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

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Motivation Contd.

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

Electricity-related CO₂ 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?

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

- 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)
Price Dynamics of Low Carbon Investment in The UK Electricity Transmission Grid_IAEE 2021

**Steps for UK Low-Carbon Investment Simulation**

- 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; efficiency, electricity price, capital cost; operating cost; discount rate
  - Endogenous inputs: electricity output; 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

\[
CF = \sum_{y=t}^{n} \frac{(epp_{t} \times p_{exp}) - ((VC_{f,c,p,t} \times epp_{t}) + f_{c,p,t})}{(1+r)^{y}}
\]

Net present value (NPV)

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

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

- 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; efficiency, electricity price, capital cost; operating cost; discount rate
- Endogenous inputs: electricity output; 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
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Interface of the UK low-carbon electricity investment model

**Statistical Properties**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Number of Nodes</strong></td>
<td>465</td>
</tr>
<tr>
<td><strong>Number of Transmission Lines</strong></td>
<td>357</td>
</tr>
<tr>
<td><strong>Average Degree</strong></td>
<td>1.535</td>
</tr>
<tr>
<td><strong>Average Weighted Degree</strong></td>
<td>1.535</td>
</tr>
<tr>
<td><strong>Network Diameter</strong></td>
<td>31</td>
</tr>
<tr>
<td><strong>Graph Density</strong></td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Connected Components</strong></td>
<td>202</td>
</tr>
<tr>
<td><strong>Average Clustering Coefficient</strong></td>
<td>0.119</td>
</tr>
<tr>
<td><strong>Average Path Length</strong></td>
<td>11.478</td>
</tr>
</tbody>
</table>
Baseline result
• **Results (+NZ targets)**

  2024 phase-out coal

  2030 phase-out nuclear (except 2)
Results

(price, price + NZ 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