Parameters
dict_values (*dict*) – All input data in dict format

Return type
Update dict[PROJECT_DATA] by included energyVectors (LES_ENERGY_VECTOR_S)

Notes

Function tested with - C1.test_define_energy_vectors_from_busses

multi_vector_simulator.C0_data_processing.**define_excess_sinks**(*dict_values*)

Define energy excess sinks for each bus

Parameters
dict_values (*dict*) – All simulation parameters

Return type
Updates dict_values

multi_vector_simulator.C0_data_processing.**define_missing_cost_data**(*dict_values*, *dict_asset*)

Parameters

- **dict_values**
- **dict_asset**

Returns

multi_vector_simulator.C0_data_processing.**define_sink**(*dict_values*, *asset_key*, *price*, *inflow_direction*, *energy_vector*, *asset_type=None*, ***kwargs*)

This automatically defines a sink for an oemof-sink object. The sinks are added to the energyConsumption assets.

Parameters

- **dict_values** (*dict*) – All information of the simulation
- **asset_key** (*str*) – label of the asset to be generated
- **price** (*float*) – Price of dispatch of the asset

- **inflow_direction** (*str*) – Direction from which energy is provided to the sink
- **kwargs** (*Misc*) – Common parameters: -

Returns

- *Updates dict_values[ENERGY_BUSSES] if outflow_direction not in it*
- *Updates dict_values[ENERGY_CONSUMPTION] with a new sink*

Notes

Examples: - Used to define excess sinks for all energyBusses - Used to define feed-in sink for each DSO

The pytests for this function are not complete. It is started with: - C0.test_define_sink() and only the assertion messages are missing

multi_vector_simulator.C0_data_processing.**define_source**(*dict_values*, *asset_key*, *outflow_direction*, *energy_vector*, *emission_factor*, *price=None*, *timeseries=None*, *asset_type=None*)

Defines a source with default input values. If kwargs are given, the default values are overwritten.

Parameters

- **dict_values** (*dict*) – Dictionary to which source should be added, with all simulation parameters
- **asset_key** (*str*) – key under which the asset is stored in the asset group
- **energy_vector** (*str*) – Energy vector the new asset should belong to
- **emission_factor** (*dict*) – Dict with a unit-value pair of the emission factor of the new asset
- **price** (*dict*) – Dict with a unit-value pair of the dispatch price of the source. The value can also be defined though FILENAME and HEADER, making the value of the price a timeseries. Default: None
- **timeseries** (*pd.Dataframe*) – Timeseries defining the availability of the source. Currently not used. Default: None

Returns

- *Updates dict_values[ENERGY_BUSSES] if outflow_direction not in it*
- *Standard source defined as*

Notes

The pytests for this function are not complete. It is started with: - C0.test_define_source() - C0.test_define_source_exception_unknown_bus() - C0.test_define_source_timeseries_not_None() - C0.test_define_source_price_not_None_but_with_scalar_value() Missing: - C0.test_define_source_price_not_None_but_timeseries(), ie. value defined by FILENAME and HEADER

multi_vector_simulator.C0_data_processing.**define_transformer_for_peak_demand_pricing**(*dict_values*, *dict_dso*, *transformer_name*, *timeseries_availability*)

Defines a transformer for peak demand pricing in energyConverion

Parameters

- **dict_values** (*dict*) – All simulation parameters
- **dict_dso** (*dict*) – All values connected to the DSO
- **transformer_name** (*str*) – label of the transformer to be added
- **timeseries_availability** (*pd.Series*) – Timeseries of transformer availability. Introduced to cover peak demand pricing.

Return type
Updated dict_values with newly added transformer asset in the energyConversion asset group.

multi_vector_simulator.C0_data_processing.**determine_dispatch_price**(*dict_values*, *price*, *source*)

This function needs to be re-evaluated.

Parameters

- **dict_values**
- **price**
- **source**

multi_vector_simulator.C0_data_processing.**determine_months_in_a_peak_demand_pricing_period**(*number_of_pric*
sim-
u-
la-
tion_period_len

Check if the number of peak demand pricing periods is valid. Warns user that in case the number of periods exceeds 1 but the simulation time is not a year, there could be an unexpected number of timeseries considered. Raises error if number of peak demand pricing periods is not valid.

Parameters

- **number_of_pricing_periods** (*int*) – Defined in csv, is number of pricing periods within a year
- **simulation_period_lenght** (*int*) – Defined in csv, is number of days of the simulation

Returns
months_in_a_period – Number of months that make a period, will be used to determine availability of dso assets

Return type
float

multi_vector_simulator.C0_data_processing.**energyConsumption**(*dict_values*, *group*)

Parameters

- **dict_values**
- **group**

Returns

multi_vector_simulator.C0_data_processing.**energyConversion**(*dict_values*, *group*)

Add lifetime capex (incl. replacement costs), calculate annuity (incl. om), and simulation annuity to each asset

Parameters

- **dict_values**
- **group**

Returns

multi_vector_simulator.C0_data_processing.**energyProduction**(*dict_values*, *group*)

Parameters

- **dict_values**
- **group**

Returns

multi_vector_simulator.C0_data_processing.**energyProviders**(*dict_values*, *group*)

Parameters

- **dict_values**
- **group**

Returns

multi_vector_simulator.C0_data_processing.**energyStorage**(*dict_values*, *group*)

Parameters

- **dict_values**
- **group**

Returns

multi_vector_simulator.C0_data_processing.**evaluate_lifetime_costs**(*settings*, *economic_data*, *dict_asset*)

Evaluates specific costs of an asset over the project lifetime. This includes: - LIFETIME_PRICE_DISPATCH (C2.determine_lifetime_price_dispatch) - LIFETIME_SPECIFIC_COST - LIFETIME_SPECIFIC_COST_OM - ANNUITY_SPECIFIC_INVESTMENT_AND_OM - SIMULATION_ANNUITY

The DEVELOPMENT_COSTS are not processed here, as they are not necessary for the optimization.

Parameters

- **settings** (*dict*) – dict of simulation settings, including: - EVALUATED_PERIOD
- **economic_data** (*dict*) – dict of economic data of the simulation, including - project duration (PROJECT_DURATION) - discount factor (DISCOUNTFACTOR) - tax (TAX) - CRF - ANNUITY_FACTOR
- **dict_asset** (*dict*) – dict of all asset parameters, including - SPECIFIC_COSTS - SPECIFIC_COSTS_OM - LIFETIME

Returns

- *Updates asset dict with*
- *- LIFETIME_PRICE_DISPATCH (C2.determine_lifetime_price_dispatch)*
- *- LIFETIME_SPECIFIC_COST*
- *- LIFETIME_SPECIFIC_COST_OM*
- *- ANNUITY_SPECIFIC_INVESTMENT_AND_OM*
- *- SIMULATION_ANNUITY*

- - *SPECIFIC_REPLACEMENT_COSTS_INSTALLED*
- - *SPECIFIC_REPLACEMENT_COSTS_OPTIMIZED*

Notes

Tested with: - test_evaluate_lifetime_costs_adds_all_parameters() - Test_Economic_KPI.test_benchmark_Economic_KPI_C2_E2

multi_vector_simulator.C0_data_processing.**get_timeseries_multiple_flows**(*settings*, *dict_asset*, *file_name*, *header*)

Parameters

- **dict_asset**
- **asset** (*dictionary of the*)
- **file_name**
- **series** (*name of the file to read the time*)
- **header**
- **provided** (*name of the column where the timeseries is*)

multi_vector_simulator.C0_data_processing.**process_all_assets**(*dict_values*)

defines dict_values['energyBusses'] for later reference

Processes all assets of the energy system by evaluating them, performing economic pre-calculations and validity checks.

Parameters
dict_values (*dict*) – All simulation inputs

Returns
dict_values – Updated dict_values with pre-processes assets, including economic parameters, busses and auxiliary assets like excess sinks and all assets connected to the energyProviders.

Return type
dict

Notes

Tested with: - test_C0_data_processing.test_process_all_assets_fixcost()

multi_vector_simulator.C0_data_processing.**process_maximum_cap_constraint**(*dict_values*, *group*, *asset*, *subasset=None*)

Processes the maximumCap constraint depending on its value.

- If MaximumCap not in asset dict: MaximumCap is None
- If MaximumCap < installedCap: invalid, MaximumCapValueInvalid raised
- If MaximumCap == 0: invalid, MaximumCap is None
- If group == energyProduction and filename not in asset_dict (dispatchable assets): pass
- If group == energyProduction and filename in asset_dict (non-dispatchable assets): MaximumCapNormalized == MaximumCap*peak(timeseries), MaximumAddCapNormalized == MaximumAddCap*peak(timeseries)

Parameters

- **dict_values** (*dict*) – dictionary of all assets
- **group** (*str*) – Group that the asset belongs to (str). Used to acces sub-asset data and for error messages.
- **asset** (*str*) – asset name
- **subasset** (*str or None*) – subasset name. Default: None.

Notes

Tested with: - test_process_maximum_cap_constraint_maximumCap_undefined() - test_process_maximum_cap_constraint_maximumCap_is_None() - test_process_maximum_cap_constraint_maximumCap_is_int - test_process_maximum_cap_constraint_maximumCap_is_float() - test_process_maximum_cap_constraint_maximumCap_is_0() - test_process_maximum_cap_constraint_maximumCap_is_int_smaller_than_installed_cap() - test_process_maximum_cap_constraint_group_is_ENERGY_PRODUCTION_fuel_source() - test_process_maximum_cap_constraint_group_is_ENERGY_PRODUCTION_non_dispatchable_asset() - test_process_maximum_cap_constraint_subasset()

Returns

- *Updates the asset dictionary.*
- ** Unit of MaximumCap is asset unit*

multi_vector_simulator.C0_data_processing.**process_normalized_installed_cap**(*dict_values*, *group*, *asset*, *subasset=None*)

Processes the normalized installed capacity value based on the installed capacity value and the chosen timeseries.

Parameters

- **dict_values** (*dict*) – dictionary of all assets
- **group** (*str*) – Group that the asset belongs to (str). Used to acces sub-asset data and for error messages.
- **asset** (*str*) – asset name
- **subasset** (*str or None*) – subasset name. Default: None.

Notes

Tested with: - test_process_normalized_installed_cap()

Return type
Updates the asset dictionary with the normalizedInstalledCap value.

multi_vector_simulator.C0_data_processing.**receive_timeseries_from_csv**(*settings*, *dict_asset*, *input_type*, *is_demand_profile=False*)

Parameters

- **settings**
- **dict_asset**
- **type**

Returns

multi_vector_simulator.C0_data_processing.**replace_nans_in_timeseries_with_0**(*timeseries*, *label*)

Replaces nans in the timeseries (if any) with 0

Parameters

- **timeseries** (*pd.Series*) – demand or resource timeseries in dict_asset (having nan value(s) if any), also of parameters that are not defined as scalars but as timeseries
- **label** (*str*) – Contains user-defined information about the timeseries to be printed into the eventual error message

Returns
timeseries – timeseries without NaN values

Return type
pd.Series

Notes

Function tested with - C0.test_replace_nans_in_timeseries_with_0()

multi_vector_simulator.C0_data_processing.**treat_multiple_flows**(*dict_asset*, *dict_values*, *parameter*)

This function consider the case a technical parameter on the json file has a list of values because multiple inputs or outputs busses are considered. :param dict_values: :param dictionary of current values of the asset: :param parameter: :param usually efficiency. Different efficiencies will be given if an asset has multiple inputs or outputs busses: :param : :param so a list must be considered.:

Module C1 - Verification

Module C1 is used to validate the input data compiled in A1 or read in B0.

In A1/B0, the input parameters were parsed to str/bool/float/int. This module tests whether the parameters are in correct value ranges: - Display error message when wrong type - Display error message when outside defined range - Display error message when feed-in tariff > electricity price (would cause loop, see #119)

multi_vector_simulator.C1_verification.**all_valid_intervals**(*name*, *value*, *title*)

Checks whether *value* of *name* is valid.

Checks include the expected type and the expected range a parameter is supposed to be inside.

Parameters

- **name**
- **value**
- **title**

Returns

multi_vector_simulator.C1_verification.**check_efficiency_of_storage_capacity**(*dict_values*)

Raises error or logs a warning to help users to spot major change in PR #676.

In #676 the *efficiency* of *storage capacity' in `storage_*.csv* was defined as the storages' efficiency/ability to hold charge over time. Before it was defined as loss rate. This function raises an error if efficiency of 'storage

capacity' of one of the storages is 0 and logs a warning if efficiency of 'storage capacity' of one of the storages is <0.2.

Parameters
dict_values (*dict*) – Contains all input data of the simulation.

Notes

Tested with: - test_check_efficiency_of_storage_capacity_is_0 - test_check_efficiency_of_storage_capacity_is_btw_0_and_02 - test_check_efficiency_of_storage_capacity_is_greater_02

Returns

- *Indirectly, raises error message in case of efficiency of 'storage capacity' is 0*
- *and logs warning message in case of efficiency of 'storage capacity' is <0.2.*

multi_vector_simulator.C1_verification.**check_emission_factor_of_providers**(*dict_values*)

Logs a logging.warning message in case the grid has a renewable share of 100 % but an emission factor > 0.

This would affect the optimization if a maximum emissions contraint is used. Aditionally, it effects the KPIs connected to emissions.

Parameters
dict_values (*dict*) – Contains all input data of the simulation.

Returns

- *Indirectly, logs a logging.warning message in case tthe grid has a renewable share*
- *of 100 % but an emission factor > 0.*

Notes

Tested with: - C1.test_check_emission_factor_of_providers_no_warning_RE_share_lower_1() - C1.test_check_emission_factor_of_providers_no_warning_emission_factor_0() - C1.test_check_emission_factor_of_providers_warning()

multi_vector_simulator.C1_verification.**check_energy_system_can_fulfill_max_demand**(*dict_values*)

Helps to do oemof-solph termination debugging: Logs a logging.warning message if the aggregated installed capacity and maximum capacity (if applicable) of all conversion, generation and storage assets connected to one bus is smaller than the maximum demand. The check is applied to each bus of the energy system. Check passes when the potential peak supply is larger then or equal to the peak demand on the bus, or if the maximum capacity of an asset is set to None when optimizing.

Parameters
dict_values (*dict*) – Contains all input data of the simulation.

Returns

- *Indirectly, logs a logging.warning message if the installed and maximum capacities of*
- *conversion/generation/storage assets are less than the maximum demand, for each bus.*

Notes

Tested with: - test_check_energy_system_can_fulfill_max_demand_sufficient_capacities() - test_check_energy_system_can_fulfill_max_demand_no_maximum_capacity() - test_check_energy_system_can_fulfill_max_demand_insufficient_capacities() - test_check_energy_system_can_fulfill_max_demand_with_storage() - test_check_energy_system_can_fulfill_max_demand_suffic - test_check_energy_system_can_fulfill_max_demand_insufficient_dispatchable_production - test_check_energy_system_can_fulfill_max_demand_sufficient_non_dispatchable_production - test_check_energy_system_can_fulfill_max_demand_insufficient_non_dispatchable_production - test_check_energy_system_can_fulfill_max_demand_fails_mvs_runthrough

multi_vector_simulator.C1_verification.**check_feasibility_of_maximum_emissions_constraint**(*dict_values*)

Logs a logging.warning message in case the maximum emissions constraint could lead into an unbound problem.

If the maximum emissions constraint is used it is checked whether there is any production asset with zero emissions that has a capacity to be optimized without maximum capacity constraint. If this is not the case a warning is logged.

Parameters

dict_values (*dict*) – Contains all input data of the simulation.

Returns

- *Indirectly, logs a logging.warning message in case the maximum emissions constraint*
- *is used while no production with zero emissions is optimized without maximum capacity.*

Notes

Tested with: - C1.test_check_feasibility_of_maximum_emissions_constraint_no_warning_no_constraint() - C1.test_check_feasibility_of_maximum_emissions_constraint_no_warning_although_emission_constraint() - C1.test_check_feasibility_of_maximum_emissions_constraint_maximumcap() - C1.test_check_feasibility_of_maximum_emissions_constraint_optimizeCap_is_False() - C1.test_check_feasibility_of_maximum_emissions_constraint_no_zero_emission_asset()

multi_vector_simulator.C1_verification.**check_feedin_tariff_vs_energy_price**(*dict_values*)

Raises error if feed-in tariff > energy price of any asset in 'energyProvider.csv'. This is not allowed, as oemof otherwise is subjected to an unbound and unrealistic problem, eg. one where the owner should consume electricity to feed it directly back into the grid for its revenue.

Parameters

dict_values (*dict*) – Contains all input data of the simulation.

Returns

- *Indirectly, raises error message in case of feed-in tariff > energy price of any*
- *asset in 'energyProvider.csv'.*

Notes

Tested with: - C1.test_check_feedin_tariff_vs_energy_price_greater_energy_price() - C1.test_check_feedin_tariff_vs_energy_price_not_greater_energy_price()

multi_vector_simulator.C1_verification.**check_feedin_tariff_vs_levelized_cost_of_generation_of_productio**

Raises error if feed-in tariff > levelized costs of generation for energy asset in ENERGY_PRODUCTION with capacity to be optimized and no maximum capacity constraint.

This is not allowed, as oemof otherwise may be subjected to an unbound problem, ie. a business case in which an asset should be installed with infinite capacities to maximize revenue.

In case of a set maximum capacity or no capacity optimization logging messages are logged.

Parameters
dict_values (*dict*) – Contains all input data of the simulation.

Returns

- *Raises error message in case of feed-in tariff > levelized costs of generation for energy asset of any*
- *asset in ENERGY_PRODUCTION*

Notes

Tested with: - C1.test_check_feedin_tariff_vs_levelized_cost_of_generation_of_production_non_dispatchable_not_greater_costs(
- C1.test_check_feedin_tariff_vs_levelized_cost_of_generation_of_production_non_dispatchable_greater_costs()
- C1.test_check_feedin_tariff_vs_levelized_cost_of_generation_of_production_dispatchable_higher_dispatch_price()
- C1.test_check_feedin_tariff_vs_levelized_cost_of_generation_of_production_dispatchable_lower_dispatch_price()
- C1.test_check_feedin_tariff_vs_levelized_cost_of_generation_of_production_non_dispatchable_greater_costs_with_maxcap()
- C1.test_check_feedin_tariff_vs_levelized_cost_of_generation_of_production_non_dispatchable_greater_costs_dispatch_mode()

This test does not cover cross-sectoral invalid feedin tariffs. Example: If there is very cheap electricity generation but a high H2 feedin tariff, then it might be a business case to install a large Electrolyzer, and the simulation would fail. In that case one should set bounds to the solution.

multi_vector_simulator.C1_verification.**check_for_label_duplicates**(*dict_values*)

This function checks if any LABEL provided for the energy system model in dict_values is a duplicate. This is not allowed, as oemof can not build a model with identical labels.

Parameters
dict_values (*dict*) – All simulation inputs

Returns
pass or error message

Return type
DuplicateLabels

multi_vector_simulator.C1_verification.**check_for_sufficient_assets_on_busses**(*dict_values*)

Validation check for busses, to make sure a sufficient number of assets is connected.

Each bus has to has to have 3 or more assets connected to it. The reasoning is that each bus needs: - One asset for inflow into the bus - One asset for outflow from the bus - One energy excess asset Note, however, that this test does not check whether the assets actually serve that function, so there might be false negatives: The test can for example pass, if there are two output assets, one excess asset but no input asset, which would represent a non-sensical combination.

On the bus created for the peak demand pricing function (name includes *DSO_PEAK_DEMAND_SUFFIX*) no excess sinks are added, and therefore the rule does not have to be applied to this bus.

Parameters
dict_values (*dict*) – All simulation parameters

Return type
Logging error message if test fails

Notes

This function is tested with: - test_C1_verification.test_check_for_sufficient_assets_on_busses_example_bus_passes() - test_C1_verification.test_check_for_sufficient_assets_on_busses_example_bus_fails() - test_C1_verification.test_check_for_sufficient_assets_on_busses_skipped_for_peak_demand_pricing_bus()

multi_vector_simulator.C1_verification.**check_if_energy_vector_is_defined_in_DEFAULT_WEIGHTS_ENERGY_CARRI**

Raises an error message if an energy vector is unknown.

It then needs to be added to the DEFAULT_WEIGHTS_ENERGY_CARRIERS in constants.py

Parameters

- **energy_carrier** (*str*) – Name of the energy carrier
- **asset_group** (*str*) – Name of the asset group
- **asset** (*str*) – Name of the asset

Return type
None

Notes

Tested with: - test_check_if_energy_vector_is_defined_in_DEFAULT_WEIGHTS_ENERGY_CARRIERS_pass() - test_check_if_energy_vector_is_defined_in_DEFAULT_WEIGHTS_ENERGY_CARRIERS_fails()

multi_vector_simulator.C1_verification.**check_if_energy_vector_of_all_assets_is_valid**(*dict_values*)

Validates for all assets, whether 'energyVector' is defined within DEFAULT_WEIGHTS_ENERGY_CARRIERS and within the energyBusses.

Parameters
dict_values (*dict*) – All input data in dict format

Notes

Function tested with - test_add_economic_parameters() - test_check_if_energy_vector_of_all_assets_is_valid_fails - test_check_if_energy_vector_of_all_assets_is_valid_passes

multi_vector_simulator.C1_verification.**check_input_values**(*dict_values*)

Parameters
dict_values

Returns

multi_vector_simulator.C1_verification.**check_non_dispatchable_source_time_series**(*dict_values*)

Raises error if time series of non-dispatchable sources are not between [0, 1].

Parameters
dict_values (*dict*) – Contains all input data of the simulation.

Returns

- *Indirectly, raises error message in case of time series of non-dispatchable sources*
- *not between [0, 1].*

multi_vector_simulator.C1_verification.**check_time_series_values_between_0_and_1**(*time_series*)

Checks whether all values of *time_series* in [0, 1].

Parameters
time_series (*pd.Series*) – Time series to be checked.

Returns
True if values of *time_series* within [0, 1], else False.

Return type
bool

multi_vector_simulator.C1_verification.**lookup_file**(*file_path*, *name*)

Checks whether file specified in *file_path* exists.

If it does not exist, a FileNotFoundError is raised.

Parameters

- **file_path** – File name including path of file that is checked.
- **name** – Something referring to which component the file belongs. In `get_timeseries_multiple_flows()` the label of the asset is used.

Returns

Module C2 - Economic preprocessing

Module C2 performs the economic pre-processing of MVS' input parameters. It includes basic economic formulas.

Functionalities: - Calculate annuity factor - calculate crf depending on year - calculate specific lifetime capex, considering replacement costs and residual value of the asset - calculate annuity from present costs - calculate present costs based on annuity - calculate effective fuel price cost, in case there is a annual fuel price change (this functionality still has to be checked in this module)

multi_vector_simulator.C2_economic_functions.**annuity**(*present_value*, *crf*)

Calculates the annuity which is a fixed stream of payments incurred by investments in assets

Parameters

- **present_value** (*float*) – current equivalent value of a set of future cash flows for an asset
- **crf** (*float*) – ratio used to calculate the present value of an annuity

Returns
annuity – annuity, i.e. payment made at equal intervals

Return type
float

Notes

Tested with test_annuity()

multi_vector_simulator.C2_economic_functions.**annuity_factor**(*project_life*, *discount_factor*)

Calculates the annuity factor, which in turn in used to calculate the present value of annuities (instalments)

Parameters

- **project_life** (*int*) – time period over which the costs of the system occur
- **discount_factor** (*float*) – weighted average cost of capital, which is the after-tax average cost of various capital sources

Returns

annuity_factor – financial value "annuity factor". Dividing a present cost by tha annuity factor returns its annuity, multiplying an annuity with the annuity factor returns its present value

Return type

float

Notes

$$annuityfactor = \frac{1}{discountfactor} - \frac{1}{discountfactor \cdot (1 + discountfactor)^{projectlife}}$$

multi_vector_simulator.C2_economic_functions.**capex_from_investment**(*investment_t0*, *lifetime*, *project_life*, *discount_factor*, *tax*, *age_of_asset*, *asset_label=''*)

Calculates the capital expenditures, also known as CapEx.

CapEx represent the total funds used to acquire or upgrade an asset. The specific capex is calculated by taking into account all future cash flows connected to the investment into one unit of the asset. This includes reinvestments, operation and management costs, dispatch costs as well as a deduction of the residual value at project end. The residual value is calculated with a linear depreciation of the last investment, ie. as a even share of the last investment over the lifetime of the asset. The remaining value of the asset is translated in a present value and then deducted.

Parameters

- **investment_t0** (*float*) – first investment at the beginning of the project made at year 0
- **lifetime** (*int*) – time period over which investments and re-investments can occur. can be equal to, longer or shorter than project_life
- **project_life** (*int*) – time period over which the costs of the system occur
- **discount_factor** (*float*) – weighted average cost of capital, which is the after-tax average cost of various capital sources
- **tax** (*float*) – compulsory financial charge paid to the government
- **age_of_asset** (*int*) – age since asset installation in year
- **asset_label** (*str*) – name of the asset

Returns

- **specific_capex** (*float*) – Specific capital expenditure for an asset over project lifetime

- **specific_replacement_costs_optimized** (*float*) – Specific replacement costs for the asset capacity to be optimized, needed for E2
- **specific_replacement_costs_already_installed** (*float*) – replacement costs per unit for the currently already installed assets, needed for E2

Notes

Tested with - test_capex_from_investment_lifetime_equals_project_life() - test_capex_from_investment_lifetime_smaller_than_project_life() - test_capex_from_investment_lifetime_bigger_than_project_li

multi_vector_simulator.C2_economic_functions.**crf**(*project_life*, *discount_factor*)

Calculates the capital recovery ratio used to determine the present value of a series of equal payments (annuity)

Parameters

- **project_life** – time period over which the costs of the system occur
- **discount_factor** – weighted average cost of capital, which is the after-tax average cost of various capital sources

Returns

capital recovery factor, a ratio used to calculate the present value of an annuity

multi_vector_simulator.C2_economic_functions.**determine_lifetime_price_dispatch**(*dict_asset*, *economic_data*)

Determines the price of dispatch of an asset LIFETIME_PRICE_DISPATCH and updates the asset info.

It takes into account the asset's future expenditures due to dispatch. Depending on the price data provided, another function is executed.

Parameters

- **dict_asset** (*dict*) – Data of an asset
- **economic_data** (*dict*) – Economic data, including CRF and ANNUITY_FACTOR

Return type

Updates asset dict

Notes

Tested with - test_determine_lifetime_price_dispatch_as_int() - test_determine_lifetime_price_dispatch_as_float() - test_determine_lifetime_price_dispatch_as_list() - test_determine_lifetime_price_dispatch_as_timeseries ()

multi_vector_simulator.C2_economic_functions.**get_lifetime_price_dispatch_list**(*dispatch_price*, *economic_data*)

Determines the lifetime dispatch price in case that the dispatch price is a list.

The dispatch_price can be a list when for example if there are two input flows to a component, eg. water and electricity. There should be a lifetime_price_dispatch for each of them.

$$lifetime\_price\_dispatch_i = DISPATCH\_PRICE_i \cdot ANNUITY\_FACTOR \forall i$$

with i for all list entries

Parameters

- **dispatch_price** (*list*) – Dispatch prices of the asset as a list
- **economic_data** (*dict*) – Economic data

Returns
lifetime_price_dispatch – List of floats of lifetime dispatch price that the asset will be updated with

Return type
list

Notes

Tested with - test_determine_lifetime_price_dispatch_as_list() - test_get_lifetime_price_dispatch_list()

multi_vector_simulator.C2_economic_functions.**get_lifetime_price_dispatch_one_value**(*dispatch_price*, *economic_data*)

Lifetime dispatch price is a scalar value that is calulated with the annuity

By doing this, the operational expenditures, in the simulation only taken into account for a year, can be compared to the investment costs.

$$lifetime_price_dispatch = DISPATCH_PRICE \cdot ANNUITY_FACTOR$$

Parameters

- **dispatch_price** (*float or int*) – dispatch_price of the asset
- **economic_data** (*dict*) – Economic data

Returns
lifetime_price_dispatch – Float that the asset dict is to be updated with

Return type
float

Notes

Tested with - test_determine_lifetime_price_dispatch_as_int() - test_determine_lifetime_price_dispatch_as_float() - test_get_lifetime_price_dispatch_one_value()

multi_vector_simulator.C2_economic_functions.**get_lifetime_price_dispatch_timeseries**(*dispatch_price*, *economic_data*)

Calculates the lifetime price dispatch for a timeseries. The dispatch_price can be a timeseries, eg. in case that there is an hourly pricing. .. math:

```
lifetime\_price\_dispatch(t) = DISPATCH\_PRICE(t) \cdot ANNUITY\_FACTOR \forall t
```

Parameters

- **dispatch_price** (pandas.Series) – Dispatch price as a timeseries (eg. electricity prices)
- **economic_data** (*dict*) – Dict of economic data

Returns
lifetime_price_dispatch – Lifetime dispatch price that the asset will be updated with

Return type
float

Notes

Tested with

- test_determine_lifetime_price_dispatch_as_timeseries()
- test_get_lifetime_price_dispatch_timeseries()

multi_vector_simulator.C2_economic_functions.**get_replacement_costs**(*age_of_asset*, *project_lifetime*, *asset_lifetime*, *first_time_investment*, *discount_factor*, *asset_label=''*)

Calculating the replacement costs of an asset

Parameters

- **age_of_asset** (*int*) – Age in years of an already installed asset
- **project_lifetime** (*int*) – Project duration in years
- **asset_lifetime** (*int*) – Lifetime of an asset in years
- **first_time_investment** (*float*) – Investment cost of an asset to be installed
- **discount_factor** (*float*) – Discount factor of a project
- **asset_label** (*str*) – name of the asset

Returns

- *Per-unit replacement costs of an asset. If age_asset == 0, they need to be added to the lifetime_specific_costs of the asset.*
- *If age_asset > 0, it will be needed to calculate the future investment costs of a previously installed asset.*

multi_vector_simulator.C2_economic_functions.**present_value_from_annuity**(*annuity*, *annuity_factor*)

Calculates the present value of future instalments from an annuity

Parameters

- **annuity** (*float*) – payment made at equal intervals
- **annuity_factor** (*float*) – financial value

Returns
present_value – present value of future payments from an annuity

Return type
float

multi_vector_simulator.C2_economic_functions.**simulation_annuity**(*annuity*, *days*)

Scaling annuity to timeframe Updating all annuities above to annuities "for the timeframe", so that optimization is based on more adequate costs. Includes project_cost_annuity, distribution_grid_cost_annuity, main-grid_extension_cost_annuity for consistency eventhough these are not used in optimization.

Parameters

- **annuity** (*float*) – Annuity of an asset
- **days** (*int*) – Days to be simulated

Return type
Simulation annuity that considers the lifetime cost for the optimization of one year duration.

Notes

Tested with - test_simulation_annuity_week - test_simulation_annuity_year

4.1.5 Building the energy system model

Module D0 - Model building

Functional requirements of module D0: - measure time needed to build model - measure time needed to solve model - generate energy system model for oemof - create dictionary of components so that they can be used for constraints and some - raise warning if component not a (in mvs defined) oemof model type - add all energy conversion, energy consumption, energy production, energy storage devices model - plot network graph - at constraints to remote model - store lp file (optional) - start oemof simulation - process results by giving them to the next function - dump oemof results - add simulation parameters to dict values

class multi_vector_simulator.D0_modelling_and_optimization.**model_building**

adding_assets_to_energysystem_model(*dict_model*, *model*, ***kwargs*)

Parameters

- **dict_values** (*dict*) – dict of simulation data
- **dict_model** – Updated list of assets in the oemof energy system model
- **model** (*oemof.solph.network.EnergySystem*) – Model of oemof energy system

initialize()

Initalization of oemof model

Parameters
dict_values (*dict*) – dictionary of simulation

Return type
oemof energy model (oemof.solph.network.EnergySystem), dict_model which gathers the assets added to this model later.

plot_networkx_graph(*model*, *save_energy_system_graph=False*)

Plots a graph of the energy system if that graph is to be displayed or stored.

Parameters

- **dict_values** (*dict*) – All simulation inputs
- **model** (*oemof.solph.network.EnergySystem*) – oemof-solph object for energy system model
- **save_energy_system_graph** (*bool*) – if True, save the graph in the mvs output folder Default: False

Return type
None

plot_sankey_diagramm(*model*, *save_energy_system_graph=False*)

Prepare a sankey diagram of the simulated energy model

Parameters

- **dict_values** (*dict*) – All simulation inputs

  model: ***oemof.solph.network.EnergySystem***
  oemof-solph object for energy system model

- **save_energy_system_graph** (*bool*) – if True, save the graph in the mvs output folder Default: False

simulating(*model*, *local_energy_system*)

Initiates the oemof-solph simulation, accesses results and writes main results into dict

If an error is encountered in the oemof solver, mvs should not be allowed to continue, otherwise other errors related to the uncomplete simulation result might occur and it will be more obscure to the endusers what went wrong.

A MVS error is raised if the omoef solver warning states explicitely that "termination condition infeasible", otherwise the oemof solver warning is re-raised as an error.

Parameters

- **dict_values** (*dict*) – All simulation inputs
- **model** (*object*) – oemof-solph object for energy system model
- **local_energy_system** (*object*) – pyomo object storing all constraints of the energy system model

Return type
Updated model with results, main results (flows, assets) and meta results (simulation)

store_lp_file(*local_energy_system*)

Stores linear equation system generated with pyomo as an "lp file".

Parameters

- **dict_values** (*dict*) – All simulation input data
- **local_energy_system** (*object*) – pyomo object including all constraints of the energy system

Return type
Nothing.

multi_vector_simulator.D0_modelling_and_optimization.**run_oemof**(*dict_values*, *save_energy_system_graph=False*, *return_les=False*)

Creates and solves energy system model generated from excel template inputs. Each component is included by calling its constructor function in D1_model_components.

Parameters

- **values** (*dict*) – Includes all dictionary values describing the whole project, including costs, technical parameters and components. In C0_data_processing, each component was attributed with a certain in/output bus.

- **save_energy_system_graph** (*bool*) – if set to True, saves a local copy of the energy system's graph
- **return_les** (*bool*) – if set to True, the return also includes the local_energy_system in third position

Return type
saves and returns oemof simulation results

class multi_vector_simulator.D0_modelling_and_optimization.**timer**

initalize()

Starts a timer

stop(*start*)

Ends timer and adds duration of simulation to dict_values :param dict_values: Dict of simulation including SIMULATION_RESULTS key :type dict_values: dict :param start: start time of timer :type start: timestamp

Return type
Simulation time in dict_values

Module D1 - Oemof components

Module D1 includes all functions that are required to build an oemof model with adaptable components.

- add transformer objects (fix, to be optimized)
- add source objects (fix, to be optimized, dispatchable, non-dispatchable)
- add sink objects (fix, to be optimized, dispatchable, non-dispatchable)
- add storage objects (fix, to be optimized)
- add multiple input/output busses if required for each of the assets
- add oemof component parameters as scalar or time series values

class multi_vector_simulator.D1_model_components.**CustomBus**(**args*, ***kwargs*)

multi_vector_simulator.D1_model_components.**bus**(*model*, *name*, ***kwargs*)

Adds bus *name* to *model* and to 'busses' in *kwargs*.

Notes

Tested with: - test_bus_add_to_empty_dict() - test_bus_add_to_not_empty_dict()

multi_vector_simulator.D1_model_components.**check_list_parameters_transformers_single_input_single_outpu**

multi_vector_simulator.D1_model_components.**check_optimize_cap**(*model*, *dict_asset*, *func_constant*, *func_optimize*, ***kwargs*)

Defines a component specified in *dict_asset* with fixed capacity or capacity to be optimized.

Parameters

- **model** (*oemof.solph.network.EnergySystem object*) – See the oemof documentation for more information.

- **dict_asset** (*dict*) – Contains information about the asset like (not exhaustive): efficiency, installed capacity ('installedCap'), information on the busses the asset is connected to (f.e. 'inflow_direction', 'outflow_direction').
- **func_constant** (*func*) – Function to be applied if optimization not intended.
- **func_optimize** (*func*) – Function to be applied if optimization not intended.
- **oemof** (*Required are busses and a dictionary belonging to the respective*)
- **asset.** (*type of the*)
- **busses** (*dict, optional*)
- **sinks** (*dict, optional*)
- **sources** (*dict, optional*)
- **transformers** (*dict, optional*)
- **storages** (*dict, optional*)

Returns

- Indirectly updated *model* and dict of asset in *kwargs* with the component object.
- *TODOS*
- ^^^^
- *Might be possible to drop non invest optimization in favour of invest optimization if max_capactiy*
- *attributes ie. are set to 0 for fix (but less beautiful, and in case of generator even blocks nonconvex opt.).*

Notes

Tested with: - test_check_optimize_cap_raise_error()

multi_vector_simulator.D1_model_components.**chp**(*model*, *dict_asset*, ***kwargs*)

Defines a chp component specified in *dict_asset*.

Depending on the 'value' of 'optimizeCap' in *dict_asset* the chp is defined with a fixed capacity or a capacity to be optimized. The chp has single input and multiple output busses.

Parameters

- **model** (*oemof.solph.network.EnergySystem object*) – See the oemof documentation for more information.
- **dict_asset** (*dict*) – Contains information about the chp like (not exhaustive): efficiency, installed capacity ('installedCap'), information on the busses the chp is connected to ('inflow_direction', 'outflow_direction'), beta coefficient.
- **busses** (*dict*)
- **sinks** (*dict, optional*)
- **sources** (*dict, optional*)
- **transformers** (*dict*)
- **storages** (*dict, optional*)

- **extractionTurbineCHP** (*dict, optional*)

Notes

The transformer has either multiple input or multiple output busses.

The following functions are used for defining the chp: * *chp_fix()* * *chp_optimize()* for investment optimization

Tested with: - test_chp_fix_cap() - test_chp_optimize_cap() - test_chp_missing_beta() - test_chp_wrong_beta_formatting() - test_chp_wrong_efficiency_formatting() - test_chp_wrong_outflow_bus_energy_vector()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with chp object.

multi_vector_simulator.D1_model_components.**chp_fix**(*model*, *dict_asset*, ***kwargs*)

Extraction turbine chp from Oemof solph. Extraction turbine must have one input and two outputs .. rubric:: Notes

Tested with: - test_to_be_written()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the extraction turbine component.

multi_vector_simulator.D1_model_components.**chp_optimize**(*model*, *dict_asset*, ***kwargs*)

Extraction turbine chp from Oemof solph. Extraction turbine must have one input and two outputs .. rubric:: Notes

Tested with: - test_to_be_written()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the extraction turbine component.

multi_vector_simulator.D1_model_components.**sink**(*model*, *dict_asset*, ***kwargs*)

Defines a sink component specified in *dict_asset*.

Depending on the 'value' of 'optimizeCap' in *dict_asset* the sink is defined with a fixed capacity or a capacity to be optimized. If a time series is provided for the sink (key 'timeseries' in *dict_asset*) it is defined as a non dispatchable sink, otherwise as dispatchable sink. The sink has multiple or a single input bus depending on the type of the key 'inflow_direction' in *dict_asset*.

Parameters

- **model** (*oemof.solph.network.EnergySystem object*) – See the oemof documentation for more information.
- **dict_asset** (*dict*) – Contains information about the storage like (not exhaustive): efficiency, installed capacity ('installedCap'), information on the busses the sink is connected to ('inflow_direction'),
- **busses** (*dict*)
- **sinks** (*dict*)
- **sources** (*dict, optional*)
- **transformers** (*dict, optional*)
- **storages** (*dict, optional*)

Notes

The following functions are used for defining the sink: * *sink_non_dispatchable()* * sink_dispatchable()

Tested with: - test_sink_non_dispatchable_single_input_bus() - test_sink_non_dispatchable_multiple_input_busses() - test_sink_dispatchable_single_input_bus() - test_sink_dispatchable_multiple_input_busses()

multi_vector_simulator.D1_model_components.**sink_demand_reduction**(*model*, *dict_asset*, ***kwargs*)

Defines a non dispatchable sink to serve critical and non-critical demand.

See *sink()* for more information, including parameters.

Notes

Tested with: - test_sink_non_dispatchable_single_input_bus() - test_sink_non_dispatchable_multiple_input_busses()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the sink object.

multi_vector_simulator.D1_model_components.**sink_dispatchable_optimize**(*model*, *dict_asset*, ***kwargs*)

Define a dispatchable sink.

The dispatchable sink is capacity-optimized, without any costs connected to the capacity of the asset. Applications of this asset type are: Feed-in sink, excess sink.

See *sink()* for more information, including parameters.

Notes

Tested with: - test_sink_dispatchable_single_input_bus() - test_sink_dispatchable_multiple_input_busses()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the sink object.

multi_vector_simulator.D1_model_components.**sink_non_dispatchable**(*model*, *dict_asset*, ***kwargs*)

Defines a non dispatchable sink.

See *sink()* for more information, including parameters.

Notes

Tested with: - test_sink_non_dispatchable_single_input_bus() - test_sink_non_dispatchable_multiple_input_busses()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the sink object.

multi_vector_simulator.D1_model_components.**source**(*model*, *dict_asset*, ***kwargs*)

Defines a source component specified in *dict_asset*.

Depending on the 'value' of 'optimizeCap' in *dict_asset* the source is defined with a fixed capacity or a capacity to be optimized. If a time series is provided for the source (key 'timeseries' in *dict_asset*) it is defined as a non dispatchable source, otherwise as dispatchable source. The source has multiple or a single output bus depending on the type of the key 'inflow_direction' in *dict_asset*.

Parameters

- **model** (*oemof.solph.network.EnergySystem object*) – See the oemof documentation for more information.
- **dict_asset** (*dict*) – Contains information about the storage like (not exhaustive): efficiency, installed capacity ('installedCap'), information on the busses the sink is connected to ('inflow_direction'),
- **busses** (** We should actually not allow multiple output*)
- **sinks** (*dict*)
- **sources** (*dict, optional*)
- **transformers** (*dict, optional*)
- **storages** (*dict, optional*)
- **TODOS**
- **^^^^^**
- **busses**
- **then** (*probably - because a pv would*)
- **example** (*feed in twice as much as solar_gen_specific for*)
- **#121** (*see issue*)

Notes

The following functions are used for defining the source: * *source_dispatchable_fix()* * *source_dispatchable_optimize()* * *source_non_dispatchable_fix()* * *source_non_dispatchable_optimize()*

Tested with: - test_source_non_dispatchable_optimize() - test_source_non_dispatchable_fix() - test_source_dispatchable_optimize_normalized_timeseries() - test_source_dispatchable_optimize_timeseries_not_normalized_tim - test_source_dispatchable_fix_normalized_timeseries() - test_source_dispatchable_fix_timeseries_not_normalized_timeseries()

multi_vector_simulator.D1_model_components.**source_dispatchable_fix**(*model*, *dict_asset*, ***kwargs*)

Defines a dispatchable source with a fixed capacity.

See *source()* for more information, including parameters.

Notes

Tested with: - test_source_dispatchable_fix_normalized_timeseries() - test_source_dispatchable_fix_timeseries_not_normalized_t

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the source object.

multi_vector_simulator.D1_model_components.**source_dispatchable_optimize**(*model*, *dict_asset*, ***kwargs*)

Defines a dispatchable source with a fixed capacity.

See *source()* for more information, including parameters.

Notes

Tested with: - test_source_dispatchable_optimize_normalized_timeseries() - test_source_dispatchable_optimize_timeseries_not_normalized_timeseries()

Returns

Indirectly updated *model* and dict of asset in *kwargs* with the source object.

multi_vector_simulator.D1_model_components.**source_non_dispatchable_fix**(*model*, *dict_asset*, ***kwargs*)

Defines a non dispatchable source with a fixed capacity.

See *source()* for more information, including parameters.

Notes

Tested with: - test_source_non_dispatchable_fix()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the source object.

multi_vector_simulator.D1_model_components.**source_non_dispatchable_optimize**(*model*, *dict_asset*, ***kwargs*)

Defines a non dispatchable source with a capacity to be optimized.

See *source()* for more information, including parameters.

Notes

Tested with: - test_source_non_dispatchable_optimize()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the source object.

multi_vector_simulator.D1_model_components.**storage**(*model*, *dict_asset*, ***kwargs*)

Defines a storage component specified in *dict_asset*.

Depending on the 'value' of 'optimizeCap' in *dict_asset* the storage is defined with a fixed capacity or a capacity to be optimized.

Parameters

- **model** (*oemof.solph.network.EnergySystem object*) – See the oemof documentation for more information.
- **dict_asset** (*dict*) – Contains information about the storage like (not exhaustive): efficiency, installed capacity ('installedCap'), information on the busses the storage is connected to ('inflow_direction', 'outflow_direction'),
- **busses** (*dict*)
- **sinks** (*dict, optional*)
- **sources** (*dict, optional*)
- **transformers** (*dict, optional*)
- **storages** (*dict*)

Notes

The following functions are used for defining the storage: * *storage_fix()* * *storage_optimize()*

Tested with: - test_storage_optimize() - test_storage_fix()

multi_vector_simulator.D1_model_components.**storage_fix**(*model*, *dict_asset*, ***kwargs*)

Defines a storage with a fixed capacity.

See *storage()* for more information, including parameters.

Notes

Tested with: - test_storage_fix()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the storage object.

multi_vector_simulator.D1_model_components.**storage_optimize**(*model*, *dict_asset*, ***kwargs*)

Defines a storage with a capacity to be optimized.

See *storage()* for more information, including parameters.

Notes

Tested with: - test_storage_optimize() - test_storage_optimize_investment_minimum_0_float() - test_storage_optimize_investment_minimum_0_time_series() - test_storage_optimize_investment_minimum_1_rel_float() - test_storage_optimize_investment_minimum_1_abs_float() - test_storage_optimize_investment_minimum_1_rel_times_series() - test_storage_optimize_investment_minimum_1_abs_times_series()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the storage object.

multi_vector_simulator.D1_model_components.**transformer**(*model*, *dict_asset*, ***kwargs*)

Defines a transformer component specified in *dict_asset*.

Depending on the 'value' of 'optimizeCap' in *dict_asset* the transformer is defined with a fixed capacity or a capacity to be optimized. The transformer has multiple or single input or output busses depending on the types of keys 'inflow_direction' and 'outflow_direction' in *dict_asset*.

Parameters

- **model** (*oemof.solph.network.EnergySystem object*) – See the oemof documentation for more information.
- **dict_asset** (*dict*) – Contains information about the transformer like (not exhaustive): efficiency, installed capacity ('installedCap'), information on the busses the transformer is connected to ('inflow_direction', 'outflow_direction').
- **busses** (*dict*)
- **sinks** (*dict, optional*)
- **sources** (*dict, optional*)
- **transformers** (*dict*)
- **storages** (*dict, optional*)

Notes

The transformer has either multiple input or multiple output busses.

The following functions are used for defining the transformer: * *transformer_constant_efficiency_fix()* * *transformer_constant_efficiency_optimize()*

Tested with: - test_transformer_optimize_cap_single_busses() - test_transformer_optimize_cap_multiple_input_busses() - test_transformer_optimize_cap_multiple_output_busses() - test_transformer_fix_cap_single_busses() - test_transformer_fix_cap_multiple_input_busses() - test_transformer_fix_cap_multiple_output_busses()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with transformer object.

multi_vector_simulator.D1_model_components.**transformer_constant_efficiency_fix**(*model*, *dict_asset*, ***kwargs*)

Defines a transformer with constant efficiency and fixed capacity.

See *transformer()* for more information, including parameters.

Notes

Tested with: - test_transformer_fix_cap_single_busses() - test_transformer_fix_cap_multiple_input_busses() - test_transformer_fix_cap_multiple_output_busses()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the transformer object.

multi_vector_simulator.D1_model_components.**transformer_constant_efficiency_optimize**(*model*, *dict_asset*, ***kwargs*)

Defines a transformer with constant efficiency and a capacity to be optimized.

See *transformer()* for more information, including parameters.

Notes

Tested with: - test_transformer_optimize_cap_single_busses() - test_transformer_optimize_cap_multiple_input_busses() - test_transformer_optimize_cap_multiple_output_busses()

Return type
Indirectly updated *model* and dict of asset in *kwargs* with the transformer object.

Module D2 - Model constraints

This module gathers all constraints that can be added to the MVS optimisation. we will probably require another input CSV file or further parameters in simulation_settings.

Future constraints are discussed in issue #133 (https://github.com/rl-institut/multi-vector-simulator/issues/133)

constraints should be tested in-code (examples) and by comparing the lp file generated.

multi_vector_simulator.D2_model_constraints.**add_constraints**(*local_energy_system*, *dict_values*, *dict_model*)

Adds all constraints activated in constraints.csv to the energy system model.

Possible constraints: - Minimal renewable factor constraint :param local_energy_system: Energy system model generated from oemof-solph for the energy system scenario, including all energy system assets. :type local_energy_system: :oemof-solph: <oemof.solph.model> :param dict_values: All simulation parameters :type dict_values: dict :param dict_model: Dictionary including the oemof-solph component assets, which need to be connected with constraints :type dict_model: dict of :oemof-solph: <oemof.solph.assets>

Returns

local_energy_system – Updated object local_energy_system with the additional constraints and bounds.

Return type

oemof-solph
<oemof.solph.model>

Notes

The constraints can be validated by evaluating the LP file. Additionally, there are validation tests in *E4_verification_of_constraints*.

Tested with: - D2.test_add_constraints_maximum_emissions() - D2.test_add_constraints_maximum_emissions_None() - D2.test_add_constraints_minimal_renewable_share() - D2.test_add_constraints_minimal_renewable_share_is_0() - D2.test_add_constraints_net_zero_energy_requirement_is_true() - D2.test_add_constraints_net_zero_energy_requirement_is_fa

multi_vector_simulator.D2_model_constraints.**constraint_maximum_emissions**(*model*, *dict_values*, *dict_model=None*)

Resulting in an energy system adhering to a maximum amount of emissions.

Parameters

- **model** – Model to which constraint is added.
- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*None*) – To match other constraint function's format

Notes

Tested with: - D2.test_constraint_maximum_emissions()

multi_vector_simulator.D2_model_constraints.**constraint_minimal_degree_of_autonomy**(*model*, *dict_values*, *dict_model*)

Resulting in an energy system adhering to a minimal degree of autonomy.

Please be aware that the minimal degree of autonomy is not applied to each sector individually, but to the overall energy system (via energy carrier weighting).

Parameters

- **model** – Model to which constraint is added.
- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Notes

The renewable factor of the whole energy system has to adhere for following constraint:

$$minimaldegreeofautonomy \cdot (\sum localdemand \cdot weightingfactor) <= \sum localdemand \cdot weightingfactor - \sum consu$$

Tested with: - Test_Constraints.test_benchmark_minimal_degree_of_autonomy()

multi_vector_simulator.D2_model_constraints.**constraint_minimal_renewable_share**(*model*, *dict_values*, *dict_model*)

Resulting in an energy system adhering to a minimal renewable factor.

Please be aware that the renewable factor that has to adhere to the minimal renewable factor is not the one of one specific sector, but of the overall energy system. This means that eg. 1 kg H2 is produced renewably, it goes into account with a heavier weighting factor then one renewably produced electricity unit.

Parameters

- **model** – Model to which constraint is added.
- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Notes

The renewable factor of the whole energy system has to adhere for following constraint:

$$minimalrenewablefactor <= \frac{\sum renewablegeneration \cdot weightingfactor}{\sum renewablegeneration \cdot weightingfactor + \sum non - renewablegeneration \cdot weighting}$$

Tested with: - Test_Constraints.test_benchmark_minimal_renewable_share_constraint()

multi_vector_simulator.D2_model_constraints.**constraint_net_zero_energy**(*model*, *dict_values*, *dict_model*)

Resulting in an energy system that is a net zero energy (NZE) or plus energy system.

Please be aware that the NZE constraint is not applied to each sector individually, but to the overall energy system (via energy carrier weighting).

Parameters

- **model** – Model to which constraint is added.
- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Notes

The constraint reads as follows:

$$\sum_i E_{feedin,DSO}(i) \cdot w_i - E_{consumption,DSO}(i) \cdot w_i >= 0$$

Tested with: - Test_Constraints.test_net_zero_energy_constraint()

multi_vector_simulator.D2_model_constraints.**prepare_constraint_minimal_renewable_share**(*dict_values*, *dict_model*)

Prepare creating the minimal renewable factor constraint by processing dict_values

Parameters

- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Returns

- **renewable_assets** (*dict*) – Dictionary of all assets with renewable generation in the energy system. Defined by: oemof_solph_object_asset, weighting_factor_energy_carrier, renewable_share_asset_flow, oemof_solph_object_bus
- **non_renewable_assets** (*dict*) – Dictionary of all assets with renewable generation in the energy system. Defined by: oemof_solph_object_asset, weighting_factor_energy_carrier, renewable_share_asset_flow, oemof_solph_object_bus

multi_vector_simulator.D2_model_constraints.**prepare_demand_assets**(*dict_values*, *dict_model*)

Perpare demand assets by processing *dict_values*

Used for the following constraints: - minimal degree of autonomy

Parameters

- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Notes

Tested with: - test_prepare_demand_assets()

Returns
demands – Dictionary of all assets with all demands in the energy system. Defined by: oemof_solph_object_asset, weighting_factor_energy_carrier, oemof_solph_object_bus

Return type
dict

multi_vector_simulator.D2_model_constraints.**prepare_energy_provider_consumption_sources**(*dict_values*, *dict_model*)

Prepare energy provider consumption sources by processing *dict_values*.

Used for the following constraints: - minimal degree of autonomy - net zero energy (NZE)

Parameters

- **dict_values** (*dict*) – All simulation parameters

- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Notes

Tested with: - test_prepare_energy_provider_consumption_sources()

Returns
energy_provider_consumption_sources – Dictionary of all assets that are sources for the energy consumption from energy providers in the energy system. Defined by: oemof_solph_object_asset, weighting_factor_energy_carrier, oemof_solph_object_bus

Return type
dict

multi_vector_simulator.D2_model_constraints.**prepare_energy_provider_feedin_sinks**(*dict_values*, *dict_model*)

Prepare energy provider feedin sinks by processing *dict_values*.

Used for the following constraints: - net zero energy (NZE)

Parameters

- **dict_values** (*dict*) – All simulation parameters
- **dict_model** (*dict of :oemof-solph: <oemof.solph.assets>*) – Dictionary including the oemof-solph component assets, which need to be connected with constraints

Notes

Tested with:

- test_prepare_energy_provider_feedin_sinks()

Returns
energy_provider_feedin_sinks – Dictionary of all assets that are sinks for the energy feed-in to energy providers in the energy system. Defined by: oemof_solph_object_asset, weighting_factor_energy_carrier, oemof_solph_object_bus

Return type
dict

4.1.6 Post-processing and evaluation

Module E0 - evaluation

Module E0 evaluates the oemof results and calculates the KPI - define dictionary entry for kpi matrix - define dictionary entry for cost matrix - store all results to matrix

multi_vector_simulator.E0_evaluation.**evaluate_dict**(*dict_values*, *results_main*, *results_meta*)

Processes all simulation outputs by evaluating oemof results, asset capacities and dispatch as well as all KPIs.

Parameters

- **dict_values** (*dict*) – simulation parameters
- **results_main** (*DataFrame*) – oemof simulation results as output by processing.results()

- **results_meta** (*DataFrame*) – oemof simulation meta information as output by processing.meta_results()

Notes

Tested with: - test_E0.evaluation.test_evaluate_dict_append_new_fields() - test_E0.evaluation.test_evaluate_dict_important_fields_in_output_dict() - test_E0.evaluation.test_evaluate_dict_fields_values_in_

multi_vector_simulator.E0_evaluation.**initalize_kpi**(*dict_values*)

Adds basic structure of KPI to dict_values to gather them later on.

Parameters
dict_values (*dict*) – All simulation data, but without any results

Return type
Updated dict_values with KPI structure, made up from KPI_COST_MATRIX, KPI_SCALAR_MATRIX and KPI_SCALARS_DICT.

multi_vector_simulator.E0_evaluation.**process_fixcost**(*dict_values*)

Adds fix costs of the project to the economic evaluation of the energy system.

Parameters
dict_values (*dict*) – All simulation data with inputs and results of the assets

Return type
Updated dict_values with costs attributed in dict values also appended to the dict_values[KPI] (scalar results)

Notes

Function is tested with: - test_E0_evaluation.test_process_fixcost()

multi_vector_simulator.E0_evaluation.**store_result_matrix**(*dict_kpi*, *dict_asset*, *fix_cost=False*)

Storing results to vector and then result matrix for saving it in csv. Defined value types: Str, bool, None, dict (with key "VALUE"), else (int, float)

Parameters

- **dict_kpi** (*dict*) – dictionary with the two kpi groups (costs and scalars), which are pd.DF
- **dict_asset** (*dict*) – all information known for a specific asset
- **fix_cost** (*Boolean*) – If fix_cost is True, then no new row is added to KPI_SCALAR_MATRIX, as there are no KPI to update. Costs in KPI_COST_MATRIX however are added.

Return type
Updated dict_kpi DF, with new row of kpis of the specific asset.

Module E1 process results

Module E1 processes the oemof results. - receive time series per bus for all assets - write time series to dictionary - get optimal capacity of optimized assets - add the evaluation of time series

multi_vector_simulator.E1_process_results.**add_info_flows**(*evaluated_period*, *dict_asset*, *flow*, *type=None*, *bus_name=None*)

Adds *flow* and total flow amongst other information to *dict_asset*.

Parameters

- **evaluated_period** (*int*) – The number of days simulated with the energy system model.
- **dict_asset** (*dict*) – Contains information about the asset *flow* belongs to.
- **flow** (*pd.Series*) – Time series of the flow.
- **type** (*str, default: None*) – type of the flow, only exception is "STORAGE_CAPACITY".
- **bus_name** (*str or None*) – The name of the current bus (for asset connected to more than one bus)

Returns

- Indirectly updates *dict_asset* with the *flow*, the total flow, the annual
- *total flow, the maximum of the flow ('peak_flow') and the average value of*
- *the flow ('average_flow'). As Storage capacity is not a flow, an aggregation of the timeseries does not make sense*
- *and the parameters TOTAL_FLOW, ANNUAL_TOTAL_FLOW, PEAK_FLOW, AVERAGE_FLOW are added set to None.*

Notes

Tested with: - E1.test_add_info_flows_365_days() - E1.test_add_info_flows_1_day() - E1.test_add_info_flows_storage_capacity()

multi_vector_simulator.E1_process_results.**convert_components_to_dataframe**(*dict_values*)

Dataframe used for the component table of the report

Parameters
dict_values (*dict*) – output values of MVS

Return type
pandas.DataFrame

Notes

Tested with:

- test_E1_process_results.test_convert_components_to_dataframe()

multi_vector_simulator.E1_process_results.**convert_cost_matrix_to_dataframe**(*dict_values*)

Dataframe used for the cost matrix table of the report

Parameters
dict_values (*dict*) – output values of MVS

Return type
pandas.DataFrame

multi_vector_simulator.E1_process_results.**convert_costs_to_dataframe**(*dict_values*)

Dataframe used for the costs piecharts of the report

Parameters
dict_values (*dict*) – output values of MVS

Return type
pandas.DataFrame

multi_vector_simulator.E1_process_results.**convert_demand_to_dataframe**(*dict_values*, *sector_demands=None*)

Dataframe used for the demands table of the report

Parameters

- **dict_values** (*dict*) – output values of MVS
- **sector_demands** (*str*) – Name of the sector of the energy system whose demands must be returned as a df by this function Default: None

Return type
pandas.DataFrame

multi_vector_simulator.E1_process_results.**convert_kpi_sector_to_dataframe**(*dict_values*)

Processes the sector KPIs so that they can be included in the report

Parameters
dict_values (*dict*) – output values of MVS

Returns
kpi_sectors_dataframe – Dataframe to be displayed as a table in the report

Return type
pandas.DataFrame

Notes

Currently, as the KPI_UNCOUPLED_DICT does not hold any units, the table printed in the report is unit-les.

multi_vector_simulator.E1_process_results.**convert_scalar_matrix_to_dataframe**(*dict_values*)

Dataframe used for the scalar matrix table of the report

Parameters
dict_values (*dict*) – output values of MVS

Return type
pandas.DataFrame

multi_vector_simulator.E1_process_results.**convert_scalars_to_dataframe**(*dict_values*)

Processes the scalar system-wide KPI so that they can be included in the report

Parameters
dict_values (*dict*) – output values of MVS

Returns
kpi_scalars_dataframe – Dataframe to be displayed as a table in the report

Return type
pandas.DataFrame

Notes

Currently, as the KPI_SCALARS_DICT does not hold any units, the table printed in the report is unit-les.

multi_vector_simulator.E1_process_results.**cut_below_micro**(*value*, *label*)

Function trims results of oemof optimization to positive values and rounds to 0, if within a certain precision threshold (of -10^-6)

Oemof termination is dependent on the simulation settings of oemof solph. Thus, it can terminate the optimization if the results are with certain bounds, which can sometimes lead to negative decision variables (capacities, flows). Negative values do not make sense in this context. If the values are between -10^-6 and 0, we assume that they can be rounded to 0, as they result from the precision settings of the solver. In that case the value is overwritten for the futher post-processing. This should also avoid SOC timeseries with doubtful values outside of [0,1]. If any value is a higher negative value then the threshold, its value is not changed but a warning raised. Similarily, if a positive devision variable is detected that has a value lower then the theshold, it is assumed that this only happends because of the solver settings, and the values below the theshold are rounded to 0.

Parameters

- **value** (*float or pd.Series*) – Decision variable determined by oemof
- **label** (*str*) – String to be mentioned in the debug messages

Returns

value – Decision variable with rounded values in case that slight negative values or positive values were observed.

Return type

float of pd.Series

Notes

Tested with: - E1.test_cut_below_micro_scalar_value_below_0_larger_threshold - E1.test_cut_below_micro_scalar_value_below_0_smaller_threshold - E1.test_cut_below_micro_scalar_value_0 - E1.test_cut_below_micro_scalar_value_larger_0 - E1.test_cut_below_micro_scalar_value_larger_0_smaller_threshold - E1.test_cut_below_micro_pd_Series_below_0_larger_threshold - E1.test_cut_below_micro_pd_Series_below_0_smaller_thresh - E1.test_cut_below_micro_pd_Series_0 - E1.test_cut_below_micro_pd_Series_larger_0 - E1.test_cut_below_micro_pd_Series_larger_0_smaller_threshold

multi_vector_simulator.E1_process_results.**get_flow**(*settings*, *bus*, *dict_asset*, *flow_tuple*, *multi_bus=None*)

Adds flow of *bus* and total flow amongst other information to *dict_asset*.

Depending on *direction* the input or the output flow is used.

Parameters

- **settings** (*dict*) – Contains simulation settings from *simulation_settings.csv* with additional information like the amount of time steps simulated in the optimization ('periods').
- **bus** (*dict*) –

  Contains information about a specific bus. Information about the scalars, if they exist, like investment or initial capacity in key 'scalars' (pd.Series) and the flows between the component and the bus(ses) in key 'sequences' (pd.DataFrame).
- **dict_asset** (*dict*) – Contains information about the asset.
- **flow_tuple** (*tuple*) – Entry of the oemof-solph outputs to be evaluated

- **multi_bus** (*str or None*) – The name of the current bus (for asset connected to more than one bus)

Returns

- Indirectly updates *dict_asset* with the flow of *bus*, the total flow, the annual
- *total flow, the maximum of the flow ('peak_flow') and the average value of*
- *the flow ('average_flow').*

multi_vector_simulator.E1_process_results.**get_optimal_cap**(*bus*, *dict_asset*, *flow_tuple*)

Retrieves optimized capacity of asset specified in *dict_asset*.

Parameters

- **bus** (*dict*) – Contains information about the busses linked to the asset specified in *dict_asset*. Information about the scalars like investment or initial capacity in key 'scalars' (pd.Series) and the flows between the component and the busses in key 'sequences' (pd.DataFrame).
- **dict_asset** (*dict*) – Contains information about the asset.
- **flow_tuple** (*tuple*) – Key of the oemof-solph outputs dict mapping the value to be evaluated

Returns

- Indirectly updated *dict_asset* with optimal capacity to be added
- *('optimizedAddCap').*
- *TODOS*
- ^^^^
- * *direction as optimal parameter or with default value None (direction is* – not needed if 'optimizeCap' is not in *dict_asset* or if it's value is False

multi_vector_simulator.E1_process_results.**get_parameter_to_be_evaluated_from_oemof_results**(*asset_group*, *asset_label*)

Determine the parameter that needs to be evaluated to determine an asset`s optimized flow and capacity.

Parameters

- **asset_group** (*str*) – Asset group to which the evaluated asset belongs
- **asset_label** (*str*) – Label of the asset, needed for log message

Returns

parameter_to_be_evaluated – Parameter that will be processed to get the dispatch and capacity of an asset

Return type

str

Notes

Tested by: - test_get_parameter_to_be_evaluated_from_oemof_results()

multi_vector_simulator.E1_process_results.**get_results**(*settings*, *bus_data*, *dict_asset*, *asset_group*)

Reads results of the asset defined in *dict_asset* and stores them in *dict_asset*.

Parameters

- **settings** (*dict*) – Contains simulation settings from *simulation_settings.csv* with additional information like the amount of time steps simulated in the optimization ('periods').
- **bus_data** (*dict*) – Contains information about all busses in a nested dict. 1st level keys: bus names; 2nd level keys:

  'scalars': (pd.Series) (does not exist in all dicts) 'sequences': (pd.DataFrame) - contains flows between components and busses
- **dict_asset** (*dict*) – Contains information about the asset.
- **asset_group** (*str*) – Asset group to which the evaluated asset belongs

Return type

Indirectly updates *dict_asset* with results.

multi_vector_simulator.E1_process_results.**get_state_of_charge_info**(*dict_asset*)

Adds state of charge timeseries and average value of the timeseries to the storage dict.

Parameters

dict_asset (*dict*) – Dict of the asset, specifically including the STORAGE_CAPACITY

Return type

Updated dict_asset

Notes

Tested with: - E1.test_get_state_of_charge_info()

multi_vector_simulator.E1_process_results.**get_storage_results**(*settings*, *storage_bus*, *dict_asset*)

Reads storage results of simulation and stores them in *dict_asset*.

Parameters

- **settings** (*dict*) – Contains simulation settings from *simulation_settings.csv* with additional information like the amount of time steps simulated in the optimization ('periods').
- **storage_bus** (*dict*) – Contains information about the storage bus. Information about the scalars like investment or initial capacity in key 'scalars' (pd.Series) and the flows between the component and the busses in key 'sequences' (pd.DataFrame).
- **dict_asset** (*dict*) – Contains information about the storage like capacity, charging power, etc.

Returns

- Indirectly updates *dict_asset* with simulation results concerning the
- *storage*.

multi_vector_simulator.E1_process_results.**get_timeseries_per_bus**(*dict_values*, *bus_data*)

Reads simulation results of all busses and stores time series.

Parameters

- **dict_values** (*dict*) – Contains all input data of the simulation.
- **bus_data** (*dict Contains information about all busses in a nested dict.*) – 1st level keys: bus names; 2nd level keys:

  'scalars': (pd.Series) (does not exist in all dicts) 'sequences': (pd.DataFrame) - contains flows between components and busses

Notes

Tested with: - test_get_timeseries_per_bus_two_timeseries_for_directly_connected_storage()

#Todo: This is a duplicate of the *E1.get_flow()* assertions, and thus *E1.cut_below_micro* is applied twice for each flow. This should rather be merged into the other functions.

Return type
Indirectly updated *dict_values* with 'optimizedFlows' - one data frame for each bus.

multi_vector_simulator.E1_process_results.**get_tuple_for_oemof_results**(*asset_label*, *asset_group*, *bus*)

Determines the tuple with which to access the oemof-solph results

The order of the parameters in the tuple depends on the direction of the flow. If the asset is defined... a) ...by its influx from a bus, the bus has to be named first in the touple b) ...by its outflux into a bus, the asset has to be named first in the touple

Parameters

- **asset_label** (*str*) – Name of the asset
- **asset_group** (*str*) – Asset group the asset belongs to
- **bus** (*str*) – Bus that is to be accessed for the asset´s information

Returns
flow_tuple – Keys to be accessed in the oemof-solph results

Return type
tuple of str

Notes

Tested with - test_get_tuple_for_oemof_results()

multi_vector_simulator.E1_process_results.**get_units_of_cost_matrix_entries**(*dict_economic*, *kpi_list*)

Determines the units of the costs KPI to be stored to :class: DataFrame.

Parameters

- **dict_economic** – Economic project data
- **kpi_list** – List of cost matrix entries

Returns
unit_list – List of units for the :class: DataFrame to be created

Return type
list

multi_vector_simulator.E1_process_results.**translate_optimizeCap_from_boolean_to_yes_no**(*optimize_cap*)

Translates the boolean OPTIMIZE_CAP to a yes-no value for readability of auto report

Parameters
optimize_cap (*bool*) – Setting whether asset is optimized or not

Returns
optimize – If OPTIMIZE_CAP==True: "Yes", else "No".

Return type
str

Notes

Tested with: - test_E1_process_results.test_translate_optimizeCap_from_boolean_to_yes_no()

Module E2 - Economic processing

The module processes the simulation results regarding economic parameters: - calculate lifetime expenditures based on variable energy flows - calculate lifetime investment costs - calculate present value of an asset - calculate revenue - calculate yearly cash flows of whole project for project lifetime (cash flow projection) - calculate fuel price expenditures calculate upfront investment costs - calculate operation management costs (FOM) - calculate upfront investment costs (UIC) - calculate annuity per asset - calculate annuity for the whole project - calculate net present value - calculate levelised cost of energy - calculate levelised cost of energy carriers (electricity, H2, heat)

exception multi_vector_simulator.E2_economics.**MissingParametersForEconomicEvaluation**

Warning if one or more parameters are missing for economic post-processing of an asset

multi_vector_simulator.E2_economics.**all_list_in_dict**(*dict_asset*, *list*)

Checks if all items of a list are withing the keys of a dictionary

Parameters

- **dict_asset** (*dict*) – Dict with the keys to be evaluated
- **list** (*list*) – List of keys (parameter in strings) that should be in dict

Returns
boolean – True: All items in keys of the dict False: At least one item is not in keys of the dict

Return type
bool

multi_vector_simulator.E2_economics.**calculate_costs_replacement**(*specific_replacement_of_initial_capacity*, *specific_replacement_of_optimized_capacity*, *initial_capacity*, *optimized_capacity*)

Calculate (the present value of) the replacement costs over the project lifetime

Parameters

- **specific_replacement_of_initial_capacity** (*float*) – Per-unit replacement costs of an asset that was pre-existing at the location
- **specific_replacement_of_optimized_capacity** (*float*) – Per-unit replacement costs of an asset that is to be installed
- **initial_capacity** (*float*) – Initial capacity installed

- **optimized_capacity** (*float*) – Additional capacity to be installed, as optimized

Returns
costs_replacements – Aggregated replacement costs over the project lifetime

Return type
float

multi_vector_simulator.E2_economics.**calculate_costs_upfront_investment**(*specific_cost*, *capacity*, *development_costs*)

Calculate investment costs of an asset Depending on the specific_cost provided, either the total asset's lifetime investment costs or the upfront investment costs are calculated,

Parameters

- **specific_cost** (*float*) –
  a) Specific per-unit investment costs of an asset over its lifetime, including all replacement costs
  b) Specific per-unit investment costs of an asset in year 0
- **capacity** (*float*) – Capacity to be installed
- **development_costs** (*float*) – Fix development costs, ie. an expense not related to the capacity that is installed. Could be planning costs of the asset.

Returns
costs_investment – a) Total investment costs of an asset over its lifetime, including all replacement costs b) Upfront investment costs in year 0

Return type
float

multi_vector_simulator.E2_economics.**calculate_dispatch_expenditures**(*dispatch_price*, *flow*, *asset*)

Calculate the expenditures connected to an asset due to its dispatch

Parameters

- **dispatch_price** (*float, int or pd.Series*) – Dispatch price of an asset (variable costs), ie. how much has to be paid for each unit of dispatch Raises error if type does not match a) lifetime_price_dispatch (taking into account all years of operation) b) price_dispatch (taking into account one year of operation)
- **flow** (*pd.Series*) – Dispatch of the asset
- **asset** (*str*) – Label of the asset

Returns

- *a) Total dispatch expenditures of an asset*
- *b) Annual dispatch expenditures of an asset*

multi_vector_simulator.E2_economics.**calculate_operation_and_management_expenditures**(*specific_om_cost*, *installed_capacity*, *optimized_add_capacity*)

Calculate operation and management expenditures

Parameters

- **specific_om_cost** (*float*) –

a) specific operation and management costs per unit in year 0

b) specific operation and management costs per unit for the whole project lifetime

- **installed_capacity** (*float*) – Capacity installed initially
- **optimized_add_capacity** (*float*) – Capacity installed within the optimization scenario

Returns
costs_operation_and_management – a) Operation and management expenditures in year 0 b) Total operation and management expenditures over the project lifetime

Return type
float

multi_vector_simulator.E2_economics.**calculate_total_asset_costs_over_lifetime**(*costs_investment*, *cost_operational_expenditures*)

Calculate costs of an asset over whole lifetime

Parameters

- **costs_investment** (*float*) – Investment costs over whole lifetime
- **cost_operational_expenditures** (*float*) – Operation and management as well as dispatch expenditures over whole lifetime

Returns
total_asset_costs_over_lifetime – costs of an asset over whole lifetime, including upfront investment costs, development costs, replacement costs, operation and management expenditures, dispatch expenditures

Return type
float

multi_vector_simulator.E2_economics.**calculate_total_capital_costs**(*upfront*, *replacement*)

Calculate total capital expenditures

Parameters

- **upfront** (*float*) – Upfront investments at t=0, including development costs
- **replacement** (*float*) – Replacement costs of pre-installed and new assets

Returns
cost_total_investment – Total capital costs

Return type
float

multi_vector_simulator.E2_economics.**calculate_total_operational_expenditures**(*operation_and_management_expe*
dis-
patch_expenditures)

Calculate total expenditures of an asset (operational costs)

Parameters

- **operation_and_management_expenditures** (*float*) –

a) operation and management expenditures per annum for the installed capacity

b) operation and management expenditures for whole project lifetime for the installed capacity

- **dispatch_expenditures** (*float*) –

a) dispatch expenditures per annum for the installed capacity

b) dispatch expenditures for whole project lifetime for the installed capacity

Returns

total_operational_expenditures – a) total operational expenditures per annum for installed capacity b) total operational expenditures for whole project lifetime for installed capacity

Return type

float

multi_vector_simulator.E2_economics.**get_costs**(*dict_asset*, *economic_data*)

Calculates economic KPI of the asset handed to the function

Parameters

- **dict_asset** (*dict*) – Asset to be evaluated. Warning messages in place in case that the asset should not be evaluated.
- **economic_data** (*dict*) – Economic data of the project

Returns

- *Updated dict_asset with following KPI*
- *- COST_INVESTMENT*
- *- COST_UPFRONT*
- *- COST_REPLACEMENT*
- *- COST_TOTAL*
- *- COST_OM*
- *- COST_DISPATCH*
- *- COST_OPERATIONAL_TOTAL*
- *- ANNUITY_TOTAL*
- *- ANNUITY_OM*
- *Tested with*
- *- test_all_cost_info_parameters_added_to_dict_asset()*
- *- Test_Economic_KPI.test_benchmark_Economic_KPI_C2_E2()*

multi_vector_simulator.E2_economics.**lcoe_assets**(*dict_asset*, *asset_group*)

Calculates the levelized cost of electricity (lcoe) of each asset. [Follow this link for information](docs/MVS_Outputs.rst)

Parameters

- **dict_asset** (*dict*) – Dictionary defining an asset
- **asset_group** (*str*) – Defining to which asset group the asset belongs

Returns

- *Updates the asset dictionary with the calculated LCOE_ASSET.*
- **Storages have four values LCOE_ASSET** (*One for the overall storage including all costs, and one each for the components.*)

Notes

$$LCOE\_ASSET = \frac{A}{E_{throughput}}$$

If $E_{throughput} = 0, LCOE\_ASSET = 0$

Module E3 - Indicator calculation

In module E3 the technical KPI are evaluated: - calculate renewable share - calculate degree of autonomy (DA) - calculate degree of net zero energy (NZE) - calculate total generation of each asset and total_internal_generation - calculate total feedin electricity equivalent - calculate energy flows between sectors - calculate degree of sector coupling - calculate onsite energy fraction (OEF) - calculate onsite energy matching (OEM)

multi_vector_simulator.E3_indicator_calculation.**add_degree_of_autonomy**(*dict_values*)

Determines degree of autonomy and adds KPI to dict_values

Parameters

dict_values (*dict*) – dict with all project information and results, after applying total_renewable_and_non_renewable_energy_origin and total_demand_and_excess_each_sector

Returns

- *None* – updated dict_values with the degree of autonomy
- *Tested with*
- *- test_add_degree_of_autonomy()*

multi_vector_simulator.E3_indicator_calculation.**add_degree_of_net_zero_energy**(*dict_values*)

Determines degree of net zero energy (NZE) and adds KPI to dict_values.

Parameters

dict_values (*dict*) – dict with all project information and results, after applying total_renewable_and_non_renewable_energy_origin and total_demand_and_excess_each_sector

Returns

updated dict_values with the degree of net zero energy

Return type

None

Notes

As for other KPI, we apply a weighting based on Electricity Equivalent.

Tested with - test_add_degree_of_net_zero_energy()

multi_vector_simulator.E3_indicator_calculation.**add_degree_of_sector_coupling**(*dict_values*)

Determines the aggregated flows in between the sectors and the Degree of Sector Coupling.

Takes into account the value of different energy carriers.

Parameters

dict_values (*dict*) – dictionary with all project inputs and results, specifically the energyConversion assets and the outputs.

Returns

- *Energy equivalent of total conversion flows*

- .. *math::* – E_{conversion,eq} = sum_{i}{E_{conversion} (i) cdot w_i} with i are conversion assets

multi_vector_simulator.E3_indicator_calculation.**add_levelized_cost_of_energy_carriers**(*dict_values*)

Adds levelized costs of all energy carriers and overall system to the scalar KPI.

Parameters
dict_values (*dict*) – All simulation inputs and results

Returns
Updated KPI_SCALAR_DICT

Return type
Add *ATTRIBUTED_COSTS* and *LCOeleq* for each energy carrier as well as *LCOeleq* for overall energy system

Notes

Tested with:

- test_E3_indicator_calculation.test_add_levelized_cost_of_energy_carriers_one_sector()
- test_E3_indicator_calculation.test_add_levelized_cost_of_energy_carriers_two_sectors()

multi_vector_simulator.E3_indicator_calculation.**add_onsite_energy_fraction**(*dict_values*)

Determines onsite energy fraction (OEF), i.e. self-consumption, and adds KPI to dict_values

Parameters
dict_values (*dict*) – dict with all project information and results after applying total_renewable_and_non_renewable_energy_origin

Returns

- *None* – updated dict_values with onsite energy fraction KPI
- *Tested with*
- *- test_add_onsite_energy_fraction()*

multi_vector_simulator.E3_indicator_calculation.**add_onsite_energy_matching**(*dict_values*)

Determines onsite energy matching (OEM), i.e. self-sufficiency, and adds KPI to dict_values

Parameters
dict_values (*dict*) – dict with all project information and results after applying total_renewable_and_non_renewable_energy_origin and total_demand_and_excess_each_sector and add_onsite_energy_fraction

Returns

- *None* – updated dict_values with onsite energy matching KPI
- *Tested with*
- *- test_add_onsite_energy_matching()*

multi_vector_simulator.E3_indicator_calculation.**add_renewable_factor**(*dict_values*)

Determination of renewable share of one sector

Parameters
dict_values – dict with all project information and results, after applying add_total_renewable_and_non_renewable_energy_origin

Returns
updated dict_values with renewable factor of each sector as well as system-wide indicator

Return type
type

Notes

Updates the KPI with RENEWABLE_FACTOR for each sector as well as system-wide KPI.

Tested with - test_renewable_factor_one_sector - test_renewable_factor_two_sectors - TestTechnicalKPI.renewable_factor_and_renewable_share_of_local_generation()

multi_vector_simulator.E3_indicator_calculation.**add_renewable_share_of_local_generation**(*dict_values*)

Determination of renewable share of local energy production

Parameters

dict_values
dict with all project information and results, after applying add_total_renewable_and_non_renewable_energy_origin

sector
Sector for which renewable share is being calculated

:returns: updated dict_values with renewable share of each sector as well as the system-wide KPI
:rtype: type
.. rubric:: Notes
Updates the KPI with RENEWABLE_SHARE_OF_LOCAL_GENERATION for each sector as well as system-wide KPI.
Tested with
*** test_renewable_share_of_local_generation_one_sector()**
*** test_renewable_share_of_local_generation_two_sectors()**
*** TestTechnicalKPI.renewable_factor_and_renewable_share_of_local_generation()**

multi_vector_simulator.E3_indicator_calculation.**add_specific_emissions_per_electricity_equivalent**(*dict_va*

Calculates the specific emissions of the energy system per kWheleq and adds KPI to *dict_values*.

Parameters
dict_values (*dict*) – All simulation inputs and results including TOTAL_EMISSIONS calculated in *E3.calculate_emissions_from_flow*.

Notes

This funtion is run after *E3.calculate_emissions_from_flow*.

Tested with: - E3.test_add_specific_emissions_per_electricity_equivalent()

Returns
Updated *dict_values* with SPECIFIC_EMISSIONS_ELEQ in kgCO2eq/kWheleq (UNIT_SPECIFIC_EMISSIONS).

Return type
None

multi_vector_simulator.E3_indicator_calculation.**add_total_consumption_from_provider_electricity_equival**

Determines the total consumption from energy providers with weighting of electricity equivalent.

Parameters
dict_values (*dict*) – dict with all project information and results

Returns
updated dict_values with KPI : - TOTAL_CONSUMPTION_FROM_PROVIDERS + electricity, - TOTAL_CONSUMPTION_FROM_PROVIDERS + electricity + SUFFIX_ELECTRICITY_EQUIVALENT - TOTAL_CONSUMPTION_FROM_PROVIDERS + SUFFIX_ELECTRICITY_EQUIVALENT

Return type
None

Notes

Tested with: - E3.test_add_total_consumption_from_provider_electricity_equivalent() - E3.test_add_total_consumption_from_provider_electricity_equivalent_two_providers_one_energy_carrier

multi_vector_simulator.E3_indicator_calculation.**add_total_emissions**(*dict_values*)

Calculates the total emission of the energy system in kgCO2eq/a and adds KPI to *dict_values*.

Parameters
dict_values (*dict*) – All simulation inputs and results

Returns
Updated *dict_values* with TOTAL_EMISSIONS of the energy system in kgCO2eq/a (UNIT_EMISSIONS).

Return type
None

Notes

Tested with: - E3.test_add_total_emissions()

multi_vector_simulator.E3_indicator_calculation.**add_total_feedin_electricity_equivalent**(*dict_values*)

Determines the total grid feed-in with weighting of electricity equivalent.

Parameters
dict_values (*dict*) – dict with all project information and results

Returns

- *None* – updated dict_values with KPI : total feedin
- *Tested with*
- *- test_add_total_feedin_electricity_equivalent()*
- *- test_add_total_feedin_electricity_equivalent_two_providers_one_energy_carrier*

multi_vector_simulator.E3_indicator_calculation.**add_total_renewable_and_non_renewable_energy_origin**(*dict_*

Identifies all renewable generation assets and summs up their total generation to total renewable generation

Parameters
dict_values – dict with all project input data and results up to E0

Returns
Updated dict_values with total internal/overall renewable and non-renewable energy origin

Return type
type

Notes

Tested with - test_total_renewable_and_non_renewable_origin_of_each_sector()

multi_vector_simulator.E3_indicator_calculation.**all_totals**(*dict_values*)

Calculate sum of all cost parameters

Parameters
dict_values – dict all input parameters and results up to E0

Returns
List of all total cost parameters for the project

Return type
type

Notes

The totals are calculated for following parameters: - costs_total - costs_om_total - costs_investment_over_lifetime - costs_upfront_in_year_zero - costs_dispatch - costs_cost_om - annuity_total - annuity_om

The levelized_cost_of_energy_of_asset are dropped from the list, as they do not hold any actual meaning for the whole energy system. The LCOE of the energy system is calculated seperately.

multi_vector_simulator.E3_indicator_calculation.**calculate_electricity_equivalent_for_a_set_of_aggregate**

Calculates the electricity equivalent for a dict of aggregated flows and writes it to the KPI

Parameters

- **dict_values** (*dict*) – All simulation parameters
- **dict_of_aggregated_flows** (*dict*) – Dict of aggragated flows, with keys of energy carriers.
- **kpi_name** (*str*) – Name of the KPI to write to the results

Return type
Updated dict_values.

multi_vector_simulator.E3_indicator_calculation.**calculate_emissions_from_flow**(*dict_asset*)

Calculates the total emissions of the asset in 'dict_asset' in kg per year.

Parameters
dict_asset (*dict*) – Contains information about the asset.

Notes

Tested with: - E3.test_calculate_emissions_from_flow() - E3.test_calculate_emissions_from_flow_zero_emissions

Returns
Updated *dict_asset* with TOTAL_EMISSIONS of the asset in kgCO2eq/a (UNIT_EMISSIONS).

Return type
None

multi_vector_simulator.E3_indicator_calculation.**equation_degree_of_autonomy**(*total_consumption_from_energy_pr*
total_demand)

Calculates the degree of autonomy (DA).

The degree of autonomy describes the relation of how much demand is supplied by local generation (as opposed to grid conumption) compared to the total demand of the system.

Parameters

- **total_consumption_from_energy_provider** (*float*) – total energy consumption from providers
- **total_demand** (*float*) – total demand

Returns

- *float* – degree of autonomy
- .. *math::* – DA &=frac{sum_i {E_{demand} (i) cdot w_i} - sum_{i} {E_{consumption,provider,j} (j) cdot w_j}}{sum_i {E_{demand} (i) cdot w_i}}
- **A DA = 0** (*Demand is fully supplied by DSO consumption*)
- **DA = 1** (*System is autonomous, ie. no DSO consumption is necessary*)
- **Notice** (*As above, we apply a weighting based on Electricity Equivalent.*)
- *Tested with*
- *- test_equation_degree_of_autonomy()*

multi_vector_simulator.E3_indicator_calculation.**equation_degree_of_net_zero_energy**(*total_feedin*, *total_grid_consumption*, *total_demand*)

Calculates the degree of net zero energy (NZE).

In NZE systems import and export of energy is allowed while the balance over one year should be zero, thus the degree of net zero energy would be 1. The Degree of net zero energy indicates how close the system gets to the NZE ideal. If more energy is exported than imported it is plus-energy system (degree of NZE > 1).

Parameters

- **total_feedin** (*float*) – total grid feed-in in electricity equivalents
- **total_grid_consumption** (*float*) – total consumption from energy provider in electricity equivalents
- **total_demand** (*float*) – total demand in electricity equivalents

Returns
degree of net zero energy

Return type
float

Notes

$$Degree of NZE = 1 + \frac{(\sum_i E_{gridfeedin}(i) \cdot w_i - E_{gridconsumption}(i) \cdot w_i)}{\sum_i E_{demand,i} \cdot w_i}$$

Degree of NZE = 1 : System is a net zero energy system, as E_feedin = E_grid_consumption Degree of NZE > 1 : system is a plus-energy system, as E_feedin > E_grid_consumption Degree of NZE < 1 : system does not reach net zero balance. The degree indicates by how much it fails to do so. Degree of NZE = 0 : system has no internal production, as E_dem = E_grid_consumption.

Tested with - test_equation_degree_of_net_zero_energy() - test_equation_degree_of_net_zero_energy_is_zero() - test_equation_degree_of_net_zero_energy_is_one() - test_equation_degree_of_net_zero_energy_greater_one()

multi_vector_simulator.E3_indicator_calculation.**equation_degree_of_sector_coupling**(*total_flow_of_energy_conv*, *total_demand_equivalent*)

Calculates degree of sector coupling.

Parameters

- **total_flow_of_energy_conversion_equivalent** (*float*) – Energy equivalent of total conversion flows
- **total_demand_equivalent** (*float*) – Energy equivalent of total energy demand

Returns

- *float* – Degree of sector coupling based on conversion flows and energy demands in electricity equivalent.
- *.. math:: –*

  DSC=frac{sum_{i,j}{E_{conversion} (i,j) cdot w_i}}{sum_i {E_{demand} (i) cdot w_i}}

  with i,j epsilon [Electricity,H2…]

multi_vector_simulator.E3_indicator_calculation.**equation_levelized_cost_of_energy_carrier**(*cost_total*, *crf*, *total_flow_energy_*, *total_demand_elec*, *total_flow_energy_*)

Calculates LCOE of each energy carrier of the system.

Based on distributing the NPC of the energy system over the total weighted energy demand of the local energy system. This avoids that a conversion asset has to be defined as being used for a specific sector only, or that an energy production asset (eg. electricity) which is mainly used for powering energy conversion assets for another energy carrier (eg. H2) are increasing the costs of the first energy carrier (electricity), eventhough the costs should be attributed to the costs of the end-use of generation.

Parameters

- **cost_total** (*float*)
- **crf** (*float*)

- **total_flow_energy_carrier_eleq** (*float*)
- **total_demand_electricity_equivalent** (*float*)
- **total_flow_energy_carrier** (*float*)

Returns

- **lcoe_energy_carrier** (*float*) – Levelized costs of an energy carrier in a sector coupled system
- **attributed_costs** (*float*) – Costs attributed to a specific energy carrier

Notes

Please refer to the conference paper presented at the CIRED Workshop Berlin (see readthedocs) for more detail.

The costs attributed to an energy carrier are calculated from the ratio of electricity equivalent of the energy carrier demand in focus to the electricity equivalent of the total demand:

$$attributedcosts = NPC \cdot \frac{Totalelectricityequivalentofenergycarrierdemand}{Totalelectricityequivalentofdemand}$$

The LCOE sets these attributed costs in relation to the energy carrier demand (in its original unit):

$$LCOEenergycarrier = \frac{attributedcosts \cdot CRF}{totalenergycarrierdemand}$$

Tested with: - test_equation_levelized_cost_of_energy_carrier_total_demand_electricity_equivalent_larger_0_total_flow_energy_
- test_equation_levelized_cost_of_energy_carrier_total_demand_electricity_equivalent_larger_0_total_flow_energy_carrier_is_0
- test_equation_levelized_cost_of_energy_carrier_total_demand_electricity_equivalent_is_0_total_flow_energy_carrier_is_0()

multi_vector_simulator.E3_indicator_calculation.**equation_onsite_energy_fraction**(*total_generation*, *total_feedin*)

Calculates onsite energy fraction (OEF), i.e. self-consumption.

OEF describes the fraction of all locally generated energy that is consumed by the system itself.

Parameters

- **total_generation** (*float*) – Energy equivalent of total generation flows
- **total_feedin** (*float*) – Total feed into the grid

Returns

- *float* – Onsite energy fraction.
- .. *math::* – OEF &=frac{sum_{i} {E_{generation} (i) cdot w_i} - E_{gridfeedin}(i) cdot w_i}{sum_{i} {E_{generation} (i) cdot w_i}} &OEF epsilon text{[0,1]}
- *Tested with*
- *- test_equation_onsite_energy_fraction()*

multi_vector_simulator.E3_indicator_calculation.**equation_onsite_energy_matching**(*total_generation*, *total_feedin*, *total_excess*, *total_demand*)

Calculates onsite energy matching (OEM), i.e. self-sufficiency.

OEM describes the fraction of the total demand that can be covered by the locally generated energy.

Parameters

- **total_generation** (*float*) – Energy equivalent of total conversion flows
- **total_feedin** (*float*) – Total feed into the grid
- **total_excess** (*float*) – Total Excess energy
- **total_demand** (*float*) – Total demand

Returns

- *Onsite energy matching.*
- .. *math::* – OEM &=frac{sum_{i} {E_{generation} (i) cdot w_i} - E_{gridfeedin}(i) cdot w_i - E_{excess}(i) cdot w_i}{sum_i {E_{demand} (i) cdot w_i}}

  &OEM epsilon text{[0,1]}
- *Tested with*
- *- test_equation_onsite_energy_matching()*

multi_vector_simulator.E3_indicator_calculation.**equation_renewable_share**(*total_res*, *total_non_res*)

Calculates the renewable share

Parameters

- **total_res** – Renewable generation of a system
- **total_non_res** – Non-renewable generation of a system

Returns
Renewable share

Return type
type

Notes

Used both to calculate RENEWABLE_FACTOR and RENEWABLE_SHARE_OF_LOCAL_GENERATION.

Equation:

$$RES = \frac{total_res}{total_non_res + total_res}$$

The renewable share is relative to generation, but not consumption of energy, the renewable share can not be larger 1. If there is no generation or consumption from a DSO within an energyVector and supply is solely reached by energy conversion from another vector, the renewable share is defined to be zero.

- renewable share = 1 - all energy in the energy system is of renewable origin
- renewable share < 1 - part of the energy in the system is of renewable origin
- renewable share = 0 - no energy is of renewable origin

Tested with:

- test_renewable_share_equation_no_generation()
- test_renewable_share_equation_below_1()
- test_renewable_share_equation_is_0()

- test_renewable_share_equation_is_1()

multi_vector_simulator.E3_indicator_calculation.**total_demand_and_excess_each_sector**(*dict_values*)

Calculation of the total demand and total excess of each sector

Both in original energy carrier unit and electricity equivalent

Parameters
dict_values – dict with all project input data and results up to E0

Returns

- *Updated KPI_SCALARS_DICT with*
- *- total demand of each energy carrier (original unit)*
- *- total demand of each energy carrier (electricity equivalent)*
- *- total demand in electricity equivalent*
- *- total excess of each energy carrier (original unit)*
- *- total excess of each energy carrier (electricity equivalent)*
- *- total excess in electricity equivalent*

Notes

Tested with - test_add_levelized_cost_of_energy_carriers_one_sector() - test_add_levelized_cost_of_energy_carriers_two_sectors - TestTechnicalKPI.renewable_factor_and_renewable_share_of_local_generation()

multi_vector_simulator.E3_indicator_calculation.**weighting_for_sector_coupled_kpi**(*dict_values*, *kpi_name*)

Calculates the weighted kpi for a specific kpi_name both for a single sector and system-wide

Parameters

- **dict_values** – dict with all project information and results, including KPI_UNCOUPLED_DICT with the specifc kpi_name in question
- **kpi_name** – str with the kpi which should be weighted

Returns
Append specific KPI that describes sector-coupled system to dict_values[KPI][KPI_SCALARS_DICT] Appends specific KPI in energy equivalent to each sector to dict_values[KPI][KPI_UNCOUPLED_DICT]

Return type
type

Module E4 - Verification of results

- Detect excessive excess generation
- Verify that minimal renewable share constraint is adhered to
- Verfiy that maximum emission constraint is adhered to
- Verfiy that net zero energy (NZE) constraint is adhered to

multi_vector_simulator.E4_verification.**detect_excessive_excess_generation_in_bus**(*dict_values*)

Warning for any bus with excessive excess generation is given.

A logging.warning message is printed when the ratio between total outflows and total inflows of a bus is < 0.9.

Parameters
dict_values

Returns

- *- Nothing if the there is no excessive excess generation*
- *- Prints logging.warning message for every bus with excessive excess generation.*

multi_vector_simulator.E4_verification.**maximum_emissions_test**(*dict_values*)

Tests if maximum emissions constraint was correctly applied.

Parameters
dict_values (*dict*) – all input parameters and results up to E0

Returns

- *Nothing*
- *- Nothing if the constraint is confirmed*
- *- Prints logging.warning message if the difference from the constraint is < 10^-6.*
- *- Prints a logging.error message if the difference from the constraint is >= 10^-6.*

Notes

Tested with: - E4.test_maximum_emissions_test_passes() - E4.test_maximum_emissions_test_fails()

multi_vector_simulator.E4_verification.**minimal_constraint_test**(*dict_values*, *minimal_constraint*, *bounded_result*)

Test if minimal constraint was correctly applied

Parameters

- **dict_values** (*dict*) – Dict of all simulation information
- **minimal_constraint** (*str*) – Key to access the value of the minimal bound of parameter subjected to constraint to be tested
- **bounded_result** (*str*) – Key to access the value of the resulting parameter to be compared to minimal_bound

Returns

- *Nothing*
- *- Nothing if the constraint is confirmed*
- *- Prints logging.warning message if the deviation from the constraint is < 10^-6.*
- *- Prints a logging.error message if the deviation from the constraint is >= 10^-6.*

Notes

Executed to test - MINIMAL_DEGREE_OF_AUTONOMY vs. RENEWABLE_FACTOR - MINIMAL_RENEWABLE_FACTOR vs. DEGREE_OF_AUTONOMY

Tested with: - E4.test_minimal_constraint_test_passes() - E4.test_minimal_constraint_test_fails()

multi_vector_simulator.E4_verification.**net_zero_energy_constraint_test**(*dict_values*)

Tests if net zero energy constraint was correctly applied.

Parameters

dict_values (*dict*) – all input parameters and results up to E0

Returns

- *Nothing*
- *- Nothing if the constraint is confirmed*
- *- Prints logging.warning message if the difference from the constraint is < 10^-6.*
- *- Prints a logging.error message if the difference from the constraint is >= 10^-6.*

Notes

Tested with: - E4.test_net_zero_energy_constraint_test_fails() - E4.test_net_zero_energy_constraint_test_passes()

multi_vector_simulator.E4_verification.**verify_state_of_charge**(*dict_values*)

This function checks the state of charge of each storage component It raises warning log messages if the SoC has a physically infeasible value

Parameters

dict_values (*dict*) – Dictionary with all information regarding the simulation, specifically including the energyStorage assets

Returns

- *- Nothing if there are no physically infeasible SoC values for the storage components*
- *- Prints log messages to console and log file if there are physically impossible SoC values*

Notes

Tested with: - test_E4_verification.test_verify_state_of_charge_feasible() - test_E4_verification.test_verify_state_of_charge_soc_below_zero() - test_E4_verification.test_verify_state_of_charge_soc_above_

4.1.7 Output

Module F0 - Output

The model F0 output defines all functions that store evaluation results to file. - Aggregate demand profiles to a total demand profile - Plot all energy flows for both 14 and 365 days for each energy bus - Store timeseries of all energy flows to excel (one sheet = one energy bus) - Execute function: plot optimised capacities as a barchart (F1) - Execute function: plot all annuities as a barchart (F1) - Store scalars/KPI to excel - Process dictionary so that it can be stored to Json - Store dictionary to Json

multi_vector_simulator.F0_output.**evaluate_dict**(*dict_values*, *path_pdf_report=None*, *path_png_figs=None*)

This is the main function of F0. It calls all functions that prepare the simulation output, ie. Storing all simulation output into excellent files, bar charts, and graphs.

Parameters

- **dict_values** – dict Of all input and output parameters up to F0
- **path_pdf_report** (*(str)*) – if provided, generate a pdf report of the simulation to the given path
- **path_png_figs** (*(str)*) – if provided, generate png figures of the simulation's results to the given path

Returns
NA

Return type
type

multi_vector_simulator.F0_output.**parse_simulation_log**(*path_log_file*, *dict_values*)

Gather a log file with several log messages, this function gathers them all and inputs them into the dict with all input and output parameters up to F0

Parameters

- **path_log_file** (*str/None*) – path to the mvs log file Default: None
- **dict_values** – dict Of all input and output parameters up to F0

Return type
Updates the results dictionary with the log messages of the simulation

Notes

This function is tested with: - test_F0_output.TestLogCreation.test_parse_simulation_log

multi_vector_simulator.F0_output.**store_as_json**(*dict_values*, *output_folder=None*, *file_name=None*)

Converts dict_values to JSON format and saves dict_values as a JSON file or return json

Parameters

- **dict_values** (*(dict)*) – dict to be stored as json
- **output_folder** (*(path)*) – Folder into which json should be stored Default None
- **file_name** (*(str)*) – Name of the file the json should be stored as Default None

Returns

- *If file_name is provided, the json variable converted from the dict_values is saved under*
- *this file_name, otherwise the json variable is returned*

multi_vector_simulator.F0_output.**store_scalars_to_excel**(*dict_values*)

All output data that is a scalar is storage to an excellent file tab. This could for example be economical data or technical data.

Parameters
dict_values – dict Of all input and output parameters up to F0

Returns
Excel file with scalar data

Return type
type

multi_vector_simulator.F0_output.**store_timeseries_all_busses_to_excel**(*dict_values*)

This function plots the energy flows of each single bus and the energy system and saves it as PNG and additionally as a tab and an Excel sheet.

Parameters
dict_values – dict Of all input and output parameters up to F0

Returns
Plots and excel with all timeseries of each bus

Return type
type

Module F1 - Plotting

Module F1 describes all the functions that create plots.

- creating graphs for energy flows
- creating bar chart for capacity
- creating pie chart for cost data
- creating network graph for the model brackets only working on Ubuntu

class multi_vector_simulator.F1_plotting.**ESGraphRenderer**(*energy_system=None*, *filepath='network'*, *img_format=None*, *legend=True*, *txt_width=10*, *txt_fontsize=10*, ***kwargs*)

add_bus(*label='Bus'*, *subgraph=None*)

add_component(*label='component'*, *subgraph=None*)

add_sink(*label='Sink'*, *subgraph=None*)

add_source(*label='Source'*, *subgraph=None*)

add_storage(*label='Storage'*, *subgraph=None*)

add_transformer(*label='Transformer'*, *subgraph=None*)

connect(*a*, *b*)

Draw an arrow from node a to node b

Parameters

- **a** (*oemof.solph.network.Node*) – An oemof node (usually a Bus or a Component)
- **b** (*oemof.solph.network.Node*) – An oemof node (usually a Bus or a Component)

render(***kwargs*)

Call the render method of the DiGraph instance

sankey(*results*)

Return a dict to a plotly sankey diagram

view(***kwargs*)

Call the view method of the DiGraph instance

multi_vector_simulator.F1_plotting.**convert_plot_data_to_dataframe**(*plot_data_dict*, *data_type*)

Parameters

- **plot_data_dict** (*dict*) – timeseries for either demand or supply
- **data_type** (*str*) – one of DEMANDS or RESOURCES

Returns
df – timeseries for plotting

Return type
pandas:*pandas.DataFrame*<*frame*>,

multi_vector_simulator.F1_plotting.**create_plotly_barplot_fig**(*x_data*, *y_data*, *plot_title=None*, *trace_name=''*, *legends=None*, *x_axis_name=None*, *y_axis_name=None*, *file_name='barplot.png'*, *file_path=None*)

Create figure for specific capacities barplot

Parameters

- **x_data** (*list, or pandas series*) – The list of abscissas of the data required for plotting.
- **y_data** (*list, or pandas series, or list of lists*) – The list of ordinates of the data required for plotting.
- **plot_title** (*str*) – The title of the plot generated. Default: None
- **trace_name** (*str*) – Sets the trace name. The trace name appear as the legend item and on hover. Default: “”
- **legends** (*list, or pandas series*) – The list of the text written within the bars and on hover below the trace_name Default: None
- **x_axis_name** (*str*) – Default: None
- **y_axis_name** (*str*) – Default: None
- **file_name** (*str*) – Name of the image file. Default: “barplot.png”
- **file_path** (*str*) – Path where the image shall be saved if not None

Returns
fig – figure object

Return type
plotly.graph_objs.Figure

multi_vector_simulator.F1_plotting.**create_plotly_flow_fig**(*df_plots_data*, *x_legend=None*, *y_legend=None*, *plot_title=None*, *color_list=None*, *file_name='flows.png'*, *file_path=None*)

Generate figure of an asset’s flow.

Parameters

- **df_plots_data** (pandas.DataFrame) – dataFrame with timeseries of the asset's energy flow
- **x_legend** (*str*) – Default: None
- **y_legend** (*str*) – Default: None
- **plot_title** (*str*) – Default: None
- **color_list** (*list of str or list to tuple (hexadecimal or rbg code)*) – list of colors Default: None
- **file_name** (*str*) – Name of the image file. Default: "flows.png"
- **file_path** (*str*) – Path where the image shall be saved if not None Default: None

Returns
fig – figure object

Return type
plotly.graph_objs.Figure

multi_vector_simulator.F1_plotting.**create_plotly_line_fig**(*x_data*, *y_data*, *plot_title=None*, *x_axis_name=None*, *y_axis_name=None*, *color_for_plot='#0A2342'*, *file_path=None*)

Create figure for generic timeseries lineplots

Parameters

- **x_data** (*list, or pandas series*) – The list of abscissas of the data required for plotting.
- **y_data** (*list, or pandas series, or list of lists*) – The list of ordinates of the data required for plotting.
- **plot_title** (*str*) – The title of the plot generated. Default: None
- **x_axis_name** (*str*) – Default: None
- **y_axis_name** (*str*) – Default: None
- **file_path** (*str*) – Path where the image shall be saved if not None

Returns
figure object

Return type
fig plotly.graph_objs.Figure

multi_vector_simulator.F1_plotting.**create_plotly_piechart_fig**(*title_of_plot*, *names*, *values*, *color_scheme=None*, *file_name='costs.png'*, *file_path=None*)

Generate figure with piechart plot.

Parameters

- **title_of_plot** (*str*) – title of the figure
- **names** (*list*) – List containing the labels of the slices in the pie plot.
- **values** (*list*) – List containing the values of the labels to be plotted in the pie plot.

- **color_scheme** (*instance of the px.colors class of the Plotly express library*) – This parameter holds the color scheme which is palette of colors (list of hex values) to be applied to the pie plot to be created. Default: None
- **file_name** (*str*) – Name of the image file. Default: "costs.png"
- **file_path** (*str*) – Path where the image shall be saved if not None Default: None

Returns
fig – figure object

Return type
plotly.graph_objs.Figure

multi_vector_simulator.F1_plotting.**extract_plot_data_and_title**(*dict_values*, *df_dem=None*)

Dataframe used for the plots of demands and resources timeseries in the report

Parameters

- **dict_values** (*dict*) – output values of MVS
- **df_dem** (pandas.DataFrame) – summarized demand information for each demand

Return type
pandas.DataFrame

multi_vector_simulator.F1_plotting.**fixed_width_text**(*text*, *char_num=10*)

Add linebreaks every char_num characters in a given text.

Parameters

- **text** (*obj:'str'*) – text to apply the linebreaks
- **char_num** (*obj:'int'*) – max number of characters in a line before a line break Default: 10

Returns
obj – the text with line breaks after every char_num characters

Return type
'str'

multi_vector_simulator.F1_plotting.**get_color**(*idx_line*, *color_list=None*)

Pick a color within a color list with periodic boundary conditions

Parameters

- **idx_line** (*int*) – index of the line in a plot for which a color is required
- **colors** (*list of str or list to tuple (hexadecimal or rbg code)*) – list of colors Default: None

Return type
The color in the color list corresponding to the index modulo the color list length

multi_vector_simulator.F1_plotting.**get_fig_style_dict**()

multi_vector_simulator.F1_plotting.**plot_instant_power**(*dict_values*, *file_path=None*)

Plotting timeseries of instantaneous power for each assets within the energy system

Parameters

- **dict_values** (*dict*) – all simulation input and output data up to this point
- **file_path** (*str*) – Path where the image shall be saved if not None Default: None

Returns
multi_plots – Dict with html DOM id for the figure as keys and `plotly.graph_objs.Figure` as values

Return type
dict

`multi_vector_simulator.F1_plotting.`**`plot_optimized_capacities`**(*dict_values*, *file_path=None*)

Plot capacities as a bar chart.

Parameters

- **`dict_values`** – dict Of all input and output parameters up to F0
- **`file_path`** (*str*) – Path where the image shall be saved if not None Default: None

Return type
Dict with html DOM id for the figure as key and `plotly.graph_objs.Figure` as value

`multi_vector_simulator.F1_plotting.`**`plot_piecharts_of_costs`**(*dict_values*, *file_path=None*)

Plotting piecharts of different cost parameters (ie. annuity, total cost, etc…)

Parameters

- **`dict_values`** (*dict*) – all simulation input and output data up to this point
- **`file_path`** (*str*) – Path where the image shall be saved if not None Default: None

Returns
pie_plots – Dict with html DOM id for the figure as keys and `plotly.graph_objs.Figure` as values

Return type
dict

`multi_vector_simulator.F1_plotting.`**`plot_sankey`**(*dict_values*)

`multi_vector_simulator.F1_plotting.`**`plot_timeseries`**(*dict_values*, *data_type='demands'*, *sector_demands=None*, *max_days=None*, *color_list=None*, *file_path=None*)

Plot timeseries as line chart.

Parameters

- **`dict_values`** – dict Of all input and output parameters up to F0
- **`data_type`** (*str*) – one of DEMANDS or RESOURCES Default: DEMANDS
- **`sector_demands`** (*str*) – Name of the sector of the energy system Default: None
- **`max_days`** (*int*) – maximal number of days the timeseries should be displayed for
- **`color_list`** (*list of str or list to tuple (hexadecimal or rbg code)*) – list of colors Default: None
- **`file_path`** (*str*) – Path where the image shall be saved if not None Default: None

Return type
Dict with html DOM id for the figure as key and `plotly.graph_objs.Figure` as value

`multi_vector_simulator.F1_plotting.`**`save_plots_to_disk`**(*fig_obj*, *file_name*, *file_path=''*, *width=None*, *height=None*, *scale=None*)

This function saves the plots generated using the Plotly library in this module to the outputs folder.

Parameters

- **fig_obj** (*instance of the classes of the Plotly go library used to generate the plots in this auto-report*) – Figure object of the plotly plots
- **file_name** (*str*) – The name of the PNG image of the plot to be saved in the output folder.
- **file_path** (*str*) – Path where the image shall be saved
- **width** (*int or float*) – The width of the picture to be saved in pixels. Default: None
- **height** (*int or float*) – The height of the picture to be saved in pixels. Default: None
- **scale** (*int or float*) – The scale by which the plotly image ought to be multiplied. Default: None

Return type
Nothing is returned. This function call results in the plots being saved as .png images to the disk.

Module F2 - Autoreport

This script generates a report of the simulation automatically, with all the important data.

multi_vector_simulator.F2_autoreport.**create_app**(*results_json*, *path_sim_output=None*)

Initializes the app and calls all the other functions, resulting in the web app as well as pdf.

This function specifies the layout of the web app, loads the external styling sheets, prepares the necessary data from the json results file, calls all the helper functions on the data, resulting in the auto-report.

Parameters

- **results_json** (*json results file*) – This file is the result of the simulation and contains all the data necessary to generate the auto-report.
- **path_sim_output** (*str*) – Path to the mvs simulation's output files' folder Default: output path saved in the result_json

Returns
app – This app holds together all the html elements wrapped in Python, necessary for the rendering of the auto-report.

Return type
instance of the Dash class within the dash library

multi_vector_simulator.F2_autoreport.**create_demands_section**(*output_JSON_file*, *sectors=None*)

This function creates a HTML Div element that holds an entire section with either the demands or the resources

Parameters

- **output_JSON_file** (*dict*) – Dict with all simulation parameters
- **sectors** (*list*) – List holding the names of sectors of the energy system as strings Default: None

Return type
Function call to insert_subsection() that generates the demands section of the autoreport

multi_vector_simulator.F2_autoreport.**encode_image_file**(*img_path*)

Encode image files to load them in the dash layout under img html tag

Parameters
img_path (*str*) – path to the image file

Returns
encoded_img – encoded bytes of the image file

Return type
bytes

multi_vector_simulator.F2_autoreport.**insert_body_text**(*body_of_text*)

This function is for rendering blocks of text within the sub-sections.

Parameters
body_of_text (*str*) – Typically a single-line or paragraph of text.

Returns
A html element that renders the paragraph of text in the Dash app layout.

Return type
html.P()

multi_vector_simulator.F2_autoreport.**insert_headings**(*heading_text*)

This function is for creating the headings such as information, input data, etc.

Parameters
heading_text (*str*) – Big headings for several sub-sections.

Returns
A html element with the heading text encased container.

Return type
html.P()

multi_vector_simulator.F2_autoreport.**insert_log_messages**(*log_dict*)

This function inserts logging messages that arise during the simulation, such as warnings and error messages, into the auto-report.

Parameters
log_dict (*dict*) – A dictionary containing the logging messages collected during the simulation.

Returns
This html element holds the children html elements that produce the lists of warnings and error messages for both print and screen versions of the auto-report.

Return type
html.Div()

multi_vector_simulator.F2_autoreport.**insert_plotly_figure**(*fig*, *id_plot=None*, *print_only=False*)

Insert a plotly figure in a dash app layout

Parameters

- **fig** (plotly.graph_objs.Figure) – figure object
- **id_plot** (*str*) – Id of the graph. Should be unique. Default: None
- **print_only** (*bool*) – Used to determine if a web version of the plot is to be generated or not. Default: False

Returns
Html Div component containing an image for the print-only version and a plotly figure for the online (no-print) app (in the app the user can interact with plotly figure, whereas the image is static).

Return type
dash_html_components.Div

multi_vector_simulator.F2_autoreport.**insert_subsection**(*title*, *content*, ***kwargs*)

Inserts sub-sections within the Dash app layout, such as Input data, simulation results, etc.

Parameters

- **title** (*str*) – This is the title or heading of the subsection.
- **content** (*list*) – This is typically a list of html elements or function calls returning html elements, that make up the body of the sub-section.
- **kwargs** (*Any possible optional arguments such as styles, etc.*)

Returns

This returns the sub-section of the report including the tile and other information within the sub-section.

Return type

html.Div()

multi_vector_simulator.F2_autoreport.**make_dash_data_table**(*df*, *title=None*)

Function that creates a Dash DataTable from a Pandas dataframe.

Parameters

- **df** (pandas.DataFrame) – This dataframe holds the data from which the dash table is to be created.
- **title** (*str*) – An optional title for the table. Default: None

Returns

This element contains the title of the dash table and the dash table itself encased in a child html.Div() element.

Return type

html.Div()

multi_vector_simulator.F2_autoreport.**open_in_browser**(*app*, *timeout=600*)

Runs the dash app in a thread an open a browser window

Parameters

- **app** (*instance of the Dash class, part of the dash library*)
- **timeout** (*int or float*) – Specifies the number of seconds that the web app should be open in the browser before timing out.

Return type

Nothing, but the web app version of the auto-report is displayed in a browser.

multi_vector_simulator.F2_autoreport.**print_pdf**(*app=None*, *path_pdf_report='/home/docs/checkouts/readthedocs.org/user_builds/multi-vector-simulator/checkouts/latest/docs/MVS_outputs/out.pdf'*)

Runs the dash app in a thread and print a pdf before exiting

Parameters

- **app** (*instance of the Dash class of the dash library*) – Default: None
- **path_pdf_report** (*str*) – Path where the pdf report should be saved.

Return type

None, but saves a pdf printout of the provided app under the provided path

multi_vector_simulator.F2_autoreport.**ready_capacities_plots**(*dict_values*, *only_print=False*)

Insert the capacities bar plots in a dash html layout

Parameters

- **dict_values** (*dict*) – Dict with all simulation parameters
- **only_print** (*bool*) – Setting this value true results in the function creating only the plot for the PDF report, but not the web app version of the auto-report. Default: False

Returns
cap_plots – List containing the capacities bar plots dash components

Return type
list

multi_vector_simulator.F2_autoreport.**ready_costs_pie_plots**(*dict_values*, *only_print=False*)

Insert the pie plots in a dash html layout

Parameters

- **dict_values** (*dict*) – Dict with all simulation parameters
- **only_print** (*bool*) – Setting this value true results in the function creating only the plot for the PDF report, but not the web app version of the auto-report. Default: False

Returns
pie_plots – List containing the cost pie plots dash components

Return type
list

multi_vector_simulator.F2_autoreport.**ready_flows_plots**(*dict_values*, *only_print=False*)

Generate figure for each assets' flow of the energy system.

Parameters

- **dict_values** (*dict*) – Dict with all simulation parameters
- **only_print** (*bool*) – Setting this value true results in the function creating only the plot for the PDF report, but not the web app version of the auto-report. Default: False

Returns
multi_plots – List containing the assets' timeseries plots as dash components

Return type
list

multi_vector_simulator.F2_autoreport.**ready_sankey_diagram**(*dict_values*, *only_print=False*)

multi_vector_simulator.F2_autoreport.**ready_timeseries_plots**(*dict_values*, *data_type='demands'*, *only_print=False*, *sector_demands=None*)

Insert the timeseries line plots in a dash html layout.

Parameters

- **dict_values** (*dict*) – Dict with all simulation parameters
- **data_type** (*str*) – one of DEMANDS or RESOURCES Default: DEMANDS
- **only_print** (*bool*) – Setting this value true results in the function creating only the plot for the PDF report, but not the web app version of the auto-report. Default: False
- **sector_demands** (*str*) – Name of the sector of the energy system Default: None

Returns
plots – List containing the timeseries line plots dash components

Return type
list

4.2 Release Notes

TBD (adapt the changelog)

4.3 License

The MVS is licensed with the **GNU General Public License v2.0**. The GNU GPL is the most widely used free software license and has a strong copyleft requirement. When distributing derived works, the source code of the work must be made available under the same license. There are multiple variants of the GNU GPL, each with different requirements.

4.4 Contributing to MVS

4.4.1 Proposed workflow

The workflow is described in the CONTRIBUTING.md file in the repository.

4.4.2 Unit tests (pytests)

When developing code for the MVS please make sure that you always also develop test in `tests`. We integrate those unit tests with `pytest`. Make sure that your tests are as lightweight as possible - this means that you do not always have to run the whole code to test for one feature, but can test a function with a standalone tests. Please refer to the other tests that have already been introduced.

Always aim for the test coverage button on the main page of the github repository to reach 100%!

When you do have to run the MVS itself for a test, eg. for benchmark tests, please always use the arguments *-f -log warning* to make the test results better readable.

4.4.3 Build documentation

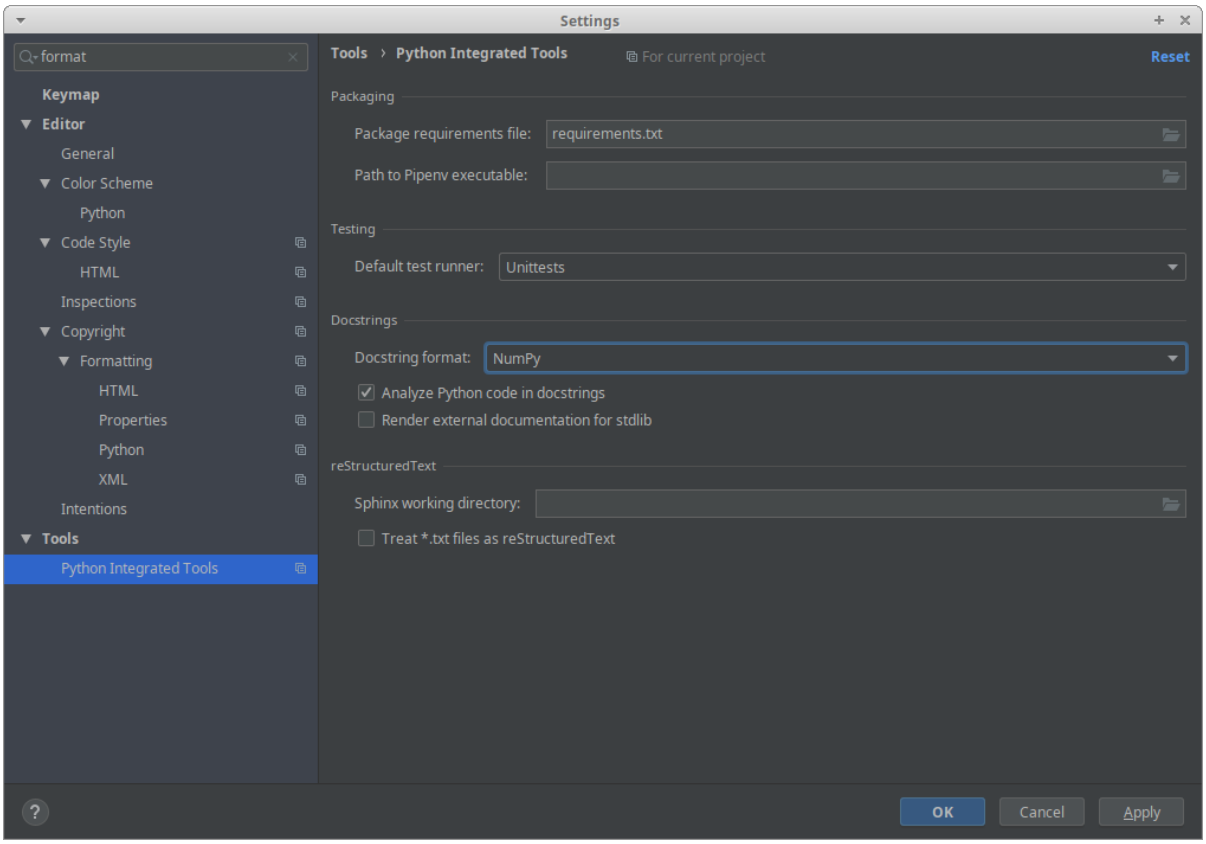
You can build the documentation locally moving inside the *docs/* folder and typing

```
html build
```

into a console, then go to *docs/_build/* and open *index.html* into your favorite browser.

All functions in the code will be automatically documented via their docstrings. Please make sure they follow the Numpy format.

Here is how to set that in pycharm



4.4.4 Format of Docstrings

Please add docstrings for every function you add. As docstrings are a powerful means of documentation we give an example here:

Download: `Example docstring`

```
import pandas as pd


def example_function(arg1, argN):
    r"""
    One line no more that 80 character explaining very shortly what the function does

    More detailed explanation about the function,
    can have several lines

    Parameters
    ----------
    arg1 : str or list(str)
        description of arg1
        Default: <default value here>.

    ...

    argN : str or list(str)
```

(continues on next page)

(continued from previous page)

```
    description of argN
    Default: <default value here>.

Returns
-------
:class:`pandas.DataFrame<frame>`
    here comes the description
(In case of no return, you can write what the function changes, e.g. updates
`variable_x` with `y`.)

Notes
-----
You can cite the references below using [1]_ or [2]_  add maths equations like this:

.. math:: P=\frac{1}{8}\cdot\rho_{hub}\cdot d_{rotor}^{2}
    \cdot\pi\cdot v_{wind}^{3}\cdot cp\left(v_{wind}\right)

with:
    P: power [W], :math:`\rho`: density [kg/m^3], d: diameter [m],
    v: wind speed [m/s], cp: power coefficient

You can also indicate here which tests are covering this function:
This function is tested with:
- tests.test_example_function()

References
----------
.. [1] paper 1
.. [2] paper 2

Examples
--------
# Here you can write some basic python code that is tested with pytest
>>> import src.C2_economic_functions as e_funcs
>>> CAPEX = e_funcs.capex_from_investment(
...    investment_t0=220000, lifetime=20, project_life=20,
...    discount_factor=0.1, tax=0.15)
>>> round(CAPEX, 7)
253000.0

"""
return pd.DataFrame(...)
```

4.5 Publications and Bibliography

4.5.1 Scientific Publications

The MVS is currently under development in the H2020 research project *E-LAND*. Still, there are already some references where additional information can be found regarding its intention, application, and method. More information about E-LAND can be found on the research project website: E-LAND Horizon 2020. Novel solutions for decarbonized energy islands

Articles

- **(Farrukh, 2022)**
  Farhan Farrukh, Ciara Dunks, Martha Marie Hoffmann, Per Olav Dypvik: *Assessment of the potential of local solar generation for providing ship shore power in the Norwegian harbour Port of Borg*, 2022 18th International Conference on the European Energy Market (EEM), DOI: 10.1109/EEM54602.2022.9921031, Link

- **(Puranik, 2022)**
  Sanket Puranik, Martha M. Hoffmann, Farhan Farrukh, Sunil Sharma: *Optimal investments into rooftop solar and batteries for a distribution grid company and prosumers: A case study in India.*, Conference Paper, 2022 IEEE 7th International Energy Conference (ENERGYCON). DOI: 10.1109/ENERGYCON53164.2022.9830341. Link

- **(Hoffmann, 2020b)**
  Martha M. Hoffmann, Sanket Puranik, Marc Juanpera, José M. Martín-Rapún, Heidi Tuiskula, & Philipp Blechinger: *Investment planning in multi-vector energy systems: Definition of key performance indicators*, Conference paper, presented at the CIRED 2020 Berlin Workshop (CIRED 2020), Berlin / online. 2020. DOI: Link <10.5281/zenodo.4449918

Reports

- **(AHK Chile, 2021)**
  Christoph Meyer, Mar Ortiz, Annika Schüttler. AHK Chile, August 2021: German: Einsatz von grünem Wasserstoff zur netzfernen Stromversorgung in Insel- und kleineren Stromnetzen in Chile. Spanish: Uso de hidrógeno verde para el suministro de energía fuera de la red en microrredes y redes pequeñas de electricidad en Chile. Available on: Link

- **(E-LAND, 2021b)**
  Martha Hoffmann, Ciara Dunks, Sabine Haas. May 2021: Innovative Multi-Vector Simulator. Deliverable 4.4

Posters

- **(E-LAND, 2021a)**
  E-LAND, 2021: Multi-Vector Simulator. Planning the energy supply system of the future. Product sheet. Available: Link

- **(Hoffmann, 2020a)**
  Martha M. Hoffmann, Sanket Puranik, Marc Juanpera, José M. Martín-Rapún, Heidi Tuiskula, & Philipp Blechinger: *Investment planning in multi-vector energy systems: Definition of key performance indicators*, Conference poster, presented at the CIRED 2020 Berlin Workshop (CIRED 2020), Berlin / online: DOI: 10.5281/zenodo.4449969

Presentations

- : (Puranik, 2021): Sanket Puranik, Martha M. Hoffmann, Isidoros Kokos, Sergio Herraiz, Per Gjerløw: *Facilitating Local Multi-Vector Energy Systems with the E-LAND toolbox*, Workshop at "Sustainable Places 2021", Link

- **(Herraiz, 2021)**
  Sergio Herraiz, Martha M. Hoffmann: *Facilitating local multi-vector energy systems: Integrated investment and operational planning*. Präsentation in Session 8: Cross-sectoral linkages and integration, Day 2: Linking Sectors and Technologies at the EMP-E 2021 (26-28. Oktober 2021), online. conference schedule

- **(Hoffmann, 2020c)**
  Introducing an open source simulation tool for sector-coupled energy system optimization: Multi-Vector Simulator (MVS) Presentation at Energy Modelling Platform for Europe (EMP-E) 2020, 06. – 08. October 2020, online. Link to session: Youtube

- **(Hoffmann, 2020d)**
  Multi-Vector Simulator, session: *Building on experience: What to take from individual models for the oemof-community*, presentation at oemof developer meeting, 02. - 04. December 2020, online. Link: conference schedule

Master thesis

- **(Backhaus, 2021*)**
  Andra Backhaus: *Analyzing the application of different energy cell sizes as an approach for the integration of decentralized renewable energy sources*. Master of Science Thesis, Albert-Ludwigs Universität Freiburg. To be submitted in June 2021. Written in scope of the H2020 research project open_plan

- **(Gering, 2021*)**
  Marie-Claire Gering: *Modellierung und Analyse von sektorgekoppelten Energiesystemen mit photovoltaisch betriebenen Wärmepumpen und thermischen Energiespeichern*. Master of Science Thesis, Technische Universität Berlin. To be submitted in June 2021. Written in scope of the research project GRECO.

- **(El Mir, 2020)**
  Ursula El Mir: *Identification of a Validation Method for Open Source Simulation Tools and Application of Said Method to the MVS: Multi-Vector Simulator - Sector Coupled Systems*. Master of Science Thesis, Delft University of Technology. September 2020. Link: http://resolver.tudelft.nl/uuid:50c283c7-64c9-4470-8063-140b56f18cfe . Written in scope of the H2020 research project E-LAND

4.5.2 Reference projects

As an publicly developed open-source tool, the MVS can also be used, adapted and improved in other projects. The current projects that an serve as a reference for MVS utilization are listed.

H2020 research project GRECO and tool pvcompare

Within the H2020 research project GRECO the model `pvcompare` (github reprository) was developed to compare the benefits of different PV technologies in local energy systems in different energy supply scenarios. It uses MVS for optimizing these energy systems and calculating specific KPIs. Functionalities of `pvcompare` include among others the calculation of an area potential for PV on roof-tops and facades, heat and electricity demand profiles, PV feed-in time series for different technologies, temperature dependent COPs for heat pumps and pre-calculations for a stratified thermal storage. `pvcompare` concentrates on the integration of PV technologies into local energy systems but could easily be enhanced to analyze other conversion technologies. Checkout the documentation to learn more about `pvcompare`.

H2020 research project open_Plan

The H2020 research project open_plan aims to build an open source tool to plan the design of a single energy cell. It will extend on the existing features of MVS to fullfil the requirements of its pilot projects. The project open_plan is funded until December 2022, the development of the graphical user interface will take place on the github repository of open_plan.

Consulting project with AHK Chile

The MVS was applied to three case study locations in Chile to determine the local potential to use hydrogen for storing renewable generation. The locations included a grid on an island (Melinka), a region (Aysén) and a industrial site (Multiexport). More information can be found on the RLI website. A report in German and Spanish is available.

4.5.3 Bibliography

This RTD referenced following sources:

- **(Bloess, 2017)**
  Andreas Bloess, Wolf-Peter Schill, Alexander Zerrahn: *Power-to-heat for renewable energy integration: A review of technologies, modeling approaches, and flexibility potentials*. Applied Energy, 2018. DOI: 10.1016/j.apenergy.2017.12.073
- **(Ringkjøb, 2018)**
  Hans-Kristian Ringkjøb, Peter M. Haugan, Ida Marie Solbrekke: *A review of modelling tools for energy and electricity systems with large shares of variable renewables*. Renewable and Sustainable Energy Reviews, 2018. DOI: 10.1016/j.rser.2018.08.002

4.6 Cite MVS

If you use the MVS, please cite the tool as

> Hoffmann, Martha M., Duc, Pierre-Francois, & Haas, Sabine. (2021, March 4). Multi-Vector Simulator (Version v0.5.5, beta release). Zenodo. DOI: 10.5281/zenodo.4610237

in your reference section.

4.7 Troubleshooting

4.7.1 Installation

Python package "pygraphviz"

The installation of pygraphviz can cause errors. You can circumvent this issue by setting the `simulation_setting`, `plot_nx_graph` to `False`. If you need to plot the network graphs (set parameter `plot_nx_graph` to `True`) or run all pytests, check if we already have a solution for your OS/distribution:

Ubuntu 18.4: Pygraphviz could not be installed with pip. Solution:

> sudo apt-get install python3-dev graphviz libgraphviz-dev pkg-config
>
> pip install pygraphviz

Windows 10 Installing via

> pip install -r requirements.txt

results in an error:

> error: Microsoft Visual C++ 14.0 is required. Get it with "Build Tools for Visual Studio": https://visualstudio.microsoft.com/downloads/

You can find fixes on stackoverflow If you have `conda` installed, activate your environment and run

> conda install -c alubbock graphviz pygraphviz

Then you need to configure the `dot` command on your computer to be able to use graphviz

> dot -c

Python package "xlrd"

On **Windows** there can be issues installing xlrd. This could solve your troubles:

1. Delete `xlrd` from requirements.txt
2. Download the `xlrd-1.2.0-py2.py3-none-any.whl` file from here.
3. Copy the file to main directory of the project on your laptop
4. Install it manually writing `pip install xlrd-1.2.0-py2.py3-none-any.whl`

Python package "wkhtmltopdf"

There can be issues installing `wkhtmltopdf`. Solution can be found on the packages documentation.

cbc-solver

While with Ubuntu the installation of the cbc solver should work rather well, even when adding it to the environment variables (like described in the installation instructions) can sometimes not work on Windows. This was experienced with Windows 10.

A workaround is to directly put the `cbc.exe` file into the root of the MVS repository, ie. in the same folder where also the `CHANGELOG.md` file is located. Python/Oemof/Pyomo then are able to find the solver.

pyppeteer

If you are using OS X, you might need to install this package separately with `conda` using:

conda install -c conda-forge pyppeteer

or

conda install -c conda-forge/label/cf202003 pyppeteer

More information is available on their website.

4.7.2 Error messages and MVS termination

Even though we try to keep the error messages of the MVS clear and concise, there might be a some that are harder to understand. This especially applies to error messages that occur due to the termination of the oemof optimization process.

json.decoder.JSONDecodeError

If the error `json.decoder.JSONDecodeError` is raised, there is a formatting issue with the json file that is used as an input file.

Have you changed the json file manually? Please check for correct formatting, ie. apostrophes, commas, brackets, and so on.

If you have not changed the Json file yourself please consider raising an issue in the github project.

4.8 Bug report

Have a look at *Troubleshooting* section.

Please submit your bug reports via our github issues

CHAPTER

FIVE

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PYTHON MODULE INDEX

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