# 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:**

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# 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:

& Operation	Environme	nt & Visual	Solar	System integration	Tools	Settings & H	lelp
windPR	O Samples	Support p	age 🧲	Teamviewer support	🔆 Sen	d error report	•
	2	Service Supr	oort				

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	Meteo object or PARK calculation
• Solar	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.

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# 3. METEO OBJECT WITH PRICES

Start by inserting a  $\swarrow$  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-m	ar.21.txt - Notepad			-		×
File Edit Format View	Help					
HourUTC HourDK els	potprices_Sp	otPriceEUR_	DK1			~
2021-03-11T23:00:00	+00:00	2021-03-121	00:00:00	17,61		
2021-03-11T22:00:00	+00:00	2021-03-117	23:00:00	12,13		
2021-03-11T21:00:00	+00:00	2021-03-111	22:00:00	27,08		
2021-03-11T20:00:00	+00:00	2021-03-111	21:00:00	24,64		~
<						>
	Ln 1, Col 1	100%	Windows (CRLF)	UTF-8	3	

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

🍯 Me	teorologic	al Data	(Default M	leteo d	ata descrip	ion (18))							
Positio	n Layers	Guide	Purpose	Data	Graphics	Statistics	Shear	Report	Description				
5	Files/folde	ers (mu	st have ex	act sa	me structu	re, if differ	ent stru	ctured fi	les, add more	import filters)			
ort	C:\Us	ers\min	n\Documer	nts\Wi	ndPRO Dat	a\Standaro	ls\DK_1	_Spotpri	ce_2018-mar.	21.bt	Add file(s)	Add fold	er(s)
setup										Г	Remove	Edit	
₽ 2											View file	]	
bratio											(@)	Online data	
- -	Time zon	e for me	asureme	nts:	Same	as in the p	roject p	roperties	: (UTC+01:00	) Brussel +			
figuratio	Structure	or the r	lies (impo	rt fiitei	·):					Auto det	ect Lo	ad 9	iave
	Select	all colur	nns Se	et all s	elected col	umns to:	Ignore		- Sub ty	pe:	+ Unit:		
	Time sta	mps an	e logged in	n:	Beginnir	ig of a peri	iod	-	0 second	s 🕕	🗌 Use	text-to-numbe	r T
5	Line with 1	header	Header Tab	field s	eparator *	First line	with dat	a Dat Tat	a field separa o	tor Addition	al ~		
Ιſ	Column	Header				First data	1		Channel	Туре	Sub type	Unit	Heig
1		HourUT	с			2021-03-1	1T23:0	0:00+00	:00	Time stamp +	Date&Tim +	y-m-d h:m	
2		HourDK				2021-03-1	2T00:0	0:00					
3		elspotpr	ices_Spo	tPrice	EUR_DK1	17,61				Electricity Pr -	Mean -	€/MWh ×	1.

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:

	Meteorological Data (Default Meteo data description (18))													
Positio	on Layers	Guide	Purpose	Data	Graphics	Statistics	Shear	Report	Descriptio	on				
H	Name		Height [m	] Dat	ta type		Disp	lm. heig	ht First d	lata	Last d	ata		
port	A		1.0	- Oth	her/unkno	wn 🦂		0.0 n	n				0.0 mont	hs
setup	2 Time series													
0	Activa	e	Lock ex	isting ti	me series	from:			-		Deviation fro	m standard tir	ne [min]	0
libra	Column	Requir	ed signal		Based	on			Signal na	ime	Low limit	High limit		
tion	Electricity Price elspotprices_SpotPriceEUR_DK1 Electricity Price													
G	Pressure A													
igura		Deman Power	d											
ation		Electric	ty Price											
Dat		Solar i Solar i	rradiation	(direct)										
a set		Solar i	rradiation	(diffuse	e) 🔻									
ę														
-														
ime s		lanal		alamat	7									
e la	Add s	ignal	Delete	signal										

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.

# 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

500MWh_DK_Comm	unityDem	nand_2018-20.txt	-		×
File Edit Format Vie	w Help	<b>)</b>			
Date-time D	emand	(kW)			^
01-01-2018 00:00		50,81			
01-01-2018 01:00		50,53			
01-01-2018 02:00		50,93			
01-01-2018 03:00		53,14			
01-01-2018 04:00		59,10			
01_01_2018 05·00		67 /9			~
<					>
Ln 1, Col 1	100%	Windows (CRLF)	UTF-8	3	

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:

Line with header Header fi		leader field separator	First line	e with data Da		ata field separator Ac			onal		
1	т	rab -	2		Та	ab	÷	None	*		
Column	Header	First data	Channel	Туре		Sub type	Unit		Height	Name	Converte
1	Date-time	01-01-2018 00:00		Time stamp	Ŧ	Date&Tim +	d-m-y	h:m			01/01/20:
2	Demand (kV	W) 50,81		Demand	Ŧ	Mean -	kW	*	0.00	Demand (kW)_Mean	50.8 kW

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

500kW F	PV-plant (2)			
Area:	Area_ 1	 Update selected area	÷	Calculation Setup

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

SOLAR PV (Photovoltaic AEP b	ased on METEO)	cles Costs	Output	Description					
Meteo data:	For calculation			Offect in minutes:					
Solar irradiance	ERA5(T) Recta	ngular Grid	N5 -	0 auto					
Divide in direct/diffuse based on: Erbs model (P1 +									
Model for transferring irradiance from horizontal to inclined plane: Perez model - Default value (°C):									
Temperature	ERA5(T) Recta	ngular Grid	N5 -	20.0					
Humidity (optional)	ERA5(T) Recta	ngular Grid	_N5 -	Update data					
Show data	Scale calcul	ation data							
Output Interval									
● Use all O Use pe	eriod 30/12/1	899 -	30/12	2/1899 - Use last					

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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:

<u>F</u> ile	Definitions	Geo Data	Climate	Energy	Loads & Ope	eration	Environ	ment & Visual	Solar	System integration
	HYBRID	WINDBANK	eGri	d 🆀	eGrid catalogue	۶,	Grid table	📥 WTG ca	talogue	
	System Integra	ation			Electrical			WTG Dat	а	

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

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

Add PARK Calculation	Add PV Calculation	Add Black Production	Add Energy Prices
Add Wind Production	Add PV Production	Add Green Production	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:

Setup Units Ex	etup Units External Grid / Import Cost Time Series Storage(s) Cost and Lifetime Finance Energy value												
Data type	Name	Loaded	Start	End	Rated Power [I	Reduction [*	Interval [min.]	Development	Include in scali	Micro Grid			
PV Production - 1	Solar PV - PV Te	05/09/2023 10.3	01/01/2017	01/01/2020	510.00	0.0	60	No in-/decrease		inside			
Demand - from I	Demand - 500M	05/09/2023 10.3	01/01/2018	01/01/2021			60	No in-/decrease	¥	inside			
Electricity Prices	Energy Price - D	05/09/2023 10.3	01/01/2018	11/03/2021	-		60	No in-/decrease					

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



Development

No in-/decrease

2% Inflation

**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
~
✓

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

Micro Grid	
inside	Ŧ
inside	Ŧ

**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):

iost Model(s)	Ma	mo Solar-PV large	> 100kW				
Solar-PV large > 100kW Solar-PV medium < 100kW Solar PV > 100kW	P	rices fixed in year:	2020	Default Inde	κ: No in-/decrease		
	0	ategory	Cost function value	Unit	Cost Index	Replace every n years (0=none)	Temporary example plant cost
	~	0. DEVEX					
		Development	1.00	% of CAPEX			3,92
	~	1. CAPEX - pr. kW					
		Solar panels	230.00	EUR/kW	No in-/decrease	0	117,30
		Inverters	50.00	EUR/kW	No in-/decrease	0	25,50
		Sub structures	20.00	EUR/kW	No in-/decrease	0	10,20
		Grid, internal	10.00	EUR/kW	No in-/decrease	0	5,10
		Grid, external	160.00	EUR/kW	No in-/decrease	0	81,60
		Installation	190.00	EUR/kW	No in-/decrease	0	96,90
		Land purchase	0.00	EUR/kW	No in-/decrease	0	
	1	Other/contingency	110.00	EUR/kW	No in-/decrease	0	56,10
		Tracker costs	0.00	EUR/kW	No in-/decrease	0	
	~	2. OPEX (Annual from	n year 1) - example	column is lifetime	e cost		
		08M	5.00	EUR/kW	No in-/decrease		51,00
		Land rent	2.30	EUR/kW	No in-/decrease		23,46
	~	3. ABEX (Year after p	roject end)				
		Abandonment	0.00	ELIR/MA	No in-/decrease		

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:

Time series start: 🕕	January	*	2018	Time resolution:	60 Minutes	*
Operation start:	January	*	2024	Operation years:	20	

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:

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

windPRO now calculates the energy balance and costs:

	Annual e	nergy, life	etime average		Raw costs, hour price weight			
Туре	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 volume	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)													
Туре	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 volui	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 %	0
Show:		
<ul> <li>NPVe (exclusive interests a</li> </ul>	and fees)	
<ul> <li>NPVi (inclusive interests ar</li> </ul>	nd 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 +	OpEx +	Interest /	Purchase /	Export /	Subsidy [	Tax / Tariff	Total [ EUR]						
CapEx - G	AbEx [ EUR]	Fees [ EUR]	Import [ E	Curtailme	EUR]	[ 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.



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:

Se	tup Units	External Grid /	Import Cost	Time Series	Storage(s	) Cost and	Lifetime	Finance	Energy value				
	Grid Cap	pacities port = Import Aicro grid plants	(system)	Import	1,000.0	Export		kw	Added grid expansion for the used capabilit 0.0	i costs ies EUR			
	Witho	ut, "All imported	(reference)		1,000.0			kW	0.0	EUR			
	Energy	y Cost (factor)		1.000	-	Default Ind	iex	•	Fixed Tan     Calculate	ff		55.000	EUR/MWh
	Energ	y Tax		160.000 E	UR/MWh	Default Ind	ex	•	Cost develop	ment	Default Index		EUR

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:

Impor	rt Energy Cost			Cost development		Та	nff			
Ene	argy Cost (factor)	1.000		Default Index			Fixed Tariff		55.000	EUR/MWh
Ene	argy Cost (offset)	0.000	EUR/MWh	Default Index	*		Calculated Tariff			Edit
Ene	ergy Tax	160.000	EUR/MWh	Default Index			Cost development	Default Index		

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	s for MicroGrid	with demand in	nside compare	d 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	Ŧ
LCO	E: 50.797 EUR/	MWh			Optimize	Result to	o File	Simulate	
IRR:	16.82 %				Time Graphs	Result G	raphs	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:

Setup Units E	oternal Grid / In	port Cost Til	ne Series Sto	rage(s) (	Cost and Lifetin	ne Finance	Energy value							
Show Cost	Show Cost Development													
Ph	Plant Export Used in Micro Grid / Sale to Demand Grid Curtaliment Price Curtaliment													
Data tuna	Name	Cost (Instar	Cost (ellow	of Sub-	sh frue to	tory Tay [1	Teeff (EUR)M	Subably (D.B.)	Teriff (D.R/M	Energy Tax [E	Cost (farter)	Cost (offset) [	Cost (factor)	Cost (effect) [

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:

Setu	Units	External	Grid / Import	Cost 1	Time Series	s Storag	e(s) (	Cost and Lifetime	Finance	En	ergy velue						
Loar				96.0	of Investmen	nt		Loan Amount (El	aR]		Loan Type		Period		Interest Rate	Edit	
¥ 0:	Solar P	/ - PV Tes	t Project 500	kw [P	V Production	n] - (392	1,700 E	uR)									
P	100%	nance					100.00		392	,700	Nominal Loan /	Annuity		10	5.0	0	Edit
	Add	.cian		Delete	Loan	1	Owne	er start capital:			0 EUR	Interest on po	sitive cash balance:		0.00 %		
							Intere	sit / year			1 -	Interest on ne	pative cash balance:		0.00 %		

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:

Nam	e PV 100% finance					All currenc	ies in: EUR			
Det	scription of Financing		Dist	oursements						
т	ype:	Nominal Ioan	- To	tal plant cost	: 392,700 EUR					
		Annuihu	Lo	an share:	100 %					
~	moruzation:	permany		Date	Principal		Paid Out			
			1	2024-01		202 20	201	2 700		
			*	2024-01		392,70	, 354	4700		
ayn	nent Grace Period: 0	Years 0	Months Paym	ient(s) per Ye	ear:	1 *				
	Name of Fee	Time of Paymer	nt	Value		Unit			Add Fe	e
			chie data b					Г	Delete F	-ee
			Shu uata u	o display>						-
no	Date	Total Payment	Interest Rab	e display>	Interest and Fees *)	Insta	Iment	Remaining	Debt	
no	Date at opening	Total Payment	Interest Rab	e	Interest and Fees *)	Insta	Iment	Remaining	Debt	0
no	Date at opening 2024-12-01	Total Payment 50,856	Interest Rat	e 5.00	Interest and Fees *)	.635	Iment 31,221	Remaining	Debt 361,	0
no	Date at opening 2024-12-01 2025-12-01	Total Payment 50,856 50,856	Interest Rab	e 5.00 5.00	Interest and Fees *) 19 18	635 ,074	Iment 31,221 32,783	Remaining	Debt 361, 328,	0 479 696
no	Date at opening 2024-12-01 2025-12-01 2026-12-01	Total Payment 50,856 50,856 50,856	Interest Rab	e 5.00 5.00 5.00	Interest and Fees *) 19 18 16	635 074 435	Iment 31,221 32,783 34,422	Remaining	Debt 361, 328, 294,	0 479 696 274
no	Date at opening 2024-12-01 2025-12-01 2026-12-01 2027-12-01	Total Payment 50,854 50,856 50,856 50,856 50,856	Interest Rab	e 5.00 5.00 5.00 5.00 5.00	Interest and Fees *) 19 18 16 14	635 ,074 ,435 ,714	Iment 31,221 32,783 34,422 36,143	Remaining	Debt 361, 328, 294, 258,	0 479 696 274 132
	Date at opening 2024-12-01 2025-12-01 2026-12-01 2027-12-01 2027-12-01	Total Payment 50,854 50,855 50,856 50,856 50,856 50,856	Interest Rate	e 5.00 5.00 5.00 5.00 5.00 5.00 5.00	Interest and Fees *) 19 18 16 14 12	635 074 435 ,714 907	Iment 31,221 32,783 34,422 36,143 37,950	Remaining	Debt 361, 328, 294, 258, 220,	0 479 696 274 132 182
no t	Date at opening 2024-12-01 2025-12-01 2026-12-01 2026-12-01 2028-12-01 2028-12-01	Total Payment 50,856 50,856 50,856 50,856 50,856 50,856 50,856	Interest Ration	e 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.0	Interest and Fees *) 19 18 16 14 12 11	635 ,074 ,435 ,714 ,907 ,009	Iment 31,221 32,783 34,422 36,143 37,950 39,847	Remaining	Debt 361, 328, 294, 258, 220, 180,	0 479 696 274 132 182 334
no I I I I I I I	Date at opening 2024-12-01 2025-12-01 2026-12-01 2027-12-01 2028-12-01 2029-12-01 2029-12-01	Total Payment 50,856 50,856 50,856 50,856 50,856 50,855 50,855	Interest Ration	e 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.0	Interest and Fees *) 19 18 16 14 12 11 9	635 ,074 ,435 ,714 ,907 ,009 ,017	Iment 31,221 32,783 34,422 36,143 37,950 39,847 41,840	Remaining	Debt 361, 328, 294, 258, 220, 180, 138,	0 479 696 274 132 182 334 495
no L L L L L L L L L L L L L L L L L L L	Date at opening 2024-12-01 2025-12-01 2025-12-01 2027-12-01 2028-12-01 2029-12-01 2039-12-01 2031-12-01	Total Payment 50,856 50,856 50,856 50,856 50,856 50,856 50,856 50,956 50,956	<ul> <li>Interest Rab</li> <li>5</li> <li>5</li> <li>5</li> <li>5</li> <li>5</li> <li>5</li> <li>5</li> <li>5</li> <li>5</li> </ul>	e 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.0	Interest and Fees *) 19 18 16 14 12 11 9 6	635 635 704 435 714 907 009 017 925	iment 31,221 32,783 34,422 36,143 37,950 39,847 41,840 43,932	Remaining	Debt 361, 328, 294, 258, 220, 180, 138, 94,	0 479 696 274 132 182 334 495 563
no 1 2 3 4 5 6 7 8 9 10	Date at opening 2024-12-01 2025-12-01 2025-12-01 2027-12-01 2029-12-01 2029-12-01 2029-12-01 2030-12-01 2031-12-01	Total Payment 50,855 50,855 50,855 50,855 50,855 50,855 50,855 50,855 50,855	<pre><nu interest="" rat="" s="" s<="" td="" u="" uoto=""><td>e 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.0</td><td>Interest and Fees *) 19 18 16 14 12 11 9 6 4</td><td>635 674 435 714 907 009 007 925 728</td><td>Iment 31,221 32,783 34,422 36,143 37,959 39,847 41,840 43,932 46,128</td><td>Remaining</td><td>Debt 361, 328, 294, 258, 220, 180, 138, 94, 48,</td><td></td></nu></pre>	e 5.00 5.00 5.00 5.00 5.00 5.00 5.00 5.0	Interest and Fees *) 19 18 16 14 12 11 9 6 4	635 674 435 714 907 009 007 925 728	Iment 31,221 32,783 34,422 36,143 37,959 39,847 41,840 43,932 46,128	Remaining	Debt 361, 328, 294, 258, 220, 180, 138, 94, 48,	

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

DevE CapE	x + x - 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
39	96,627.0	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
39	96,627.0	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: 50.7	97 EUR/	MWh			Optimize	Result to	File	Simulate
IRR: 16.82	%				Time Graphs	Result G	raphs	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:

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

#### 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 PVplant will generate the lowest lifetime costs.

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

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.
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.
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.
	Shedding:					Savings (43.0	1,158,446.
0.0	0.0	0.0	543,612.1			2,148,172.6	2,691,784.
E: 50.797 EUR/	MWh			Optimize	Result to	o File	Simulate
8.83.%	N.			Time Granhs	Result G	anhs (	PTI-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 dd to add a storage:

Setup Units Externa	Grid / Import Cost	ime 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:

		Initial	value		Op	timization				
Enable	Technology	Factor	Size	Min. facto	Max Fact	Factor	Size	Unit	1752	Ourrect optimization
	Wind	1,000	0,0	0,00	2,00	1,000	0,0	kw	43 1.760	000
	PV	1,000	510,0	0,00	15,00	1,000	510,0	kW	1.750	000
	Other Green	1,000	0,0	0,00	2,00	1,000	0,0	kw	0 1.730	000
	Black	1,000	0,0	0,00	2,00	1,000	0,0	kw	1.720	000
M	Storage Volume	1,000	100,0	0,00	5,00	2,360	236,0	kWh	a 1,710	000
	Charger	1,000	100,0	0,00	2,00	0,391	39,1	kw	⊒ 1.690.	000
	Dicharger	1,000	100,0	0,00	2,00	0,205	20,5	kW	S 1.680	000
Grey li	ines are not selected for "include ger size = discharger size	t in scaling*	5	itart cost:	[	1.750	615,3 E	UR	1.630 1.630 1.620 1.610	000
	Optimize Sho	w costs as:	0	optimized o	ost;	1.650	517,8 E	UR	1.590	000
		) per year	5	iavings (5,8	3%):		097,7	UR	1.580.	000
	windter a	Charles .								20 40 60 80 10 Number of steps
	HIII NOT THE FILL FILL									

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:

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

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 resultto-files. Click the "Result to File" button:

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

And select one of the following file outputs:

<u>O</u>pen Debug folder... <u>E</u>nergy Balance <u>F</u>inance, each plant, dynamic F<u>i</u>nance, pr. technology, fixed format

**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:

Calculations (4)						
*	* Name		Created	Calculated		
Þ	✓ ₩ +	IYBRID:	05/09/2023 10.30.44	05/09/2023 14.32.45		
		Main Results				
		Energy Balance				
		Cash Flow by Technology				
		Accounting Balance				
		Plant Budget Costs				
		Indices				
		Energy Cost Overview				
		Plant Overview				

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 <u>energyPRO</u>.