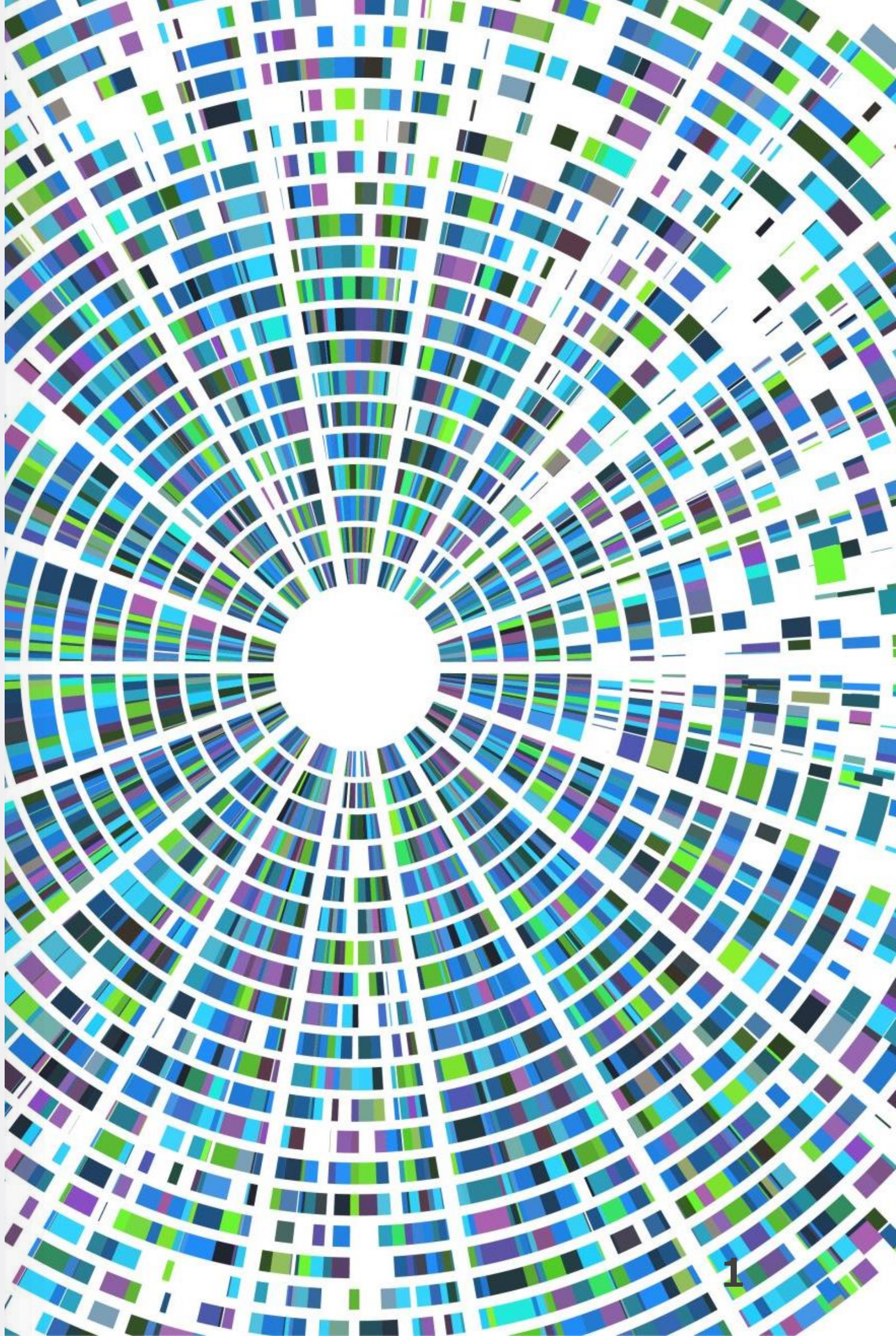
DYNAMIC MECHANISMS OF LOW-CARBON INVESTMENT DECISIONS IN THE UK ELECTRICITY GRID NETWORK

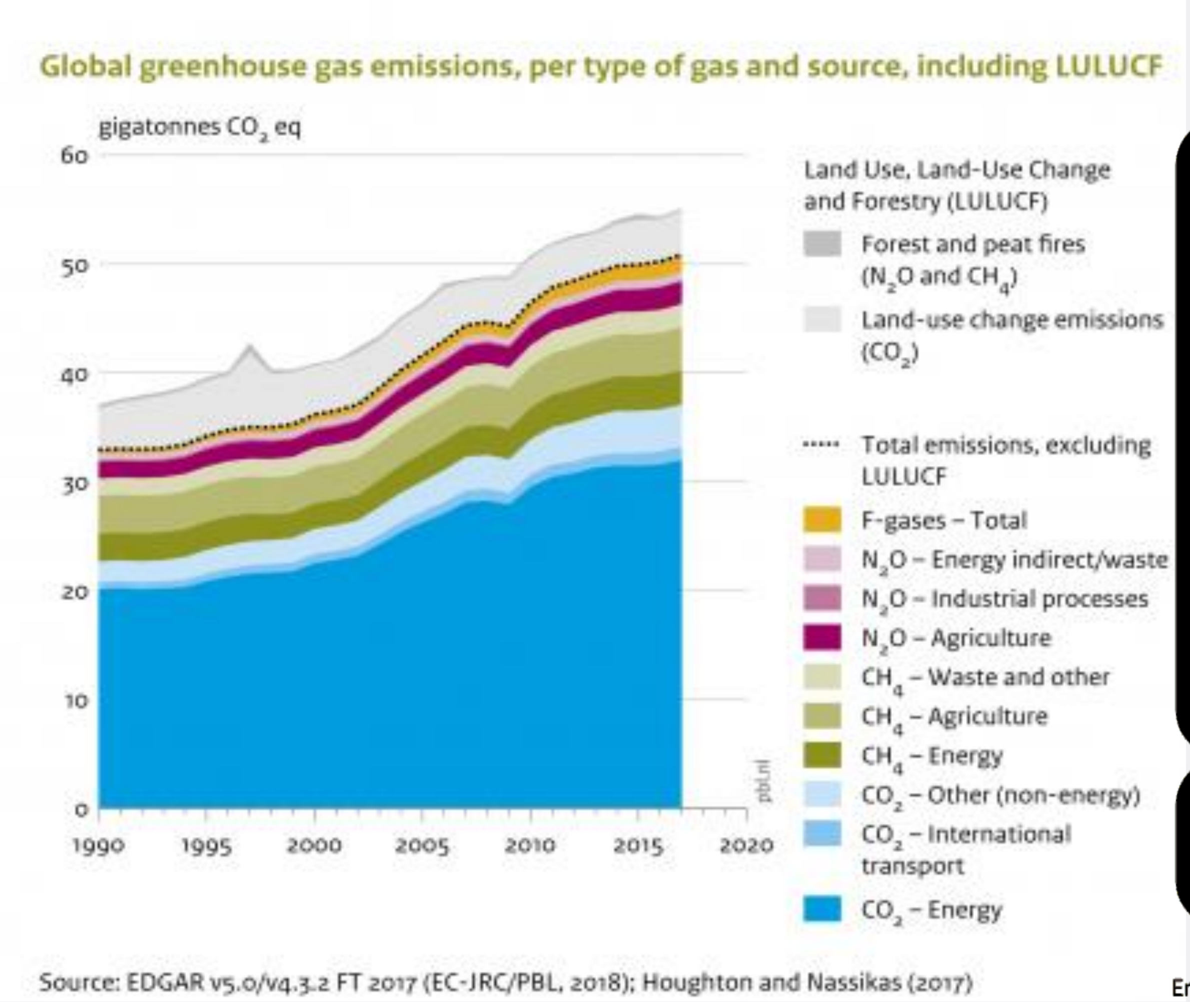
SAHEED BELLO & DUNCAN ROBERTSON
SCHOOL OF BUSINESS AND ECONOMICS
LOUGHBOROUGH UNIVERSITY

IAEE CONFERENCE, 8 JUNE 2021

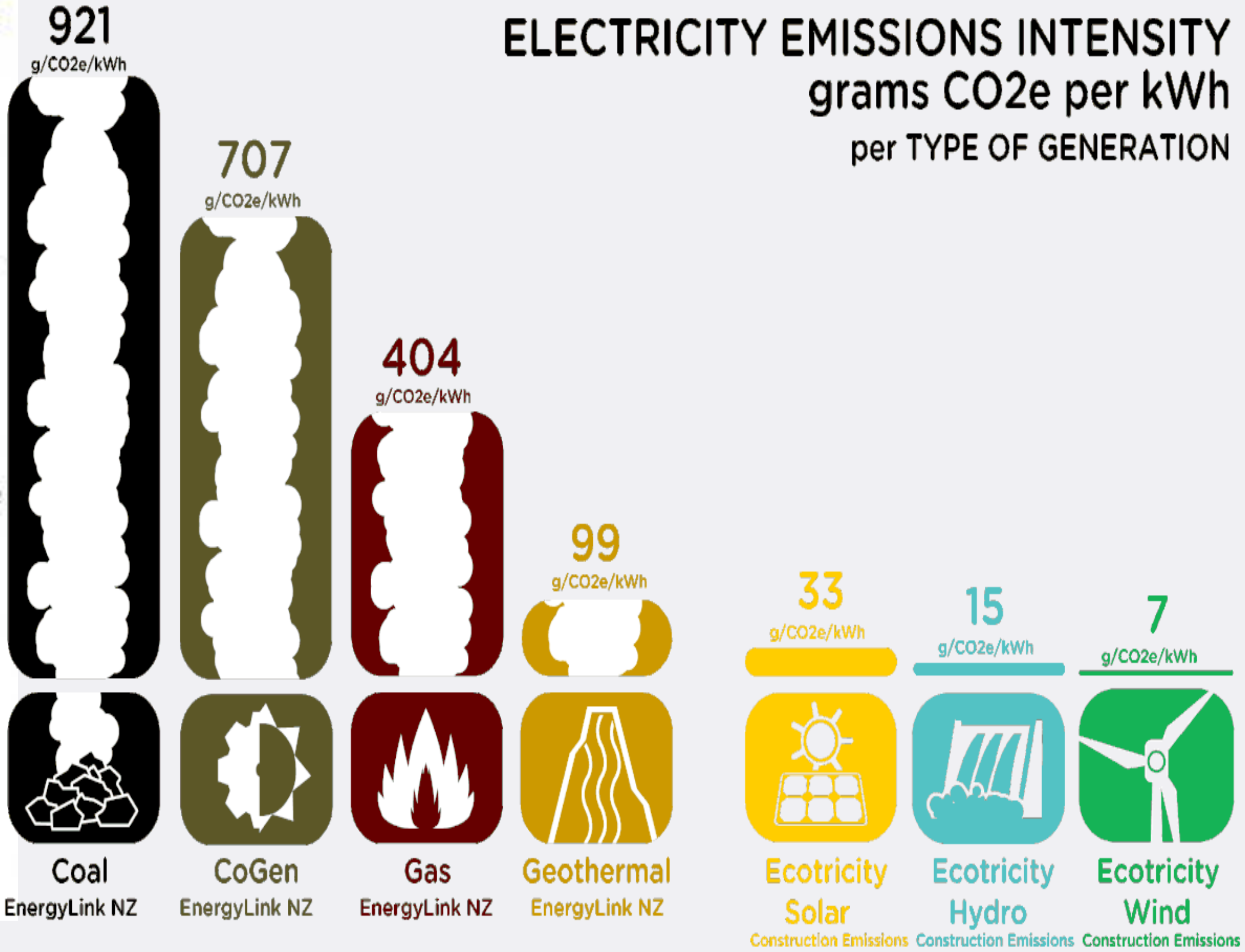


CONTENT

Motivation



Global greenhouse gas emissions, per type of gas and source, including LULUCF
gigatonnes CO_2 eq
60
50
40
30
20
10
0
1990
1995
2000
2005
2010
2015
2020
pbl.nl
Land Use, Land-Use Change and Forestry (LULUCF)
Forest and peat fires (N_2O and CH_4)
Land-use change emissions (CO_2)
Total emissions, excluding LULUCF
F-gases – Total
N_2O – Energy indirect/waste
N_2O – Industrial processes
N_2O – Agriculture
CH_4 – Waste and other
CH_4 – Agriculture
CH_4 – Energy
CO_2 – Other (non-energy)
CO_2 – International transport
CO_2 – Energy
Source: EDGAR v5.0/v4.3.2 FT 2017 (EC-JRC/PBL, 2018); Houghton and Nassikas (2017)



ELECTRICITY EMISSIONS INTENSITY
grams CO2e per kWh
per TYPE OF GENERATION
921
g/CO2e/kWh
Coal
EnergyLink NZ
707
g/CO2e/kWh
CoGen
EnergyLink NZ
404
g/CO2e/kWh
Gas
EnergyLink NZ
99
g/CO2e/kWh
Geothermal
EnergyLink NZ
33
g/CO2e/kWh
Ecotricity Solar
Construction Emissions
15
g/CO2e/kWh
Ecotricity Hydro
Construction Emissions
7
g/CO2e/kWh
Ecotricity Wind
Construction Emissions

Motivation Contd.

Greenhouse gases(GHGs) emissions - 80% global warming (United Nations, 2017)

Electricity-related CO_2 emissions constitute the largest (IPCC, 2014)

Solution: Decarbonise electricity sector

(Bertsch et al., 2016)

Renewable energy sources e.g., Solar, Wind

Research Question

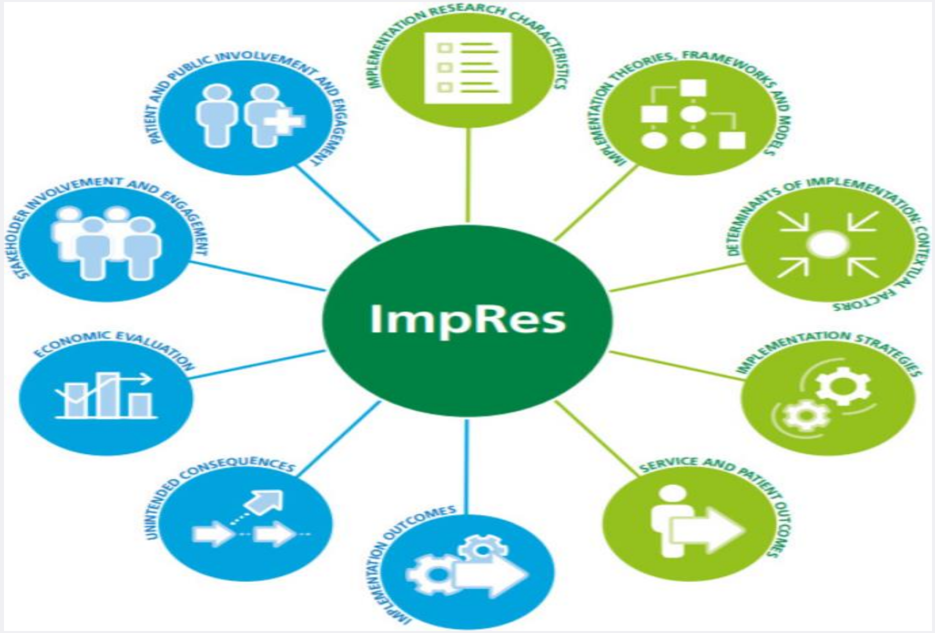
What is the effect of electricity price and carbon price on low-carbon investment decisions in the context of UK Electricity Grid?

Related Literature

Simulation model

Solar and wind with gas	Solar and wind with static grid network	Electricity grid network (resilience), with no renewable concerns
Ignoring electricity network (Deetjen et al., 2018; Liu et al., 2018)	(Schlott et al., 2018; Zou et al., 2018)	(Espejo et al., 2018; Azzolin et al., 2018; Kim et al.. 2017)

- Firm-level low carbon investment decisions(fuel and carbon prices): Kraan, Kramer and Nikolic (2018), Flora and Vargiolu (2020) and Barazza and Strachan (2020)
- This paper extends: Flora and Vargiolu (2020) by examining the effect of electricity, fuel and carbon prices on low-carbon investment decisions in the UK intra-country real grid network.
- The main contributions:
  - UK real electricity network topology on the choices of adopting generation technologies
  - applies a technique that combine both network and agent-based methods based on empirical datasets(ENTSO-E, BEIS, National Grid, DUKES etc.)



Approaches

Constructing the UK Electricity Grid

- How? Using the European Network Transmission System Operator for Electricity(ENTSO-E) Grid Map
- Properties of nodes (plants and substations): capacity(MW) and generation type(ENTSOE); operation year etc (BEIS)
- Properties of link (Transmission lines): Voltage (ENTSOE)

Incorporating the Grid into Agent-based platform(Netlogo)

- Information used to setup the model: capacify factor, fuel efficiency, capital cost, operating cost, electricity price, fuel price, carbon price , discount rate, lifetime etc.(Source: UK National Grid, BEIS, literature, etc)

Steps for UK Low-Carbon Investment Simulation

Start

- Import electricity grid network
- Turtles (power plant and substations)
- Links (transmission lines)

NPV

- Inputs used to calculate this:
- Exogeneous inputs: Plant lifetime; capacity; capacity factor; efficienncy, electricity price, capital cost; operating cost; discount rate
- Endogenous inputs: electricity ouput; fuel consumption; carbon emission

Decision rules

- Remove plant if NPV < 0 and highest negative NPV
- Choose new plant: NPV> 0 and highest positive NPV

Outcomes

i. Electricity generation technology mix

ii. Renewable electricity penetration

iii. CO2 emissions

iv, total investment

v. Share of investment by technology type

Operating cash-flow(CF) is

$$CF = \sum_{y=t}^{n} \frac{(ep_{p,t} \times p_{exp,t}) - ((vc_{f,c,p,t} \times ep_{p,t}) + fc_{p,t}}{(1+r)^{y}}$$

Net present value(NPV)

$$\text{NPV} = CF - \left(\frac{CAPEX_{p,t}}{l_p} \times n \right)$$

Procedures for developing the UK low-carbon investment simulation model

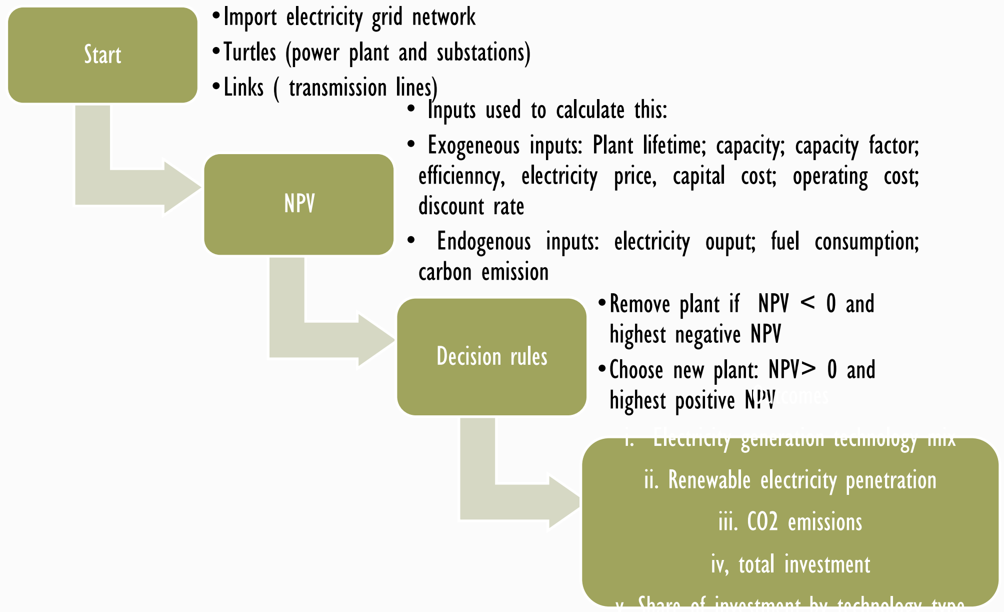
Procedure name	Features	Input/parameters used
Setup	- Loading the grid network into the model - Assign attributes to power plants and substations - Adding new attributes such as shape, size, age, colour - Computing variables such as electricity generation, investment cost etc.	- Installed capacity, year of operation are input variables in this procedure. - Parameters such as capital-cost, capacity factor, exchange rate are utilized.
SetupRevenue	- This is a subset of Setup procedure to calculate revenue per plant	- It uses electricity price and electricity generation to obtain the revenue - Electricity price is an exogenous input variable while generation is obtained in the model Setup
Setuptot.fuelcost	- This is a subset of Setup procedure to calculate fuel cost for coal, gas, and nuclear power plants	- This utilises fuel-used variable derived from electricity generation by multiplying with parameters such as fuel efficiency and fuel price variable
SetupCarbon-emissions	- A Setup subset that calculates total carbon emissions	- carbon-intensity parameter and fuel used variable
SetupCarbon-cost	- A Setup subset that calculates value of total carbon emissions	- multiplies total carbon emissions with exogenous carbon price
SetupOperCost	- This subset calculates the total operating cost for each plant	- parameters such as fixed and variable operation and maintenance cost complemented with installed capacity and electricity generation
Setupprofit	- This procedure calculates the operating profit for each plant	- It subtracts total operating cost from revenue
CalculateNPV	- This procedure computes the net present value of each plant	- It applies parameters such as interest rate and economic lifetime on the operating profit
do-layout	- This procedure allows us to adjust the grid network layout	- It adjusts the layout connecting nodes(power plants and substations) and link(transmission lines)
go	- This procedure allows to implement investment decision rules	- Remove power plants with NPV less or equal zero - Replace the removed power plants with new ones that take attributes from the highest NPV plant in the network - With underlying assumption that new plants maintain the same installed capacity and links of the removed plants.

Simulation model operation

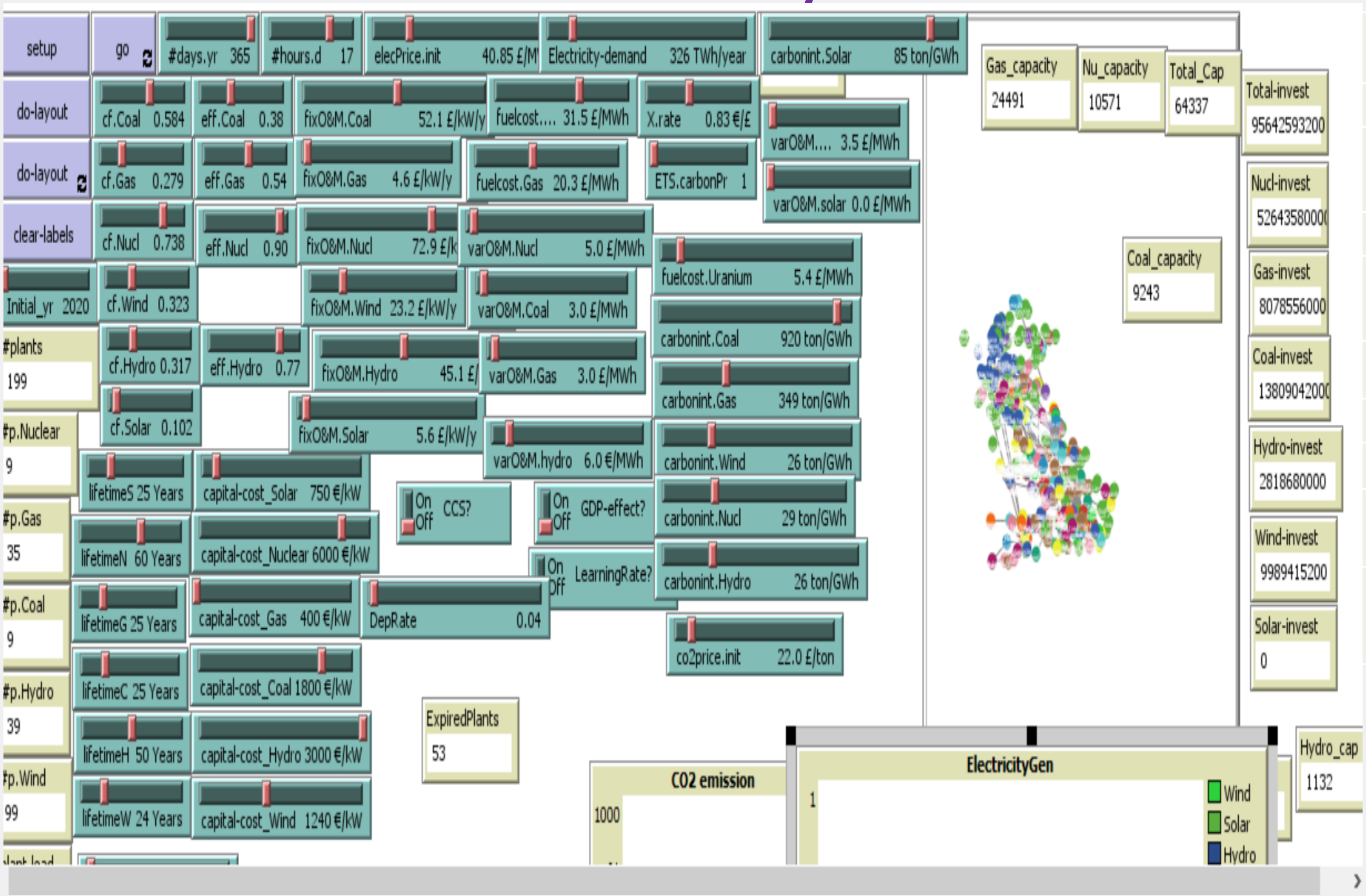
Simulation periods(Yearly resolution): 30 years (2020-2050)

- Setup: based on previous years information to obtain operating profit at the initial year
- Assumption: Fixed(installed capacity, capacity factor, capital cost etc.)

Investment decision rules to run the model



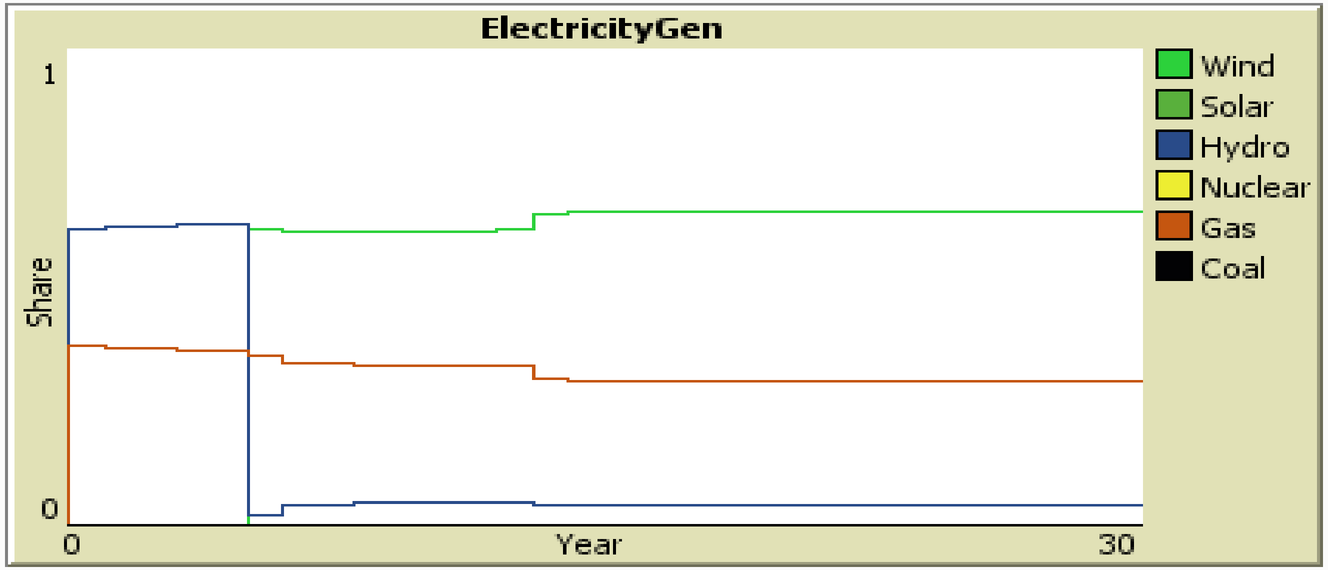
Interface of the UK low-carbon electricity investment model



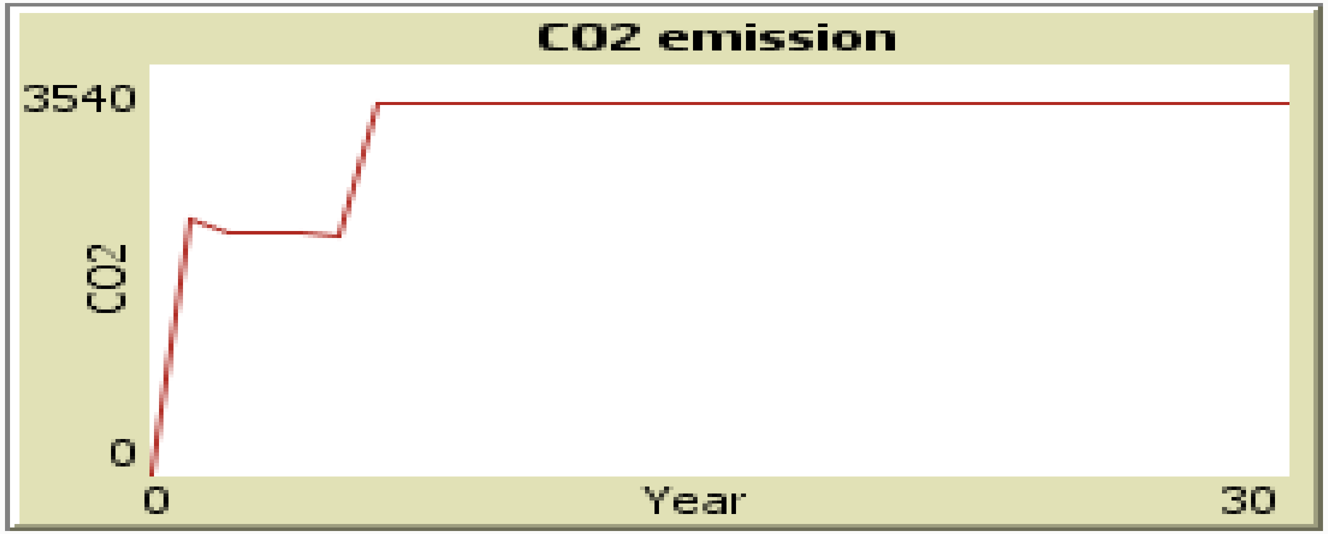
	Statistical Properties
Number of Nodes	465
Number of Transmission Lines	357
Average Degree	1.535
Average Weighted Degree	1.535
Network Diameter	31
Graph Density	0.003
Connected Components	202
Average Clustering Coefficient	0.119
Average Path Length	11.478

Baseline result

UK ELECTRICITY MIX 2020-2050



UK ELECTRICITY-RELATED CO2 EMISSIONS(TONS) 2020-2050

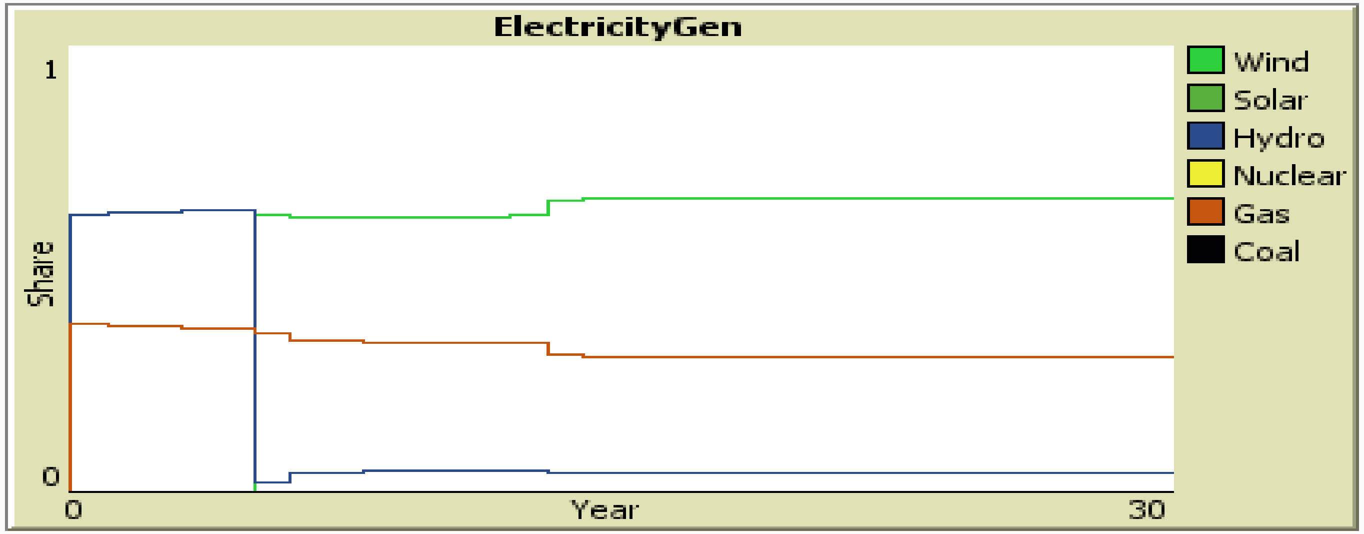


- **Results(+NZ targets)**

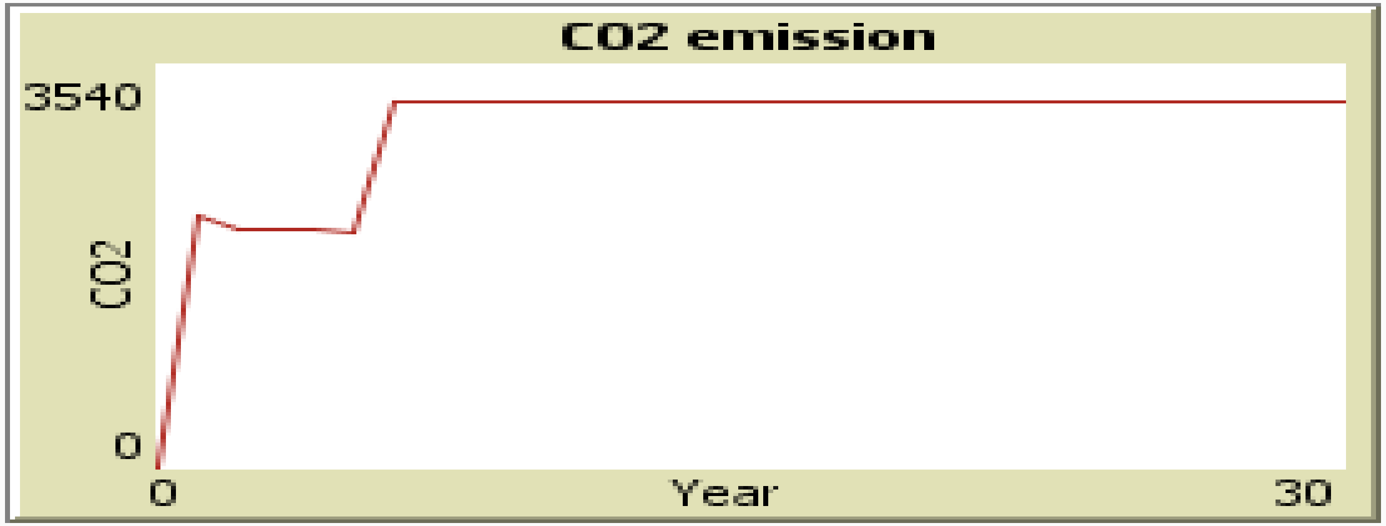
  2024 phase-out coal

  2030 phase-out nuclear(except 2)

UK ELECTRICITY MIX 2020-2050



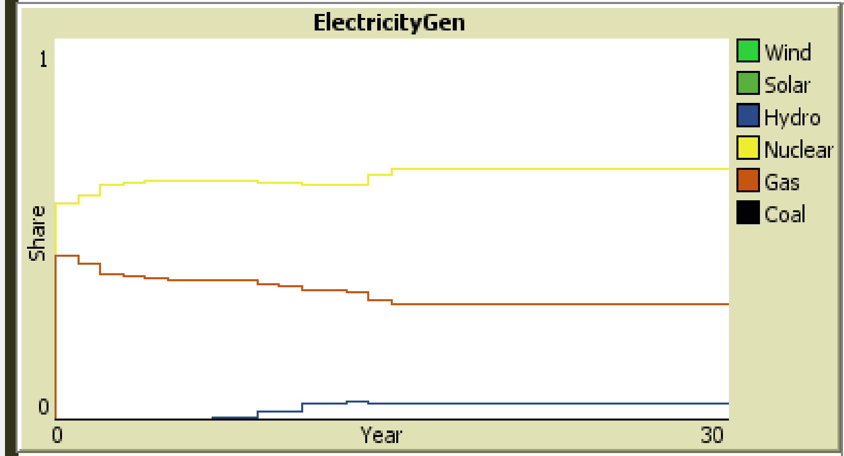
UK ELECTRICITY-RELATED CO2 EMISSIONS(TONS) 2020-2050

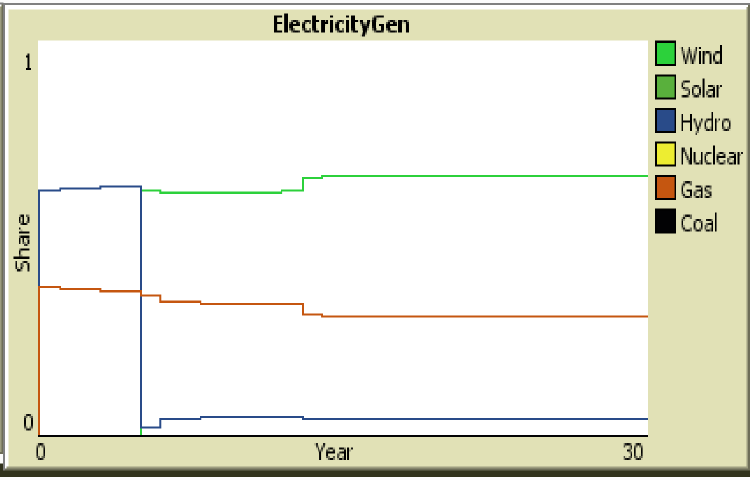


Results

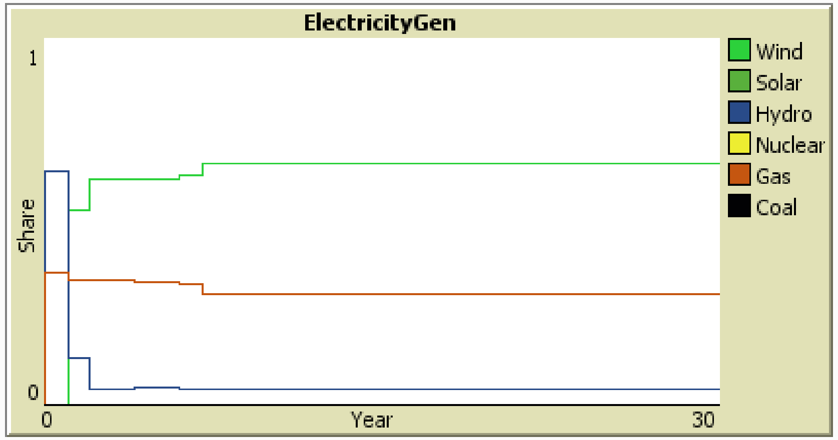
(price, price + NZ targets)

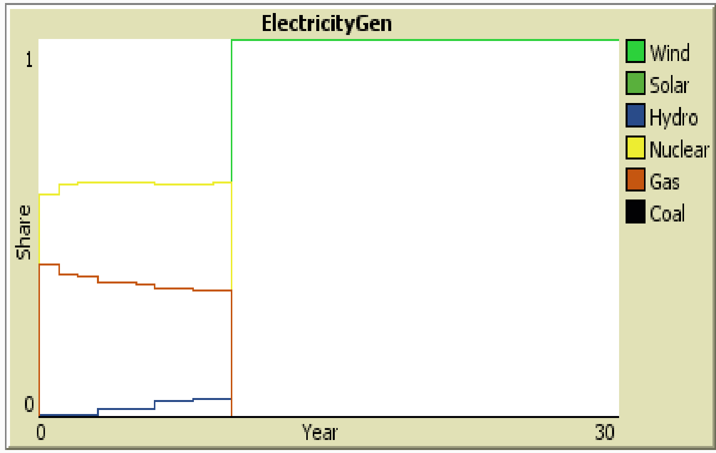
HIGH ELECTRICITY PRICE (£65/MWH) VS HIGH CARBON PRICE(£200/T)



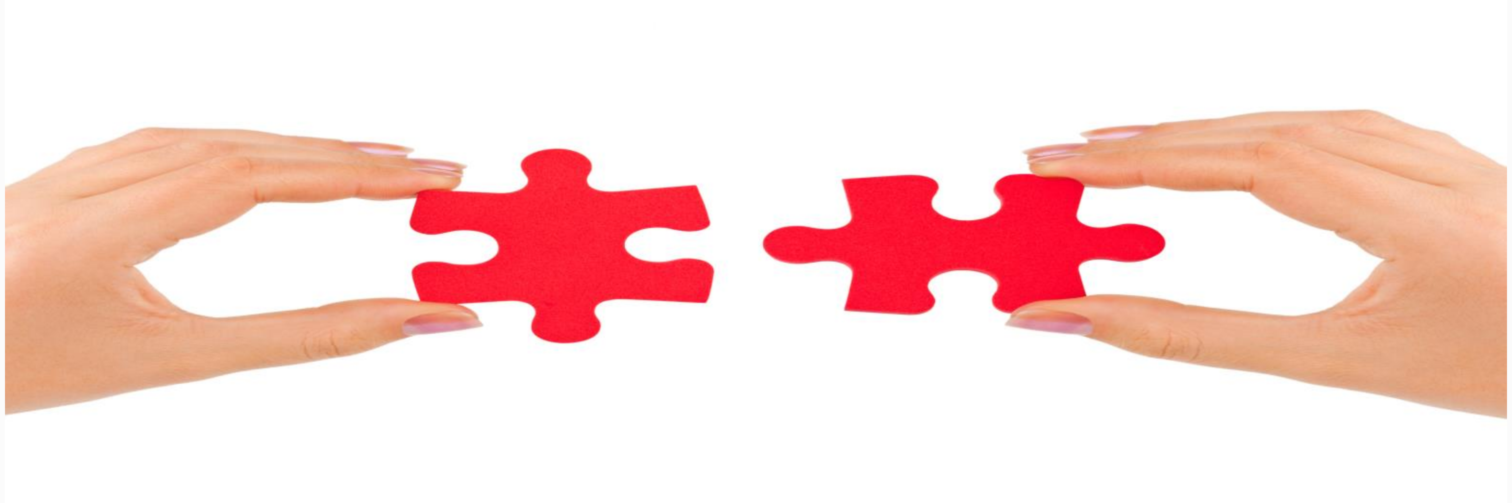


PRICE(LHP) + POLICY TARGETS VS HIGH PRICE(HPP) + POLICY TARGETS





Conclusions



- Fills the research gap between electricity grid network and low-carbon electricity investment decisions in the UK context

Findings:

- All coal plants exit before 2022 in the absence of government intervention; high electricity price (2050 nuclear-gas-hydro mix); high carbon price (2050 wind-gas-hydro mix)
- LHP + NZ targets leads 2050 wind-gas-hydro mix; HPP + NZ targets leads to nuclear-gas-hydro mix before 2030, and 100% wind after 2030

THANK YOU

I The UK net-zero policy targets into the model

❑ Policy targets

- 2050 100% Carbon emission reduction
- 2030 40GW of offshore wind (e.g. through CfD)
- 2024 coal phase out
- 2030 end all nuclear generation with the exception of Sizewell B & Hinkley Point C
- Aggregate electricity demand could be double out to 2050 due to electrification of cars and vans; and increased use of clean electricity for heating instead of gas
- No particular generation mix of 2050; no plan for any specific technology solution; the future generation mix could be composed of wind and solar
- Carbon pricing: the UK new Emission Trading Scheme (UK ETS) is up & running by January 2021. Change in emission caps and sectors