Submit one report (paper only) in the drop box outside MScBase consisting of:

1. A well documented Xpress model for the planning problem.
2. A report on the tasks below

This assignment considers the problem of designing a system with the optimal mix of generation types and storage. We assume this design is for a new system for some time in the future (a "green field" plan).

The value of a particular investment will be assessed by running an operational model over some "typical" periods of the year (referred to as *slices*), and then combining the optimal average operational cost with the CAPEX of the investment.

The assignment is split into two Tasks:

Task 1: Operational problem: Extend the operational model of Assignment 2 to include load and generation shedding and run it using data from Great Britain.

Task 2: Planning problem: Implement an solve an investment model and analyse results.

The **Operational Problem** is to find the optimal cost and optimal generation in each half hour over a ***Slice*** of time.

- Data is available for an entire year.
- A slice is specified by its initial period (half hour) and its final period. Slices are treated as being cyclic, *i.e.* the first period follows from the last period.

Modify your model from Assignment 2 to:

- Allow load to be shed at the load shed penalty cost.
- Allow the heat store to be cooled at 0 cost.
- Allow generation to be shed at 0 cost.
  - This is needed when wind and solar generation are greater than the demand plus the capacity to use the surplus for storage or heating.
- Operate for arbitrary slices specified by their first and last periods.

Task 1: Test Operational Model

- See end of document for system data
- Use the slice
  - Summer: 2 days from hour 4580 (i.e. 96 half hours)
- The wind and solar generation is twice the 2015 values.
- There is no CO_2 limit but a tax of £18/tonne of CO_2 .
- The maximum output of generator types, the input capacities of stores and the max line flow are ⟶

  The Electricity storage capacity is 25GWh

Equipment	GW
Diesel	1.0
OCGT	7.5
CCGT	21.0
Coal	16.0
Wind	13.85
Solar	8.76
Electricity Store	3.3
Heat Store	20.3
B1-B2	8.8

Include in Report:

1. Solve the above case and report:
   (a) average total operational cost (*i.e.* total cost / total number of hours)
   (b) average power output of each generator
   (c) average power shed at each bus
   (d) average power input to electricity store and to heat store
   (e) maximum energy in electricity store
   (f) maximum excess energy in heat store (i.e. max energy above the energy at 19°C)
2. Present the following 3 plots. In each the horizontal axis is the period
   Plot 1: on the vertical axis
   (a) electric power required to meet load excluding heat
   (b) electric power required to meet load including heat
   (c) power output of Coal + CCGT + OCGT + Diesel + Wind + Solar
   (d) power output of Coal + CCGT + OCGT + Diesel + Wind
   (e) power output of Coal + CCGT + OCGT + Diesel
   (f) power output of Coal + CCGT + OCGT
   (g) power output of Coal + CCGT
   (h) power output of Coal

2. (cont)

   Plot 2: on the vertical axis

   (a) energy in the electric store

   (b) heat energy in the heat store (assuming energy in store is 0 at 19°C).

   Plot 3: on the vertical axis the 2 locational marginal prices.

The **Planning Problem** is to find the capacities of each type of generator, the storage power and energy capacities and the line capacities that minimizes the combination of the capital and operational costs.

We do this by selecting representative slices of operational conditions (e.g. winter week and a summer week) and giving each a weight that represents what proportion of time it represents, then minimizing the total CAPEX and OPEX costs.
Modify your operational model to:

- Make the capacities of generators, storage (power and energy) and lines variables and include the CAPEX in the objective. (There should be a capacity variable for wind and solar and we assume that the pattern of wind and solar generation stays the same as the amount is scaled up.)
- A set of slices are specified, each with a weight and a start and end period.
- The goal is to find:
  (a) the optimal capacities of each type generation, the input power capacity and storage capacity of the PHES store, and the input capacity of the heat pump
  (b) the average utilization (*i.e.* load factor) for each generation and storage type
  (d) how the optimal investments depend on the CO2 emission limit.

- Use the following two slices to represent the whole year
  - Winter: 12 days from hour 360, with weight 0.45/h
  - Summer: 2 days from hour 4580, with weight 0.55/h

Include in Report:

3. The average CO_2 output ($= Z$ say) in the optimal solution without a CO2 limit.
4. A table with columns for CO_2 limits of $1.0Z$, $0.7Z, 0.5Z, 0.2Z$ and $0.1Z$ and rows for:
   (a) total hourly CAPEX
   (b) total hourly OPEX,
   (c) CO2 marginal cost
   (d) generator capacities and input electric power capacites of stores
   (e) PHES storage capacity (in hours at full input)
   (f) Generator and storage average load factors.
5. Plots as in report section 2 for each slice in the $Z = 0.2$ case.
6. An analysis of important features of all the above results.

There are 2 buses,

All wind is connected to bus B1. Everything else is connected to bus B2.

Generator Type	Fuel	Efficiency	Life yr	CAPEX £/kW	Fix OM £/kW-yr	Var OM £/MWh
g	f_g	E_g	Y_g	F_g^{CPX}	F_g^{OM}	V_g^{OM}
Diesel	Diesel	0.34	25	320	3.00	0.00
OCGT	Gas	0.35	30	480	5.00	7.36
CCGT	Gas	0.53	30	726	10.91	2.32
Coal	Coal	0.39	35	2083	26.84	3.17
Wind	Wind		25	3700	42.54	0.00
Solar PhotoV	Sun		20	2220	14.53	0.00
PHES Power (/electric in)		0.67	20	510	9.90	2.34
Heat Pump (/electric in)		2.8	20	3280	12.00	3.00
B1-B2			25	500	7.00	0.00

The PHES Store has a lifetime of 20 years, a CAPEX of £15.3/kWh of storage capacity and no other costs. There is no upper limit on the amount of storage that can be installed. The power capacity and storage capacities can be chosen independently.

2015 GB installed Capacities:

Wind	13.85 GW
Solar PV	8.76 GW

- The wind, solar and demand powers and the external temperatures are in Y15-v4. All periods are half an hour.
- The wind and solar data give the power generation corresponding to the 2015 installed capacities. For other installed capacities the generation scales proportionally.

Properties of Heat Store

Q^{Mass}	(GWh/°C)	139.6
P^{Loss}	(GW/°C)	4.48
$T^{\text{S+}}$	(°C)	23
$T^{\text{S-}}$	(°C)	19

Fuel	**CO2 emissions** tonne-CO2/MWh	**Cost** £/MWh
f	W_f	C_f^{fuel}
Diesel	0.250	28.10
Gas	0.181	12.11
Coal	0.318	5.74

Penalty for disconnecting load, $C^{\text{Load}} = £3000$/MWh: CO2 tax, $C^{\text{CO2}} = 0$

The above data is available in assign2.xlsx and Y15-v4.xlsx *on the on Data web page*

If generator g generates p_g^{G} MW then its hourly OPEX is

$$V_g = \left(V_g^{\mathrm{OM}} + \frac{C_{f_g}^{\mathrm{fuel}} + C^{\mathrm{CO2}} W_{f_g}}{E_g} \right) p_g^{\mathrm{G}}$$

If H is the number of hours in a year and the installed capacity of generator type g is P_g^{G}, then its hourly CAPEX is

$$F_g = \frac{1}{H} \left(\frac{F_g^{\mathrm{CPX}}}{Y_g} + F_g^{\mathrm{OM}} \right) P_g^{\mathrm{G}}$$

If V_s^{S} is the average total hourly OPEX in slice s and w_s is the weight of that slice, then the weighed average hourly OPEX is:

$$V^{\mathrm{S}} = \sum_s w_s V_s^{\mathrm{S}}$$