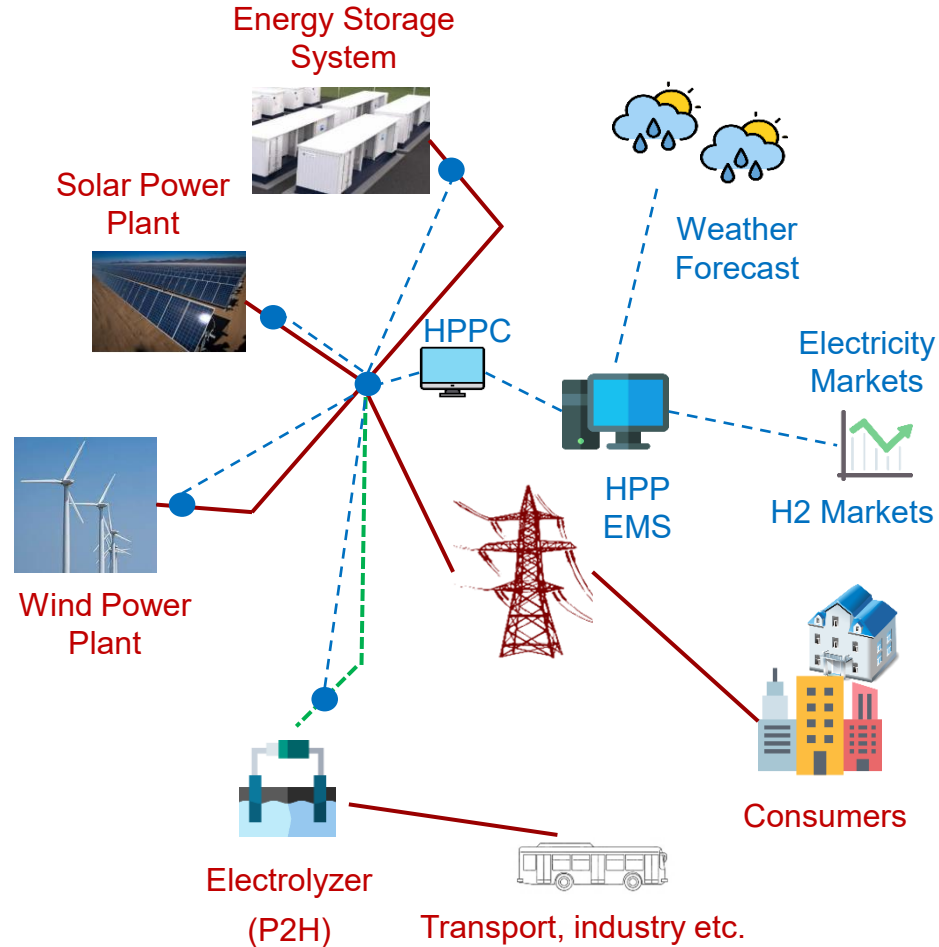


# Hybrid Power Plant & HyDesign

# Hybrid Power Plant – Utility scale

## Multi-technology, co-located and grid connected



### General Features

More than one generation sources involved

All assets are owned by same company so higher controllability

More RES integration with same grid connection

### Motivation

To reduce cost/ maximize revenue from different energy markets

One common energy management system

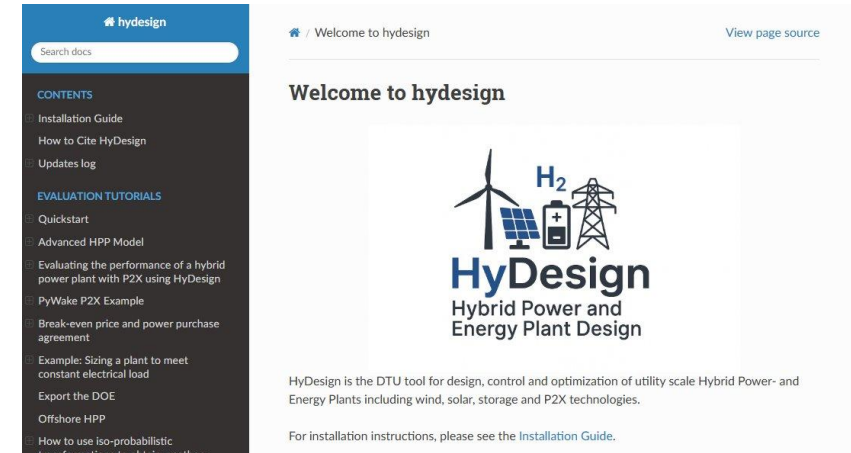
Reduced curtailment means more value of RE

Optimal utilization of land

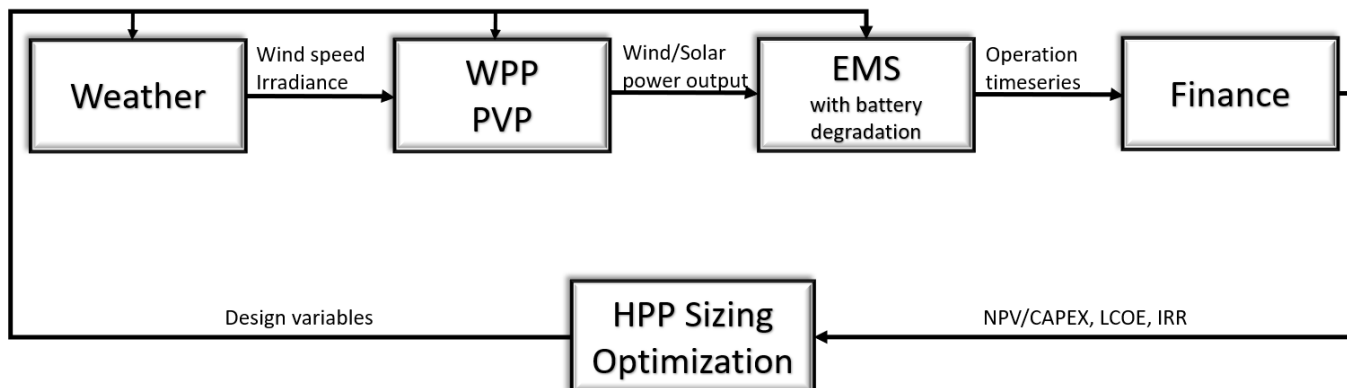
More flexibility allows for decommissioning of fossil fuel-based generators

# HyDesign: Python-based open-source tool

- HyDesign is a software platform for design and operation of utility-scale hybrid power plants
- Can be used for:
  - sizing optimization of HPP
  - evaluation of a specific plant design
- Objective function is user specified (min LCOE, max NPV/CAPEX...)
- Key components: wind, solar, battery, hydrogen, grid-connection
- Multi-disciplinary optimization problem implemented in OpenMDAO



<https://topfarm.pages.windenergy.dtu.dk/hydesign/>



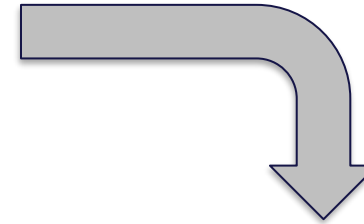
# Optimal sizing methodology of HPP

## Inputs

- Electricity prices
- H2 price and demand
- Site location for weather data
- Technologies cost



## Optimization



Output (Design Variables)				Output
Wind	Solar	Battery	P2H	Finance model
Rotor diameter, hub height	AC power	Power rating	Electrolyzer capacity	NPV/CAPEX
Area of land	Surface tilt angle	Energy storage Capacity	H2 storage capacity	IRR
Rated power	Surface azimuth angle			LCOE, LCOH
Number of wind turbines				AEP, AHP
Wind power density				Number of batteries

# Instructions to install HyDesign

You can follow these steps. Be mindful of a space between e and . in step 5. It throws crazy errors otherwise.

The instructions for HyDesign installation are as follows:

<https://topfarm.pages.windenergy.dtu.dk/hydesign/installation.html> (reference link)

---

Pre-requisite: Anaconda installed (reference link: <https://docs.anaconda.com/free/anaconda/install/>)

Installation on Laptop through Anaconda terminal:

---

1. git clone <https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign.git>
  2. cd hydesign
  3. conda env create --file environment.yml
  4. conda activate hydesign
  5. pip install -e .
- 

If Step 1 doesn't work, you may need to do this first-> conda install git

# Let's see how HyDesign looks, and how it works.....

- Gitlab repository:  
<https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign>
- At the bottom -> link to documentation ->  
<https://topfarm.pages.windenergy.dtu.dk/hydesign>

# Start – working with a notebook

## To evaluate a HPP design

### Advanced HPP Model

#### Evaluating the performance of a hybrid power plant using HyDesign

HyDesign is an open-source tool for design and optimization of utility scale wind-solar-storage based hybrid power plants.

In this notebook we will evaluate a hybrid power plant design in a specific location.

A hybrid power plant design consists on selecting the following parameters:

##### Wind Turbine design:

1. Clearance [m] (**clearance**): Height from the ground to rotor tip at lowest position. This parameter controls the wind turbine hub height
2. Specific power of the wind turbine [MW/m<sup>2</sup>] (**sp**): Defined as  $sp = p_{rated} / (\pi * R^2)$ , it controls the turbine rotor size for a given power produce more power at lower wind speeds, but are more expensive.
3. Rated power of the wind turbine [MW] (**p<sub>rated</sub>**)

##### Wind Plant design:

4. Number of wind turbines in the wind plant [-] (**Nwt**)
5. Wind power installation density [MW/km<sup>2</sup>] (**wind Mw per km2**): This parameter controls how closely spaced are the turbines, which in turn affects the total power output.

- Open the example notebook ‘**Advanced\_hpp\_model.ipynb**’ (in the folder ...\\hydesign\\docs\\notebooks) – evaluating the performance of HPP.
- Run the cells to evaluate a given plant design and calculate the econometrics.

# Advanced\_hpp\_model.ipynb

```
examples_sites = pd.read_csv(f'{examples_filepath}examples_sites.csv', index_col=0, sep=';')
examples_sites
```

	case	name	longitude	latitude	altitude	input_ts_fn	sim_pars_fn
0	India	Indian_site_good_wind	77.500226	8.334294	679.803454	India/GWA2/input_ts_Indian_site_good_wind.csv	India/hpp_pars.yml
1	India	Indian_site_good_solar	68.542204	23.542099	29.883557	India/GWA2/input_ts_Indian_site_good_solar.csv	India/hpp_pars.yml
2	India	Indian_site_bad_solar_bad_wind	77.916878	17.292316	627.424643	India/GWA2/input_ts_Indian_site_bad_solar_bad_...	India/hpp_pars.yml
3	Europe	France_good_solar	4.229736	44.422011	204.000000	Europe/GWA2/input_ts_France_good_solar.csv	Europe/hpp_pars.yml
4	Europe	France_good_wind	-0.864258	48.744116	302.000000	Europe/GWA2/input_ts_France_good_wind.csv	Europe/hpp_pars.yml
5	Europe	France_bad_solar_n_wind	2.167969	47.428087	140.000000	Europe/GWA2/input_ts_France_bad_solar_n_wind.csv	Europe/hpp_pars.yml
6	Europe	Germany_bad_solar_n_wind	10.766602	49.310798	442.000000	Europe/GWA2/input_ts_Germany_bad_solar_n_wind.csv	Europe/hpp_pars.yml
7	Europe	Germany_good_wind	7.873535	53.287111	5.000000	Europe/GWA2/input_ts_Germany_good_wind.csv	Europe/hpp_pars.yml
8	Europe	Denmark_good_solar	11.813965	55.397760	42.000000	Europe/GWA2/input_ts_Denmark_good_solar.csv	Europe/hpp_pars.yml
9	Europe	Denmark_good_wind	8.594398	56.227322	85.000000	Europe/GWA2/input_ts_Denmark_good_wind.csv	Europe/hpp_pars_BM.yml

```
name = 'Denmark_good_wind'
ex_site = examples_sites.loc[examples_sites.name == name]
```

Select example site of interest and change the name as per the list.



## Advanced\_hpp\_model.ipynb

In this cell, enter the design of HPP of your interest

- Select the size of HPP:
  - wind plant size in MW in terms of number of WT and rated power of WT:  $N_{wt} * P_{rated}$ ;
  - solar\_MW;
  - battery size
    - b\_P: battery power in MW
    - b\_E\_h: battery energy hours

```
start = time.time()

clearance = 10
sp = 350
p_rated = 5
Nwt = 70
wind_MW_per_km2 = 7
solar_MW = 80
surface_tilt = 50
surface_azimuth = 180
solar_DCAC = 1.5
b_P = 50
b_E_h = 3
cost_of_batt_degr = 10
```

# Advanced\_hpp\_model.ipynb

## The output of the HPP model evaluation:

Objective function: maximize NPV/CAPEX

NPV: Net present Value

IRR: Internal rate of return

LCOE: Levelized cost of electricity

CAPEX: Total capital expenditure

OPEX: Total operational expenditure

AEP: Annual energy production

GUF: Grid utilization factor

Grid [MW]: grid capacity

Total curtailment [GWh]: for 25 years

Total curtailment with deg [GWh]: for 25 years considering the impact of degradation

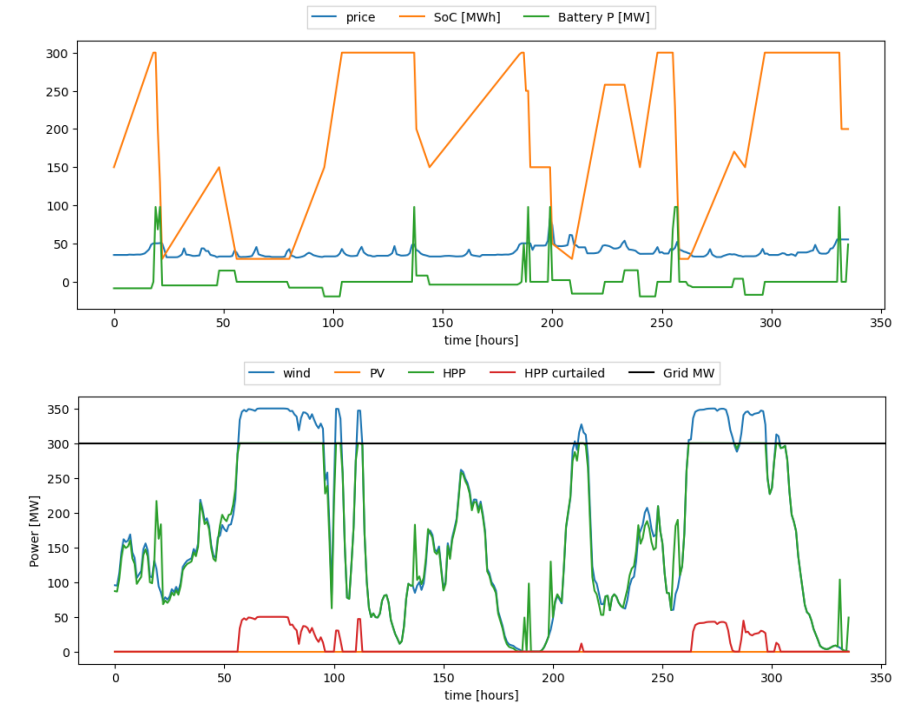


```
NPV_over_CAPEX: 0.207
NPV [MEuro]: 78.996
IRR: 0.078
LCOE [Euro/MWh]: 47.474
Revenues [MEuro]: 27.171
CAPEX [MEuro]: 382.218
OPEX [MEuro]: 6.040
Wind CAPEX [MEuro]: 267.506
Wind OPEX [MEuro]: 5.365
PV CAPEX [MEuro]: 33.500
PV OPEX [MEuro]: 0.675
Batt CAPEX [MEuro]: 15.230
Batt OPEX [MEuro]: 0.000
Shared CAPEX [MEuro]: 65.982
Shared OPEX [MEuro]: 0.000
penalty lifetime [MEuro]: 0.000
AEP [GWh]: 733.508
GUF: 0.279
grid [MW]: 300.000
wind [MW]: 350.000
solar [MW]: 100.000
Battery Energy [MWh]: 150.000
Battery Power [MW]: 50.000
Total curtailment [GWh]: 337.661
Total curtailment with deg [GWh]: 152.556
Awpp [km2]: 50.000
Apvp [km2]: 1.226
Plant area [km2]: 50.000
Rotor diam [m]: 134.867
Hub height [m]: 77.434
Number of batteries used in lifetime: 2.000
Break-even PPA price [Euro/MWh]: 31.519
Capacity factor wind [-]: 0.202
```

# Advanced\_hpp\_model.ipynb – plotting results – EMS operation

```
n_days_plot = 14
plt.figure(figsize=[12,4])
plt.plot(price_t[:24*n_days_plot], label='price')
plt.plot(b_E_SOC_t[:24*n_days_plot], label='SoC [MWh]')
plt.plot(b_t[:24*n_days_plot], label='Battery P [MW]')
plt.xlabel('time [hours]')
plt.legend(loc='upper center', bbox_to_anchor=(0.5, 1.15),
          ncol=3, fancybox=0, shadow=0)

plt.figure(figsize=[12,4])
plt.plot(wind_t[:24*n_days_plot], label='wind')
plt.plot(solar_t[:24*n_days_plot], label='PV')
plt.plot(hpp_t[:24*n_days_plot], label='HPP')
plt.plot(hpp_curt_t[:24*n_days_plot], label='HPP curtailed')
plt.axhline(grid_MW, label='Grid MW', color='k')
plt.xlabel('time [hours]')
plt.ylabel('Power [MW]')
plt.legend(loc='upper center', bbox_to_anchor=(0.5, 1.15),
          ncol=5, fancybox=0, shadow=0)
```



## Save EMS results

```
results_1year = {'Electricity Price': price_t[:8760], 'Wind Power': wind_t[:8760], 'Solar Power': solar_t[:8760], 'HPP Power': hpp_t[:8760], 'Curtailed Power': hpp_curt_t[:8760], 'Battery SOC': b_E_SOC_t[:8760], 'Battery Power': b_t[:8760]}
df = pd.DataFrame(results_1year)
df.to_csv('EMS_out_DK_good_solar.csv')
```

## More input files

Additionally, there are 2 input files used:

- For technologies cost - '**hpp\_pars.yml**' in the folder ...\\hydesign\\hydesign\\examples\\Europe
- For weather data – select the file corresponding to the selected location – '**input\_ts\_XXXXX**' in the folder ...\\hydesign\\hydesign\\examples\\Europe\\GWA2

The data represents wind speed (WS) and wind direction (WD) at different hub heights, direct normal irradiance (DNI), diffused horizontal irradiance (DHI), global horizontal irradiance (GHI) and spot market electricity prices – with an hourly resolution for one year.

[Note: the weather data and electricity prices are user inputs and can be updated in this file.](#)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		WS_1	WS_50	WS_100	WS_150	WS_200	WD_1	WD_50	WD_100	WD_150	WD_200	temp_air_1	ghi	dni	dhi	Price
2	1/1/2012 0:00	2.803428	6.289076	8.109687	8.777118	10.33508	163.2749	166.8879	170.5735	179.0672	181.6893	276.7673	0.035121	0	0.035121	35.171
3	1/1/2012 1:00	2.791624	6.275261	8.093319	8.910806	10.40799	166.335	170.3653	174.4807	181.7799	184.4725	277.3744	0.01756	0	0.01756	35.171
4	1/1/2012 2:00	3.036807	6.656427	8.54771	9.467695	10.865	168.6747	172.2646	175.9297	181.4956	184.1347	278.0159	0	0	0	35.171
5	1/1/2012 3:00	3.405581	7.233561	9.23767	10.43509	11.79302	176.7051	179.3924	182.1396	185.4649	187.9601	278.6559	0	0	0	35.171
6	1/1/2012 4:00	3.649363	7.54244	9.584774	10.86428	12.08176	188.3958	190.483	192.6083	195.2514	197.9662	279.2908	0	0	0	35.171

## Input file – hpp\_pars.yml

examples > Europe > ! hpp\_pars.yml

```

1  # -----
2  # HPP Global
3  # -----
4  G_MW: 300 # Grid capacity
5  year: '2012' # Single representative year
6  N_life: 25
7
8  # -----
9  # Wind
10 # -----
11 wind_turbine_cost: 640_000 # [Euro/MW] for reference turbine
12 wind_civil_works_cost: 260_000 # [Euro/MW]
13 wind_fixed_onm_cost: 12_600 # Wind fixed O&M cost per year [Euro/MW /year]
14 wind_variable_onm_cost: 1.35 #[EUR/MWh_e] Danish Energy Agency
15
16 d_ref: 145
17 hh_ref: 100
18 p Rated_ref: 5.0 #[MW]
19
20 # Degradation
21 wpp_efficiency: 1
22 wind_deg_yr: [0, 25]
23 wind_deg: [0, 0.25] #25yr * 1%/yr
24 share_WT_deg_types: 0.5
25
26 # -----
27 # PV
28 # -----
29 solar_PV_cost: 110_000 # [Euro/MW DC]
30 solar_hardware_installation_cost: 100_000 # [Euro/MW DC]
31 solar_inverter_cost: 20_000 #[Euro/MW]
32 solar_fixed_onm_cost: 4_500 # Solar O&M cost per year [Euro/MW] DC
33 land_use_per_solar_MW: 0.01226 # Danish energy agency
34

```

Grid connection capacity

Wind turbine cost

Solar PV cost

# Evaluate a HPP design with Power-to-Hydrogen

- Open the example notebook 'HPP\_evaluation\_P2X.ipynb' (in the folder ...\\hydesign\\docs\\notebooks) – evaluating the performance of HPP with hydrogen.

### Evaluating the HPP model

In this cell, enter the design of HPP with P2H.

- Select the size of HPP:
  - wind plant size in MW:  $N_{wt} * P_{rated}$ ;
  - Solar plant size in MW:  $solar\_MW$ ;
  - battery size
    - $b\_P$ : battery power in MW
    - $b\_E\_h$ : battery energy hours)
  - Electrolyzer size in MW:  $P_{ptg\_MW}$

```
[ ] start = time.time()

clearance = 10
sp = 353
p_rated = 2
Nwt = 145
wind_MW_per_km2 = 5.02
solar_MW = 50
surface_tilt = 27.35
surface_azimuth = 194.38
DC_AC_ratio = 1.22
b_P = 9
b_E_h = 8
cost_of_batt_degr = 3.34
ptg_MW = 100
```

# Efficiency curve of electrolyzers

The efficiency curve parameter of different electrolyzer technologies used are:

- For technologies cost - '**Electrolyzer\_efficiency\_curves.csv**' in the folder  
...\\hydesign\\hydesign\\examples\\Europe ...\\hydesign\\hydesign\\examples\\Europe

[Note: the efficiency and hydrogen production curve parameters are user inputs and can be updated in this file.](#)



# HPP\_evaluation\_P2X.ipynb – for HPP with hydrogen

## The output of the HPP model evaluation:

Objective function: maximize NPV/CAPEX

NPV: Net present Value

IRR: Internal rate of return

LCOE: Levelized cost of electricity

CAPEX: Total capital expenditure

OPEX: Total operational expenditure

AEP: Annual energy production

GUF: Grid utilization factor

Grid [MW]: grid capacity

Total curtailment [GWh]: for 25 years

Annual\_H2 [kg]: H2 production in one year

```
NPV_over_CAPEX: 0.090
NPV [MEuro]: 29.802
IRR: 0.066
LCOE [Euro/MWh]: 31.318
CAPEX [MEuro]: 330.666
OPEX [MEuro]: 11.200
penalty lifetime [MEuro]: 0.000
AEP [GWh]: 1155.963
GUF: 0.440
annual H2 [kg]: 1610665.418
grid [MW]: 300.000
wind [MW]: 290.000
solar [MW]: 50.000
PtG [MW]: 100.000
Battery Energy [MWh]: 72.000
Battery Power [MW]: 9.000
Total curtailment [GWh]: 0.000
Awpp [km2]: 57.769
Rotor diam [m]: 84.934
Hub height [m]: 52.467
Number_of_batteries: 1.000

exec. time [min]: 0.2549054265022278
```

# How to perform sizing optimization?

- Look for the following sizing script and run the Python files after adjusting some parameters for your use case:
  - 'simple\_sizing\_example.py'** (in the folder ...\\hydesign\\examples\\scripts) – for HPP sizing
  - 'simple\_sizing\_example\_P2X.py'** (in the folder ...\\hydesign\\examples\\scripts) – for HPP sizing with P2H

```
inputs = {
    'example': 9,
    'name': None,
    'longitude': None,
    'latitude': None,
    'altitude': None,
    'input_ts_fn': None,
    'sim_pars_fn': None,

    'opt_var': "NPV_over_CAPEX",
    'num_batteries': 5,
    'n_procs': 1,
    'n_doe': 32,
    'n_clusters': 1,
    'n_seed': 0,
    'max_iter': 5,
    'final_design_fn': 'hydesign_design_9.csv',
    'npred': 3e4,
    'tol': 1e-6,
    'min_conv_iter': 2,
    'work_dir': './',
    'hpp_model': hpp_model,
}
```

← Select the example site number of your interest

↑ Output file name

Select the sizing design variable as a fixed value (specify the value) or as a variable (specify the bounds)

```
kwargs['variables'] = {
    'clearance [m]':
        # {'var_type': 'design',
        #   'limits': [10, 60],
        #   'types': 'int'
        # },
        {'var_type': 'fixed',
         'value': 10
        },
    'sp [W/m2]':
        # {'var_type': 'design',
        #   'limits': [200, 359],
        #   'types': 'int'
        # },
        {'var_type': 'fixed',
         'value': 350
        },
    'p_rated [MW]':
        # {'var_type': 'design',
        #   'limits': [1, 10],
        #   'types': 'int'
        # },
        {'var_type': 'fixed',
         'value': 5
        },
    'Nwt':
        {'var_type': 'design',
         'limits': [50, 100],
         'types': 'int'
        },
        # {'var_type': 'fixed',
        #   'value': 0
        # },
}
```

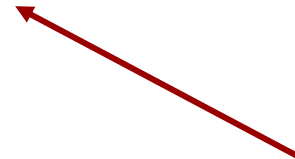
**If HyDesign installation doesn't work for you, then try the assignment with [Google Colab](#).**

# Accessing notebooks through Google Colab

<https://topfarm.pages.windenergy.dtu.dk/hydesign>

**Notebook 1:** Advanced HPP Model -> HPP size evaluation

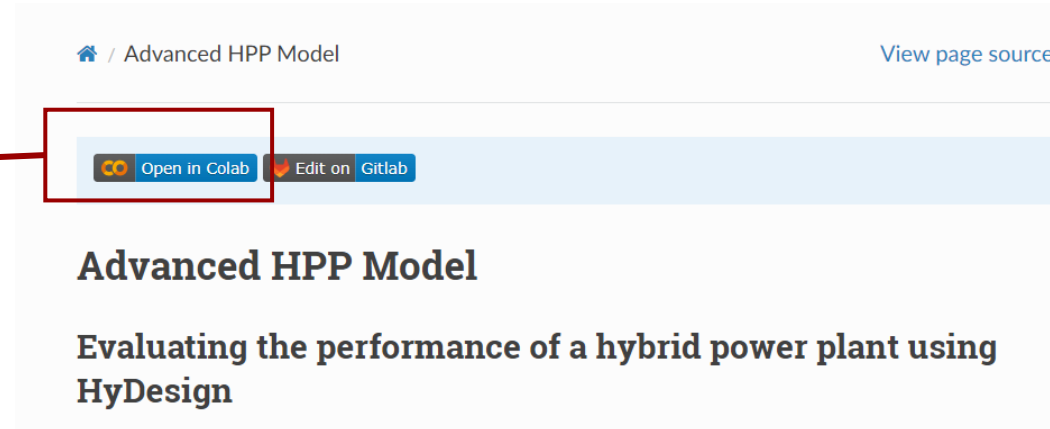
**Notebook 2:** Evaluating the performance of a hybrid power plant with P2X using HyDesign -> HPP size evaluation with Power-to-Hydrogen



The screenshot displays the HyDesign web application. On the left, a dark sidebar contains a 'CONTENTS' menu. Under the 'TUTORIALS' section, 'Advanced HPP Model' and 'Evaluating the performance of a hybrid power plant with P2X using HyDesign' are listed and highlighted with a red rectangular box. A red arrow points from the text 'Notebook 2' to this box. The main content area on the right is titled 'Welcome to hydesign' and includes a search bar, a 'Get Started' section with a 'Quickstart' link, and a 'Contents' list with an 'Installation Guide' link. The top of the page shows the 'hydesign' logo and version '1.3.4'.

# Accessing notebooks through Google Colab

Open the notebook in Google Colab



- Run each cell
- Check for the list of example sites (select the site of interest).
- Change the site name accordingly.

	case	name	longitude	latitude	altitude
0	India	Indian_site_good_wind	77.500226	8.334294	679.803454
1	India	Indian_site_good_solar	68.542204	23.542099	29.883557
2	India	Indian_site_bad_solar_bad_wind	77.916878	17.292316	627.424643
3	Europe	France_good_solar	4.229736	44.422011	204.000000
4	Europe	France_good_wind	-0.864258	48.744116	302.000000
5	Europe	France_bad_solar_n_wind	2.167969	47.428087	140.000000
6	Europe	Germany_bad_solar_n_wind	10.766602	49.310798	442.000000
7	Europe	Germany_good_wind	7.873535	53.287111	5.000000
8	Europe	Denmark_good_solar	11.813965	55.397760	42.000000
9	Europe	Denmark_good_wind	8.594398	56.227322	85.000000

```
[11] name = 'Denmark_good_wind'
      ex_site = examples_sites.loc[examples_sites.name == name]

      longitude = ex_site['longitude'].values[0]
      latitude = ex_site['latitude'].values[0]
      altitude = ex_site['altitude'].values[0]
```

# Accessing notebooks through Google Colab

- In this cell, the evaluation of a HPP design is done
- Select the size of HPP:
  - wind plant size in MW:  $Nwt * P\_rated$ ;
  - solar\_MW;
  - battery size
    - b\_P: battery power in MW
    - b\_E\_h: battery energy hours)

## ▼ Evaluating the HPP model

```
✓ [13] start = time.time()  
23s  
  
clearance = 10  
sp = 350  
p_rated = 5  
Nwt = 62  
wind_MW_per_km2 = 7  
solar_MW = 50  
surface_tilt = 50  
surface_azimuth = 180  
solar_DCAC = 1.5  
b_P = 20  
b_E_h = 3  
cost_of_batt_degr = 5
```

# Accessing notebooks through Google Colab

## The output of the HPP model evaluation:

Objective function: maximize NPV/CAPEX 

NPV: Net present Value

IRR: Internal rate of return

LCOE: Levelized cost of electricity

CAPEX: Total capital expenditure

OPEX: Total operational expenditure

AEP: Annual energy production

GUF: Grid utilization factor

Grid [MW]: grid capacity

Total curtailment [GWh]: for 25 years

Total curtailment with deg [GWh]: for 25 years  
considering the impact of degradation

```
NPV_over_CAPEX: 0.207
NPV [MEuro]: 78.996
IRR: 0.078
LCOE [Euro/MWh]: 47.474
Revenues [MEuro]: 27.171
CAPEX [MEuro]: 382.218
OPEX [MEuro]: 6.040
Wind CAPEX [MEuro]: 267.506
Wind OPEX [MEuro]: 5.365
PV CAPEX [MEuro]: 33.500
PV OPEX [MEuro]: 0.675
Batt CAPEX [MEuro]: 15.230
Batt OPEX [MEuro]: 0.000
Shared CAPEX [MEuro]: 65.982
Shared OPEX [MEuro]: 0.000
penalty lifetime [MEuro]: 0.000
AEP [GWh]: 733.508
GUF: 0.279
grid [MW]: 300.000
wind [MW]: 350.000
solar [MW]: 100.000
Battery Energy [MWh]: 150.000
Battery Power [MW]: 50.000
Total curtailment [GWh]: 337.661
Total curtailment with deg [GWh]: 152.556
Awpp [km2]: 50.000
Apvp [km2]: 1.226
Plant area [km2]: 50.000
Rotor diam [m]: 134.867
Hub height [m]: 77.434
Number of batteries used in lifetime: 2.000
Break-even PPA price [Euro/MWh]: 31.519
Capacity factor wind [-]: 0.202
```

# Accessing notebooks through Google Colab

Open this notebook in Google Colab

[Open in Colab](#) [Edit on Gitlab](#)

## Evaluating the performance of a hybrid power plant with P2X using HyDesign

In this notebook we will evaluate a hybrid power plant design in a specific location.

- Run each cell
- Check for the list of example sites (select one test site).
- Change the site name accordingly.

	case	name	longitude	latitude	altitude
0	India	Indian_site_good_wind	77.500226	8.334294	679.803454
1	India	Indian_site_good_solar	68.542204	23.542099	29.883557
2	India	Indian_site_bad_solar_bad_wind	77.916878	17.292316	627.424643
3	Europe	France_good_solar	4.229736	44.422011	204.000000
4	Europe	France_good_wind	-0.864258	48.744116	302.000000
5	Europe	France_bad_solar_n_wind	2.167969	47.428087	140.000000
6	Europe	Germany_bad_solar_n_wind	10.766602	49.310798	442.000000
7	Europe	Germany_good_wind	7.873535	53.287111	5.000000
8	Europe	Denmark_good_solar	11.813965	55.397760	42.000000
9	Europe	Denmark_good_wind	8.594398	56.227322	85.000000

```
[11] name = 'Denmark_good_wind'
      ex_site = examples_sites.loc[examples_sites.name == name]

      longitude = ex_site['longitude'].values[0]
      latitude = ex_site['latitude'].values[0]
      altitude = ex_site['altitude'].values[0]
```



# Accessing notebooks through Google Colab

- In this cell, the evaluation of a HPP with P2H design is done
- Select the size of HPP:
  - wind plant size in MW:  $Nwt * P\_rated$ ;
  - Solar plant size in MW: `solar_MW`;
  - battery size
    - `b_P`: battery power in MW
    - `b_E_h`: battery energy hours)
  - Electrolyzer size in MW: `P_ptg_MW`

## Evaluating the HPP model

```
[ ] start = time.time()

clearance = 10
sp = 353
p_rated = 2
Nwt = 145
wind_MW_per_km2 = 5.02
solar_MW = 50
surface_tilt = 27.35
surface_azimuth = 194.38
DC_AC_ratio = 1.22
b_P = 9
b_E_h = 8
cost_of_batt_degr = 3.34
ptg_MW = 100
```

# Accessing notebooks through Google Colab

## The output of the HPP model evaluation:

Objective function: maximize NPV/CAPEX

NPV: Net present Value

IRR: Internal rate of return

LCOE: Levelized cost of electricity

CAPEX: Total capital expenditure

OPEX: Total operational expenditure

AEP: Annual energy production

GUF: Grid utilization factor

Grid [MW]: grid capacity

Total curtailment [GWh]: for 25 years

**annual\_H2 [kg]: H2 production in one year**

```
NPV_over_CAPEX: 0.090
NPV [MEuro]: 29.802
IRR: 0.066
LCOE [Euro/MWh]: 31.318
CAPEX [MEuro]: 330.666
OPEX [MEuro]: 11.200
penalty lifetime [MEuro]: 0.000
AEP [GWh]: 1155.963
GUF: 0.440
annual H2 [kg]: 1610665.418
grid [MW]: 300.000
wind [MW]: 290.000
solar [MW]: 50.000
PtG [MW]: 100.000
Battery Energy [MWh]: 72.000
Battery Power [MW]: 9.000
Total curtailment [GWh]: 0.000
Awpp [km2]: 57.769
Rotor diam [m]: 84.934
Hub height [m]: 52.467
Number_of_batteries: 1.000

exec. time [min]: 0.2549054265022278
```

# Changing input file data: Method 1

To change the input parameter,

**Add the parameter** in the HPP model definition as shown in the image.

For example, now the H2 price is set to 4 €/kg.

## Initializing the HPP model

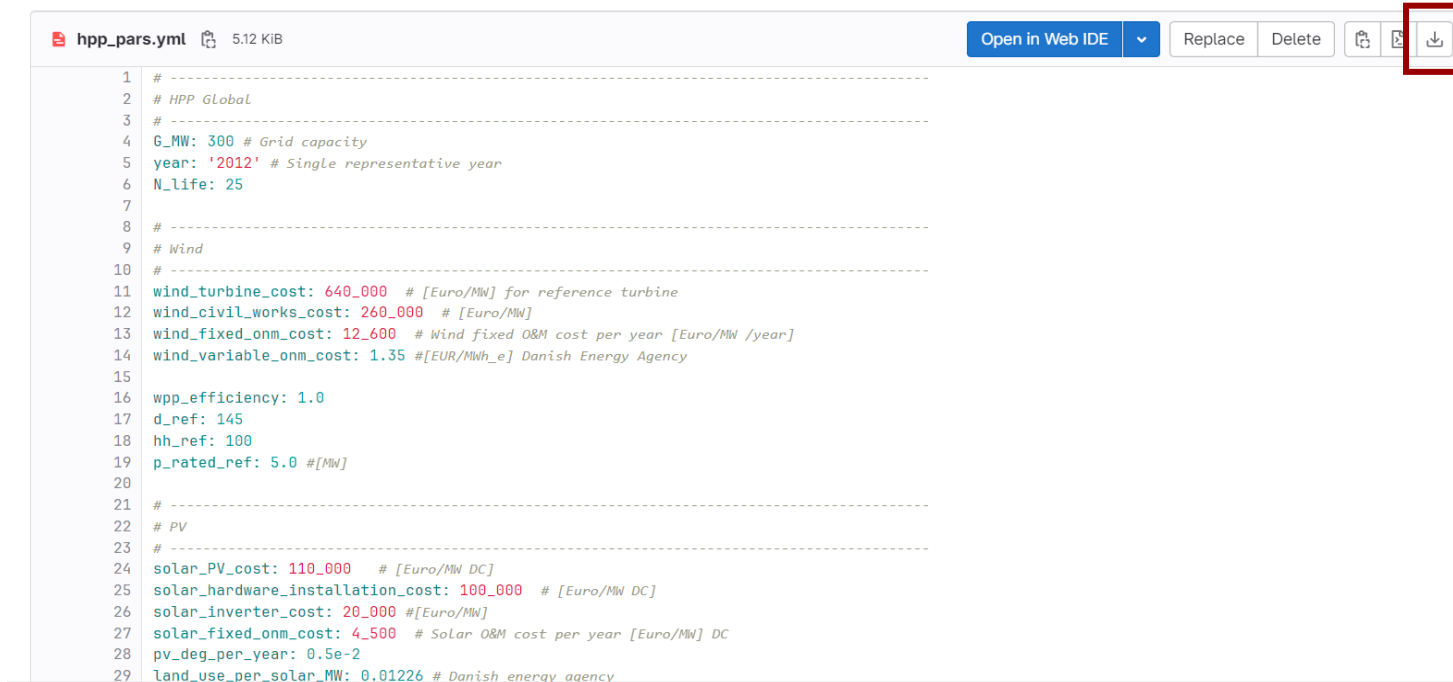
Initialize the HPP model (hpp\_model class) with the coordinates and the necessary input files.

```
hpp = hpp_model(  
    latitude=latitude,  
    longitude=longitude,  
    altitude=altitude,  
    num_batteries = 3,  
    work_dir = './',  
    sim_pars_fn = sim_pars_fn,  
    input_ts_fn = input_ts_fn,  
    H2_demand_fn = H2_demand_fn,  
    price_H2 = 4,  
)
```

# Changing input file data in Google Colab: Method 2

Download the input file 'hpp\_pars.yml' -> contains technology (Wind, solar, battery, P2H, grid connection) costs value and other parameters

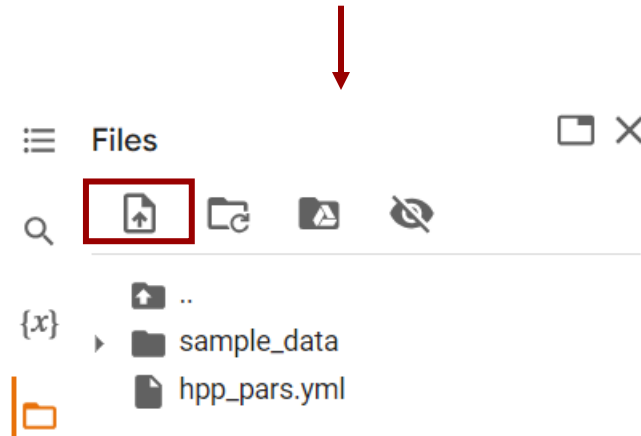
[https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign/-/blob/main/hydesign/examples/Europe/hpp\\_pars.yml](https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign/-/blob/main/hydesign/examples/Europe/hpp_pars.yml)



```
1 # -----
2 # HPP Global
3 # -----
4 G_MW: 300 # Grid capacity
5 year: '2012' # Single representative year
6 N_life: 25
7
8 # -----
9 # Wind
10 # -----
11 wind_turbine_cost: 640_000 # [Euro/MW] for reference turbine
12 wind_civil_works_cost: 260_000 # [Euro/MW]
13 wind_fixed_onm_cost: 12_600 # Wind fixed O&M cost per year [Euro/MW /year]
14 wind_variable_onm_cost: 1.35 # [EUR/MWh_e] Danish Energy Agency
15
16 wpp_efficiency: 1.0
17 d_ref: 145
18 hh_ref: 100
19 p Rated_ref: 5.0 # [MW]
20
21 # -----
22 # PV
23 # -----
24 solar_PV_cost: 110_000 # [Euro/MW DC]
25 solar_hardware_installation_cost: 100_000 # [Euro/MW DC]
26 solar_inverter_cost: 20_000 # [Euro/MW]
27 solar_fixed_onm_cost: 4_500 # Solar O&M cost per year [Euro/MW] DC
28 pv_deg_per_year: 0.5e-2
29 land_use_per_solar_MW: 0.01226 # Danish energy agency
```

## Changing input file data in Google Colab: Method 2

- Modify the input data in 'hpp\_pars.yml' as desired. Upload the modified input file 'hpp\_pars.yml' in the current directory. (Note: The file name can be renamed as well)



```
name = 'France_good_wind'
ex_site = examples_sites.loc[examples_sites.name == name]

longitude = ex_site['longitude'].values[0]
latitude = ex_site['latitude'].values[0]
altitude = ex_site['altitude'].values[0]

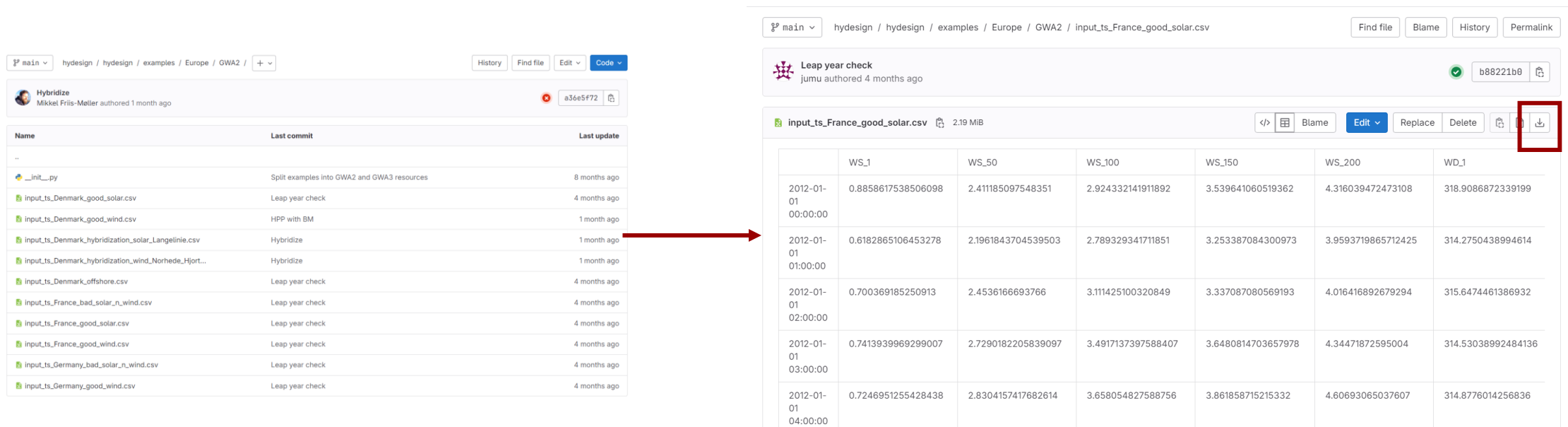
input_ts_fn = examples_filepath+ex_site['input_ts_fn'].values[0]
sim_pars_fn = 'hpp_pars.yml'
```

- Rename the input file name in the notebook to point toward the modified set of inputs.
- Re-run the evaluation function and check for the results.

# Accessing weather data file in Google Colab

Download the weather data file 'input\_ts\_XXXXX.csv' (XXXX corresponds to the site of interest) from the link below:

[https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign/-/tree/main/hydesign/examples/Europe/GWA2?ref\\_type=heads](https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign/-/tree/main/hydesign/examples/Europe/GWA2?ref_type=heads)



The screenshot shows the GitLab repository interface for the 'hydesign' project. On the left, a file list shows various CSV files. A red arrow points from the file 'input\_ts\_France\_good\_solar.csv' in the list to the right, where the file's content is displayed. The file is a CSV with 7 columns: WS\_1, WS\_50, WS\_100, WS\_150, WS\_200, and WD\_1. The data represents wind speed and wind direction at different hub heights, along with other meteorological data, for a specific location in France.

	WS_1	WS_50	WS_100	WS_150	WS_200	WD_1
2012-01-01 00:00:00	0.8858617538506098	2.411185097548351	2.924332141911892	3.539641060519362	4.316039472473108	318.9086872339199
2012-01-01 01:00:00	0.6182865106453278	2.1961843704539503	2.789329341711851	3.253387084300973	3.9593719865712425	314.2750438994614
2012-01-01 02:00:00	0.700369185250913	2.4536166693766	3.111425100320849	3.337087080569193	4.016416892679294	315.6474461386932
2012-01-01 03:00:00	0.7413939969299007	2.7290182205839097	3.4917137397588407	3.6480814703657978	4.34471872595004	314.53038992484136
2012-01-01 04:00:00	0.7246951255428438	2.8304157417682614	3.658054827588756	3.861858715215332	4.60693065037607	314.8776014256836

The data represents wind speed (WS) and wind direction (WD) at different hub heights, direct normal irradiance (DNI), diffused horizontal irradiance (DHI), global horizontal irradiance (GHI) and spot market electricity prices – with an hourly resolution for one year.