15 WINDPRO HYBRID

15.1 HYBRID – introduction

15.1.1 Introduction to HYBRID

The windPRO HYBRID module makes it possible to evaluate the technical and financial feasibility of energy plants with power production. The module handles time-varying prices against fluctuations in production and can include storage. The OPTI-Storage functionality can from windPRO 3.6 handle arbitrage (charge when price is low, discharge when price is high) and optimal handling of grid limits (minimize the grid limit curtailment).

Time varying production calculations within windPRO for Wind and PV are smoothly loaded from HYBRID module. Price time series concurrent to production data must be imported to a METEO object, similar for demand time series if relevant. (Export all to grid does not require demand time series).

To deliver renewable production directly to the demands will often give the extra benefit that taxes and tariff costs are saved, which is what often makes a Hybrid plant feasible. Demands connected to the production units can be handled as either INSIDE or OUTSIDE the system, which is conveniently named the "MicroGrid".

The module can handle scenarios from very simple systems, like if it is feasible to invest in a Solar-PV plant, and how big the plant shall be based on a given demand, to highly complex systems with wind, PV, other green and black production interacting together, as well as storage, external grid and an internal demand. The grid limitations can be set and can be given a cost to expand the grid capacity and find out if this investment is feasible, or investing in, for example, storage would be better.

Interaction with an external grid with time-varying prices is a core feature, but it is also possible not to have any interactions with an external grid; the so-called "island operation". Here a special feature is the "shedding filler", where a green or black production plant can be set to fill the gaps, when the other production units cannot fulfil the demand, and "load shedding" would be the solution without the "filler".

The basis within the module is an energy balance simulation for one year where production, price and demand time-series must be available for the same year. This simulation is repeated for all years in the financial simulation period, where changes during the simulation period are included. Changes could be that the Solar-PV plant degrades year by year, energy price levels increase or some plants or storage are brought in or taken out of the system during the simulation period. All developments by year can be controlled by freely definable indices.

For the power price simulation there is a high flexibility. Subsidies, tariffs and energy taxes can be included dependent on which plant makes the power, and where it is used. There might be a tariff just for the exported part of a specific wind plants production, while a subsidy is given to all PV production. Any possible mix can be handled.

Curtailments can be based on grid capacity as well as price. If the price is negative, the production can be shut down, like it will be curtailed when the grid limit is reached. For both curtailment types a value can be given per MWh. Shutting down by negative prices often is compensated while the plant helps the grid balance. If curtailment is due to grid limits, the power might be used for heating and assigned an appropriate value is an option. Load shedding can also be given a value. If the demand cannot be fulfilled in some hours, this has a cost, which could be the reason for investing in storage. If the load shedding is not assigned a cost, the storage would probably not be feasible.

Scaling factors for the different technologies are part of the simulation. It is easy to see the impact on the lifetime net cost when having e.g., a 50% larger PV-plant or storage. Here the **cost functions** are a very important new tool in windPRO. Plant costs and productions are automatically scaled based on size (simple scaling). Some plant cost types are based on formulas. For a wind park the turbine costs depend on specific power as well as MW, rotor area and hub height. The cabling and road costs depend on the inter-array distance, automatically calculated from the layout (i.e., this is a

simplification as the direct and shortest distances are used). Cost functions can be calibrated by the user. Having the real cost for a newly-built plant can be entered, and the specific costs calculated and used for the next plant. The initial values in the cost functions are based on comprehensive studies undertaken during 2020. The user with only a small effort will have quite realistic costs for the designed wind and PV plants and storage systems.

With the full connection between plant sizes and costs, and loans connected to plants, it is possible to find the optimal combination of plant sizes for handling the actual demand with the given price structures and variations in time. The **optimizer** will search for the plant and storage size, that results in lowest lifetime costs.

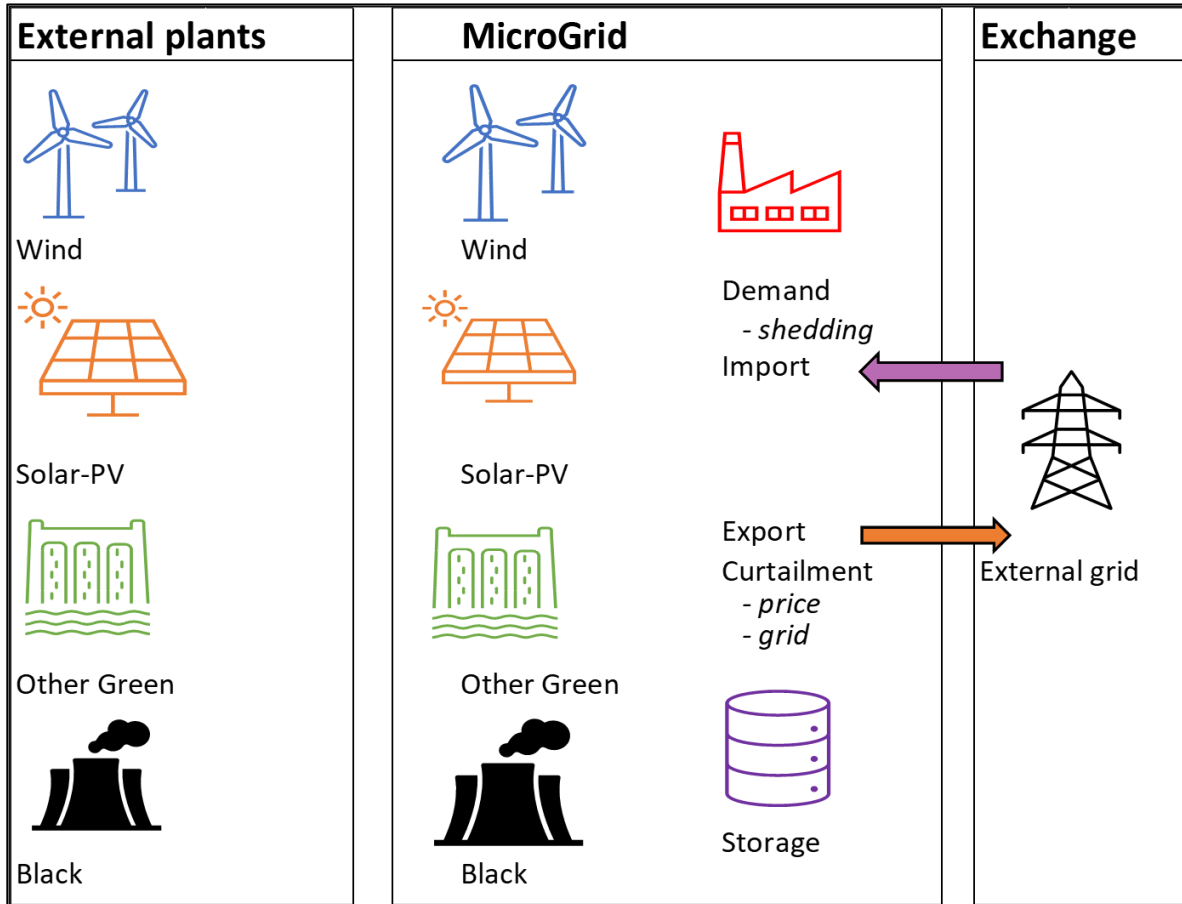Below is illustrated the basic business cases that can be calculated and optimized.

Figure 1 The demand is inside the MicroGrid.

With the demand inside the MicroGrid, there might be some savings on tariffs and energy taxes, assuming these are avoided by internal production.

External plants are plants the MicroGrid purchases power from, "owned" by external organisations. Plants inside the MicroGrid are financed and operated by the MicroGrid owner.

For demand inside the MicroGrid there is basically no income for the MicroGrid, except export. The reference the costs are compared to is that the demand "imports all". In key calculations such as NPV and IRR, the "income" for the MicroGrid is the cost the demand would have when importing all.
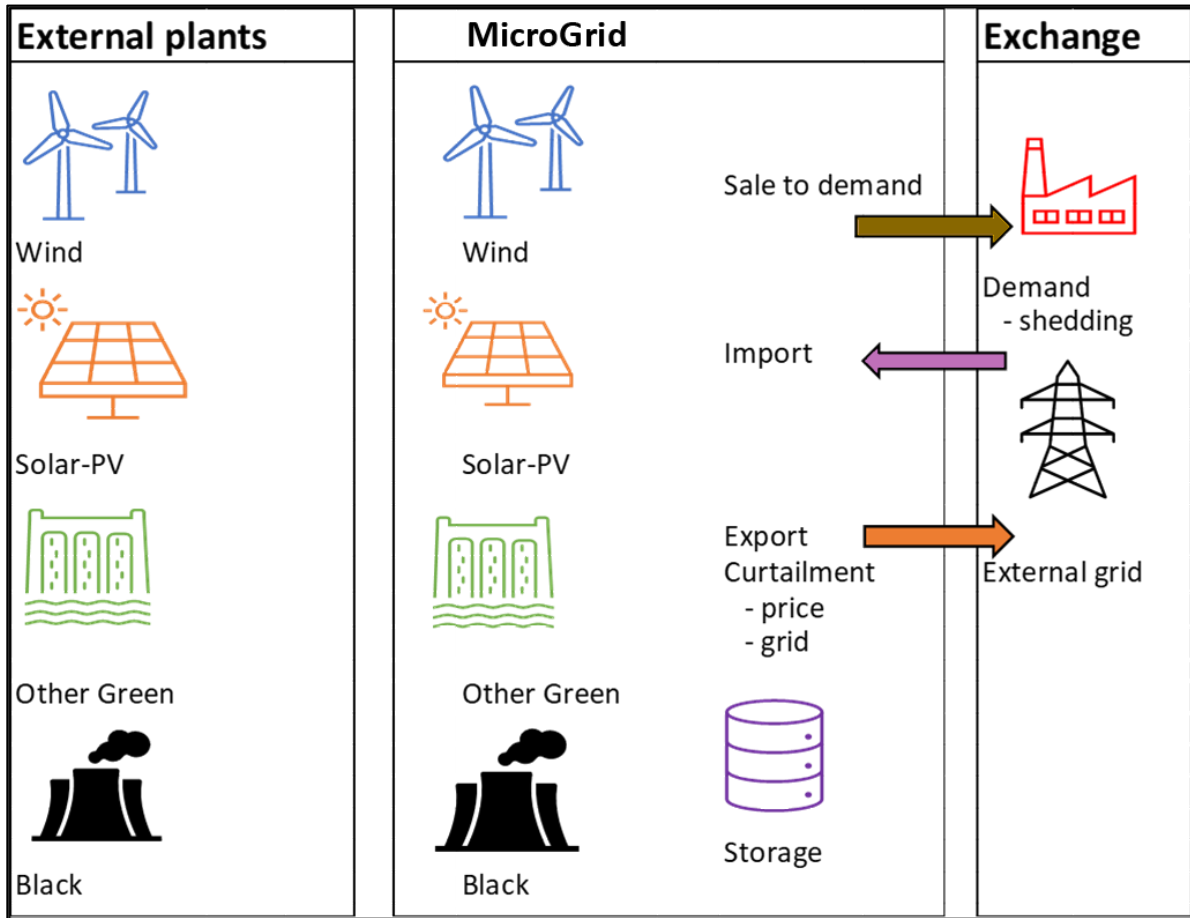
Figure 2 The demand is outside the MicroGrid.

With demand outside, the MicroGrid sells to demand based on an agreed price, which could be the marked price, but could also be a fixed price or a factor on the marked price.

Here it is simple to calculate like NPV and IRR.

The reference that is compared to in this situation is that the MicroGrid deliver to the demand based on the agreed price, but the MicroGrid import all power from the grid. Thereby the comparison to the reference holds the extra element that it can be seen if it is better for the MicroGrid to establish own production units/storage OR just to purchase from grid.
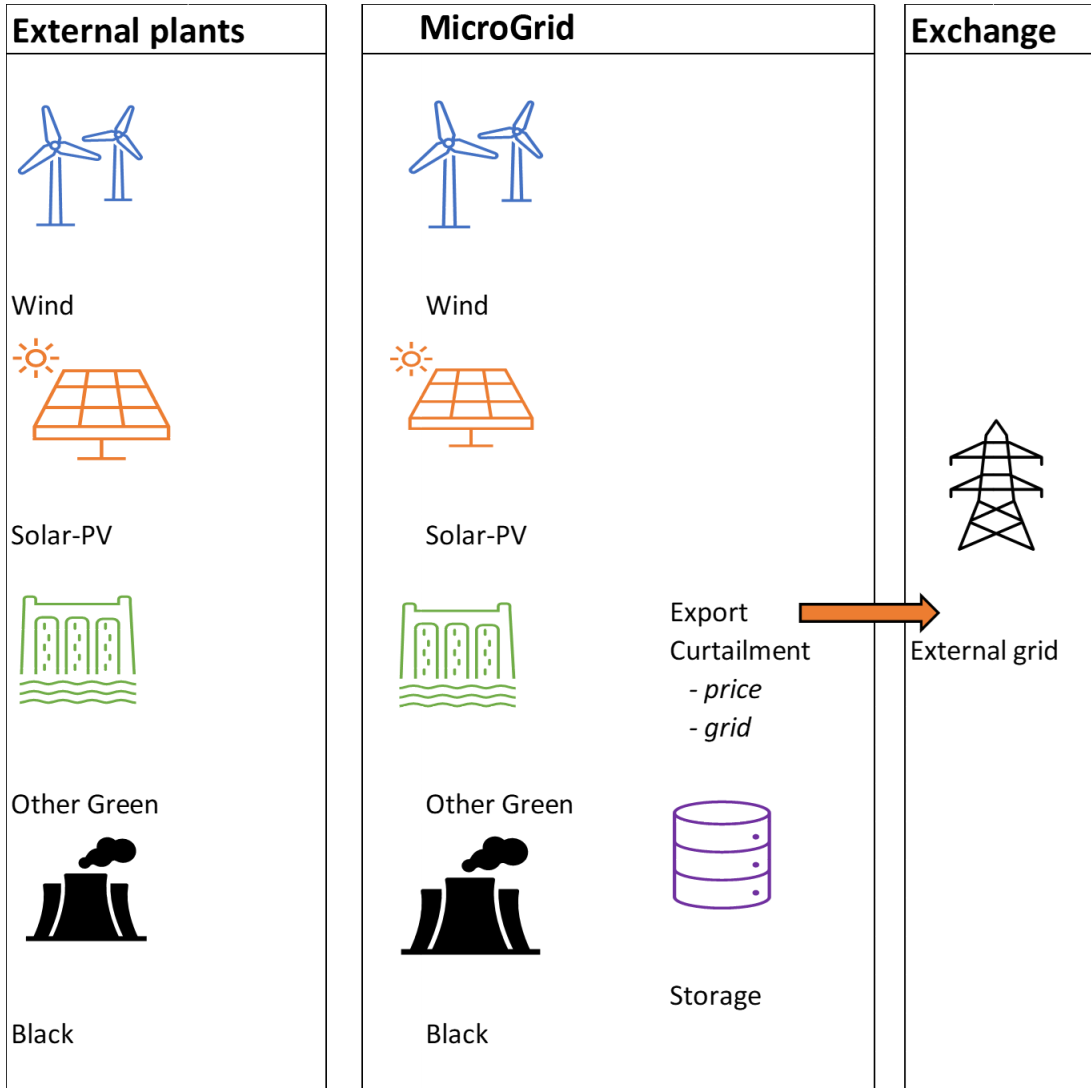
Figure 3 There are no demand, all exported.

A third variant is that there is **no demand**. A typical situation for many plants is that all power produced is exported. This situation can also be handled, along with storage, which can be relevant if there is lack of grid capacity or a limit on when or how much can be exported. The storage strategy will then be to charge storage when there is a lack of grid capacity and export to the external grid when production is below grid export capacity. Export only occurs if the electricity price is more than a user-defined threshold, if not, the export will be postponed. The new OPTI-Storage functionality handles this even more better, maximizing the income.
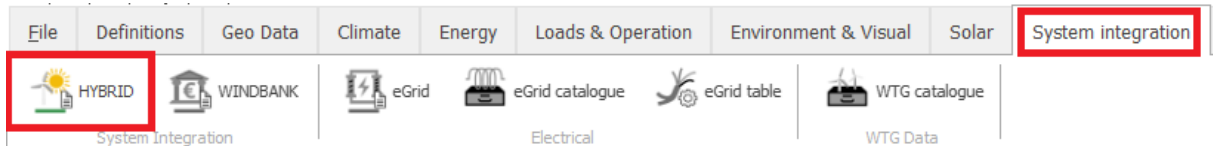
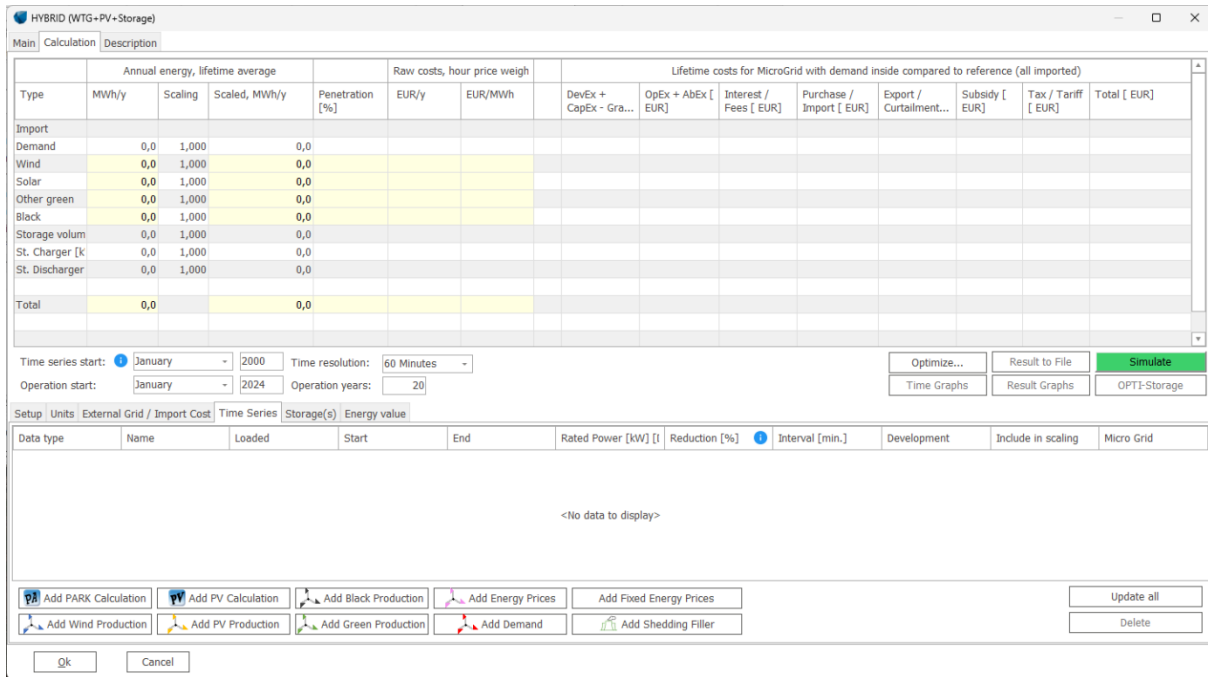Go to the System Integration tab and click on the HYBRID button to open the module.

Figure 4 The HYBRID Calculation tab or "controller".

This is where the main functions are controlled from and simulation results are visible for evaluation.

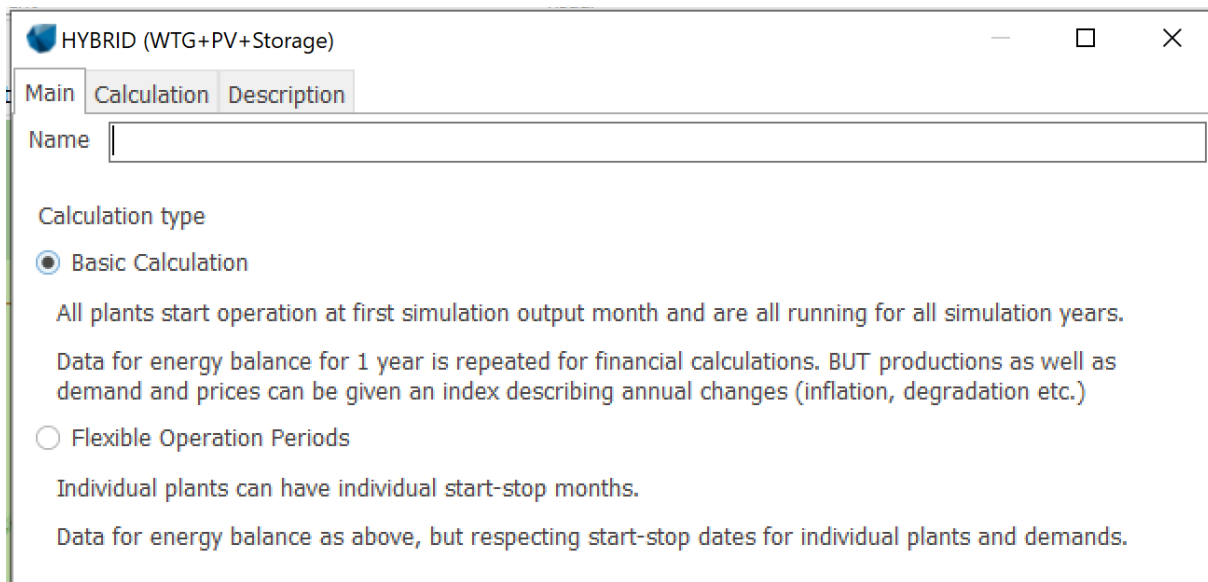On the Main tab two different "principles" of operation for the module can be selected:

Figure 5 Selection of "Basic" calculation vs. Flexible Operation Periods.

For the Basic calculation, all plants and storage are assumed to start operation in the same month and end operation in the same month. This will be the typical setup while investigating the most feasible composition.

When a more specific project is to be documented, the different plants will typically have different operation start times.

Before starting using the HYBRID module, some basic information needs to be established, described in following section.

15.2 Establish basic data

The following data should be established prior to starting the HYBRID module:

Production time-series options to use: (with a minimum hourly resolution, down to one minute can be handled)

- windPRO PARK time-varying calculaton for a wind plant
- windPRO Solar-PV calculation, which is always time-varying
- Windfarm calculation available as time-series from other (non-windPRO) calculations -> import into a METEO object
- PV-farm calculation available as time-series from other (non-windPRO) calculations -> import into a METEO object
- Other green production available as time-series -> import into a METEO object
- Black production available as time-series -> import into a METEO object

Other optional time-series: (with a minimum hourly resolution, down to one minute can be handled)

- Price time-series, normally ONLY hourly resolution while market prices typically are hourly -> import into a METEO object
- Demand time-series -> import into a METEO object

More time-series of each type can be added to a HYBRID simulation, except for the price time-series.

Note that it can be an advantage to establish longer time-series than just the one concurrent year required. Then the sensitivity to which year can be tested by selecting different starting dates for the energy balance simulation (and price).

If simulation is in an electricity market with high renewable energy penetration, it is very important that the price time-series and meteorological data are concurrent, especially when the prices can be affected by the hourly wind or solar production. A more problematic issue is if the penetration increases too much during the financial simulation period and significantly affects the price dynamic. This can only be handled by establishment of an artificial price time-series which has the expected dynamics. This is not a trivial task.

Note that when the HYBRID module is started, there will be two alternative options for auto generated time-series:

- Fixed price, where a time-series is autogenerated with same price in all time stamps
- Shedding filler, where other green or black production is filling up when demand is not fulfilled by the system due to grid import limits. This could be an island operation, for example.

15.2.1 Example data

In the folder windPRO Data\Standards, there will be examples of price time-series and demand time-series:
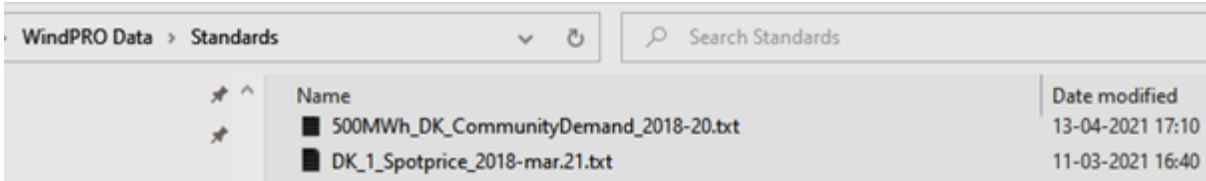
The demand simply follows the Denmark – west variations, scaled to 500 MWh/y.

For western Denmark 3 years+ spot market price data is downloaded. More Danish (and neighbouring countries) data can be reached at:
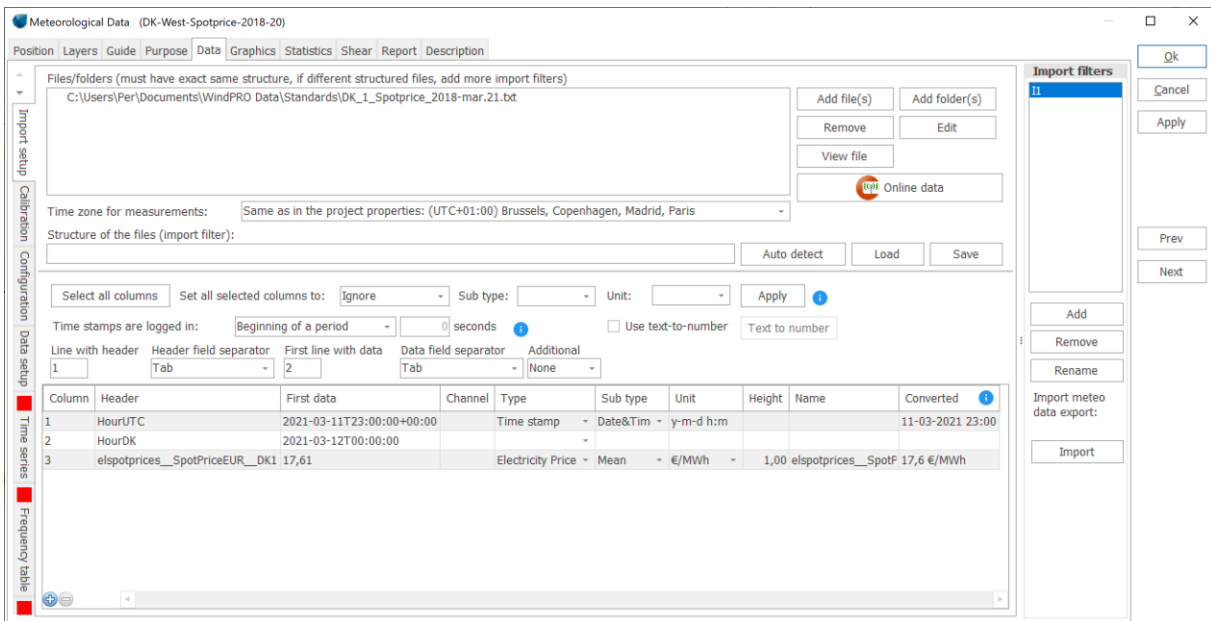
https://www.energidataservice.dk/buildreport

Figure 6 Example of import filter in METEO object for electricity prices.

Column	Required signal	Based on	Signal name	Low limit	High limit
1	Electricity Price	elspotprices__SpotPriceEUR__DK1_Mean (1,0m)	Electricity Price		

Figure 7 In Data setup, select relevant signals. Height irrelevant, but a "dummy" value must be entered.

Having the data in a METEO object makes it easy to evaluate the data, and to disable erroneous data.

The basic principle if the HYBRID module encounters disabled or missing data is to interpolate linearly. An exception is price data, where the previous hour's price is taken. It is a general principle that prices are hourly, and when the simulation is in higher resolutions than one hour, prices are not interpolated.

The demand data can be used scaled if the example is related to a much smaller or larger demand.

Example data already loaded in METEO objects can be found in the sample project (Hybrid Quick Guide) which can be downloaded from the windPRO Samples in the Data menu in windPRO.

15.3 Setting up the HYBRID simulation

Having at least a production time-series ready, a simulation can be set up. In the following example, a PARK calculation is performed for years 2018-20 based on hourly ERA5T data. The project has 7 x 75kW WTGs.

The time-series will be loaded along with the demand and price time-series from example data.

Figure 8 Loading time-series and setting scale factors, if relevant.

Here the three time-series for the completed PARK calculation, and the example data from the sample project for Demand and Prices are loaded.

The demand is scaled up by entering a scale factor of 2 in the highlighted field above to make the demand comparable to the PARK production, so the scaled demand is ~1000 MWh/y.

What can be seen is that the production from wind plant for the simulation year (2018) is 863 MWh (reduced with 10% loss set in the PARK calculation, but editable in the "Reduction" column).

Also a PV-plant is added for illustration purpose.

| Type | Annual energy, lifetime average | | | Penetrati... | Raw costs, hour price weighted | |
	MWh/y	Scaling	Scaled, MWh/y		EUR/y	EUR/MWh
Import					14.057,8	49,691
Demand	499,6	2,000	999,2		44.747,5	44,786
Wind	863,2	1,000	863,2	86,4	32.148,2	37,242
Solar	534,7	1,000	534,7	53,5	24.295,6	45,434
Other green	0,0	1,000	0,0	0,0	0,0	
Black	0,0	1,000	0,0	0,0	0,0	
Storage volume	0,0	1,000	0,0			
St. Charger [kW	0,0	1,000	0,0		0,0	0,000
St. Discharger [I	0,0	1,000	0,0	0,0	0,0	0,000
Shedding			0,0	0,0	0,0	
Total	1.398,0		1.398,0	139,9	56.443,8	40,376
			Shedding:			
All Imported ref.			0,0	0,0	44.747,5	44,786

Figure 9 After simulation, the raw costs are seen.

After a simulation has been run, the value for the individual lines is calculated. This is based on weighting the energy with prices. It can e.g. be seen that the Wind price is lower while the market price becomes lower when there is much wind production in the marked. Solar prices are higher in the example, but this will change when much more solar power is established. In the line Total, it is only the production (yellow background) that is summarised. The first line Import show values of what needs to be imported, when production do not fulfil the demand.

Penetration percentages (of scaled demand) is also seen.

These values give an initial picture of how production and demand as time-series weighted with price time-series are converted to currency based on 2018 time-series. Changing to 2020 in the "Time series starts" will use production, demand and prices for 2020:

| Type | Annual energy, lifetime average | | | Penetrati... | Raw costs, hour price weighted | |
	MWh/y	Scaling	Scaled, MWh/y		EUR/y	EUR/MWh
Import					8.934,9	36,628
Demand	499,8	2,000	999,6		25.991,7	26,001
Wind	1.004,8	1,000	1.004,8	100,5	15.853,3	15,778
Solar	537,0	1,000	537,0	53,7	12.503,5	23,285

Figure 10 Changing the simulation year will change demand as well as production and prices.

Figure 10 shows that production is a somewhat higher in 2020. The big difference is the price. The value of wind production is more than halved, and the cost of demand is reduced more than one third. This illustrates that it is of extreme importance to have a good idea of which price year to use, one that is assumed most realistic for the future, when analysing the financial feasibility of the HYBRID system.

The year is reverted to 2018, and the Simulate button is pressed. We now look at the financial feasibility of the wind park in a system from a purely market price-based viewpoint.

We will get a warning, that no cost for the wind park is included.

In the drop-down choose "Edit cost function", and create a new entry from one of the templates as illustrated below:
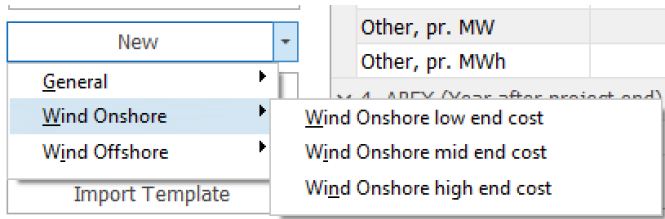

Figure 11 Selection of cost function.

The cost function must be reviewed, and might be adjusted, but this is covered later in the Chapter. In this case the costs are lowered relative to the "native" cost function for illustration purpose.

We now press the "Simulate" button and get a first calculation result:

Figure 12 First simulation result, only wind production included.

What is seen in the financial columns are the lifetime costs:

1. Development Expenditure (DEVEX) – Grants + Capital Expenditure (CAPEX)
2. Operating Expenditure (OPEX) + Abandonment Expenditure (ABEX)
3. Interests + fees (no loan included in this simulation)
4. Purchase/Import (No purchase from external plants included in this simulation, the wind park is assumed INSIDE the MicroGrid (can be chosen on time-series tab.)
5. Export/Curtailment
6. Subsidy (none defined in this simulation)
7. Tax/Tariffs (none defined in this simulation)
8. Total costs, SUM of the above.

On the bottom line "All imported" is shown, which is simply the cost if the demand was entirely imported from the grid, which is the reference. Will an investment in a wind plant pay off and make the cost of energy cheaper?

In this case the answer is "maybe".

All imported costs total 895 kEUR during the project lifetime.

The cost of the wind park – export value is 375 kEUR and the imported from grid costs are 469 kEUR, in total 844 kEUR, 51 kEUR less than if the demand continues to import all energy for the next 20 years, assuming the 2018 demand, production, and time-series.

The NPV is negative, however, at -52 kEUR. So, the savings are acceptable, but when discounting with 2.5% interest rates, (default), the value of the income in the later years is low compared to the value of the investments in the early years.

Further analyses can now be performed to further understand the financial implications of the choices made. There are many possible questions, where the HYBRID module can deliver the answers. We may need to look at financing the plant(s). We may need to include tariffs and taxes; we may need to look at expectation of future price development, etc. Variations in any or all of these will change the results of the feasibility check. These will be systematically presented and explained in the following sections.

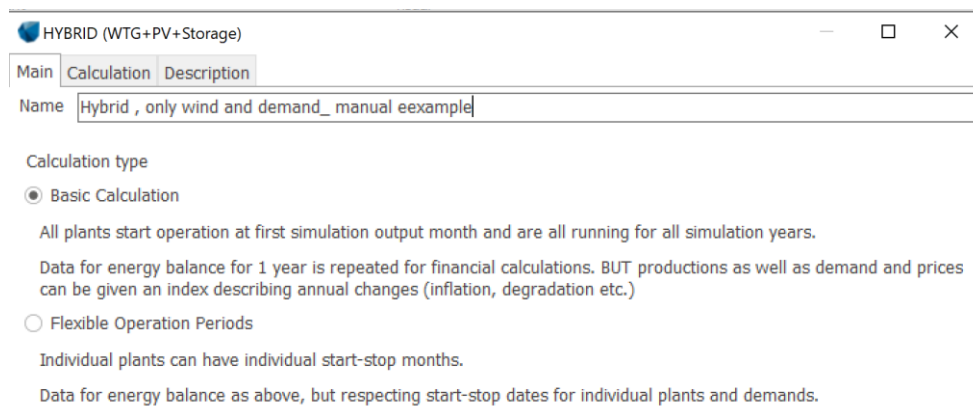### 15.3.1 Main tab, naming and calculation type

Figure 13 Selection of "Basic" calculation vs Flexible operation periods.

A calculation **name** can be entered (always recommended for any windPRO calculation).

For the Basic calculation, all plants and storage are assumed to start operation in the same year/month and end operation in the same year/month. This will be the typical setup while investigating the most feasible composition.

When a more specific project is assessed, the different plants will typically have different operational start times and some might not be operating until the final simulation year.

15.3.2 Simulation periods and resolution

The **Time-series start** is for the energy balance data, and there must be ONE full year within the concurrent part of the time-series added. It is recommended to establish time-series so at least two full years are available so that the sensitivity to selection of one year or another can be tested. The price-production dynamics for the specific year can be significant in determining the energy balance and hence the financial performance of the system. It might even be necessary to establish a "future" price dynamic to use in the simulation. For example, if much Solar-PV is assumed to be

added to the grid in the future years, this might have a negative impact on the prices in hours with much Sun.

The **Time resolution** can be set between 1 and 60 minutes. Any added time-series will be interpolated to increase time resolution, except for the price time-series, which always is treated as hourly. Later the output from windPRO PARK and Solar-PV will be able to deliver higher resolution time-series based on a resampling method being developed by EMD. At present it is only possible to deliver high time resolution output, if having high resolution data to calculate from. Also, data from METEO objects can be high time resolution.

Operation start can be any year, typically in future.

Operation years, the number of years the MicroGrid operation is simulated.

Important to mention that the energy balance calculation is repeated for each operation year. Characteristics such as degradation can be included as well as price developments, etc.
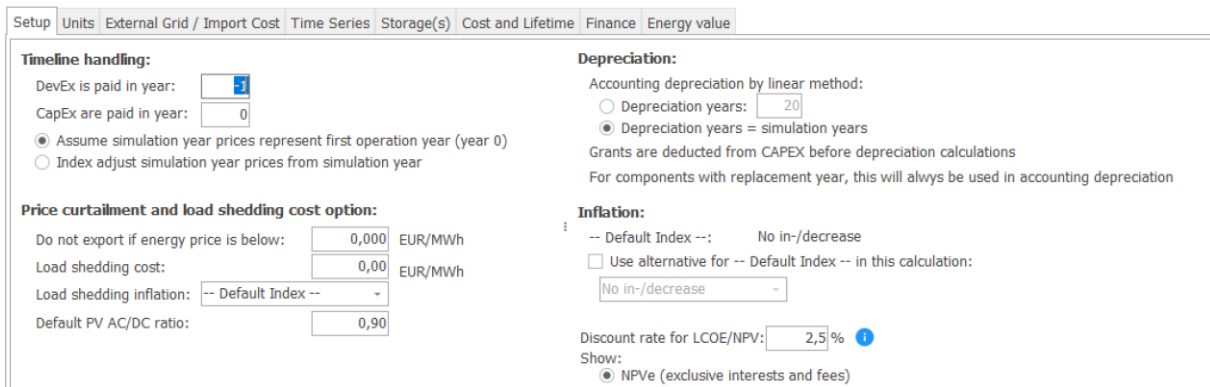
15.3.3 Calculation, Setup

Figure 14 Calculation setup collects different decision requirements.

15.3.3.1 Timeline handling
On this tab it is specified when DEVEX and CAPEX is placed in the financial simulation. The default is that DEVEX is placed at year -1, meaning that the DEVEX costs are placed 12 months before operation starts.

CAPEX is by default placed at year 0, meaning the first operation month. The reason for this choice is that finance cost is arranged so interest by default is paid first time the year where CAPEX is placed. If CAPEX is placed year -1, there will be interest and instalment costs the year before operation starts. This would be taken by the reader of the report to be a non-logical approach. One way around this is to include a loan Payment Grace Period, which often would be the real-world approach, just requiring more manual data input, than if CAPEX is placed at year 0.

Indexation of the simulation year price level is optional so the price time-series can be assumed to be the same in the first operation year as the input data. This is the default. If a second option is selected, the indices chosen where the price developments are specified will be used for the different prices.

15.3.3.2 Depreciation
There can be two types of depreciation:

Accounting depreciation is used for setting up the accounting budget, following normal accounting principles, where the value reduction of the plant is used, not the instalment costs.

Depreciation is only used on CAPEX. In real life a part of DEVEX might have a value, that should be depreciated – and the other way round, part of CAPEX might have a value that should not be part

of the depreciation. To compensate for this, the user can move costs between DEVEX and CAPEX to get a realistic representation.

The depreciation time is by default the simulation time but can be manually set. If a plant is designed for 20-year lifetime, and there is a wish to report 25 years of operation, while the plant might run for 25 years, it can be more realistic to use the 20-year depreciation time instead of simulation time.

For parts of plants where replacement years for a specific part of the plant, e.g. the inverter for a Solar-PV plant, is set to 10 years, for example, this number is always used as depreciation time for this part. It would not make sense to use a longer depreciation time for parts that are assumed replaced before the end of the simulation period. This also means that if simulating 25 years and a new inverter is bought in years 10 and 20, the final inverter will only be half depreciated. A scrap value is assumed in the reporting. When taking out the "Result to File" output data for further processing in other packages (e.g., Microsoft Excel), the time period with data is expanded with the added depreciation period, and the user of the data can decide how to handle this situation.

	A	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF
1		All PV - DevEx	All PV - CapEx	All PV - OpEx	All PV - AbEx	All PV - Export	All PV - Export subsidy	All PV - Export tax	All PV - Export tariff	All PV - Grid Curtailment	All PV - Price Curtailment	All PV - Used in MicroGrid subsidy	All PV - Used in MicroGrid tariff	All PV - Used in MicroGrid tax	All PV -	All PV - Purchase	All PV - price	All PV - Account Depreciation
2	2020	-884	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2021	0	-88435	-985	0	249	0	0	0	436	44	624	-312	0	0	0	0	-8949
4	2022	0	0	-985	0	235	0	0	0	407	42	638	-319	0	0	0	0	-8949
5	2023	0	0	-985	0	219	0	0	0	379	40	652	-326	0	0	0	0	-8949
6	2024	0	0	-985	0	207	0	0	0	355	38	667	-334	0	0	0	0	-8949
7	2025	0	0	-985	0	186	0	0	0	325	35	679	-339	0	0	0	0	-8949
8	2026	0	-13536	-985	0	169	0	0	0	300	33	691	-346	0	0	0	0	-8949
9	2027	0	0	-985	0	152	0	0	0	276	31	704	-352	0	0	0	0	-8949
10	2028	0	0	-985	0	139	0	0	0	256	28	717	-359	0	0	0	0	-8949
11	2029	0	0	-985	0	120	0	0	0	234	27	725	-362	0	0	0	0	-8949
12	2030	0	0	-985	0	109	0	0	0	214	25	733	-367	0	0	0	0	-8949
13	2031	0	-13536	-985	0	98	0	0	0	196	24	741	-371	0	0	0	0	-8949
14	2032	0	0	-985	0	89	0	0	0	179	23	752	-376	0	0	0	0	-8949
15	2033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2707
16	2034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2707
17	2035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2707
18	2036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 15 Example of depreciation handling with remaining lifetime of a component.

Figure 15 illustrates a 12-year simulation period, where the inverter has 5-year replacement time. The first 12 years, the inverter + PV plant is depreciated linearly based on the PV-plant minus inverter costs, € 6.242 per year + inverter cost/ 5 year; € 2.707, total € 8.949. These are the depreciation costs through the simulation period 2021-2032. After 2032 there will be three years lifetime remaining for the inverter, and the output lines are expanded with these years and inverter depreciation included in the three remaining years after the simulation period has ended. For manual postprocessing of data, it can be decided to include the three years cost the last simulation year or to account for this as a scrap value.

In the accounting balance reports from HYBRID module, the last three years will not be included, and it is indirectly assumed there is a scrap value.

Grants will be deducted from CAPEX before calculating depreciation. If a plant needs grants, it is basically because the cost of the plant is higher than the value. Therefore, the most correct value in the accounting balance will be the grant reduced CAPEX.

15.3.3.3   Price curtailment and load shedding cost option

If the energy price is negative, by default the plants are curtailed. (Curtailment price threshold set to 0.00). Later in Section 15.3.13 *Energy value*, a price value for curtailment due to low prices can

be set. Often the grid operator pays compensation, when the plants help the grid system when there is too much production. This can be based on quite complex calculations, not included here. But with the option to curtail at a given price threshold and enter a compensation value, the mechanism is included. Since typically only few hours in a year have negative prices the importance of the accuracy is not that high.

Load shedding can be an issue if there are grid limitations, e.g. an island operation, or simply just in a system where the production capacity is too low relative to demand. This is where establishing a MicroGrid, with possible Storage, can help and reduce the shedding. To measure the value of this, shedding can be given a cost. It might not be involving a real payment, but without a cost, the demand simply just pays less because less is used. The shedding costs can be index-linked.

A default Solar-PV AC/DC ratio is used if Solar-PV production data are from a METEO object only the AC time-series production is available. Since the Solar-PV DC power is used in the cost functions, the DC power is required and calculated from the METEO time-series using this ratio.

15.3.3.4   Inflation

Inflation can be specified by a "project default", selected in Index form:
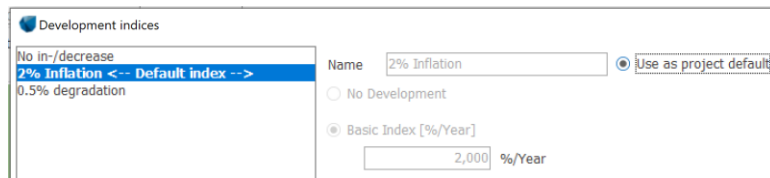
Figure 16 Selection of index used as project default.

By default, when creating a new HYBRID calculation, the "No in-/decrease" is selected as default. It will often be more convenient for the first analyses to calculate without inflation, while it is simpler to check the results.

If, for example, "2% inflation" is selected as new default in the index list, all "No in-/decrease" selections will be replaced with "2% inflation". If some indices, for example, for subsidy, are subsequently manually changed, and the default index later is changed from the manually set values will not change.

Figure 17 Alternative inflation for "fast test".

It is also possible just to check another inflation, that replaces all with the default selection. Thereby a fast test on a different inflation choice can be performed.

Note the indices that describes production development in time are NOT changed, only the financial indices.

15.3.4 **Calculation, Units**

Figure 18 Select units to handle small-medium-large projects.

Depending on the size of the project to be simulated, it is convenient to choose units that match the project size.

15.3.4.1   Currency selection

Selection of currency is by this form:

Figure 19 Selection of currencies.

Base currency for all HYBRID calculations is EUR. But any other currency can be selected to use as input/view/report currency, recalculated based on the exchange rate in the table shown.
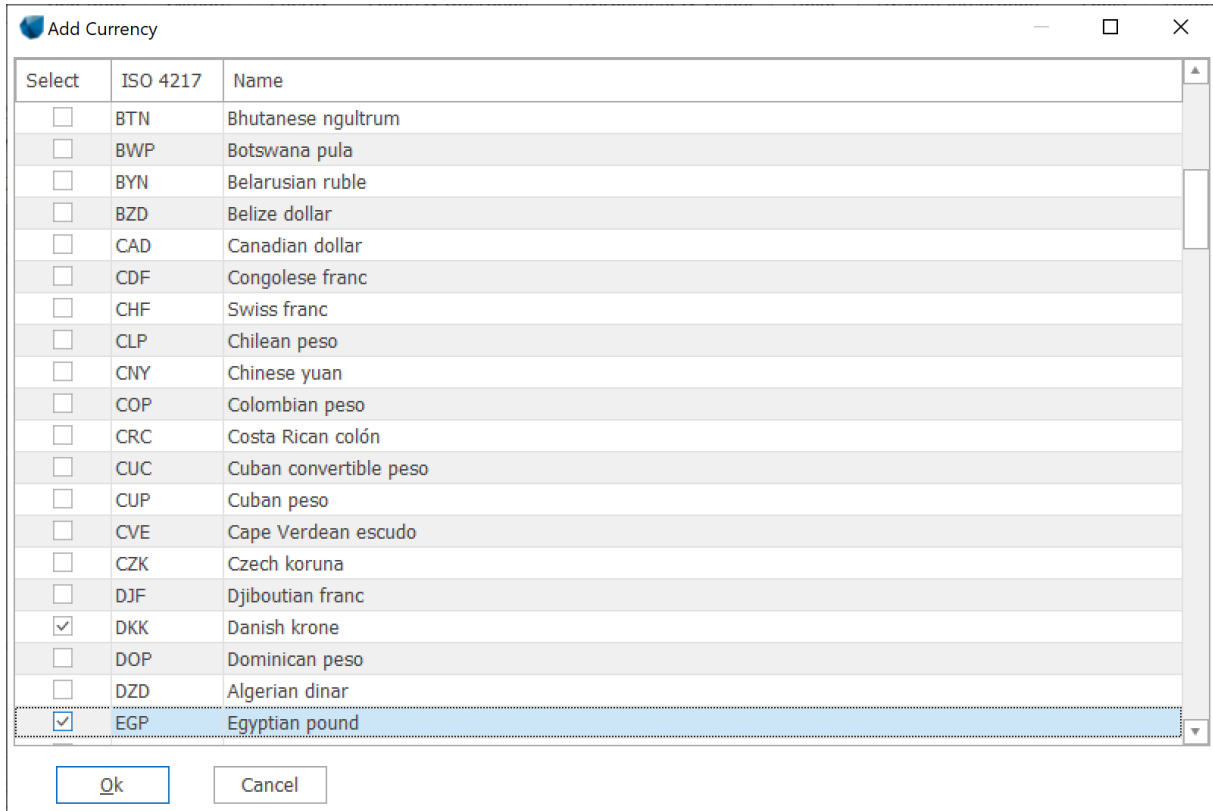
Figure 20 Add currencies from ISO 4217 list.

Here is as example with selected DKK and EGP, and the list will look:
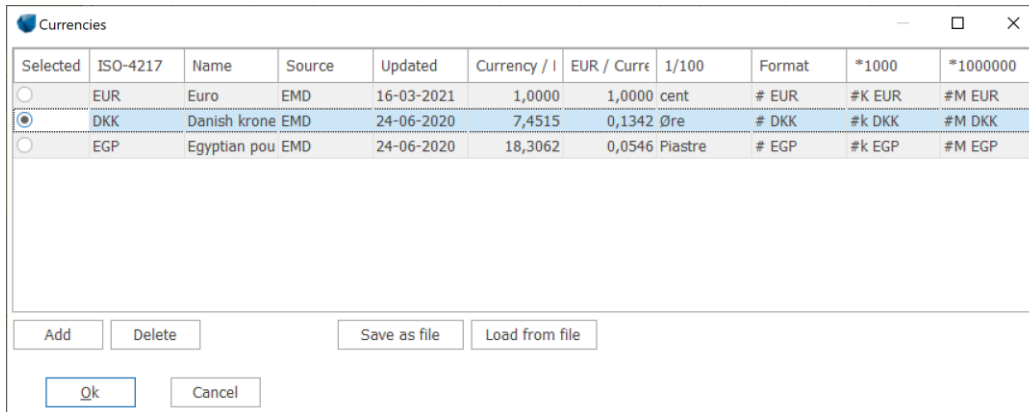
Figure 21 Currency list updated with selections.

If required, a manual change can be made, e.g. DKK/EUR to 7.4500:

Figure 22 Manual update is registered in list with USER source.

The list is with currency values from e.g., early 2020, so it is recommended that the user check actual currency exchange rates and update when relevant. Exactly which rate to use is an individual judgement or agreement with the client for whom the calculations are performed.

15.3.5 External Grid/ Import costs

Figure 23 External grid / import cost specifications.

The **Grid Capacity** is often the bottleneck for new plants. Here import/export limitations can be specified, partly for the MicroGrid, which might include a grid capacity expansion, and partly for the reference situation where all power is imported from the external grid. This also might require an expansion in case a new demand is part of the simulation which cannot be supported by the existing grid. For the two situations grid expansion costs can be included. These costs are NOT scaled in the case of modified system size but are assumed to have a fixed cost for the planned system.

For the **Import Energy Costs** the default is to use the loaded price time-series with a factor 1.0 and offset 0.0. To convert to a fixed price the factor is changed to 0.0 and the offset is then the fixed price. Values for Tariff and an Energy Tax can be entered. This is quite important, while this often will be critical for determining whether the MicroGrid will be financially feasible, where saving these costs can contribute.

For each of the input fields, a cost development index can be specified.

15.3.5.1   Calculated (Time depending) tariff

Tariffs often vary in time, where day hours have a higher tariff and night hours a lower tariff, to encourage the consumer to reduce consumption during peak load hours and thereby reduce grid expansion costs. This can be included choosing the **(o) Calculated Tariff** which opens this form:

Figure 24 Form for entering time depending tariffs.

In the left part more different period cost models can be added, in the right part the individual period cost models is defined. An example:

Figure 25 Peak hours on Monday to Friday with higher tariff, Sundays, and holidays with lower.

Important: The priority is deciding. If the two lines above were swapped, all mon-friday would get the high cost in peak hours, also on holidays, while this line would have higher priority. As defined above, Sundays and holidays always will get the low price. All non-defined times will get the default price, like e.g. Saturdays in the example.

The red background for the Holiday field, tell that no holidays has been defined yet. This is done in "Edit Holidays". Below we pick the option "Load Online", giving access to a library for all countries:
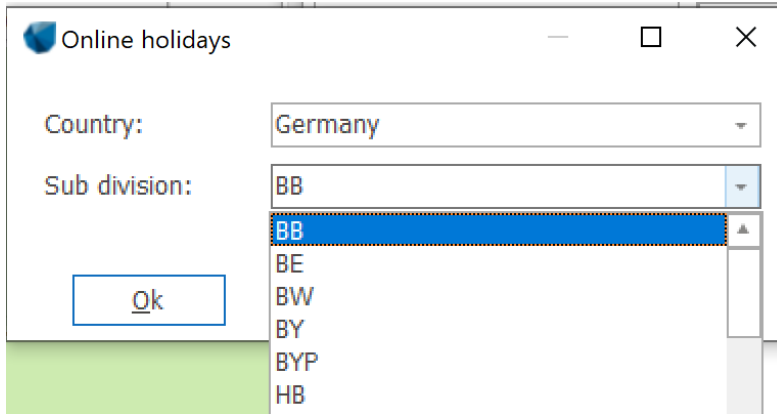
Figure 26 Online Holidays, with subdivision for some countries, like Germany.

For e.g. Germany, the individual "Bundesländer" has different holidays, and the region must be selected.
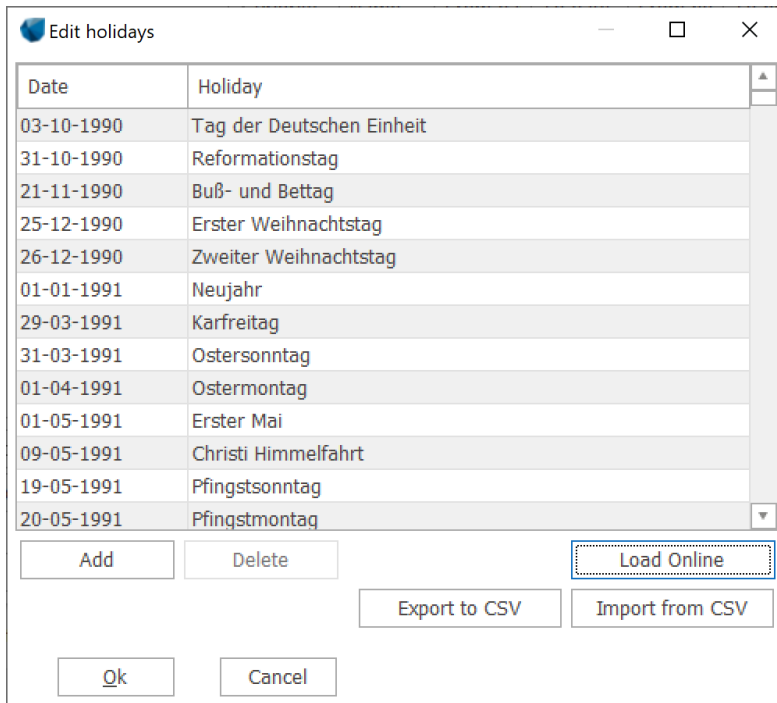
Figure 27 The edit holidays form after online import.

When downloading online, a complete series of holidays from 1990-2074 will be established. It is possible to edit manually.

The view summary button creates a graphical overview of the period cost model:
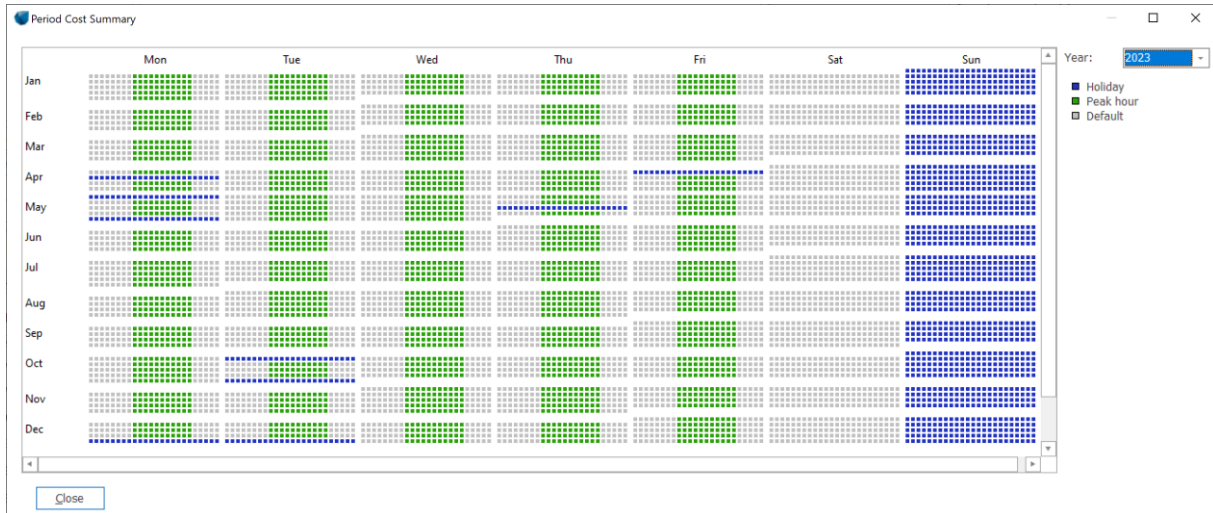
Figure 28 Period cost summary.

A specific year can be selected and it is seen where the holidays appear.

15.3.6 Time series, windPRO calculations

The time-series is the core input. For wind parks and Solar PV-plants windPRO calculations can be loaded. Quite precise time-series with expected production including elements such as curtailments (for wind parks) are available. Some important information related to the two types of calculations:

For **Wind Park calculations**, these must be time-series calculations. Here are two variants, based on MESO data or based on Measurements. The data used in calculation decides the possible time resolution.

Figure 29 PARK calculation setup with features marked important for HYBRID.

The settings in "Output to PERFORMANCE CHECK…" section of this tab will determine the output to HYBRID. If the wind farm to be used includes other turbines in the calculation, it is possible to select individual WTGs and only these will appear when loading into HYBRID. The other turbines might also give wake losses to the selected turbines.

The "Aggregated time-series values" decides the aggregation level. **This is by default monthly which cannot be used in HYBRID. Remember to change aggregation level to "None" or to a maximum of 1 hour.**

Finally, the "simple reduction", above shown as 10%, but editable, by default is transferred to HYBRID. There is no loss reduction in a PARK calculation apart from wake and curtailment losses, therefore it is often relevant to add losses here (such as grid losses, availability, etc.).

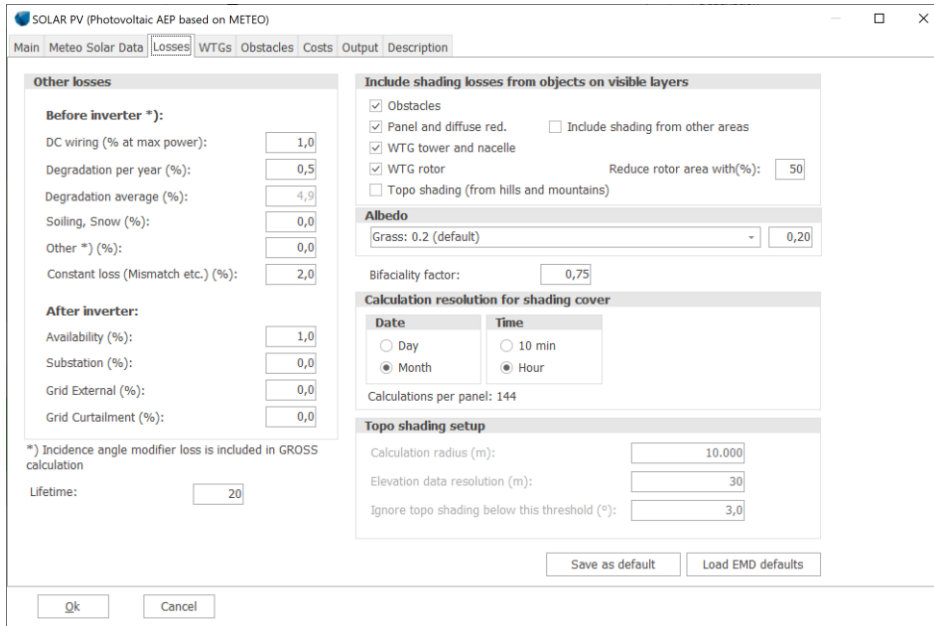For **Solar-PV calculations** a full loss specification is available in the calculation module.

Figure 30 Loss specifications in Solar-PV calculation.

When a loss is correctly specified, this loss will be deducted in the data transferred to the HYBRID module. Although **NOT the degradation loss**. This must be manually added by an index:
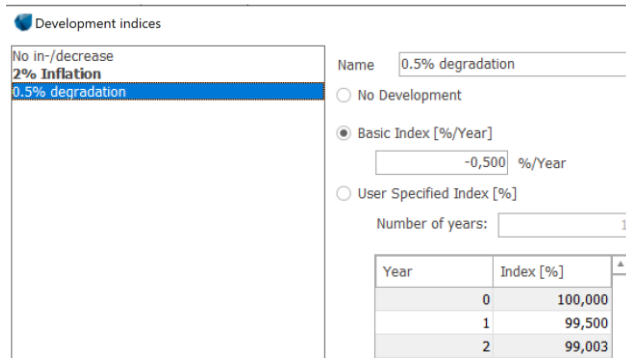

Figure 31 Creation of a degradation index.

Figure 32 Selection of degradation index.

15.3.7 **Time series, loaded from METEO objects**

Time-series from any production calculation or demand or price time-series can be imported in METEO objects, see the more comprehensive manual **Meteorological Data Handling** for details regarding how to import data. When imported and using one of the buttons marked with the METEO object symbol, the HYBRID module looks for relevant METEO objects.

Figure 33 Buttons marked with METEO object symbols require data loaded in METEO objects.
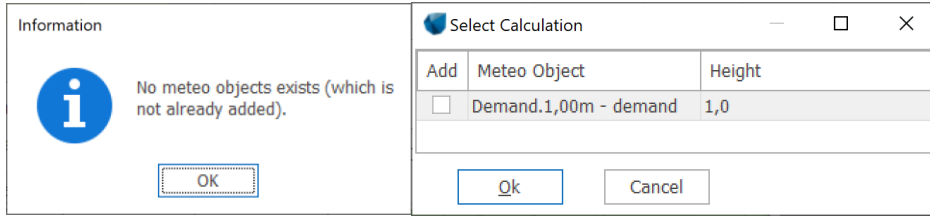

Figure 34 Left, if no match is found, right if relevant data is found.

Pressing a button look through the METEO objects and check if there are objects with these signal types loaded:

- Energy Price
- Consumption (= demand)
- Production

Select the relevant option and load by clicking OK.

Aside from wind or Solar-PV production data be:

- **Other Green**, e.g. Hydro, Geothermal, biomass-based production, etc.
- **Black,** e.g. diesel generator or other fossil fuel-based production.

Common for Other Green and Black is that they can be established in two ways:

- **As fixed time-series** (e.g. as a constant production or run of river Hydro, based on external simulations or measurements.). The time-series must be imported into a METEO object, where there must be minimum one year concurrent to the simulated wind and/or PV simulations with 1 hour time resolution or higher (down to 1 minute).
- **As Shedding filler**; The unit is producing when the sum of producing units, storage discharge and import (limited by grid capacity) cannot fulfill the demand.

Hydro with storage capabilities is not handled intelligently at present. The user must establish a production time-series, and the production will be fixed by hour.

A hydro pump storage can be handled as a storage component.

15.3.8 Time series, Fixed energy price and Shedding filler

There are two special time-series, auto generated by the module.

The fixed price time-series can be used e.g., for island operation mode, where there is no market to act against. An index can be used for change in time (annual).
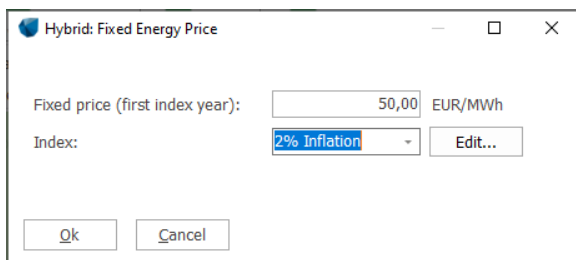

Figure 35 Fixed price time-series.

The shedding filler is used, if there are grid limitations, e.g., in an island operation mode, that prevents the demand being served by the specified production units (and storage), but instead will be served by a diesel generator or other source. This could also be a biomass-fuelled production unit or a hydro power unit with a storage capacity that makes it possible to deliver at any time where other units cannot deliver the demand.

The shedding filler can be specified as green or black. Whether it is green or black will influence the reports and graphics. In relation to the filler, a cost function can be established so the investment and operation costs (e.g. fuel costs) will be handled in the simulation. Also, the price the production is sold for including taxes, tariffs and subsidies can be specified individually per plant, where the energy price e.g. can be linked to the price time-series with a factor and offset. The default is that it follows the price time-series (factor = 1 and offset = 0).
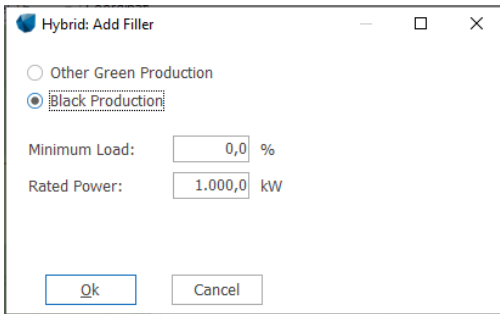

Figure 36 Shedding filler specification.

15.3.9 Time series specifications; inside/outside, scaling etc.

The **Data type** can be energy price, demand, and production, where production can be from PARK or Solar-PV calculation or from METEO objects.

Name is auto generated from source but can be edited.

Loaded tell when the given time-series was added to the simulation.

The **Start and End dates** for the loaded time-series are important, as there must be at least ONE concurrent year for all time-series used in the simulation.

Rated Power for the plant is found either in the calculation specifications or if loaded from METEO objects by finding the highest power in the time-series.

Reduction [%] gives the option to make a general reduction of each time stamp in the time-series. Often a wind park calculation will not be loss reduced and would then provide too high production figures.
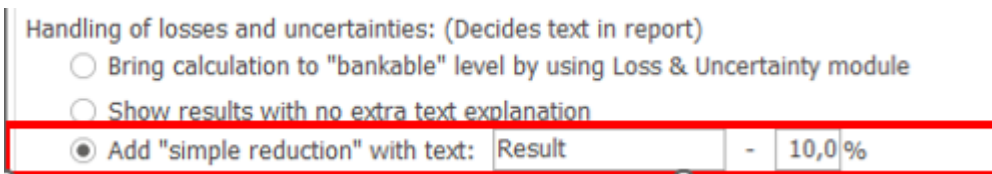

Figure 37 Loss deduction in PARK calculation.

By default, the figure for loss deduction in PARK Setup is carried over when reading the PARK calculation. This can be overwritten. In future versions, PARK will handle loss deductions more intelligently, so availability losses can be distributed in time by specific rules, for example. At present it is possible to include curtailment losses based on rules that influence the output by time step. Likewise wake losses are calculated by time step.

The time **interval in minutes** is just for information, telling which time resolution the time-series loaded are found to have.

Development can be inserted as an index, see Section 15.4. This covers the situations where a demand is expected to increase during the simulation period, or a PV plant production will degrade over the simulation period, for example.

Production and demand time-series can be marked **"include in scaling",** which means that the time-series can be scaled. This means these elements can quickly be tested, so see if a larger PV plant would be a financial better alternative, for example. The demand can be adjusted to represent a larger population, etc. And the scalable elements can be included in auto optimization.

If there are two wind parks, one that is already there, and another planned, only the planned would be relevant to mark "include in scaling" as only this wind park would change when optimizing or manually setting scale factors.

Time series can be inside or outside the **Micro grid**

Production units **INSIDE** means that the MicroGrid owners invests in the production units.

Production units **OUTSIDE** means that the MicroGrid purchases power from the units.

An "infinite" (probably with some computer limitations) number of production units, each specified as inside/outside.

Demand can also be specified by multiple time-series, although all must be inside OR outside. This limitation is designed to make it possible to compare to a reference.

The "Update all" reloads the time-series in case some have been modified/updated.

15.3.10 Storage

Storage is a central component in a HYBRID simulation due to the time-varying production from as well Wind as PV, a storage might improve the system. Basically, all types of storage can be handled although the focus here will be on batteries.

	Setup	Units	External Grid / Import Cost	Time Series	Storage(s)	Cost and Lifetime	Finance	Energy value			
Data type	Name	Volume [MWh]	Loss [%]	Charge Capacity	Charge Loss [%]	Discharge Capac	Discharge Loss [	Discharge Depth	Include in scaling
Storage	New storage	5,00	0,1	1.000,00	2,0	1.000,00	2,0	1,0	☑

Figure 38 Storage specifications.

The storage is defined by:

- Volume
- Loss (%) (standby loss)
- Charge capacity
- Charge loss (%)
- Discharge capacity
- Discharge loss (%)
- Discharge depth (%)

The size of the storage will typically be decided based on running the optimizer, see Section 15.6 *Optimizer*.

As a starting point, a storage size can be established based on, for example, 4-hour production with rated power. Having 1 MW wind and/or PV production units, a 4 MWh storage volume could make sense.

Running a simulation gives access to the Storage demand analyser, which is helpful for setting the charge/discharge capacities:
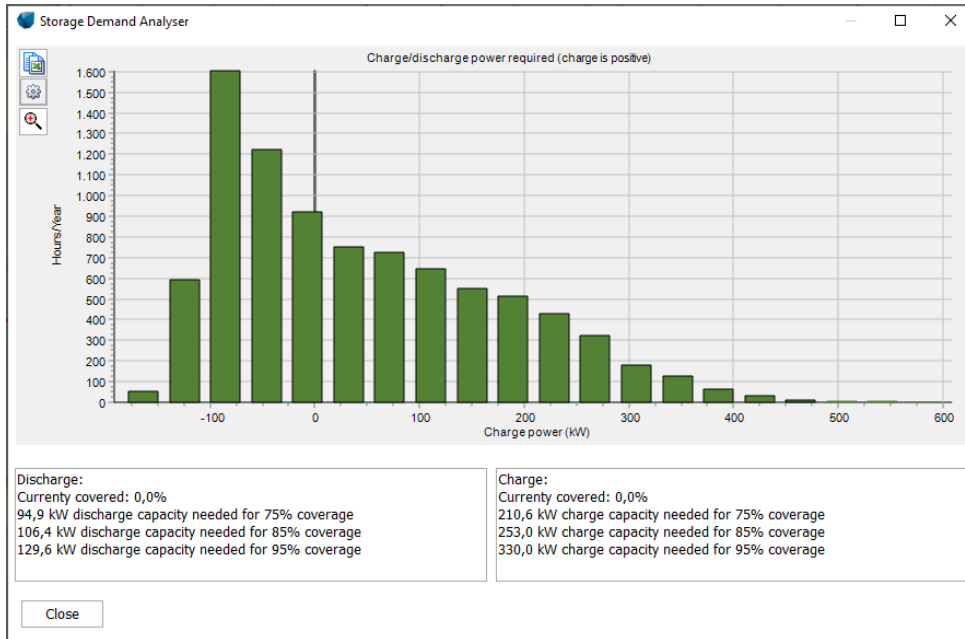
Figure 39 Storage demand analyser for selection of charge and discharge capacity needed.

Figure 39 shows how much charge/discharge capacity that will be needed for different coverage thresholds as a result of a simulation without storage.
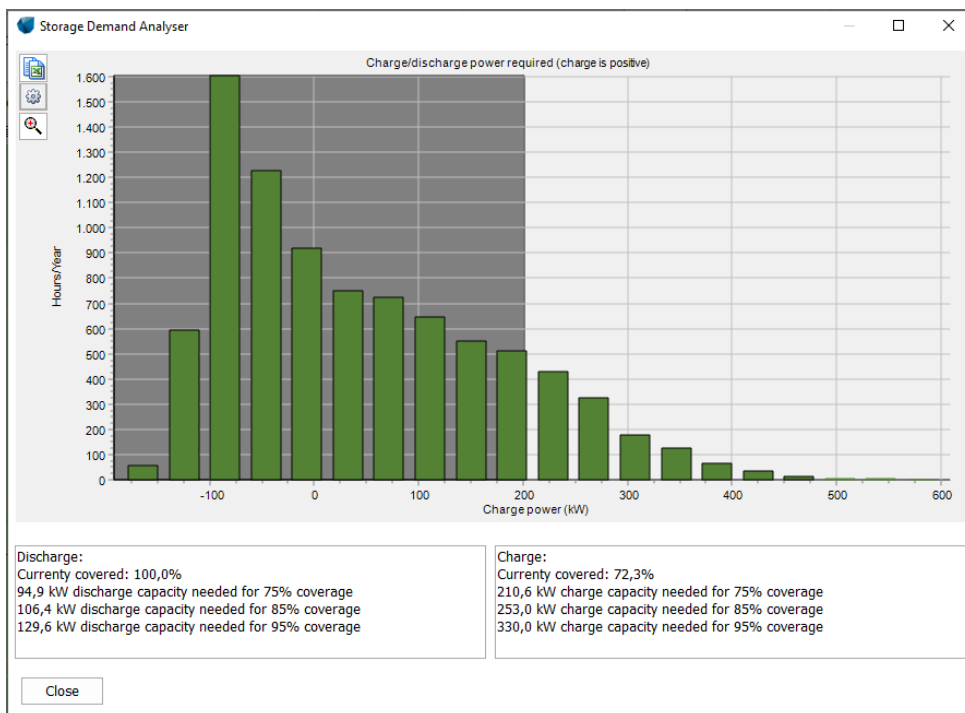

Figure 40 Re-evaluation of charge/discharge selections.

With 200 kW selected for charge as well as discharge capacity, Figure 40 shows which requirements won't be fulfilled outside the grey shaded area. The volume is set to 1 MWh – a thumb rule is that the storage volume should be 4-8 times the charging capacity, meaning it takes 4-8 hours for fully charging the battery. Adding a cost (see next paragraph), will give a first idea if the storage seems to be a good idea.

15.3.11   Cost and lifetime

Data type	Name	Cost Model	Operation Start Year	Operation Start Month	Lifetime [Years] - (0=all)
Park Production	WTG Production - WindFarm 6	Wind Onshore low end cost ▾	First output year	First output month	Full period
PV Production	Solar PV - Test plant 500 kW	Solar-PV large > 100kW ▾	First output year	First output month	Full period
Storage	New storage	No cost ▾	First output year	First output month	Full period
		-- Edit cost functions --			
		No cost			

Setup | Units | External Grid / Import Cost | Time Series | Storage(s) | Cost and Lifetime | Finance | Energy value

Figure 41 Adding a cost function.

The first time a new technology is added to a simulation, the only choices are "No cost" and "Edit cost functions". Selecting "Edit cost functions" the following form appears, where the "New" button is expanded:

New	▾
Storage ▸	Battery
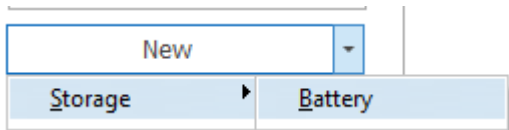
Figure 42 Establish new cost function.

Only relevant technology options will be shown. As no Storage cost function has been established so far, there are no cost functions, but there is a "New" button, that can create a storage cost, with sub-selection, Battery – future versions may add more options, like there are for wind and Solar-PV at present.

Setup | Units | External Grid / Import Cost | Time Series | Storage(s) | Cost and Lifetime | Finance | Energy value

Data type	Name	Cost Model	Operation Start Year	Operation Start Month	Lifetime [Years] - (0=all)
Park Production	WTG Production - WindFarm 6	Wind Onshore low end cost ▾	First output year	First output month	Full period
PV Production	Solar PV - Test plant 500 kW	Solar-PV large > 100kW ▾	First output year	First output month	Full period
Storage	New storage	Battery ▾	First output year	First output month	Full period

Figure 43 Selected cost functions.

The simulations have more meaning when costs are added. Figure 41 shows how cost functions can be added – by first time use first enter the "Edit cost functions". These are described in more detail in BASIS manual Chapter 2.18. The following describes how they are established/attached in HYBRID.

Figure 44 The cost function gives a first rough budget for the technology.

Figure 44 shows the cost function value, the specific costs for the different "components" within the technology. These are multiplied by the selected plant size and a "Temporary example plant cost" is shown. Temporary, while the battery size can be changed and thereby the cost automatically will change in the simulation.

The table on the right summarizes and the Cost of Storage (COS) as well as Levelized cost of storage (LCOS) and is calculated based on the cost function and some key values, that can be edited.

Clicking OK, the costs are adapted to the HYBRID simulation, with the important benefit that if the size of the plant is changed, the costs are automatically changed. This makes it possible to optimize the size.

15.3.12   Finance

Figure 45 Adding loans.

Normally energy plants are financed, as it is not that common that the investor has the cash to invest directly. Here the "Add loan" drop-down will show a line for each added plant. The loans will be "plant specific", only in this way is an optimization by technology possible.

| Setup | Units | External Grid / Import Cost | Time Series | Storage(s) | Cost and Lifetime | Finance | Energy value |

Loan	% of Investment	Loan Amount [EUR]	Loan Type	Period	Interest Rate	Edit
⌄ 2: New storage [Storage] - (290.000 EUR)						
New loan	100,00	290.000	Nominal Loan / Annuity	10	3,00	Edit...

Figure 46 Main loan specifications.

In the main loan specifications, the following can be edited:

- % of investment (automatically follow the investment by scaling/optimizing)
- Period, years
- Interest rate %

These are the most important and therefore visible/editable in the list. For further details, use the EDIT button and the more detailed form (which also appears when a new loan is added) will appear:

Figure 47 Detailed loan specification.

Here more details can be entered.

Type:

Amortization:

Also:

- Payment grace period

- Payments per year
- Fees

can be entered.

When the loan is repaid is controlled by the simulation. This is linked to the CAPEX and therefore the data will change automatically if the simulation period is changed. Postponing a project to start two years later in simulation will not require a revisiting of the loan input.

If the loan period is longer than the simulation period, the loan will continue to be paid out and costs will appear after operation end based on the simulation period. For the Result to File output, there will be an extension of the number of years in the output file, making it possible to decide if the final payment of the loan shall be put in the last simulation year. In the reports the loan will be paid out in the year after the last simulation year and appear as a cost along with ABEX if included.

15.3.12.1 Financing when reinvestments within cost functions

While the financing is auto generated/updated, for example when the plant size is changed by the scaling factors manually or through the optimizer, there are some decisions to be taken in relation to reinvestments.

For now, reinvestments are NOT financed, but will appear as a cash cost taken from the owner's cash balance. See also handling of *Depreciation* 15.3.3.2.

15.3.13   **Energy value**

Plant		Export					Used in Micro Grid / Sale to Demand			Grid Curtailment		Price Curtailment	
Data type	Name	Cost (factor)	Cost (offset)	Subsidy [EL	Energy Tax	Tariff [EUR	Subsidy [EL	Tariff [EUR	Energy Tax	Cost (factor)	Cost (offset)	Cost (factor)	Cost (offset)
System Defa		1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Wind Turbine	WTG Produc	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
PV Productio	Solar PV - T	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure 48 Input of energy value for export etc.

The value of energy that is exported can here be defined as described in Section 15.3.5 *External Grid/ Import costs*.

In addition, Subsidy, Tariff and Energy Tax can be given prices per MWh.

The production used in MicroGrid (or sold to demand, if demand outside MicroGrid) can also be given subsidy, tariff, and tax. E.g., subsidy might be given to all production from a specific technology, not only the exported.

Curtailed due to grid or price curtailment can be given a value.

All values can be specified per plant and price indices can be attached to each price, see below:

Figure 49 Index for each cost available by "Show Cost Development".

15.3.13.1 Sale to demand

Demand		Agreed Price			
Data type	Name	Cost (factor)	Change Index (factor)	Cost (offset) [EUR/MWh]	Change Index (offset)
System Default		1,00 **No in-/decrease**		0,00 **No in-/decrease**	
Demand - from Meteo Object	Demand - 500MWh/y DK-West	1,00 No in-/decrease		0,00 No in-/decrease	

Figure 50 Sale to demand price if demand outside MicroGrid.

If the demand is outside the MicroGrid, an agreed price can be entered. This can be linked to the price time-series or be fixed as described previously in Section 15.3.5 *External Grid/ Import costs*.
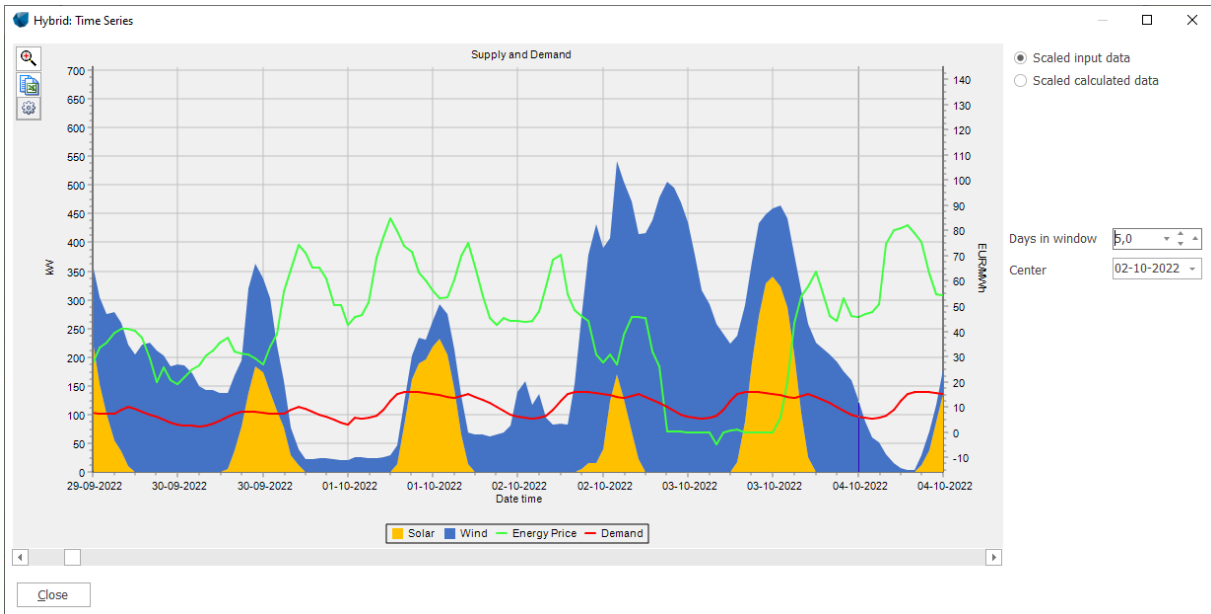
15.3.14 Time graphs

Figure 51 The scaled input data.

The first time-graph shows the raw production values after scalings and the energy price. This is just a data presentation, without simulations.
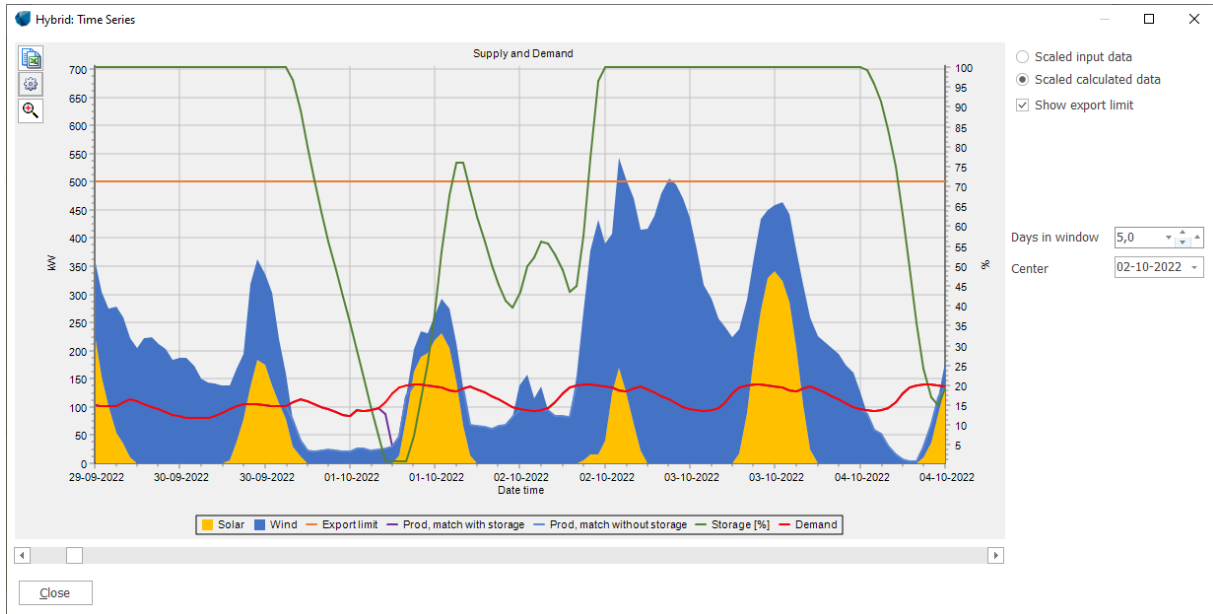
Figure 52 Energy balance simulation time-series.

The second view includes the simulation results, like storage filling. For illustration, we have included a grid export limit of 500 kW.

Figure 52 Energy balance simulation time-series. Shows how the different technologies produce along with demand and storage filling. The purple line shows how the storage "prolongs" the period where the demand is fulfilled by the local production.
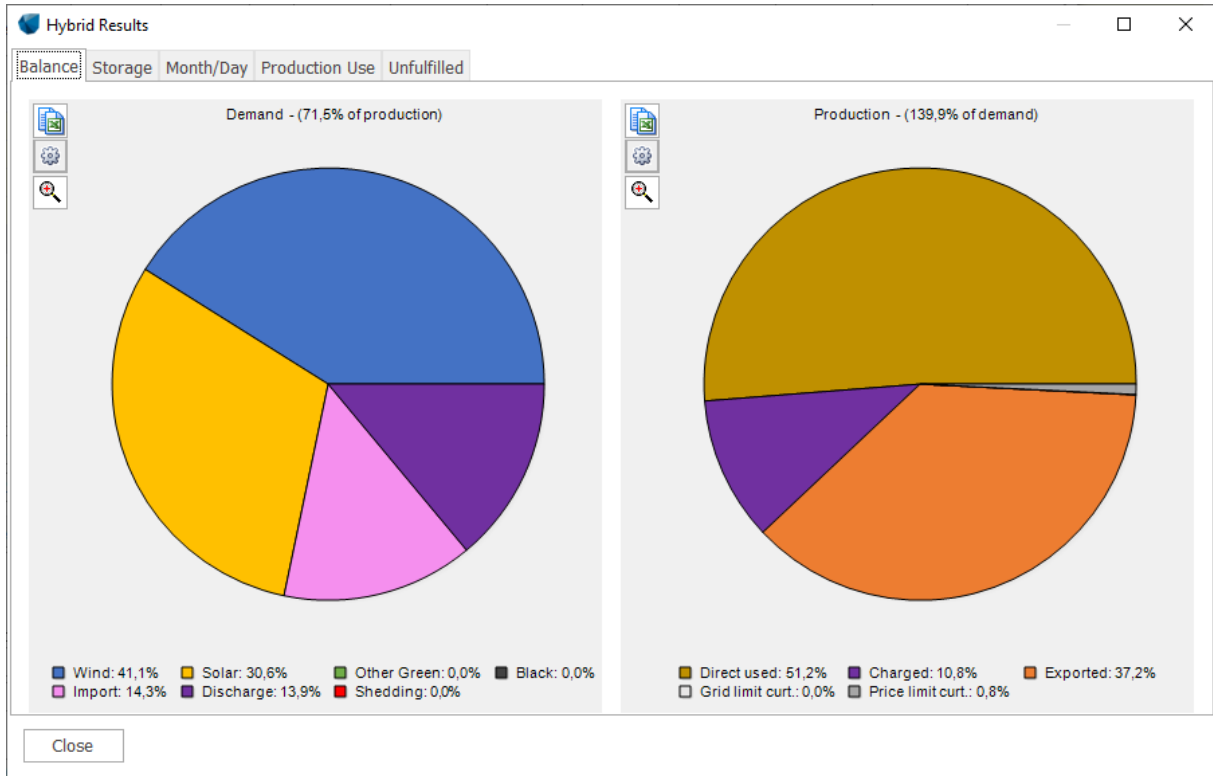
15.3.15   Result graphs

Figure 53 The Balance by Demand and Production.

Figure 49 shows how the demand is delivered by source (left). The storage here delivers 13.8% of the demand, 19.6% is imported from the external grid.

If there are no demand, this graph will show export instead.

The production distributed as directly used by demand, charged to storage, the exported part and the curtailed part are shown on the right. Note the charged percentage can be lower than the discharged, if the production is higher than the demand.

By clicking the "Excel button" the data can be extracted as the lifetime values in Wh. Note for the left graph: The production seen is the utilized production by demand (or exported if no demand), not the total production. See example below:

Table 1 Output from Balance graph, demand with added columns in Excel.

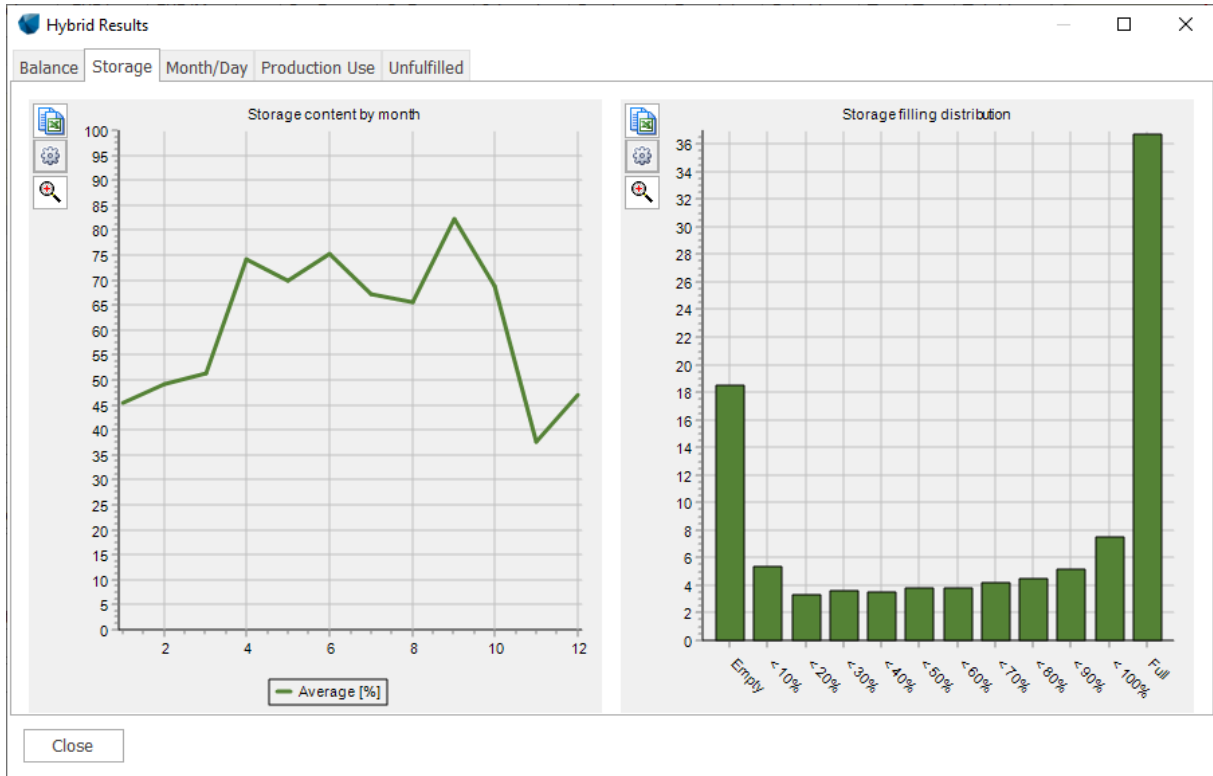|	Lifetime Wh	MWh	MWh/y
Text	Series1		
Wind: 39,2%	11744742527	11.745	587
Solar: 27,5%	8228796979	8.229	411
Other Green: 0,0%	0	-	0
Black: 0,0%	0	-	0
Import: 19,6%	5861554225	5.862	293
Discharge: 13,8%	4139405912	4.139	207
Shedding: 0,0%	0	-	0

Figure 54 Storage utilization graph.

Figure 54 Storage utilization graph. This indicates whether the storage seems well dimensioned and suited for the case.

If the average filling is very low or high, the storage is probably too large or small – or if it almost always is empty or full, it indicates that the storage not really is suited for the system.
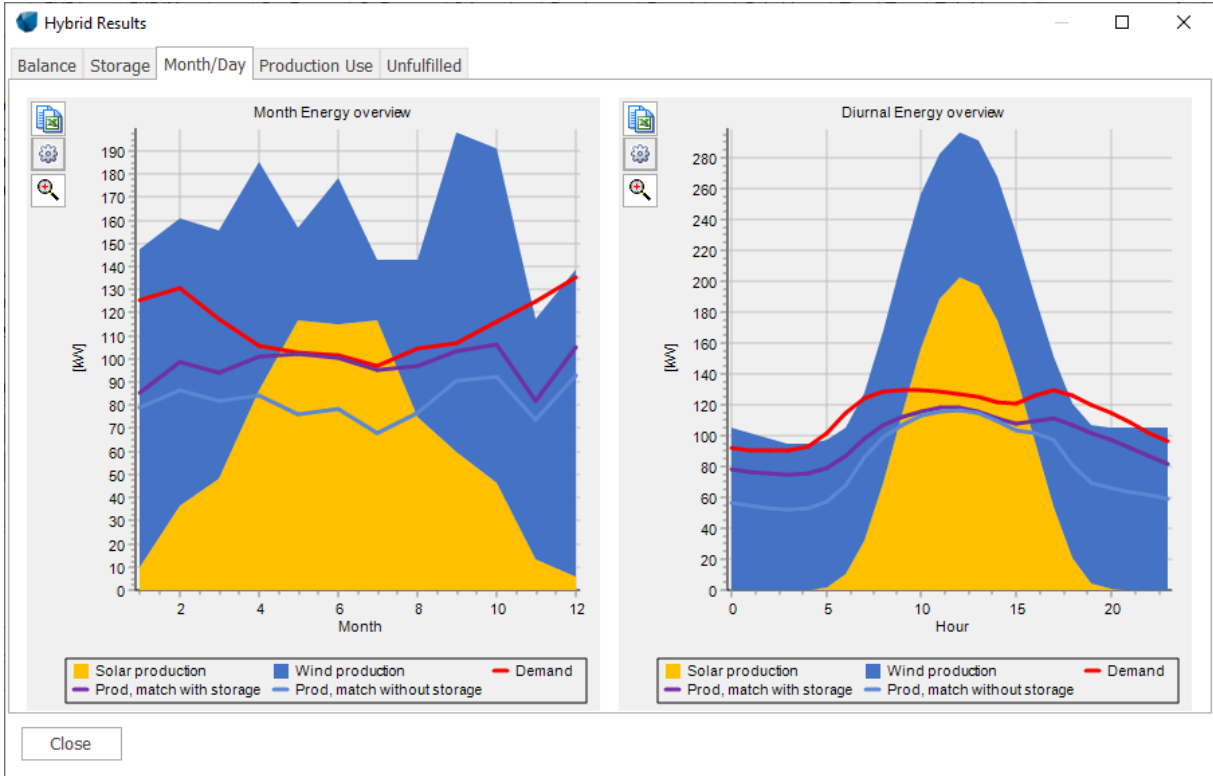
Figure 55 Month/day Energy overview.

Figure 55 shows a very useful presentation of how the production mix matches the demand. And how the optional storage improves the balance making the production closer to the demand.
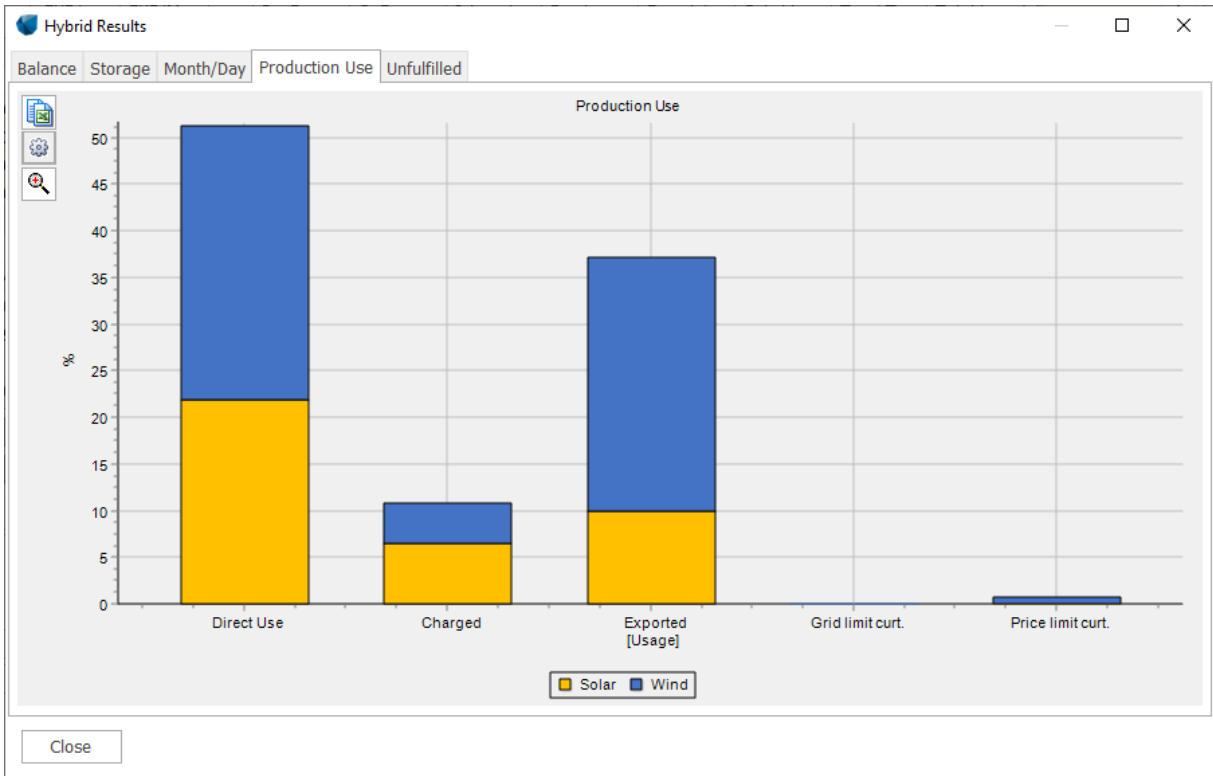

Figure 56 The Production Use.

Figure 56 shows how the different technologies are distributed by direct use, charged to storage, exported and curtailed.

Note the prioritisation behind this:

1. Black
2. Other Green
3. PV
4. Wind

The prioritization is "hard coded" based on following:

Black production is only assumed included if it "must run", e.g., a base-load coal plant.

Other Green is assumed without down regulation options, e.g., run of river Hydro.

PV can be down regulated, although this is not often seen.

Wind is the most "down regulatable" and is often used to adjust to market limits.

An example: Wind and PV are producing each 50 kW, and the demand can only take 80 kW, the 50 kW PV is allocated as "direct used", while wind is shared with 30 kW direct used and 20 kW exported. If there is storage, and this is not full, the production will only be charged if capacities allow. Thereby there is a second priority:

1. Direct use
2. Charged
3. Exported
4. Curtailed

With these two sets of priorities, the allocation of each Wh from each production technology is decided and aggregated in the energy balance simulation.
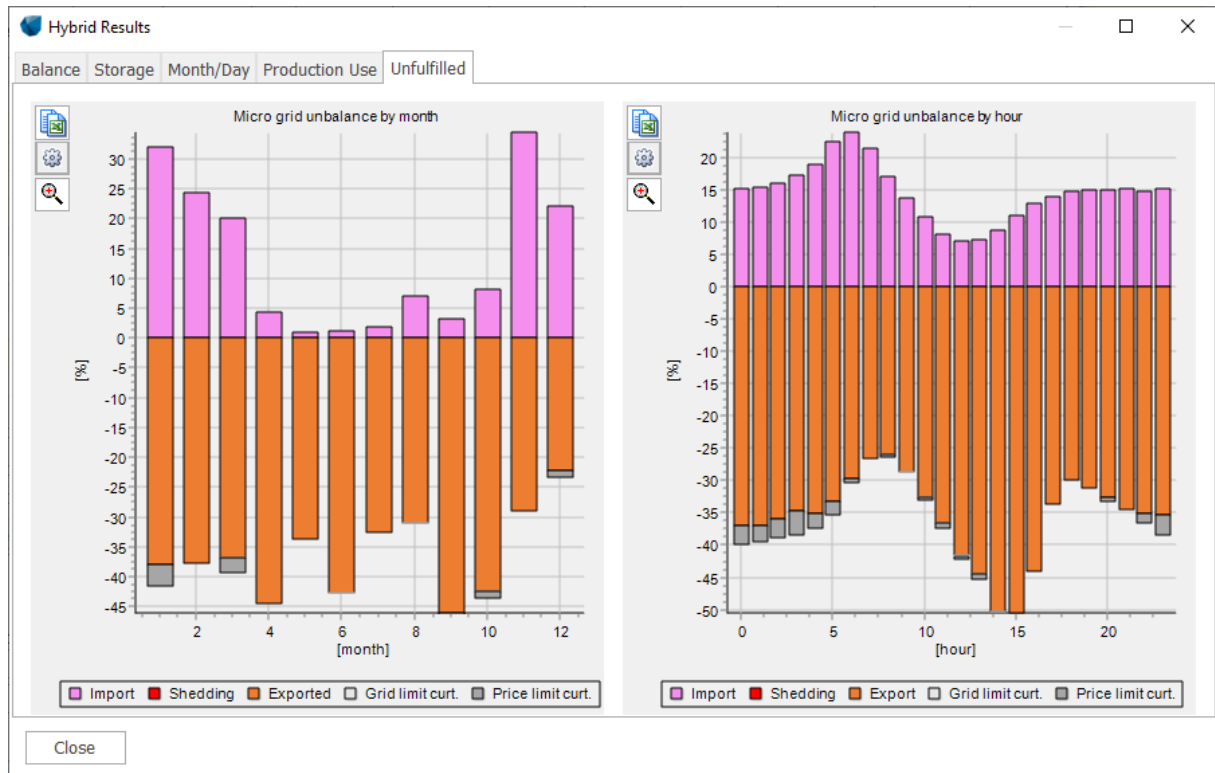

Figure 57 Unfulfilled by MicroGrid to evaluate expansion options.

Figure 57 shows where the MicroGrid cannot match the demand. Both as monthly and diurnally as annual average percentages. It is seen how much import is required, and if grid limitations, and also load shedding will be seen as positive percentages. The export and curtailment percentages are shown as negative values.

This suggests which technologies could be relevant to add. In the example shown above, it is the winter months most import is needed, this show that more wind, which has highest production in winter (in Northern Europe), could create a better balance. The diurnal pattern indicates that a larger storage might also be helpful.
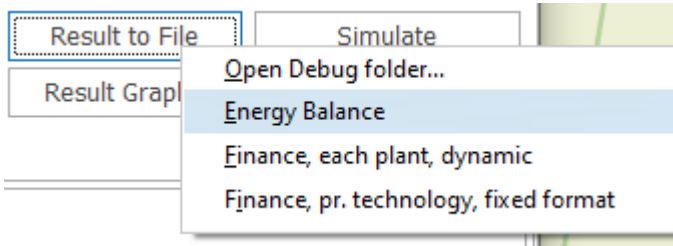
15.3.16   **Result to file**

Figure 58 Result to file output.

With the Result to File button following options are given:

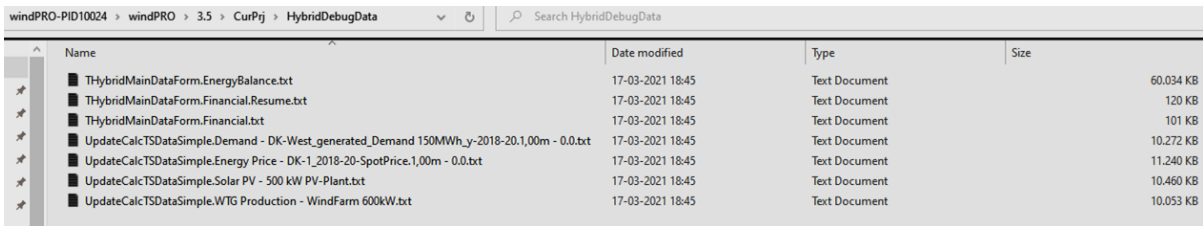**Open Debug Folder…;** opens a folder with the simulation results as text files.

Figure 59 Debug data folder with all relevant data from simulation.

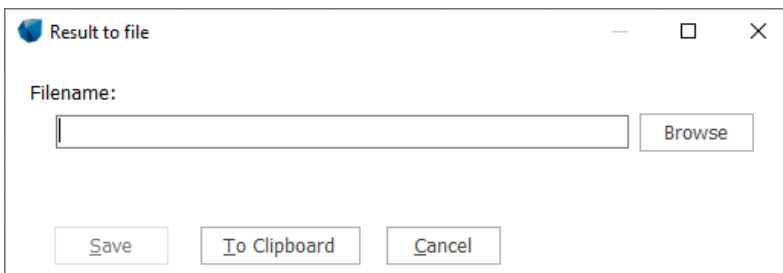**Energy Balance and Finance;** opens this window:

Figure 60 Result to file output to clipboard or file.

Data can be saved with a specified filename and location, or, more commonly, copied to the clipboard from where all data can be pasted (<Crtl> + <v>) to any text editor or more conveniently, to Microsoft Excel or a similar spreadsheet package.

Figure 61 Energy balance data in text file.

Note the energy balance data is minimum hourly data for typically 20 years with 50 data columns, so it is quite a large amount of data. To check the data, it is recommended just to simulate one year to keep the data amount reasonable. One year will normally be sufficient, while the same year is repeated, although with index corrections and possible different plant start-stop dates.

1	Date time	
2	WindProduction	[W]
3	SolarProduction	[W]
4	OtherGreenProduction	[W]
5	OtherBlackProduction	[W]
6	Demand	[W]
7	EnergyPrice	[EUR/Wh]
8	ScaledOtherGreenProduction	[W]
9	ScaledOtherBlackProduction	[W]
10	ScaledDemand	[W]
11	ScaledWindProduction	[W]
12	ScaledSolarProduction	[W]
13	DirectUsed	[W]
14	Balance	[W]
15	AkkBalance	[Wh]
16	RawCharging	[W]
17	RealCharging	[W]
18	AbsorbedCharging	[W]
19	RawDischarging	[W]
20	RealDischarging	[W]
21	StorageContentPrimo	[Wh]
22	StorageContentUltimo	[Wh]
23	StorageStandByLoss	[Wh]
24	Imported	[W]
25	Exported	[W]
26	CurtailedProductionLimit	[W]
27	CurtailedProductionPrice	[W]
28	LoadShedding	[W]
29	WindDirectUsed	[W]
30	WindCharge	[W]
31	WindCurtailPrice	[W]
32	WindExport	[W]
33	WindCurtailLimit	[W]
34	SolarDirectUsed	[W]
35	SolarCharge	[W]
36	SolarCurtailPrice	[W]
37	SolarExport	[W]
38	SolarCurtailLimit	[W]
39	GreenDirectUsed	[W]
40	GreenCharge	[W]
41	GreenCurtailPrice	[W]
42	GreenExport	[W]
43	GreenCurtailLimit	[W]
44	BlackDirectUsed	[W]
45	BlackCharge	[W]
46	BlackCurtailPrice	[W]
47	BlackExport	[W]
48	BlackCurtailLimit	[W]
49	LoadSheddingAllImport	[W]
50	Filler	[W]
51	ExportFromStorage	[W]
52	ImportToStorage	[W]
53	ImportTariffPrice	[EUR/Wh]

Figure 62 The columns (53) in energy balance simulation.

The extracted data holds for each technology what is produced and where it ends: Used by demand, exported, price curtailed, grid limit curtailed or used by charger at storage. In addition; import, shedding, storage content and loss, etc.

The finance data are similarly arranged, in two versions:

Each plant, dynamic; deliver data per plant in a dynamic structure.

Per technology, fixed format; deliver aggregated plants of same technology, but organised so that the output columns always will be the same. This is suitable for post processing or checking in Excel, for example.

Month					
Electricity Price - System Import (energy)	[EUR]	All Wind - DevEx	[EUR]	All Other Green - DevEx	[EUR]
Electricity Price - System Import (tax)	[EUR]	All Wind - CapEx	[EUR]	All Other Green - CapEx	[EUR]
Electricity Price - System Import (tariff)	[EUR]	All Wind - OpEx	[EUR]	All Other Green - OpEx	[EUR]
Electricity Price - System - Load Shedding (Wh)	[Wh]	All Wind - AbEx	[EUR]	All Other Green - AbEx	[EUR]
Electricity Price - System - Load Shedding (EUR)	[EUR]	All Wind - Export	[EUR]	All Other Green - Export	[EUR]
Electricity Price - System Import (Wh)	[Wh]	All Wind - Export subsidy	[EUR]	All Other Green - Export subsidy	[EUR]
Electricity Price - All Import (energy)	[EUR]	All Wind - Export tax	[EUR]	All Other Green - Export tax	[EUR]
Electricity Price - All Import (tax)	[EUR]	All Wind - Export tariff	[EUR]	All Other Green - Export tariff	[EUR]
Electricity Price - All Import (tariff)	[EUR]	All Wind - Grid Curtailment	[EUR]	All Other Green - Grid Curtailment	[EUR]
Electricity Price - All Import - Load Shedding (Wh)	[Wh]	All Wind - Price Curtailment	[EUR]	All Other Green - Price Curtailment	[EUR]
Electricity Price - All Import - Load Shedding (EUR)	[EUR]	All Wind - Used in MicroGrid subsidy	[EUR]	All Other Green - Used in MicroGrid s	[EUR]
Electricity Price - All Import (Wh)	[Wh]	All Wind - Used in MicroGrid tariff	[EUR]	All Other Green - Used in MicroGrid t	[EUR]
Electricity Price - System Export (energy)	[EUR]	All Wind - Used in MicroGrid tax	[EUR]	All Other Green - Used in MicroGrid t	[EUR]
Electricity Price - System Export (subsidy)	[EUR]	All Wind -	[]	All Other Green -	[]
Electricity Price - System Export (tariff)	[EUR]	All Wind - Purchase price	[EUR]	All Other Green - Purchase price	[EUR]
Electricity Price - System Export (tax)	[EUR]	All Wind -	[]	All Other Green -	[]
		All Wind - Account Depreciation	[EUR]	All Other Green - Account Depreciatio	[EUR]
Owners Capital - Primo	[EUR]	All Wind - Tax Depreciation	[EUR]	All Other Green - Tax Depreciation	[EUR]
Cashflow - Primo	[EUR]	All Wind -	[]	All Other Green -	[]
Interest Owners Capital	[EUR]	All Wind - Grant Disbursement	[EUR]	All Other Green - Grant Disbursement	[EUR]
Cashflow - Ultimo	[EUR]	All Wind - Loan Disbursement	[EUR]	All Other Green - Loan Disbursement	[EUR]
Owners Capital - Ultimo	[EUR]	All Wind - Loan Instalment	[EUR]	All Other Green - Loan Instalment	[EUR]
All Import - Owners Capital - Primo	[EUR]	All Wind - Loan Fees	[EUR]	All Other Green - Loan Fees	[EUR]
All Import - Cashflow - Primo	[EUR]	All Wind - Loan Interest	[EUR]	All Other Green - Loan Interest	[EUR]
All Import - Interest Owners Capital	[EUR]				
All Import - Cashflow - Ultimo	[EUR]	All PV - DevEx	[EUR]	All Black - DevEx	[EUR]
All Import - Owners Capital - Ultimo	[EUR]	All PV - CapEx	[EUR]	All Black - CapEx	[EUR]
Difference - Owners Capital - Primo	[EUR]	All PV - OpEx	[EUR]	All Black - OpEx	[EUR]
Difference - Cashflow - Primo	[EUR]	All PV - AbEx	[EUR]	All Black - AbEx	[EUR]
Difference - Interest Owners Capital	[EUR]	All PV - Export	[EUR]	All Black - Export	[EUR]
Difference - Cashflow - Ultimo	[EUR]	All PV - Export subsidy	[EUR]	All Black - Export subsidy	[EUR]
Difference - Owners Capital - Ultimo	[EUR]	All PV - Export tax	[EUR]	All Black - Export tax	[EUR]
		All PV - Export tariff	[EUR]	All Black - Export tariff	[EUR]
All Demand - Income	[EUR]	All PV - Grid Curtailment	[EUR]	All Black - Grid Curtailment	[EUR]
All Demand - Income (All import)	[EUR]	All PV - Price Curtailment	[EUR]	All Black - Price Curtailment	[EUR]
		All PV - Used in MicroGrid subsidy	[EUR]	All Black - Used in MicroGrid subsidy	[EUR]
All Storage - DevEx	[EUR]	All PV - Used in MicroGrid tariff	[EUR]	All Black - Used in MicroGrid tariff	[EUR]
All Storage - CapEx	[EUR]	All PV - Used in MicroGrid tax	[EUR]	All Black - Used in MicroGrid tax	[EUR]
All Storage - OpEx	[EUR]	All PV -	[]	All Black -	[]
All Storage - AbEx	[EUR]	All PV - Purchase price	[EUR]	All Black - Purchase price	[EUR]
All Storage -	[]	All PV -	[]	All Black -	[]
All Storage - Account Depreciation	[EUR]	All PV - Account Depreciation	[EUR]	All Black - Account Depreciation	[EUR]
All Storage - Tax Depreciation	[EUR]	All PV - Tax Depreciation	[EUR]	All Black - Tax Depreciation	[EUR]
All Storage -	[]	All PV -	[]	All Black -	[]
All Storage - Grant Disbursement	[EUR]	All PV - Grant Disbursement	[EUR]	All Black - Grant Disbursement	[EUR]
All Storage - Loan Disbursement	[EUR]	All PV - Loan Disbursement	[EUR]	All Black - Loan Disbursement	[EUR]
All Storage - Loan Instalment	[EUR]	All PV - Loan Instalment	[EUR]	All Black - Loan Instalment	[EUR]
All Storage - Loan Fees	[EUR]	All PV - Loan Fees	[EUR]	All Black - Loan Fees	[EUR]
All Storage - Loan Interest	[EUR]	All PV - Loan Interest	[EUR]	All Black - Loan Interest	[EUR]
				Grid Expansion - CapEx	[EUR]
				Grid Expansion - Account Depreciatio	[EUR]
				Grid Expansion - Tax Depreciation	[EUR]
				Grid Expansion - Grant Disbursement	[EUR]
				Grid Expansion - Loan Disbursement	[EUR]
				Grid Expansion - Loan Instalment	[EUR]
				Grid Expansion - Loan Fees	[EUR]
				Grid Expansion - Loan Interest	[EUR]
				Grid Expansion - All Import - CapEx	[EUR]
				Grid Expansion - All Import - Account	[EUR]
				Grid Expansion - All Import - Tax Depr	[EUR]
				Grid Expansion - All Import - Grant Dis	[EUR]
				Grid Expansion - All Import - Loan Disb	[EUR]
				Grid Expansion - All Import - Loan Inst	[EUR]
				Grid Expansion - All Import - Loan Fee	[EUR]
				Grid Expansion - All Import - Loan Inte	[EUR]

Figure 63 Finance result to file output per technology and cost type etc.

The data shown in Figure 58 has had the columns broken in three parts to present the 167 columns on one page.

Below the "block overview":

Block	Content
1	Electricity prices, System and Reference (All Imported)
2	Cashflow and cash balance, System and Reference
3	Sale to demand, System and Reference
4	STORAGE
5	WIND
6	PV
7	Other GREEN
8	BLACK
9	Grid expansion, System and Reference

A few explanations relating to the output:

There are two parallel results in the file, one for the MicroGrid (System), one for the Reference (All imported). For the latter there are relatively few columns.

A special issue to explain:

A problem is that if the demand imports all energy, it will build up a negative cash balance year on year. If interest is applied on a negative cash balance, there can be very high interest costs on the cash balance for the "all imported" variant.

This would not be so in "real world". Here the demand would pay the electricity bill year on year. But to compare the reference to the MicroGrid interest costs on the cash balance, an accumulated negative cash balance should be calculated for the reference to compare to the MicroGrid 1:1.

The negative cash balance is not accumulated for the reference and therefore does not get interest costs for reference. (Except for possible grid reinforcement loan financed costs for the reference).

Similarly, we reduce the MicroGrid cash balance interest costs with the non-included reference interest costs, so we get a 1:1 comparison.

The figures that give the difference cash balance and thereby basis for cash balance interest costs are called "Difference_xxx" found in columns 29-33.

15.4 Indices

The index specifications can be reached from where they can be selected.
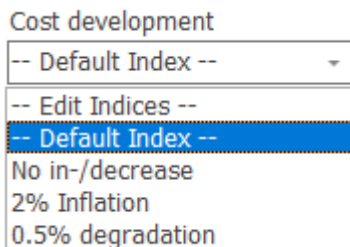
Figure 64 Indices can be selected in drop-down, or the "edit indices" chosen for defining new.

Figure 65 Development indices edit form.

Here any development index can be created, a fully free year by year value or a simple percentage regulation per year.

This can be used for example for:

- Solar PV degradation – add index to production time-series
- Subsidy that is stopped after a number of years – add index to "energy value"
- Traditional inflation

For the traditional inflation a default index can be used, (which is the selected value for all financial input fields, when starting a new calculation setup), and an index series can be chosen as the default index and hence used for all financial development functions which are not selected manually.

Figure 66 Overrule default inflation in a simulation.

At the setup tab, the default inflation can be overruled by a selected index. This makes it convenient to test the impact of different inflation values.

Note that also cost functions have indices. The cost functions used will "take over" the default index in a simulation if no manual selection is performed. This mean that the OPEX development by default is controlled by the default index, for example.

15.5   Cost functions

Cost functions is a new very important "component" in windPRO. This makes it possible to scale all plant costs by plant size and hence is suitable for optimizations.

The cost functions are documented in chapter 2.18 BASIS – cost functions.

The use of cost functions within HYBRID module are described in 15.3.11 Cost and lifetime.

15.6   Optimizer

A "simple" optimizer is established. This searches for the minimum lifetime costs by adjusting plant sizes and/or storage sizes. By utilizing cost functions for the plants/storage and by making loans linked directly to plants and scalable with investment, it is possible to find the "optimal" system. The optimal system is identified as the system with lowest lifetime costs. There will always be different opinions what is optimal. For example, 1 EUR might be saved by doubling the investment, most would find this a bad idea. Hence the optimizer should be seen as a tool to help to identify which directions to look into, including:

- Increase PV or decrease wind
- Increase storage volume or decrease charger
- Etc.

Based on the optimizer run, manual scaling modifications can be tested out where some common sense can be included in the design. Remember also that the optimizer scales costs and production linearly with plant sizes. This will not be fully real, if there is a limited area for a wind farm, for example. Adding extra turbines will also likely increase wake losses and hence a linear increase in production with plant size will not be seen.

Figure 67 Example simulation, PV-plant produces more than demand.

In Figure 66, the PV-plant produces 572 MWh/y and demand is 500 MWh/y. This "base setup" is not feasible. NPV is negative but and the lifetime costs are 5% lower with PV plant than if "All imported". A challenge for the optimizer would be: How much smaller should the PV plant be to make the project feasible.
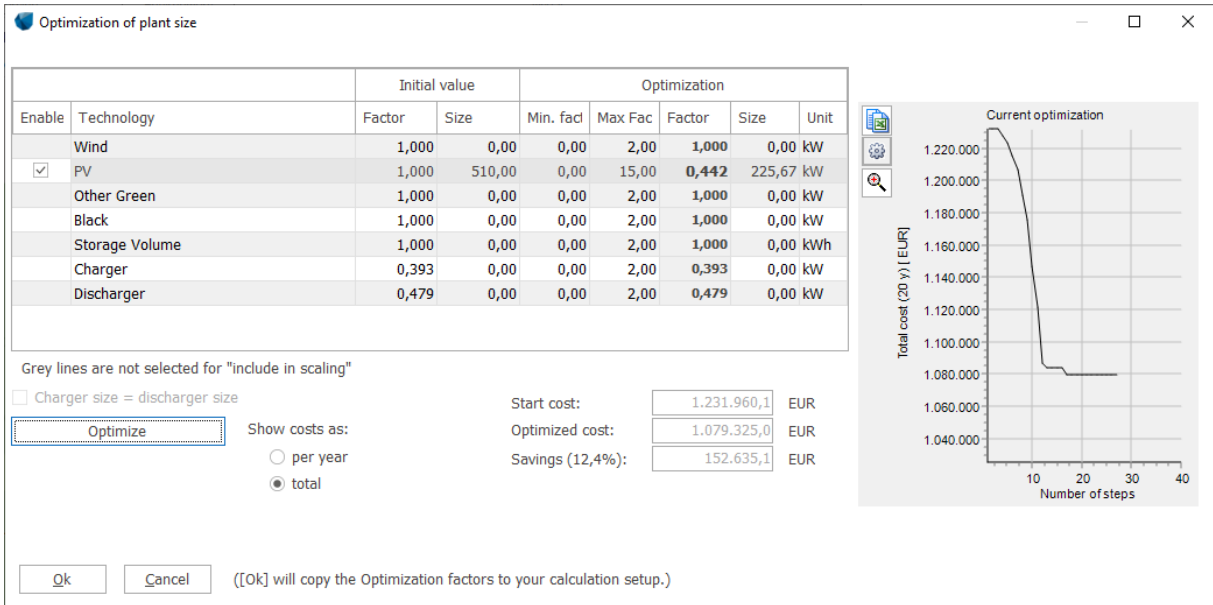
Figure 68 Optimizer find the most feasible plant size to 44% of the original plant size.

By running the optimizer, the PV-plant is reduced from 510 kW to 226 kW. Lifetime costs are reduced from 1.23 million EUR to 1.08 million EUR. Clicking on OK will return the new PV plant size to the main window:
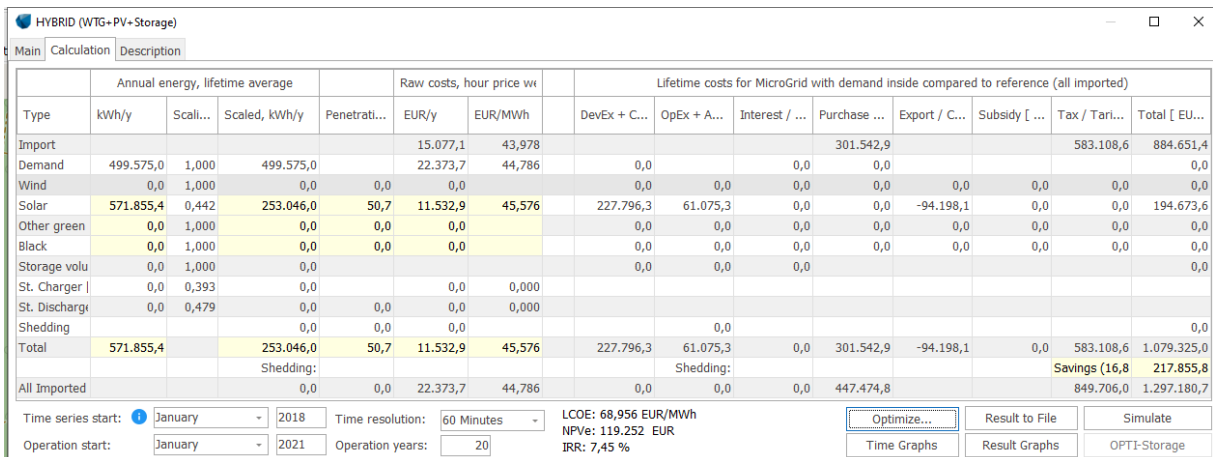

Figure 69 Overview with reduced (Optimized) PV-plant size.

The simulated total costs for the MicroGrid are 17% less than by "All imported". NPV is 119 kEUR and IRR 7.5%. This seems to be a reasonably good investment.

Will storage improve the returns even more?

Storage of 50 kW with Charger/discharger of 15 kW is added with a default cost function. No financing, meaning the Owner cash finances the storage.

A first simulation show this is a slightly poorer investment than without storage. Irr 6,8%. Now we run the optimizer, where the combined PV-plant size and storage is optimized.
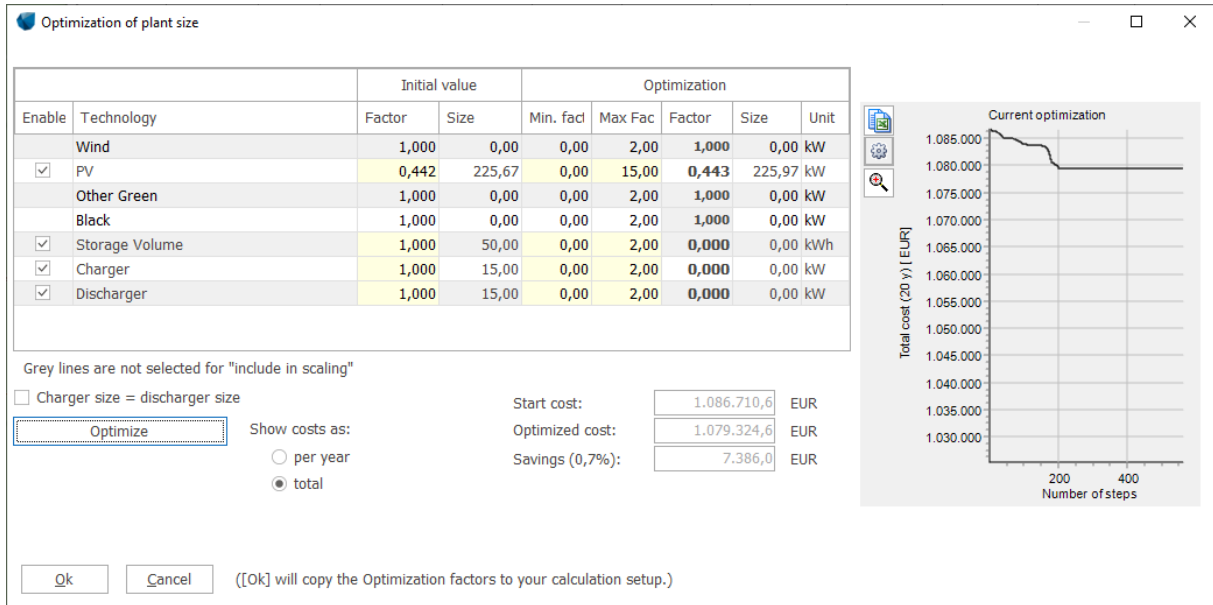
Figure 70 Optimizer concludes the battery is too expensive.

Now PV plant size as well as storage is optimized. It takes quite some time while this is somewhat more complex. The result is that the optimizer finds the storage too expensive and ends with an optimized size of 0. And the optimized PV-plant size is the same as previous.

Now a Grant is introduced. It is assumed that a Grant of 75% of the Storage costs can be obtained. Then the optimizer is re-run:
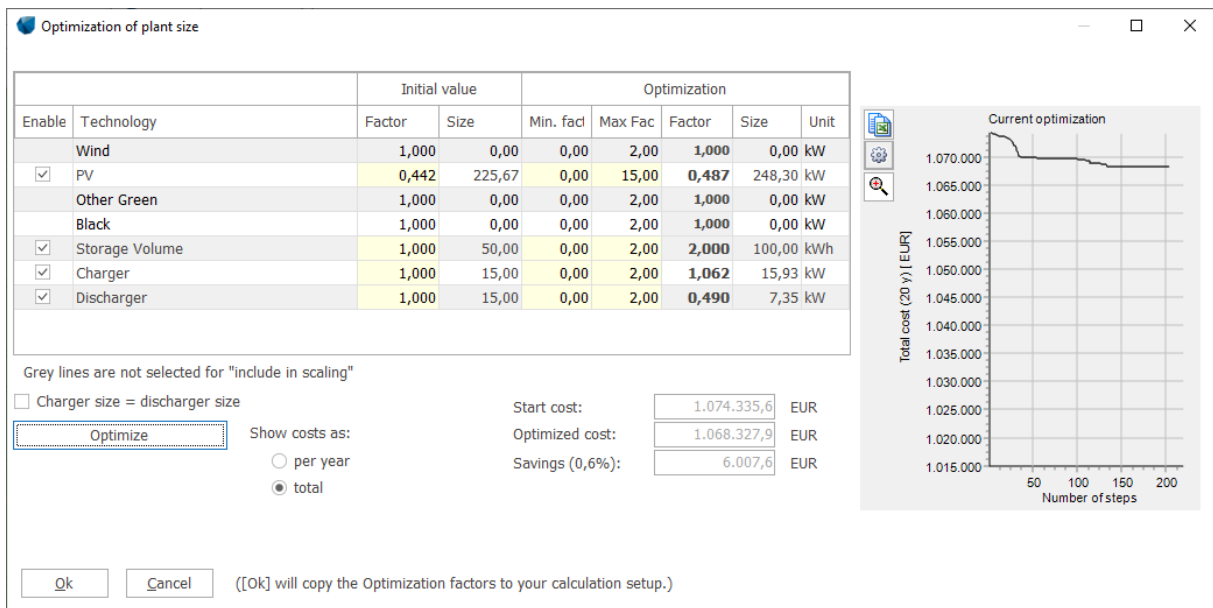
Figure 71 Optimised storage 75% Grant financed.

Now the optimizer finds that the Storage will be optimal by 100 kWh (reach the set limit of scale factor 2), with charger of 15.9 kW and discharger of 7.4 kW. The PV-plant size increases from 37% to 49% of its original size.

Type	kWh/y	Scali...	Scaled, kWh/y	Penetrati...	EUR/y	EUR/MWh	DevEx + C...	OpEx + A...	Interest / ...	Purchase ...	Export / C...	Subsidy [...	Tax / Tari...	Total [EU...
Import					13.952,0	43,937				279.039,7			540.093,1	819.132,9
Demand	499.575,0	1,000	499.575,0		22.373,7	44,786	0,0		0,0	0,0				0,0
Wind	0,0	1,000	0,0	0,0			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Solar	571.855,4	0,487	278.419,2	55,7	12.689,3	45,576	250.637,7	67.199,4	0,0	0,0	-91.569,1	0,0	0,0	226.268,0
Other green	0,0	1,000	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Black	0,0	1,000	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Storage volu	50,0	2,000	100,0				6.927,0	16.000,0	0,0		0,0			22.927,0
St. Charger	15,0	1,062	15,9		937,9	44,625								
St. Discharge	15,0	0,490	7,3	4,0	865,8	43,377								
Shedding			0,0	0,0	0,0			0,0						0,0
Total	571.855,4		278.419,2	55,7	12.689,3	45,576	257.564,8	83.199,4	0,0	279.039,7	-91.569,1	0,0	540.093,1	1.068.327,9
			Shedding:					Shedding:					Savings (17,6	228.852,8
All Imported			0,0	0,0	22.373,7	44,786	0,0	0,0	0,0	447.474,8			849.706,0	1.297.180,7

Time series start: January 2018 Time resolution: 60 Minutes
Operation start: January 2021 Operation years: 20

LCOE: 68,956 EUR/MWh
NPVe: 120.555 EUR
IRR: 6,95 %

[Optimize...] [Result to File] [Simulate]
[Time Graphs] [Result Graphs] [OPTI-Storage]

Figure 72 Costs for MicroGrid with storage.

The costs for MicroGrid as well as the NPV are now almost the same as when just having the optimized PV-plant. It is not clear whether this option would be chosen from a pure investment point of view but it might be chosen as it introduces higher system flexibility and potential additional gains by having the storage – although this also comes with higher risks. It is now very fast to test modifications. The result graphs can help pointing the user in the right directions.
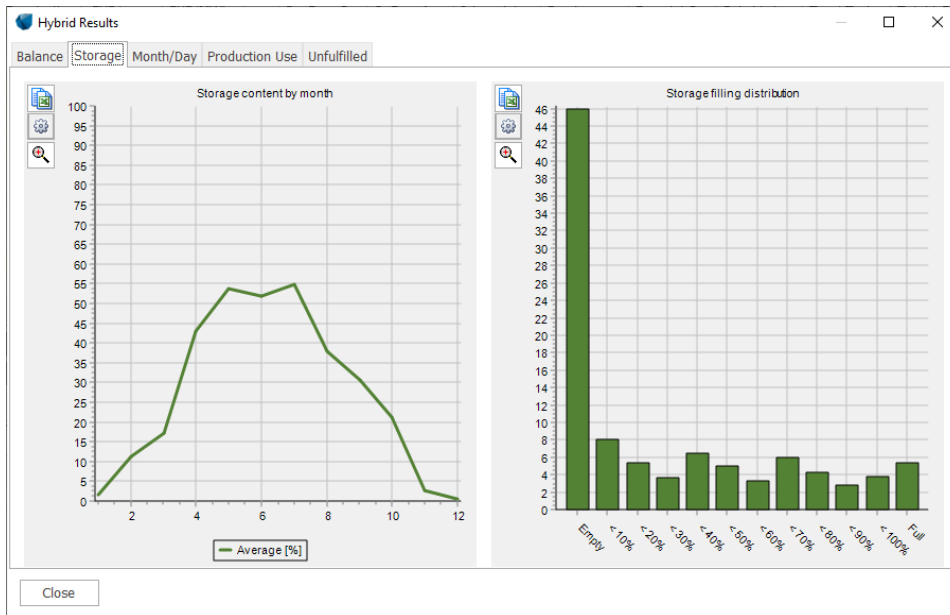
Figure 73 Storage filling indicates the storage is some too large.

For the example shown above, Figure 72 shows 70% of the time the storage is empty. This indicates that it would be better with a smaller storage. When supporting a PV-Plant in a Northern Europe country storage will have many hours empty due to the long winter period with very little Sun.
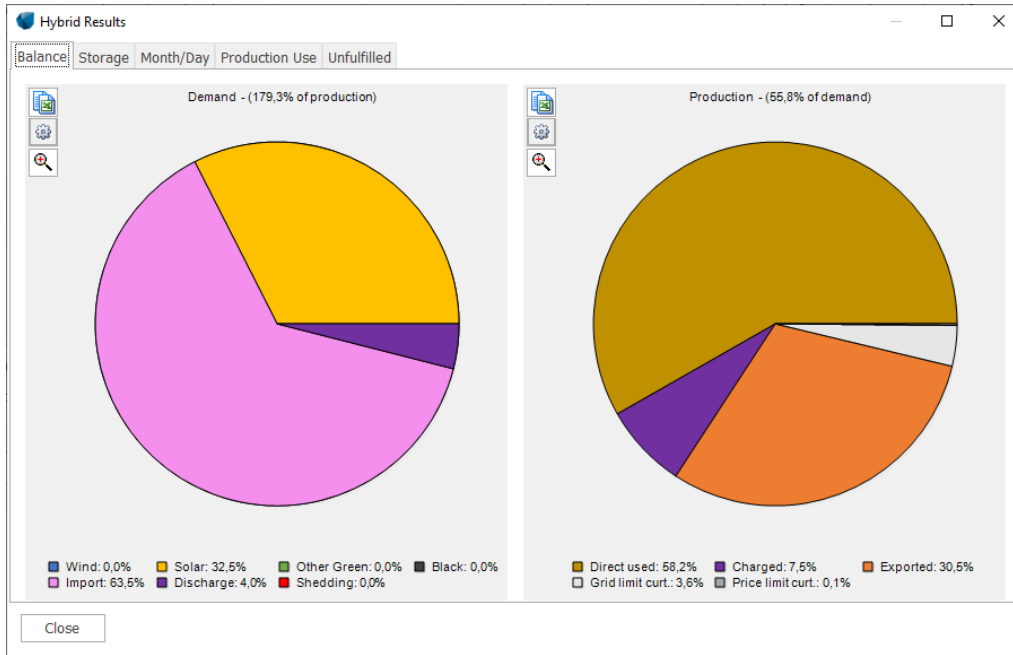
Figure 74 The result shows that 4% of the demand is taken from storage. 7.5% of production filled on storage.
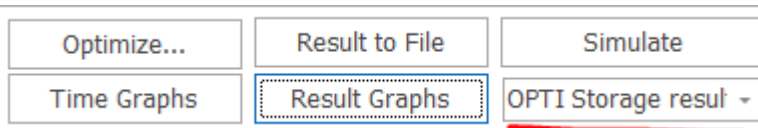
15.7   OPTI-Storage

Figure 75 OPTI-storage will run a new simulation, that optimizes the storage operation.

Starting from windPRO 3.6 it is possible to use the OPTI-Storage tool. This tool can simulate an optimal operation of the storage, where it partly:

1. Purchases electricity when it is cheap and sells when it is expensive (called arbitrage).
2. Prepare the storage for minimizing the grid limit curtailment, making sure storage is empty before a period with high production leading to grid curtailment.

Basically, the OPTI-Storage operates the storage for maximizing earnings. If there is a conflict between arbitrage and reduced grid curtailment, the optimizer choses the solution that maximizes earnings. The engine behind the OPTI storage is a MILP solver.

To be able to operate the Storage similarly in "real life" good prognoses of production and prices must be available. This is although not a major problem with the prognosis tools on the market today. But there will also be a need for an advanced controller.

Using OPTI-Storage will create a new "Result Graph":

(Based on modified data relative to previous example to illustrate partly with demand, partly without (all exported)):
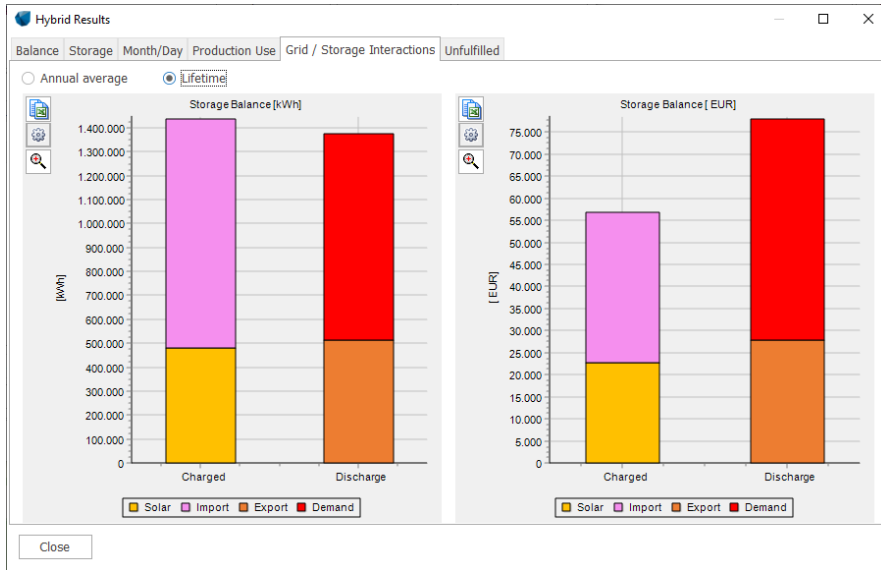
Figure 76 Result graph shows OPTI-Storage benefit where a demand is covered.

In the graph above it is shown where the charged energy comes from and where it goes to. As seen in the example to the left, there are more Charged MWh than discharged, due to loss in storage. But for the right-side graph showing the value of the MWh, the discharge has a higher value than the value of the charged. This is mainly because charging happens when prices are low, and discharging happens when prices are high. In the example above the lifetime earnings by the storage is round 20.000 EUR, with an expected investment and lifetime OPEX costs of storage of 30.000 EUR. But this is based on 2019 electricity prices, much has changed since.

In the example above the main purpose is fulfilling a demand, and the export from storage is limited, while most discharge is absorbed by the demand. In a situation where all is exported the gain by OPTI-storage operation only will be increased export, see example below:

Figure 77 Benefit by OPTI-storage operation where all is exported.

As seen in the graphic above the value of the discharge-charged is roughly the same as in the situation with a demand. What although can add more value with a demand is saved taxes and tariffs, which can bring feasibility in a storage investment, even with 2019 prices.

Type	Annual energy, lifetime average				Raw costs, hour price we			Lifetime costs for MicroGrid with demand inside compared to reference (all imported)								
	kWh/y	Scali...	Scaled, kW... ᵀ	Penetration [%]	EUR/y	EUR/MWh		DevEx + C...	OpEx + A...	Interest / ...	Purchase ...	Export / C...	Subsidy [...	Tax / Tari...	Total [EU...
Import	0,0	0,000	0,0	0,0	1.336,4	-9.453	0	0,0	0,0	0,0	26.727,7	0,0	0,0	0,0	26.727,7
Demand	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Wind	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Solar	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	3.282,1	0,0	0,0	3.282,1
Other green	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Black	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Storage volu	0,0	0,000	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	-53.631,8	0,0	0,0	-53.631,8
St. Charger	0,0	0,000	0,0	0,0	1.551,7	-5.145	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
St. Discharge	0,0	0,000	0,0	0,0	2.206,2	-0.632	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	26.727,7	-50.349,7	0,0	0,0	-23.622,0
0	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0	0,0	0,000	0,0	0,0	0,0	0,000	0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Time series start: ⓘ January ▾ 2019 Time resolution: 60 Minutes ▾   LCOE: 0,000 EUR/MWh | Optimize... | Result to File | Simulate |
Operation start: January ▾ 2021 Operation years: 20   NPVe: 17.980 EUR   IRR: 0,99 % | Time Graphs | Result Graphs | Difference ▾ |

Figure 78 Viewing the difference OPTI-storage minus non opti.

The result table have a feature to view the difference between OPTI-storage and non opti storage operation. Above is seen in the "total" field, how the OPTI storage operation generates 24.000 EUR extra. This comes from 54.000 more export from storage, reduced with 3.000 less direct export from PV (which is charged on storage) and reduced with added import from grid at a cost of 27.000 which is purchased electricity for the storage when price is low. The NPV is improved by 18.000 EUR.

The improvement by OPTI-storage is quite individual much affected by the price variations hour to hour, the grid limitations, and the production variations. But no doubt it pays off to have an advanced controller that can operate the storage close to optimal for maximizing earnings.

15.7.1 Limitations in present version of OPTI-Storage

Price curtailment and load shedding cost option:

Do not export if energy price is below:	0,000	EUR/MWh
Load shedding cost:	0,00	EUR/MWh
Load shedding inflation:	-- Default Index -- ▾	
Default PV AC/DC ratio:	0,90	

Price curtailment is always calculated based on negative prices. Setting another value in the above field, would not be respected fully due to predefined threshold within the optimizer. Therefore, the price threshold must be zero before running the OPTI-Storage.

Add Energy Prices	Add Fixed Energy Prices
Add Demand	Add Shedding Filler

The shedding filler cannot be used along with OPTI-Storage.

Optimize...	Result to File	Simulate
Time Graphs	Result Graphs	OPTI-Storage

The optimizer will not work in combination with OPTI-Storage.

15.8   Reports

The reports are built with similar structure as in other windPRO modules:

Figure 79 Report overview.

Double click on a sub report and get a preview.

Right click ->
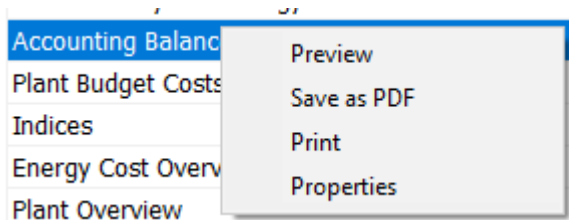
By "Properties" options such as report language can be chosen, if multiple language modules are installed. And for some reports with more pages, such as Plant Overview, the specific plants to be reported can be selected.

15.8.1 Report contents

There are following reports from HYBRID module:

Main Results – with assumptions and main results

Energy Balance – the simulations time step by time step aggregated as annual values with additional aggregated lifetime graphs.

Cash flow by technology – for each technology; Wind, PV, Other green, Black, Storage and grid reinforcement, the cash flow is shown year by year. All payments in/out are aggregated by each technology, including export, value of curtailments (if any), subsidies, taxes, tariffs related to where energy is used, DEVEX, CAPEX, OPEX, ABEX and loan reimbursements, instalments, interests, and fees. Grants are deducted. Also purchase of energy from external plants is included if any.

Accounting balance – in opposite to cash flow, accounting balance holds depreciation of CAPEX instead of CAPEX - reimbursements and loan instalments. In other words, the CAPEX is expressed by the value reduction by year instead of the actual payments related to the CAPEX and then expresses how the accounting will look in real life (as budget).

Plant Budget Costs – for each plant or storage a page shows how the costs based on cost functions are established.

Indices – the used indices in the calculations are reported.

Energy cost overview – shows the often-complex matrix of energy prices, subsidies, tariffs and taxes that can depend on as well technology as where the energy is used.

Plant overview – shows the calculated plant configuration with key figures per technology.
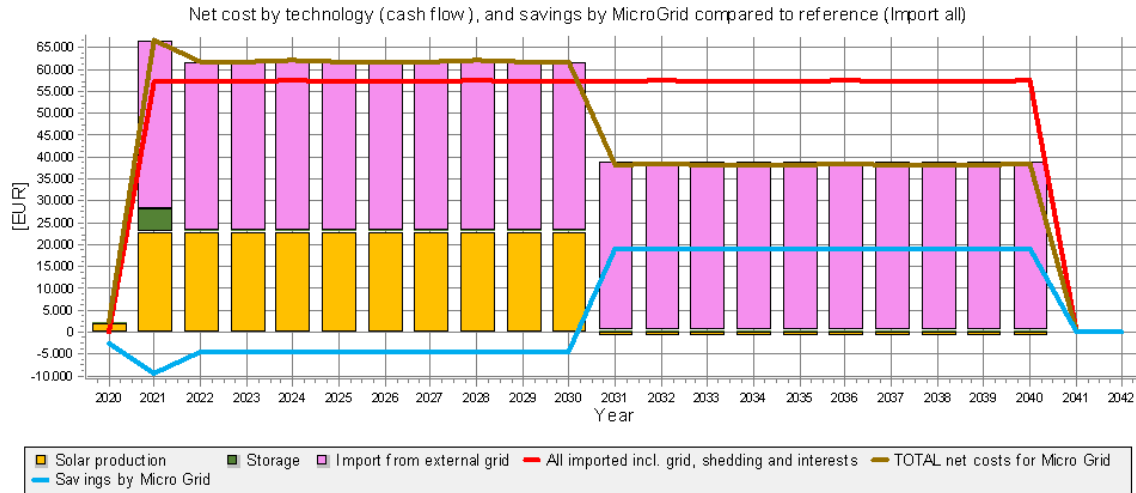
Figure 80 Example from a report, illustrated in Optimize section, cash flow by technology.

Figure 75 shows how the costs for the MicroGrid will be somewhat higher than the "All import" alternative for the first 10 years, where the loans are paid back, then it becomes lower.

The extra costs are round 5.000 EUR per year for the first 10 years, and from year 10 approximately 20.000 EUR less.

15.9   Abbreviations/explanations

DEVEX; Development expenditures

CAPEX; Capital expenditures

OPEX; Operational expenditures

ABEX; Abandonment expenditures

Shedding; Demand that is not fulfilled due to lack of grid or production capacity

Curtailment; When production is larger than can be used by demand/storage/export due to grid limitations or if a plant is shut down due to low (negative) energy prices. Note curtailment shut down can also be included in a PARK calculation, e.g. by sector management (closing turbines down when too densely spaced in certain wind directions). If included in a PARK calculation, the relevant time steps will have reduced production. This is not "seen" as curtailment by the HYBRID calculation, where only the reductions due to the HYBRID simulation will be accounted for.

15.10 List of figures