The Plan

0) Base question

1) How to develop further

2) Implement

3) UI

Questions

1) What kind of model
   - ↳ CEP? with which starting gen? 0?
   - ↳ consider existing grid layout?

2) Initial storage values?
   - → long term storage "full"
   - → short term storage

Statements

1) Solution should have a base storage for safety:

base storage $\cong$ "lenght of energy droughts"

should be an important parameter.

2) There should be enough capacity to fill back storage after drought.

Parameter: $\approx$ storage capacity Resistence after drought

minimum Recovery after drought $\geq$ n° generators

Obs: night is a small drought.

The problem

Data:

mean value, not a prediction(?)

(Load) indicative prediction (mean of observed istances) of average day divided in 15 min intervals

↳ for each season

(Generation) indicative prediction on production of average day in season

Questions:

1) It's meant as starting point?

↳ should we use other predictions?

↳ or just DROP ROP ?

2) No Hydrogen costs indicated in appendix.

(Additional, from VI)

- risk acceptance
- unlikely scenari
- lines, network ?

Output:

- Wind, Solar, Hydrogen capacities
- cost
- run on scenarios...

2 stage robust model:

Variables:

first stage

hs_n^M : maximum H_2 storage capacity at node n

he_n^M : maximum H_2 electrolizer capacity of units of H_2 which are convertable $h \in$

n_g^n : n of gens $\in \mathbb{N}^+$
(could be units of plant $\in \mathcal{Z}$)

hs_{t_n} :

$\mathcal{G}$: generator $\mathcal{H}_s$: H_2 storage

$\mathcal{H}_e$: Hydrogen electrolyzer ($p \to H_2$)

$\mathcal{H}_{fc}$: Hydrogen fuel cell ($H_2 \to P$)

$\mathcal{B}$: buses

($\mathcal{L}_e$: links ?)

($\mathcal{L}_{H_2}$: hydrogen links ?)

Second stage:

Variables

$hs_{h,t,s}$: hydro storage

$P^G_{h,t,s}$: power generated at $h \in \mathcal{H}_f$

$P^L_{h,t,s}$ power loads at $h \in \mathcal{H}_e$ conversion

Data

$P^L_{n,t}$ power load at n,t

$H^L_{n,t}$ hydrogen load

$P^G_{g,t}$: per unit of max capacity generated by g at time t

htop : H_2 to power conversion

ptoh : power to hydrog conversion

Objective: $\min \sum_{h \in \mathcal{H}} c_h \cdot S_h^M + \sum_{g \in \mathcal{G}} c_g \cdot n_g^M$

Constraints

electricity balance (?) o uguale (?)

$$\sum_{n\in\mathcal{B}} P^L_{n,t,s} + \sum_{h\in\mathcal{H}_e} P^L_{h,t,s} - \sum_{h\in\mathcal{H}_{fc}} P^G_{h,t,s} + \sum_{g\in\mathcal{G}} P^G_{n,t,s} \qquad \forall s, \forall t$$

hydrogen balance (in kg)

$$\sum_{n\in\mathcal{B}} H^L_{n,t,s} + \sum_{h\in\mathcal{H}_s} \left(hs_{h,t,s} - hs_{h(t-1),s}\right) + \sum_{h\in\mathcal{H}_{fc}} \frac{P^G_{n,t,s}}{htop} = \sum_{h\in\mathcal{H}_e} \frac{P^L_{h,t,s}}{ptoh}$$

magnitude constraints: → capacity per unit.

$$P^G_{g,t,s} = n^M_g \cdot dP_{g,t,s}$$

$$0 \le hs_{h,t,s} \le hs^M_h \qquad \forall h,t$$

$$0 \le \frac{P^L_{h,t,s}}{htop} \le hp^M_h \qquad 0 \le \frac{P^L_{e,t}}{ptoh} \le he^M$$

Limitations

1) No flow conservation constraints

on hypothetical graf

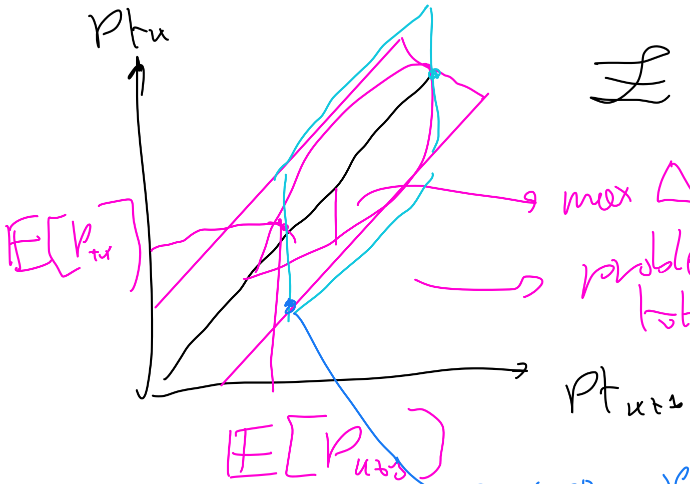
e max flows

2) We consider $n_g \in \mathbb{R}^+$

not $n_g \in \mathbb{Z}$

↳ doest really matter if we have 1 node for type of generation.

Stochastic Models idea



£

max $\Delta P_{t_{u+1}} - P_{t_u}$

problema potrebbero essere tutti 0 ~> irrealistico.

caso peggiore $\forall t$.

~> non realistico sia ammissibile.

Distrib robust

Mean-based-robust:

problems: conservative as (probably) it considers different timesteps as indipendent

Wasserstein (we would need data)

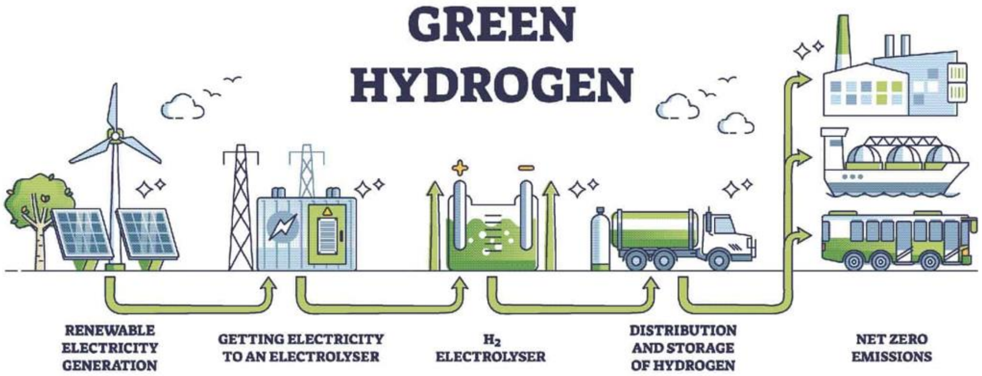
this could be solved by:

Scenario based stochastic opt

AIMMS-MOPTA 2024

Introduction

To meet decarbonization targets, renewable energy technologies need to be integrated into electricity and gas grids on a large scale. The energy grid baseload needs stability that renewable energy sources cannot always provide. Decarbonizing the grid requires that coal and natural gas no longer provide baseload support to the energy grid. To operate a fully renewable energy grid, the baseload must be supported by a stable energy source. Green hydrogen could play a key role in decarbonizing heavy industry, as well as supporting baseload power. To design a fully renewable energy system, green hydrogen electrolyzers and fuel cells could be used to support the integration of intermittent electricity sources, namely, wind and solar.



Source: https://technetics.com/hydrogen-production-the-challenges-and-practical-applications/

Problem Description

- Utilize solar and wind power plants to provide electricity to cities and industrial regions.
- Solar and wind are intermittent electricity sources which depend on weather patterns (meteorological data).
- Produce green hydrogen in electrolyzers from excess solar and wind energy.
- Utilize green hydrogen to sustain gas and feedstock demand of industry.
- Utilize fuel cells to convert green hydrogen to electricity when wind and solar power are unable to meet demand.

Components in the Energy System

- Wind turbines (electricity)
- Solar PV (electricity)
- Green hydrogen electrolyzers (green hydrogen gas)
- Green hydrogen fuel cells (electricity from green hydrogen gas)

Components in the Region

- Cities (homes and businesses - use electricity)
- Industrial districts (incl. fertilizer and chemicals production, use electricity + gas)

Problem setup:

- Electricity load nodes (cities and industrial districts)
- Gas load nodes (industrial district)

- Electricity generator nodes (solar, wind, fuel cell)
- Gas generator nodes (electrolyzers)
- Gas can be stored at electrolyzers and fuel cells for intraday use (e.g., excess renewable energy may be briefly stored as gas when gas/electricity demand is low in some periods and stored gas can be used when demand is high in other periods)
- Gas can be liquified for long-term storage at gas storage locations at electrolyzers and fuel cells
- Electrolyzer nodes take electricity as an input and output hydrogen gas. There is a conversion factor for going from electricity to gas
- Fuel cell nodes take hydrogen gas as an input, and output electricity. There is a conversion factor for going from gas to electricity
- Wind and solar electricity generation depends on meteorological conditions, thus the 'production' of electricity at these nodes is a function of wind for wind turbines, and solar irradiance for solar PVs.

?

Case Study

We must determine how much electricity needs to be injected into the energy grid to meet demand during a given period. It is crucial that demand is matched precisely with supply, as deviations from this could severely damage the grid infrastructure or cause blackouts. In the case of an integrated and fully renewable energy system, it would be useful to solve this optimization problem for both gas and electricity simultaneously, as green hydrogen can be used as gas or converted to electricity in fuel cells to supplement the baseload. Solving this problem for different instances of demand would demonstrate the capacity requirements for each component of the integrated energy system.

Data is provided for a region supporting 250,000 households and some heavy industry operations. The residential electricity load is split into 5 locations, two locations draw industrial electricity load, and 1 industrial area has demand for hydrogen gas. The number and size of Solar PV and Wind Turbine plants should be determined as part of the problem. It is intentional that the geo-spatial distribution of these components is *not* provided, as the solution should be adaptable for different regional configurations.

Capacity expansion problem

Part 1

Build a mathematical optimization model that meets all aspects of demand reliably in the fully renewable integrated energy system, based on the provided data and problem description. This should provide crucial information, such as the capacity and storage requirements for renewable electricity sources and green hydrogen electrolyzers and fuel cells.

Part 2

Build a User Interface (UI) that allows research organizations and policymakers to interact with the mathematical optimization model, evaluate and compare different scenarios, and to view the capacity requirements (this is a key factor under evaluation) for different components of the energy grid. The user could also evaluate, for example, the impact of electrolyzer or fuel cell efficiency on capacity requirements; additionally, it could allow for additional demand and meteorological input data to be used to determine whether the intermittent renewables would be adequately supplemented by green hydrogen under adverse conditions. Be creative in the types of scenarios that can be evaluated and ensure that the UI is intuitive and easy to use.

Data

The data provided includes electricity (in MWh) and hydrogen gas (in kg) demand for an industrial plant, as well as generation plants, which include solar and wind power plants, hydrogen gas production plants, and fuel cell power generation plants. Cities are powered by electricity, and industrial districts have demand for both electricity and hydrogen gas. Electricity may be sent from solar and wind plants to either an electrolyzer or a load. Hydrogen gas from an electrolyzer may be sent to industrial gas load, stored, or sent to a fuel cell. At a fuel cell, gas may be stored before converting it back to electricity and distributing the electricity to loads.

instance = 15 min slot
average
E, season

Demand forecast data for load nodes (demand point) is provided for an average full day for each quarter of the year in 15-minute intervals (96 instances). This demand data can be considered indicative of a typical demand pattern for the region during that quarter. However, it should be noted that this is a forecast, and that the actual demand could vary from these values.

mean based
robust opt

When converting hydrogen to electricity, and *vice versa,* there is a loss of efficiency involved. It can be assumed that the efficiency of most electrolyzers is 70%, and the efficiency of fuel cells is 75%. Note that the provided data states hydrogen gas demand in *kilograms*, so make use of the assumption that 1kg of hydrogen is comparable with 50kW of electricity.

The electricity supply from wind turbines and solar PV is dependent on meteorological conditions. Electricity generation data is provided for a quarterly 'average' day in the region for a single wind turbine and a single solar PV unit. The energy system must remain stable during adverse and unexpected weather conditions.

Evaluation

The project will be evaluated based on the solution techniques used, results and insights gained, as well as final recommendations. Specific focus will be placed on a team's ability to consider the perspective of policymakers and energy transition researchers, and the types of questions and insights that will be valued by these stakeholders. Additionally, creativity in collecting and using data is strongly encouraged.

Hints

- Treat the provided data as a guideline and a starting point. Supplementing this is encouraged (and necessary) to develop a complete solution. E.g., the data only show the 'average' day in each season, and this case study does not define any restrictions on the *grid layout*, nor does it consider issues such as *grid congestion*, or storage capacity limits at electrolyzers and fuel cells.

  AAA ?

- Many important parameters for this optimization problem (such as costs, efficiencies, weather conditions) differ between regions and governments, therefore it is encouraged that groups should design their model in such a way that policymakers from different regions could make use of the same optimization tool (i.e., much emphasis is placed on (a) the practical design of the mathematical optimization model and (b) the ease of interacting with the model through a UI).
- Consider the perspective of policymakers and research organizations. What questions will they be looking to answer, how would they like to interact with your model and results, and what are the assumptions or simplifications that you have used? Remember, they may not be experts in Mathematical Optimization.

- Be creative and use the problem description, data, and case study as a platform from which to add additional details or complexities.
- Strongly encouraged: mathematical curiosity, passion for learning, and enthusiasm for applying optimization techniques.

Deliverables

Your team is expected to deliver a complete solution to the case study problems. Specifically, your submission should include:

- The development of an optimization model and corresponding solution approach that, in a reasonable time, finds the optimal or near-optimal solution for the given case study.
- A user interface for your model(s) that can be used to run different scenarios to visualize results and make policy-related decisions.
- A report (max. 15 pages) describing the application and modeling approach, the solution techniques used, the results and insights obtained, and your team's final recommendations. To judge your numerical results, it is key that all mathematical programming, and algorithms you used are clearly presented in the report. The 15 pages limit includes references.

Software

You are free to use any software of your choice, but it is recommended to use AIMMS for your submission. A starter-project in AIMMS has been provided, this project allows you to read the data into AIMMS and provides a simple UI. You can then develop your mathematical optimization model and build on the UI from within this starter-project. All source code and data must be included, properly documented, and results must be reproducible.

If you are unfamiliar with using AIMMS, we recommend that you look at some of our e-learning material:

- Modeling with AIMMS
- User Interface with AIMMS

You can also use the MOPTA group in AIMMS Community to ask questions about AIMMS or this challenge.

About AIMMS: AIMMS is an industry leading rapid model building and deployment platform perfected for over 30 years. AIMMS is an enjoyable and robust way to not only build optimization models but to deploy them as optimization applications to be used by business professionals. You can develop analytical models and highly interactive end user interfaces all within the same environment. Learn more and request a free academic license from here: AIMMS Academic License.

Prizes

All participants in the AIMMS-MOPTA 2024 competition that use AIMMS software in their submission will receive a gift by post. The top three groups will be invited to present (in-person) to a panel of judges at the MOPTA 2024 conference. The prizes will be awarded as follows:

Place	Used AIMMS software	Did not use AIMMS software
1st	\$1200	\$600
2nd	\$600	\$300
3rd	\$300	\$150

Appendix

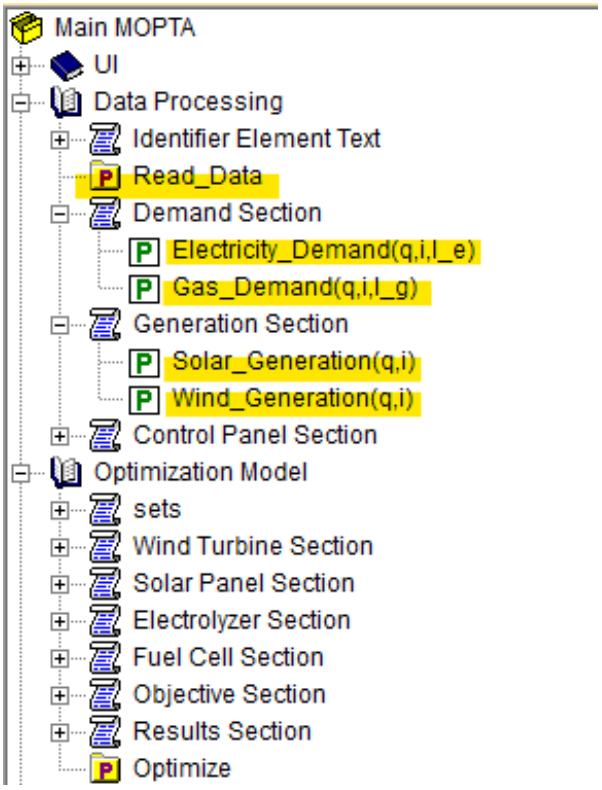
Some additional information and assumptions:

- An electrolyzer requires 50kWh of electricity to produce 1kg of hydrogen gas (including the efficiency rating of the electrolyzer)
- A fuel cell can produce 33kWh of electricity from 1kg of hydrogen gas (including the efficiency rating of the fuel cell)
- Provided wind turbine data assumes a turbine has a maximum rating of 4MW
- Provided solar PV data assumes a panel has a rating of 10kW
- It is adequate to assume that the fixed cost for a single solar panel and a single wind turbine $4000 and $3M, respectively.

Starter Project Overview

An AIMMS project has been provided as a starting point from which to rapidly begin prototyping and building your own mathematical model and user interface. Some of the key aspects of the starter project are highlighted in this section. Once you have downloaded the latest version of AIMMS and have a free academic license you can open the starter project.

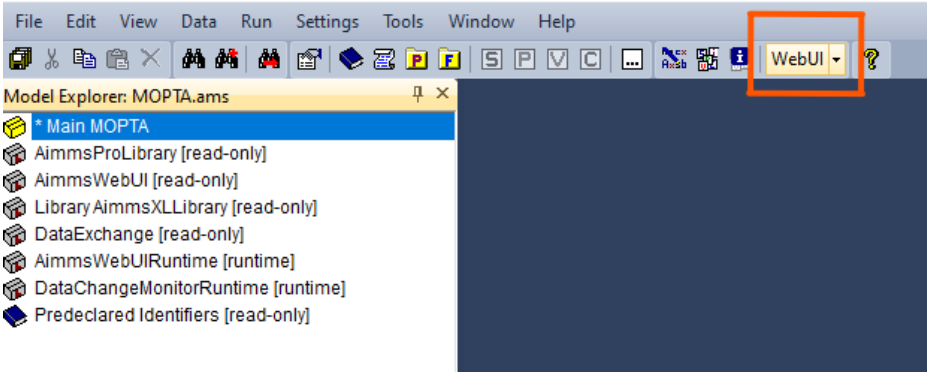
The screenshot below shows the **Model Explorer**, the highlighted procedure reads in the data from an Excel spreadsheet and populates the highlighted parameters with data from the Excel spreadsheet.



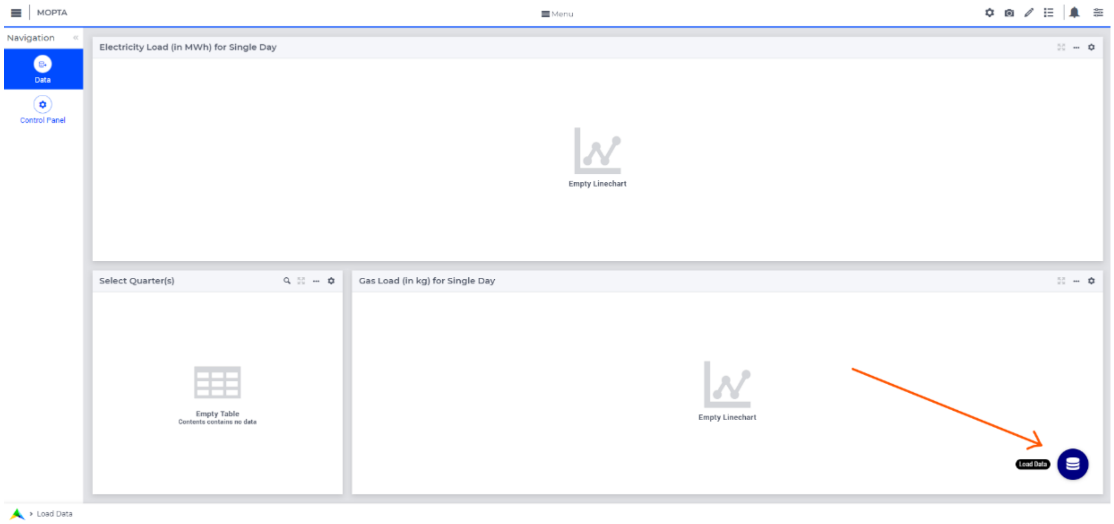
The index *q* represents the quarter in {Q1, Q2, Q3, Q4}, while *i* represents the instance in {1,...,96}. The index *l_e* represents an electricity load location, while *l_g* is a gas load location.

The Optimization Model section (see in the screenshot above) includes declaration for the main components of the model and within each of these declarations there are several parameters that may prove useful. There is also a declaration containing sets which are read in from the data and defined or adjusted using the Control Panel in the UI.

The UI can be accessed by clicking on WebUI in the AIMMS toolbar:

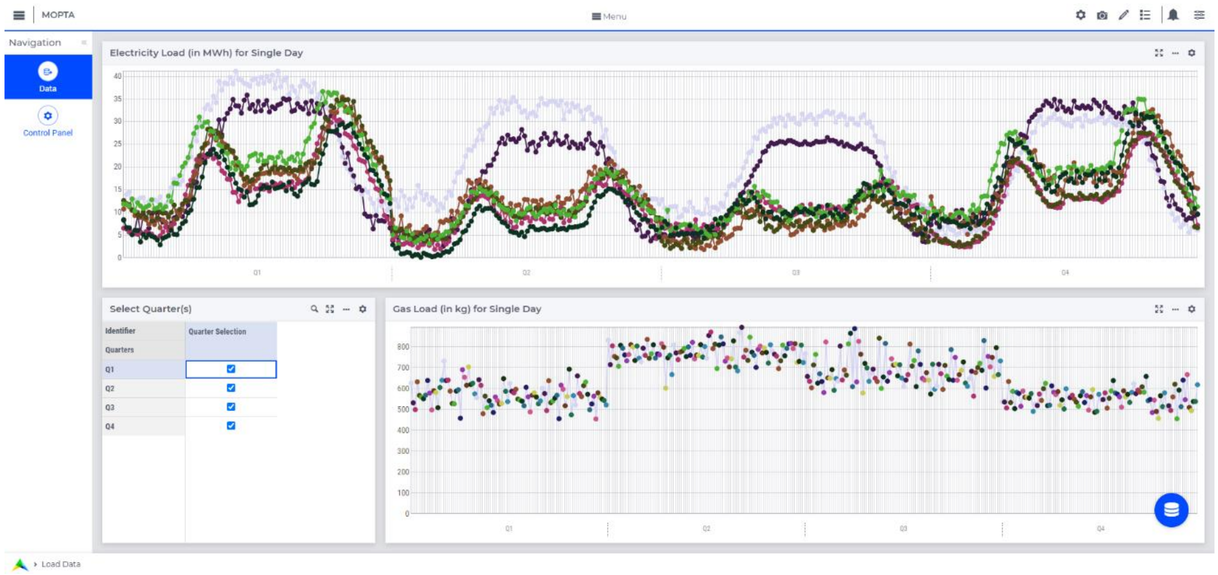


After opening the UI, click on the Load Data page action to run the Read_Data procedure.

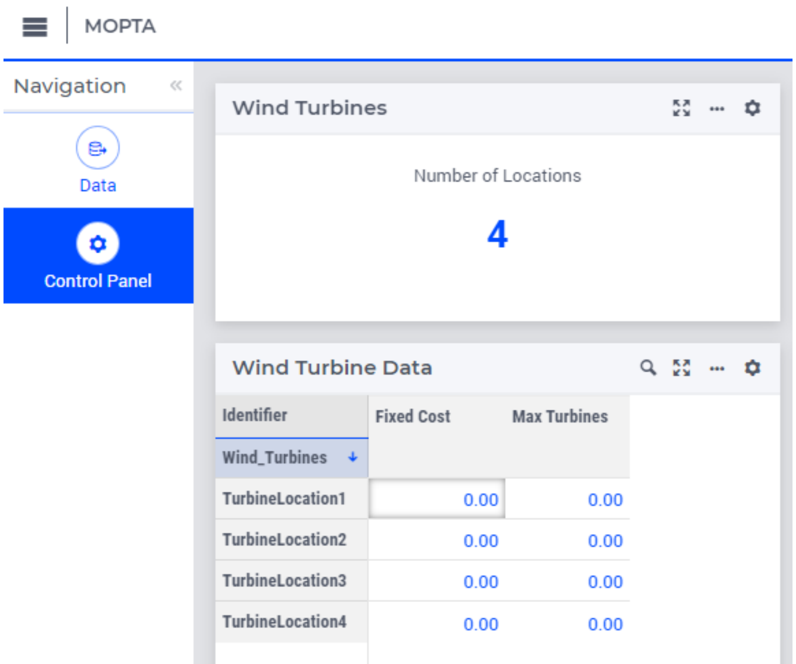


Once the data have been loaded, you can explore the different seasonal demand patterns for electricity and hydrogen gas by toggling the quarters on and off in the Select Quarter(s) table.

If all the quarters are selected, the data page should look like this:



The Control Panel page demonstrates how you could control the model parameters as a user. In this case, we have built functionality to adjust the number of locations at which wind turbines, solar panels, electrolyzers, and fuel cells can be placed. A set is created based on this number, and it is possible to adjust some parameters such as the fixed cost or maximum number of wind turbines (or solar panels) per location.



The intention behind providing the Control Panel page is to demonstrate how a basic control panel might be constructed (in this case for just a few parameters) for an end user.

Here you can find the both the Starter Project and data to start the challenge.