QUICK GUIDE – HYBRID CALCULATION WITH SOLAR & STORAGE

Purpose:

The purpose of this quick guide is to help you evaluate the financial feasibility of a HYBRID system with a Solar PV plant connected to an external grid, delivering power to the owner's demand with time varying pricing and optional investing in a storage. The use of cost functions is demonstrated, including optimization of the plant size and storage size.

Outline of Guide:

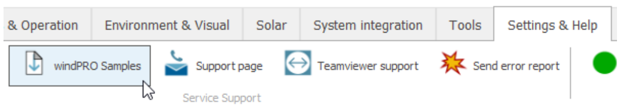
CONTENTS

1. REQUIREMENTS

The steps in this quick guide require windPRO 3.5 or newer with license to the SOLAR PV module, METEO and HYBRID module. However, this exercise can also be based on a PV production time series imported into a METEO object, which will not require the SOLAR PV module.

Optional shortcut:

As a "shortcut" the sample project for this quick guide can be downloaded here:



If you decide to use the sample project "Hybrid Quick guide" you can skip to section 4.

2. OVERVIEW

Calculating the financial feasibility of a hybrid plant requires the following information:

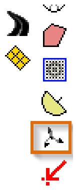
Data:	**Stored in:**
Electricity prices	Meteo object
Electricity demand	Meteo object
Power production • Wind or • Solar	 Meteo object or PARK calculation Meteo object or SOLAR-PV
Cost of energy	HYBRID module
Optional: Tax and tariffs	*HYBRID module*
Optional: Financing	*HYBRID module*
Optional: Storage	*HYBRID module*

This quick guide walks you through the import of the necessary data and setting up the calculation.

Author: Per Nielsen (pn@emd.dk) & Per Møller Nielsen (pmn@emd.dk)

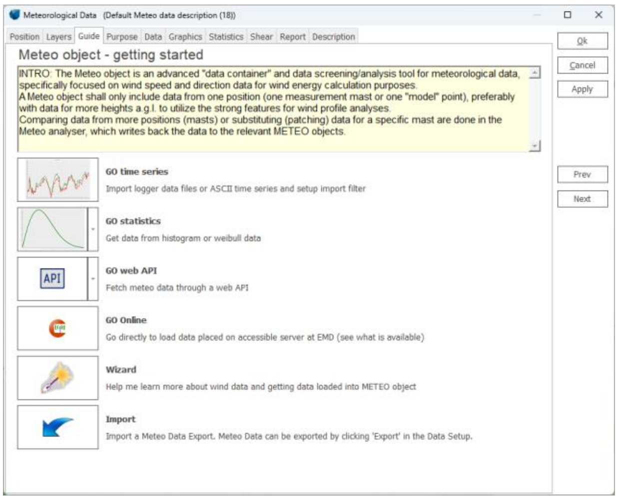
3. METEO OBJECT WITH PRICES

Start by inserting a  Meteo object on the map:



The exact geographical location is not relevant in this quick guide.

The Meteo window opens:



Select "GO time series":

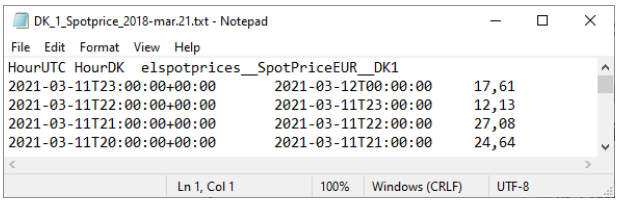
Now point out a file with hourly electricity prices for at least one year. Prices must be in EUR/MWh. If not, it is possible to scale from other currency by a scaling factor through the recalibration features in the METEO object.

A sample file is included with windPRO:

Location: \WindPRO Data\Standards\

Filename: DK_1_Spotprice_2018-mar.21.txt

This sample file contains hourly prices from the Danish DK-West electricity market in UTC time for January 2018 – March 2021. The file is TAB separated with header in line 1 and first data in line 2.

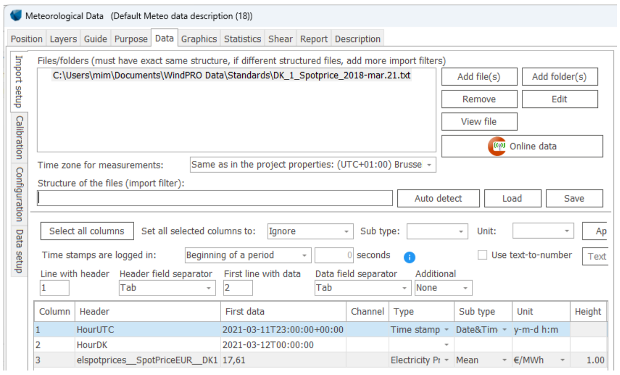

DK_1_Spotprice_2018-mar.21.txt - Notepad

File Edit Format View Help

```
HourUTC HourDK  elspotprices__SpotPriceEUR__DK1
2021-03-11T23:00:00+00:00       2021-03-12T00:00:00     17,61
2021-03-11T22:00:00+00:00       2021-03-11T23:00:00     12,13
2021-03-11T21:00:00+00:00       2021-03-11T22:00:00     27,08
2021-03-11T20:00:00+00:00       2021-03-11T21:00:00     24,64
```

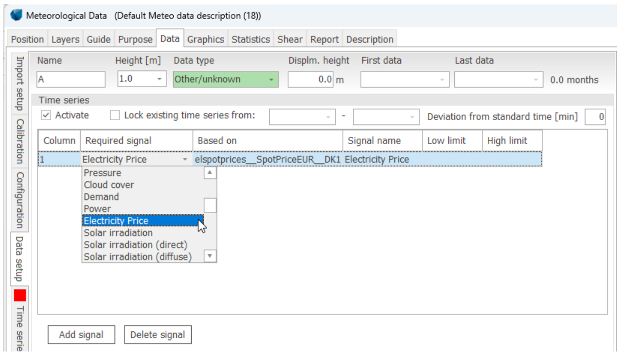
Ln 1, Col 1 | 100% | Windows (CRLF) | UTF-8

This info is used when setting up the import filter like this:

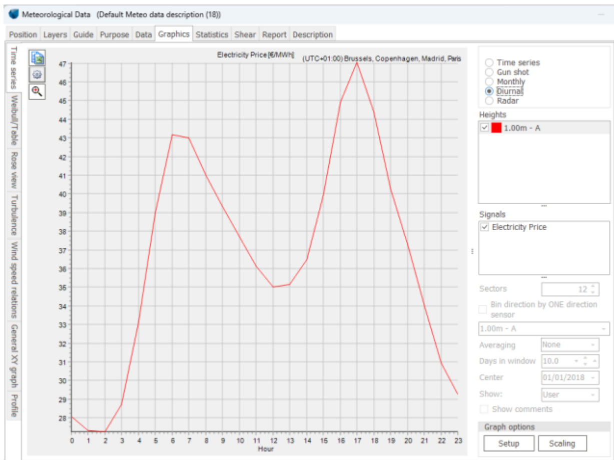


Tip: Set the height to 1 m, instead of 0 m.

With these settings, go to the Data Setup tab and add "Electricity Price" signal and (Re)load all data:



Going to the Graphics tab, it is possible to view the data by different aggregations.



The diurnal view above shows how the prices are low at night and midday, but high in the morning and late afternoon on average.

Click OK and the price data is ready for use in HYBRID.

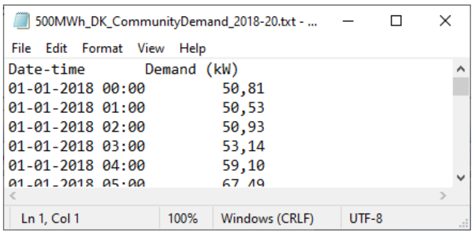
Author: Per Nielsen (pn@emd.dk) & Per Møller Nielsen (pmn@emd.dk)

4. METEO OBJECT WITH DEMAND

Similar as above, a DEMAND (or Consumption) data set can be imported. An example can be found in the same folder as before:

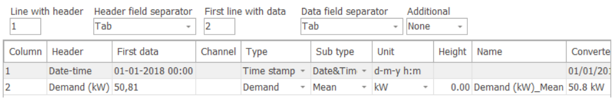
Location: \WindPRO Data\Standards\

Filename: 500MWh_DK_CommunityDemand_2018-20.txt



This demand time series is based on the measured demand variations in Denmark, DK-West system with 500 MWh/year as average. The demand can be scaled in HYBRID, so do not worry much about the size order. This example data is TAB separated and in UTC time zone.

Now, do as for the Price time series, by creating a new Meteo object and loading the data with signal type “Consumption”. This is how the import setup shall look for the consumption/demand import:



Again, set the height to 1 m, instead of 0 m, go to the Data Setup tab and now add a “Consumption” signal and (Re)load all data. Click Ok.

Now price and demand time series are available in two Meteo object. Next, we need solar PV production data.

It is possible to import a solar PV production time series created from another calculation tool into a Meteo object. However, in this example we will use the SOLAR-PV module in windPRO.

5. SOLAR-PV CALCULATION

For all details in a solar PV calculation setup, see Quick guide for this purpose:

QUICK GUIDE – SOLAR PV ENERGY CALCULATION

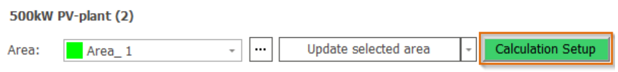
Here just the headlines:

1: Insert a PV object

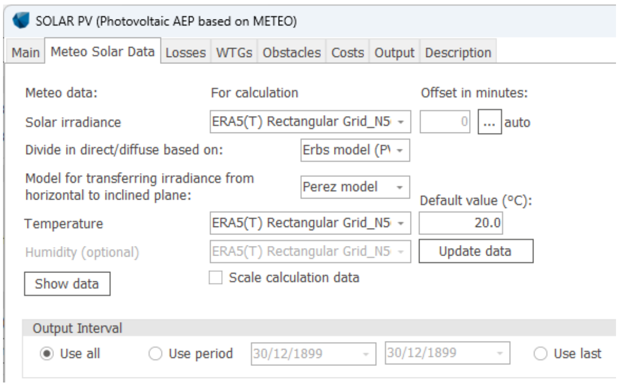
2: Design a PV plant

Just a simple square layout is fine for this example, however there are several options to configure the plant design. Please refer to the quick guide above.

3: Enter the Calculation setup



4: Download meteorological data from the EMD On-line server at the specific location by clicking the Download data button



It is important the three datasets (price, consumption, production) have concurrency. The calculation period of the solar pv production time series can be adjusted with the period selector above.

5: When the desired settings are configured, close the calculation window by clicking "Ok".

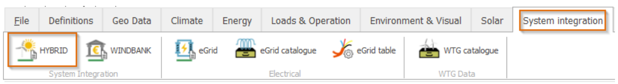
6: Click "Update Results". The results shown are temporary.

7: Therefor, once the calculation is complete, click "Create report". The data created in this report will be saved and later read by the HYBRID module.

Now we have all the needed data for the HYBRID setup.

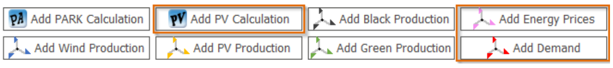
6. IMPORT TIME SERIES TO HYBRID

Now start the HYBRID module from the System integration tab:

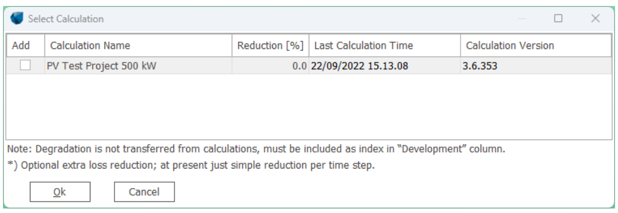


First part will be to load the different time series, in no particular order:

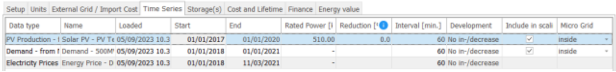
- Add PV-Calculation
- Add Energy prices
- Add Demand



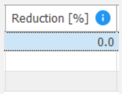
When clicking one of the "Add" buttons, we get to select either a calculation or Meteo object containing the time series corresponding to what you want to add:



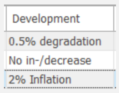
After adding all three time series (Price, demand, production), the list of loaded time series looks like this:



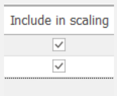
Bonus information: Additional options in "Time Series" tab (above table), but not necessary to complete this quick guide:



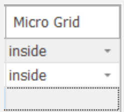
Reduction %: a reduction can be set if some losses are not included in production time series. This just reduces each time step production.



Development: *An index can be selected to change annual production in time. Indices can be freely defined. For Solar-PV production a degradation og 0.5% is typically seen. This index is predefined and should be selected here. For Electricity prices, another predefined index could be selected e.g. "2% inflation".*



Include in scaling: *Decides if a demand or production time series is "allowed" to be scaled, e.g., by the optimizer.*



Micro Grid: *The production can be placed inside or outside the microgrid. Likewise, the demand can be places inside or outside the microgrid:*

*If a **production** time series is **inside** the microgrid, the plant costs (investment, operation costs, financing etc.) is included in the simulation. See how to specify later.*

*If a **production** time series is **outside** the microgrid, power is purchased based on specified prices, which can be based on the loaded price time series or fixed.*

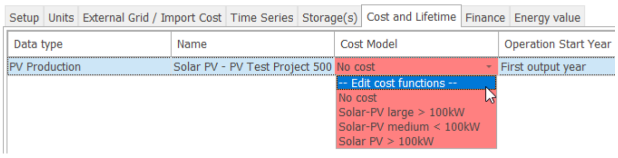
*If a **demand** time series is **inside**, there is no income from demand in the simulation. But a reference cost "All imported" is calculated for comparison – and used in NPV calculation, reports etc. as income named "Saved costs".*

*If a **demand** time series is **outside**, there is an income from "sale to demand" in the simulation based on specified pricing.*

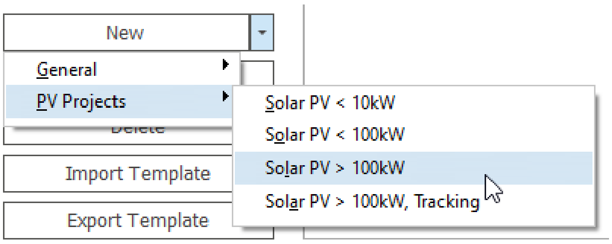
Different production time series can be placed inside as outside in same simulation. However, all demands must be inside or outside to reduce the complexity of the output.

7. COST OF PRODUCTION

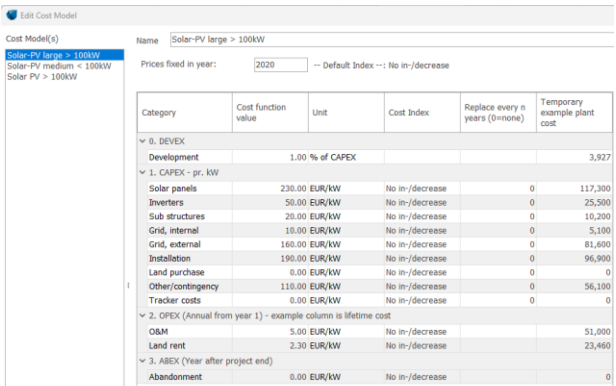
Go to the “Cost and Lifetime tab”:



Now jump to the field “No cost” and from the dropdown choose “--Edit cost functions--”. This opens the cost function form. In the lower left corner you can add cost models from 4 preset Solar PV categories:



Choosing e.g “> 100kW” fills the table with cost function values from a proprietary EMD study(2020):



Category	Cost function value	Unit	Cost Index	Replace every n years (0=none)	Temporary example plant cost
0. DEVEX					
Development	1.00	% of CAPEX			3,927
1. CAPEX - pr. kW					
Solar panels	230.00	EUR/kW	No in-/decrease	0	117,300
Inverters	50.00	EUR/kW	No in-/decrease	0	25,500
Sub structures	20.00	EUR/kW	No in-/decrease	0	10,200
Grid, internal	10.00	EUR/kW	No in-/decrease	0	5,100
Grid, external	160.00	EUR/kW	No in-/decrease	0	81,600
Installation	190.00	EUR/kW	No in-/decrease	0	96,900
Land purchase	0.00	EUR/kW	No in-/decrease	0	0
Other/contingency	110.00	EUR/kW	No in-/decrease	0	56,100
Tracker costs	0.00	EUR/kW	No in-/decrease	0	0
2. OPEX (Annual from year 1) - example column is lifetime cost					
O&M	5.00	EUR/kW	No in-/decrease		51,000
Land rent	2.30	EUR/kW	No in-/decrease		23,460
3. ABEX (Year after project end)					
Abandonment	0.00	EUR/kW	No in-/decrease		0

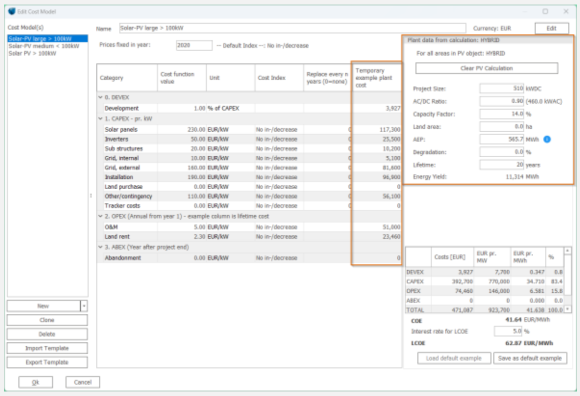
Click “Ok”, and you will return to the Hybrid window.

Now that the most basic info is established, the first simulation can be run. If there is more than one year of time series data available, the start month and year to be used in the energy balance can be chosen:

This makes it easy to check how sensitive the result is to which year is used.

Additional options in the Cost Calculator, but not necessary to complete this quick guide:

To the right of the table, is the “Temporary example plant cost”. The pre-filled values in the Cost function value column (here in EUR/kW) are applied to the loaded PV-plant, with the calculated costs shown in column “Temporary example plant cost”:

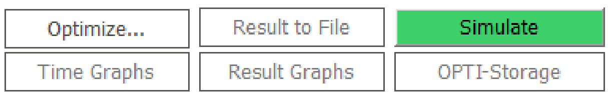


Editing in the “Temporary example plant cost” column will feed back to the “Cost function value” column, and the cost function value will be adjusted. This can be useful if you already know the latest or local prices for an identical plant and want the cost function value to match this knowledge.

Indices can be set, if e.g., you want to include a cost change in time and thereby let the prices depend on which year in the simulation the plant is set to start to operate. Or used if e.g., a specific component is set to be Replaced every 10 years, the cost Index will affect the reinvestment costs.

In this example, only one year data is used for energy balance simulation. This year is repeated for all years in the simulation period (including any optional index corrections). You can also choose to change the start of system operation and for how many years the system should operate.

Click the “Simulate” button:



windPRO now calculates the energy balance and costs:

	Annual energy, lifetime average				Raw costs, hour price weight	
Type	MWh/y	Scalin g	Scaled, MWh/y	Penetration [%]	EUR/y	EUR/MWh
Import					16,597.0	52.883
Demand	499.6	1.000	499.6		27,180.6	54.407
Wind	0.0	1.000	0.0	0.0	0.0	
Solar	565.7	1.000	565.7	113.2	31,030.3	54.854
Other green	0.0	1.000	0.0	0.0	0.0	
Black	0.0	1.000	0.0	0.0	0.0	
Storage volum	0.0	1.000	0.0			
St. Charger [k\	0.0	1.000	0.0		0.0	0.000
St. Discharger	0.0	1.000	0.0	0.0	0.0	0.000
Shedding			0.0	0.0	0.0	
Total	565.7		565.7	113.2	31,030.3	54.854
			Shedding:			
All Imported re			0.0	0.0	27,180.6	54.407

Looking at the left part of main window:

Annual energy, lifetime average:

Scaling: By entering scaling values in column 3, biased time series can be brought to the right level, e.g. if the time series demand only represent a share of the "real demand", or it can be tested if e.g. a larger PV-plant would be financial attractive.

The annual lifetime average MWh/y is displayed for the raw time series and as scaled values.

The **penetration** shows how much the production covers the demand for each technology (in %).

Raw costs, hour price weighted:

In the column's EUR/y and EUR/MWh (any other currency can be chosen) the lifetime average costs and cost/MWh can be seen by technology.

This gives a feedback on how the production matches the prices.

Lifetime costs for MicroGrid with demand inside compared to reference (all imported):

At the right-hand side of the table the lifetime costs are seen:

	Lifetime costs for MicroGrid with demand inside compared to reference (all imported)							
Type	DevEx + CapEx - G...	OpEx + AbEx [EUR]	Interest / Fees [EUR]	Purchase / Import [E...	Export / Curtailme...	Subsidy [EUR]	Tax / Tariff [EUR]	Total [EUR]
Import				331,939.8			0.0	331,939.8
Demand	0.0		0.0	0.0				0.0
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar	396,627.0	74,460.0	0.0	0.0	-409,020.7	0.0	0.0	62,066.3
Other green	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Storage volu	0.0	0.0	0.0					0.0
St. Charger [								
St. Discharge								
Shedding		0.0						0.0
Total	396,627.0	74,460.0	0.0	331,939.8	-409,020.7	0.0	0.0	394,006.0
		Shedding:					Savings (27.5'	149,606.1
All Imported	0.0	0.0	0.0	543,612.1			0.0	543,612.1

In this example, if all power is imported (last line) the total cost over 20 years will be 543kEUR.

However, by investing in the PV-plant, the import is reduced to 332kEUR (first line). This breaks down to:

- CAPEX = 396 kEUR
- OPEX = 74 kEUR
- Income from PV export = 409 kEUR
- The total cost of Import+Solar investment = 394 kEUR
- Compared to importing all electricity, investing in a solar PV plant will be 149 kEUR (27.5%) cheaper.

So, at a first glance, it seems like a sound investment idea. However, it is worth looking the Net Present Value (NPV) which is the sum of all costs and income streams discounted back to today.

LCOE: 50.797 EUR/MWh
NPVe: 27,376 EUR
IRR: 3.15 %

Using the default discount rate of 2.5%, the NPV is 27kEUR.

The LCOE is calculated just for the production units, here for the PV-plant (adding a storage will not change this but change the NPV and IRR).

NPV can be shown as NPVe – excluding finance costs or NPVi – including finance costs.

IRR is the interest rate that gives a NPVe = 0. If financing can be obtained at a lower interest than IRR, a positive NPV can be obtained, roughly spoken.

Changing the discount rate and/or the NPV setting can be done in the "Setup" tab:

Discount rate for LCOE/NPV: 2.5 %
Show:
◉ NPVe (exclusive interests and fees)
○ NPVi (inclusive interests and fees)

Financial evaluation:

Is the simulated system financially feasible?

Below, a more detailed description of right-hand side of the main window table:

Lifetime costs for MicroGrid with demand inside compared to reference (all imported)							
DevEx + CapEx - G...	OpEx + AbEx [EUR]	Interest / Fees [EUR]	Purchase / Import [E...	Export / Curtailme...	Subsidy [EUR]	Tax / Tariff [EUR]	Total [EUR]

For each technology, the following columns show the costs or income:

DevEx + CapEx – Grants: The Project development cost and capital expenditures, including reinvestments for components with limited lifetime in cost functions.

OpEx + AbEx: Operation expenditures and abandonment expenditures during lifetime.

Interests / fees: When loans are established the lifetime costs is shown (see later). In the "Demand" line possible interests cost on owner's cash balance is included (user defined).

Purchase/Import: If there is included plants outside the Micro Grid, the purchase of power from those is shown at the "technology" line. The import from grid is shown in the Import line.

Export/Curtailment: Export to grid, if any plus potential value of curtailment e.g., compensation by shutting down the plant at negative prices or if grid limits require curtailment, that might be used for e.g., heating (user defined, see later).

Subsidy: If any (user defined).

Tax/Tariffs: (user defined, see later).

Total: Sum up all columns.

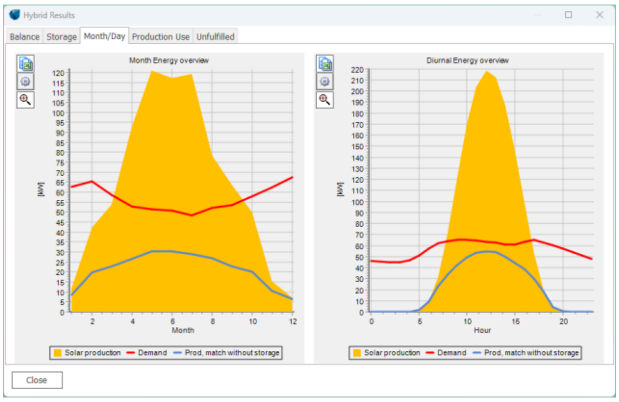
For the lower part of the table, you can notice there is a **"Shedding"** row, showing how much of the demand that cannot be delivered due to grid limitations. This can be given a value (cost) in "Setup" tab. While the MicroGrid typically will reduce the shedding compared to the "all imported" reference, the benefit by giving shedding a value will appear in the savings.

Shedding			0,0	0,0	0,0	
Total	545,3		545,3	109,1	24.830,6	45,576
			Shedding:			
All Imported			0,0	0,0	0,0	0,000

The bottom line shows the reference. If the demand is inside the microgrid the reference will be the "All imported" costs.

If the demand is outside the microgrid, then the reference will be "Import / Sale only". This assumes that the Micro Grid imports all power, but then sells to the demand at the specified sales price. This makes the reference comparable to the situation, where the demand is inside the Micro Grid.

Click on the "Result Graphs" button to see how the production matches the demand:



Here is seen how the production match the demand in average per month and hour and how much of the production that is "absorbed" by the demand based on the lifetime hourly simulations.

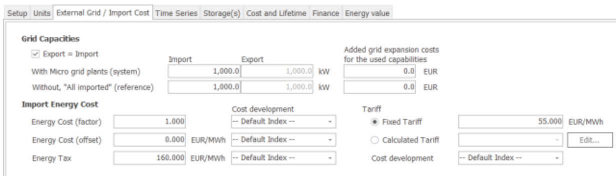
We are far from done setting up the simulation input. Here some more details.

8. TARIFF & TAX (+ MORE PRICING)

So far, the calculation assumes that all energy exchange is at marked prices based on the loaded price time series.

One of the ideas by a hybrid system (Micro Grid) is to produce energy for a demand "behind the meter" and thereby avoid tariffs and energy taxes. Additionally, to make a better utilization of a limited grid connection e.g., by including a storage.

Go to the "External Grid / Import Cost" tab:



Here grid limits can be set – for the purpose of demonstration the grid limit is set to 1000 kW on both Import and Export. The costs related to grid expansion can also be defined here. This makes it easy to evaluate how different grid expansion levels will influence the financial results and thereby use the tool to decide on this part. However, this will not be demonstrated here but should be straight forward.

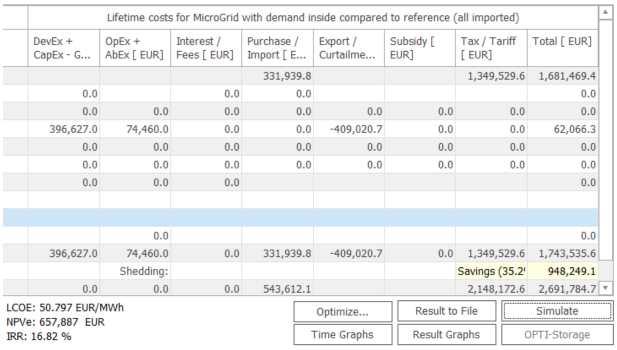
Instead, it is demonstrated how tariffs and energy taxes influence the results.

For Denmark, a private consumer or non-industry office buildings pay a tariff of around 55 EUR/MWh and an energy tax around 160 EUR/MWh.

Enter these in the Tariff and Energy Tax fields:

The Tariff can also be specified as time varying, where the user can specify different prices throughout the year. This can be done by selecting Calculated Tariff.

Once the tariffs and taxes are defined click the "Simulate" button:



Lifetime costs for MicroGrid with demand inside compared to reference (all imported)

DevEx + CapEx - G...	OpEx + AbEx [EUR]	Interest / Fees [EUR]	Purchase / Import [E...	Export / Curtailme...	Subsidy [EUR]	Tax / Tariff [EUR]	Total [EUR]
			331,939.8			1,349,529.6	1,681,469.4
0.0		0.0	0.0				0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
396,627.0	74,460.0	0.0	0.0	-409,020.7	0.0	0.0	62,066.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0					0.0
	0.0						0.0
396,627.0	74,460.0	0.0	331,939.8	-409,020.7	0.0	1,349,529.6	1,743,535.6
	Shedding:					Savings (35.2'	948,249.1
0.0	0.0	0.0	543,612.1			2,148,172.6	2,691,784.7

LCOE: 50.797 EUR/MWh
NPVe: 657,887 EUR
IRR: 16.82 %

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

Now you can see how this has a high impact on the savings and that the NPV increases, 657 kEUR, while the IRR gets as high as 16.8%.

The saved energy tariffs and taxes thereby makes the investment highly attractive.

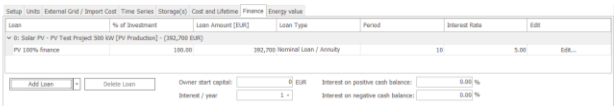
In addition to the import price settings, any price component can be specified on the "Energy value" tab:

Here you can differentiate energy prices by technology and where the energy "ends up". This can be very complex, but unfortunately it can be so in the real world. A subsidy might be given only to the exported part of the wind production and there might be a tax on black production use within the MicroGrid etc. All can be specified including price development indices on each price component:

Note that curtailment (compensations or use of production for e.g. heat) here can be given a value. Either as a factor on the marked price the specific hour (offset = 0) or as a fixed price (factor= 0). For price curtailment a fixed price should always be used, while a factor on the negative price not is a realistic compensation (the compensation would be negative).

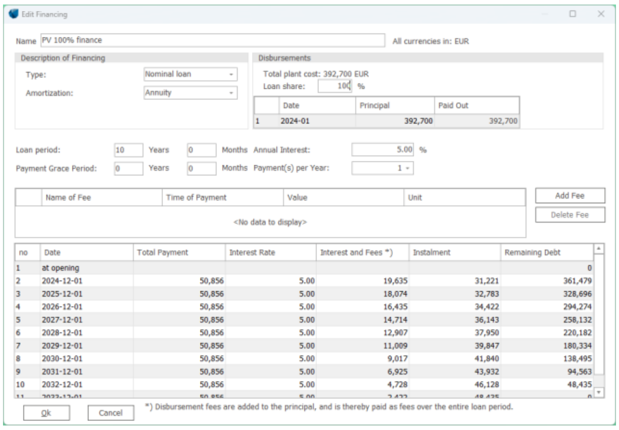
9. LOANS AND GRANTS

Energy plants are normally financed. This is entered in the "Finance" tab. Click on the "Add loan" button:

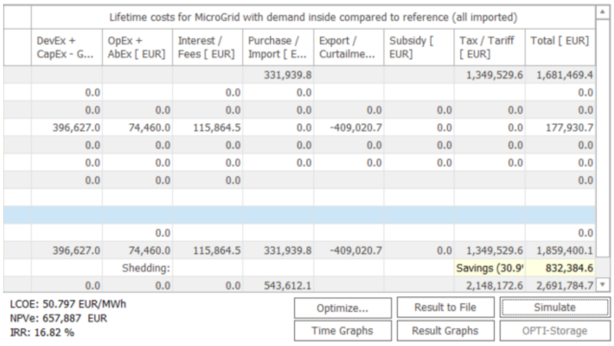


Loans are linked to plants. In order to be able to auto optimize plant sizes, there must be a 1:1 connection between loans and plants.

Here is created 100% loan financing of the PV plant with 10 year annuity loan with 3% annual interest rate:



Clicking "Ok", and then "Simulate" will run the simulation including this loan:



Lifetime costs for MicroGrid with demand inside compared to reference (all imported)							
DevEx + CapEx - G...	OpEx + AbEx [EUR]	Interest / Fees [EUR]	Purchase / Import [E...	Export / Curtailme...	Subsidy [EUR]	Tax / Tariff [EUR]	Total [EUR]
			331,939.8			1,349,529.6	1,681,469.4
0.0		0.0	0.0				0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
396,627.0	74,460.0	115,864.5	0.0	-409,020.7	0.0	0.0	177,930.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0					0.0
	0.0						0.0
396,627.0	74,460.0	115,864.5	331,939.8	-409,020.7	0.0	1,349,529.6	1,859,400.1
	Shedding:					Savings (30.9'	832,384.6
0.0	0.0	0.0	543,612.1			2,148,172.6	2,691,784.7

LCOE: 50.797 EUR/MWh
NPVe: 657,887 EUR
IRR: 16.82 %

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

The key measures, LCOE, NPVe and IRR does not change, this is what makes those evaluators robust. But the lifetime savings are reduced, as interest costs are now included.

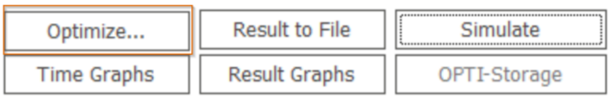
Note: Loans established as a GRANT is handled as a reduction of CAPEX, which influences the key values (LCOE, PV, IRR).

Note also that the reinvestments, e.g. renewal of the inverter every 10 years, which can be set in cost function is not financed by the specified loans, but taken from owners cash balance.

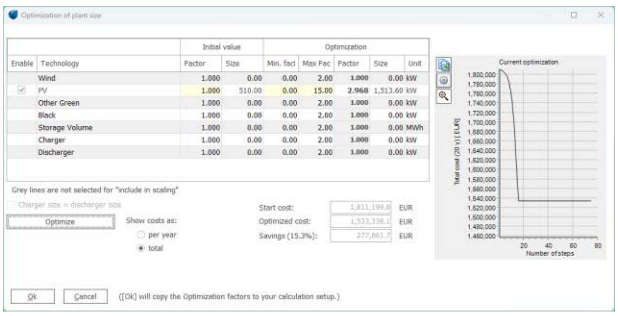
10. OPTIMIZED PV-PLANT

Figuring out the proportions of the desired energy plant can be cumbersome, so the HYBRID module has an optimizer figuring out the pv-plant size that would bring the largest savings (not necessarily best NPV).

Click the "Optimize" button:



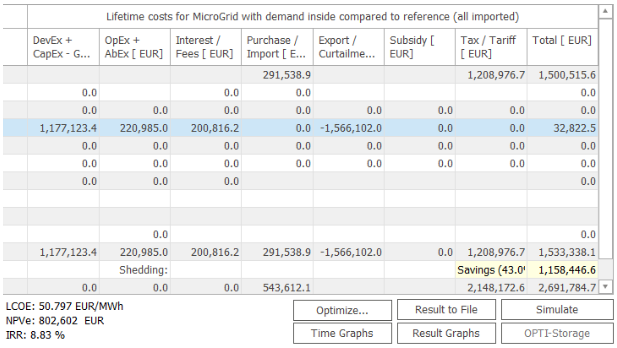
This opens the Optimizer window:



Above, we specify a min-factor of 0, and a max-factor of 15 on the PV-Plant size.

Clicking "Optimize" the optimizer will converge towards a factor 2.97. This means a 510kW*2.97 = 1513 kWp PV-plant will generate the lowest lifetime costs.

Close the window by clicking "Ok", and the main results are updated:



Lifetime costs for MicroGrid with demand inside compared to reference (all imported)							
DevEx + CapEx - G...	OpEx + AbEx [EUR]	Interest / Fees [EUR]	Purchase / Import [E...	Export / Curtailme...	Subsidy [EUR]	Tax / Tariff [EUR]	Total [EUR]
			291,538.9			1,208,976.7	1,500,515.6
0.0		0.0	0.0				0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,177,123.4	220,985.0	200,816.2	0.0	-1,566,102.0	0.0	0.0	32,822.5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0					0.0
	0.0						0.0
1,177,123.4	220,985.0	200,816.2	291,538.9	-1,566,102.0	0.0	1,208,976.7	1,533,338.1
	Shedding:					Savings (43.0'	1,158,446.6
0.0	0.0	0.0	543,612.1			2,148,172.6	2,691,784.7

LCOE: 50.797 EUR/MWh
NPVe: 802,602 EUR
IRR: 8.83 %

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

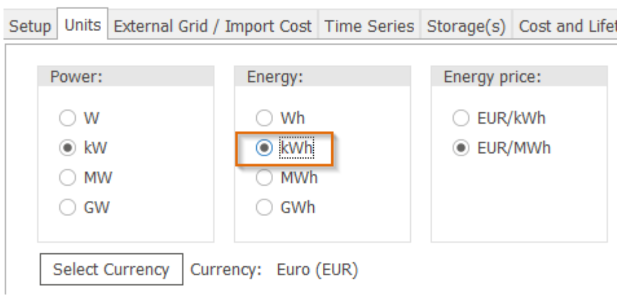
The NPV for the 1500 kW plant is 802 kEUR, around 145 kEUR higher than the 657 kEUR for the 500-kW plant. The IRR is more halved. This illustrates that a 3 times bigger plant might give added benefit, but this will probably not be worth the added risk.

A word of caution: The optimization must really be "handled with care". So far, it is just a simple "minimum lifetime cost" optimizer, which quickly can point you in the right direction when considering which modifications to add to the Hybrid system configuration and sizing. By having grid limitations, the optimizer will be more precise as it will not find marginal benefits by highly increasing the plant sizes.

11. STORAGE

Now a Battery Storage will be included. But first we will change the units from MWh to kWh as we will be adding a small battery.

Go to the "Units" tab:



Energy units from MWh to kWh seem more convenient here.

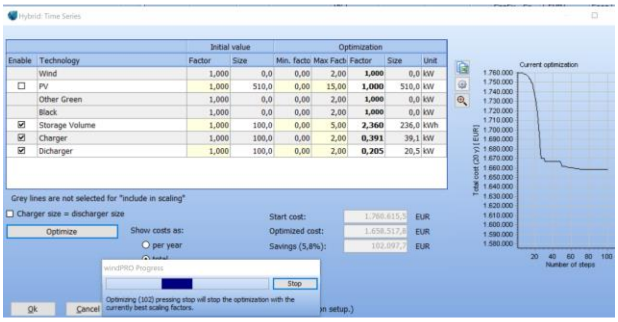
Then, click the “Storage(s)” tab and click Add to add a storage:

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

Data type	Name	Volume [kWh]	Loss [%]	Charge Capacity [kW
Storage	New storage	100.00	0.1	100.00

For this example, enter a 100 kWh storage volume, 100 kW charger and 100 kW discharger, losses are chosen as defaults. The default cost function for batteries can be added in the “Costs” tab (revisit section 6 “Cost of production”). No financing added here.

Simulate with the new battery and click the “Optimize...” button to reopen the optimizer:



Set the PV plant size back to the 500 kW (using a scale factor of 1) and disable it from optimization:

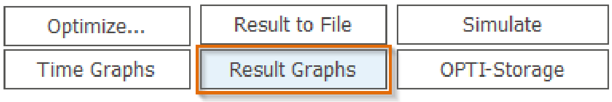
		Initial value	
Enable	Technology	Factor	Size
	Wind	1.000	0.00
☐	PV	1.000	510.00
	Other Green	1.000	0.00

Running an optimization finds the best size for storage, charger and discharger:

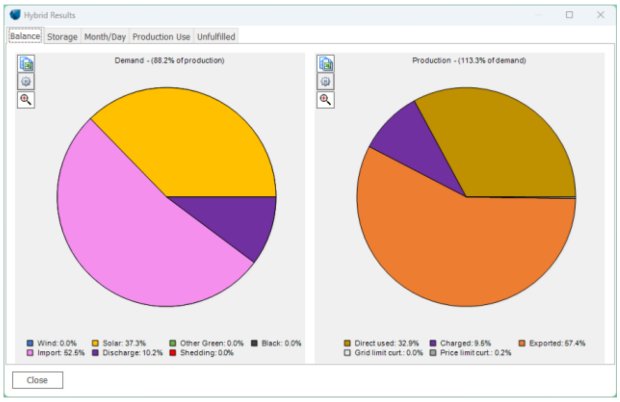
Storage volume [kWh]	100.0	2.000
St. Charger [kW]	100.0	0.459
St. Discharger [kW]	100.0	0.383

In the main window, the NPV is now 744 kEUR, almost 90 kEUR better than without storage for the 500 kW PV-plant. An important reason for this benefit is of course the very high energy tax.

Click on the “Result Graphs” button:

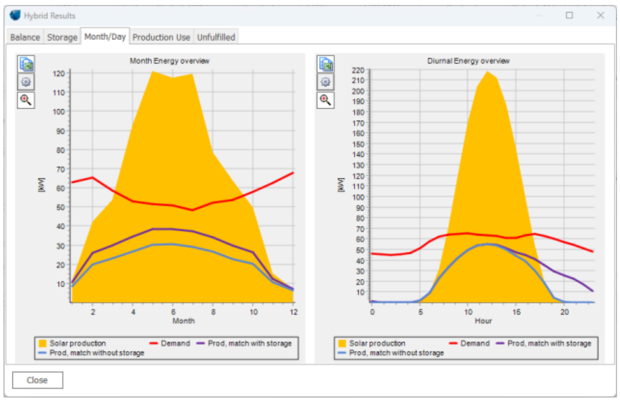


This shows how the demand is met and how the production is utilized:



The storage contributes 10.2% of the demand.

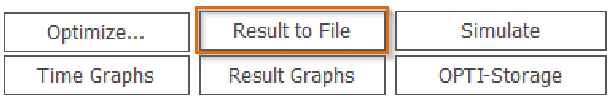
Looking at the Month/Day view, the purple line shows the improvement from the storage aggregated:



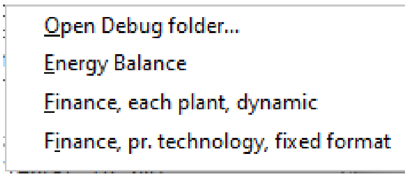
As seen, it delivers from afternoon through all night and brings the generated production closer to the demand in the Micro Grid.

12. REPORTING

The HYBRID module can output both reports and result-to-files. Click the “Result to File” button:



And select one of the following file outputs:

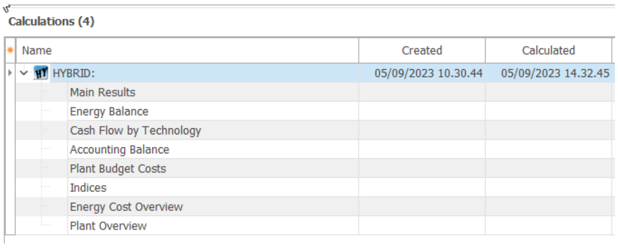


Energy Balance; is subdivided in technology and use, including storage exchange etc. It outputs the entire simulation period by time step, this can be many lines!

Finance, each plant, dynamic; present monthly in/out in EUR subdivided by plant and type.

Finance, pr. Technology, fixed format; present monthly in/out in EUR subdivided by technology and type. Here more plants of similar technology are summed, and the columns included are exact the same making this convenient when building up own post processing tools in like Excel.

To generate a PDF report, close the HYBRID calculation by clicking "Ok" and a report will appear in the calculation list:



Note the two main outputs:

Cash Flow by technology: Focuses on all in/out cash flow subdivided by technologies.

Accounting Balance: Focuses on the type of cost (interests, opex etc.) where instalments (repayment of loans) are replaced with depreciations which follow the traditional "annual accounting" principles where the value reduction of a component is the cost, not the loan repayment.

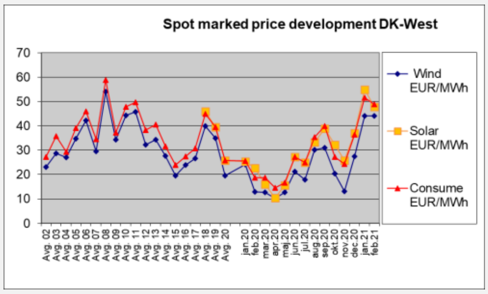
These two reports are typically the basis for the investor to take the decision on establishing the system.

Look at the reports for the simulated example.

More investigations possible

The demonstrated features here are just the most basics. There are much more potential in the module, like:

Simulation based on another year: This is probably one of the most important choices, especially for the "Nord Pool" market, where the spot market prices have huge variations latest years, with 2018 used in this guide as relatively high, but 2020 as extreme low. The right approach would be to "construct" a price time series that hold the dynamics given by the production variations from Wind and PV for the simulation year and the expected development for the next ~20 years.



How will limited grid capacity influence the system? To an extreme, a grid limit can be zero (island operation). And how large a grid expansion would be financial beneficial?

Combining more production sources: Like Wind, PV, run of river Hydro etc. where the production patterns are "locked" by the climate data.

Inclusion of black production: e.g., a base load from a coal plant. Or including a diesel generator, that "fill up" when demand cannot be fulfilled by other production units.

Handling of complex price structures: e.g., subsidies, tariffs and taxes, that can differ by technology and by where the production is delivered (inside Micro Grid, exported or curtailed).

Advanced handling of curtailment, where the price and grid curtailments can be price set: Often a compensation is paid when shutting down a plant where prices are negative. Or curtailment can have a value if the curtailment seen from grid means that the production is utilized for e.g., heating.

Note that the HYBRID module in windPRO does not handle the heating/cooling side. This can be handled by energyPRO.