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25th February 2021

UKCCS RESEARCH CENTRE

Decarbonisation of power and industry in the UK and the role of CCS

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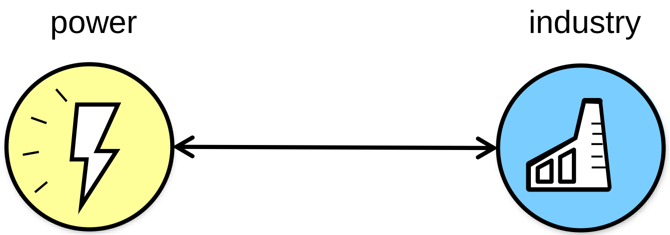
The challenge of decarbonisation in industry



Decarbonisation well understood.
Market mostly domestic.
May provide negative emissions.

Decarbonisation considered difficult.
Closely connected to international markets.
Requires offsets for residual emissions.
Abatement may add power demand.

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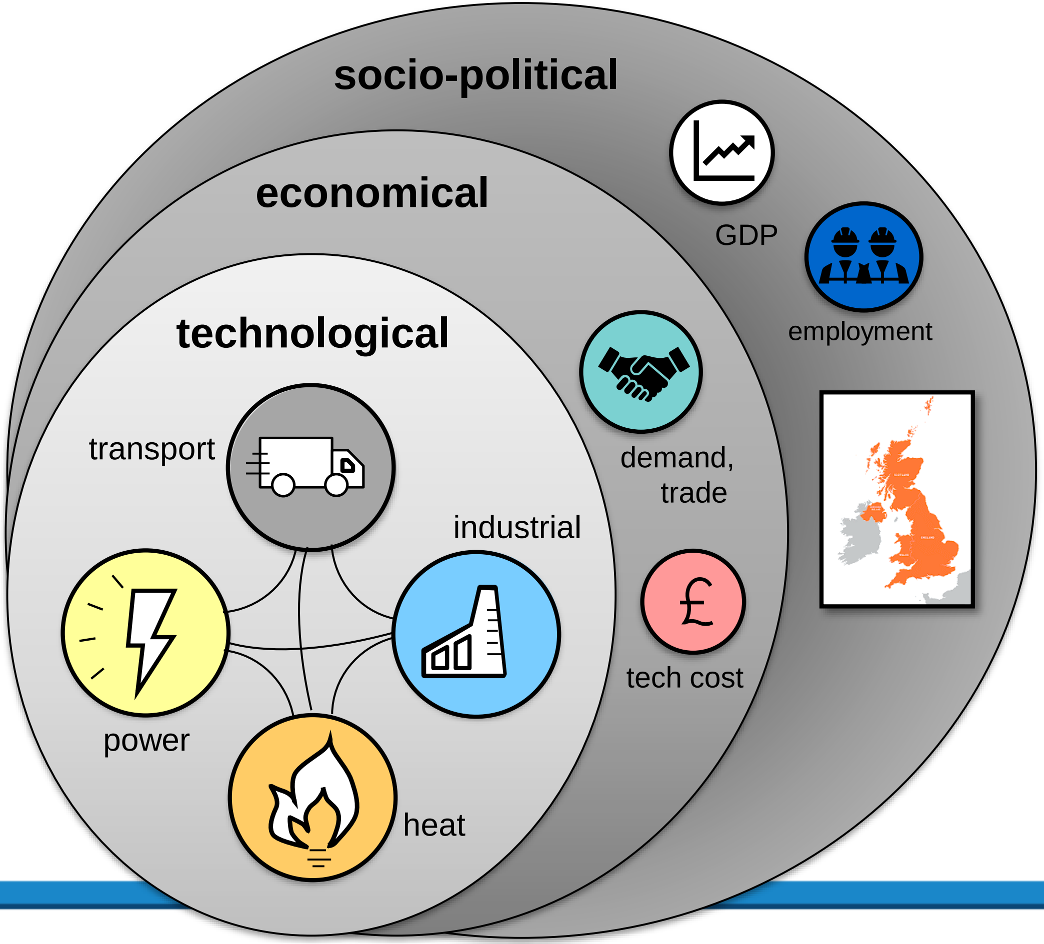
Energy Systems Optimisation Model (ESO(NE))



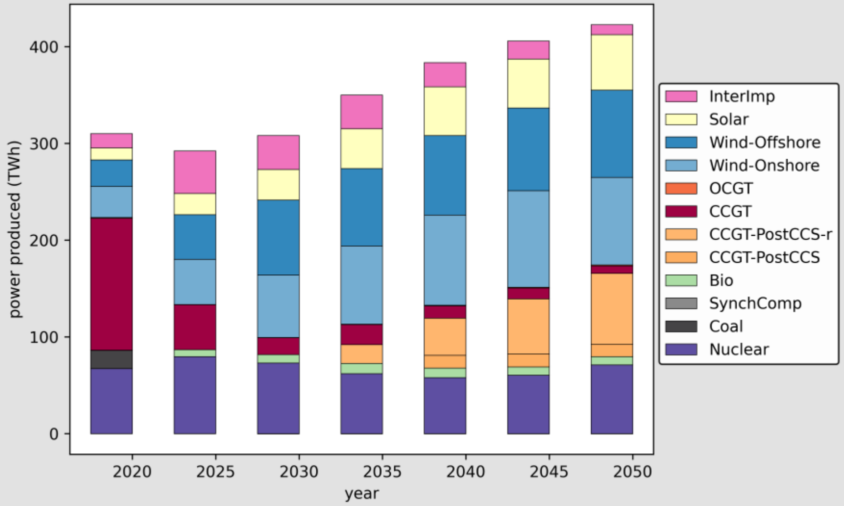
Based on a power systems model *(ESO(NE)),* we are developing our *spatially disaggregated*, *temporally explicit* energy systems model.

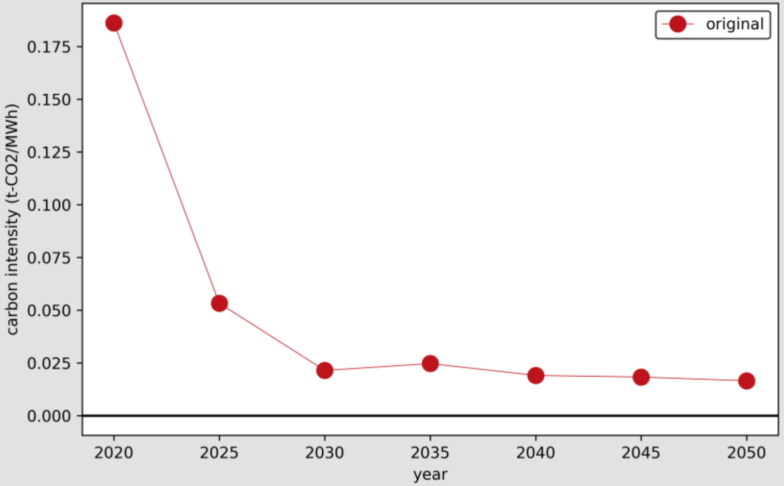
We are expanding it to include the decarbonisation of the industrial, transport and heat sectors.

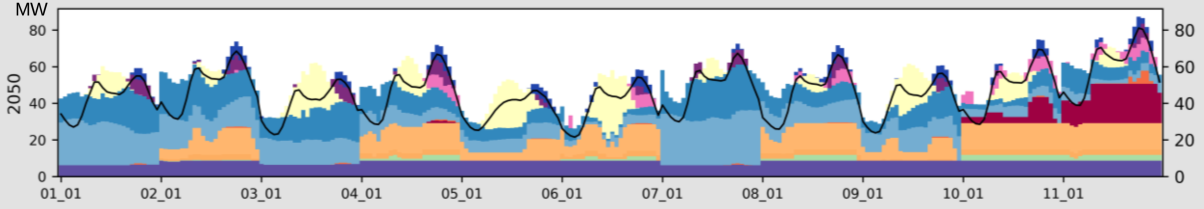
In the future, we plan to include social KPIs such as employment and GDP.

[1]-[11]

Net zero – power only – CP only







Research questions

Which industrial sectors represent the largest emitters in UK industry?

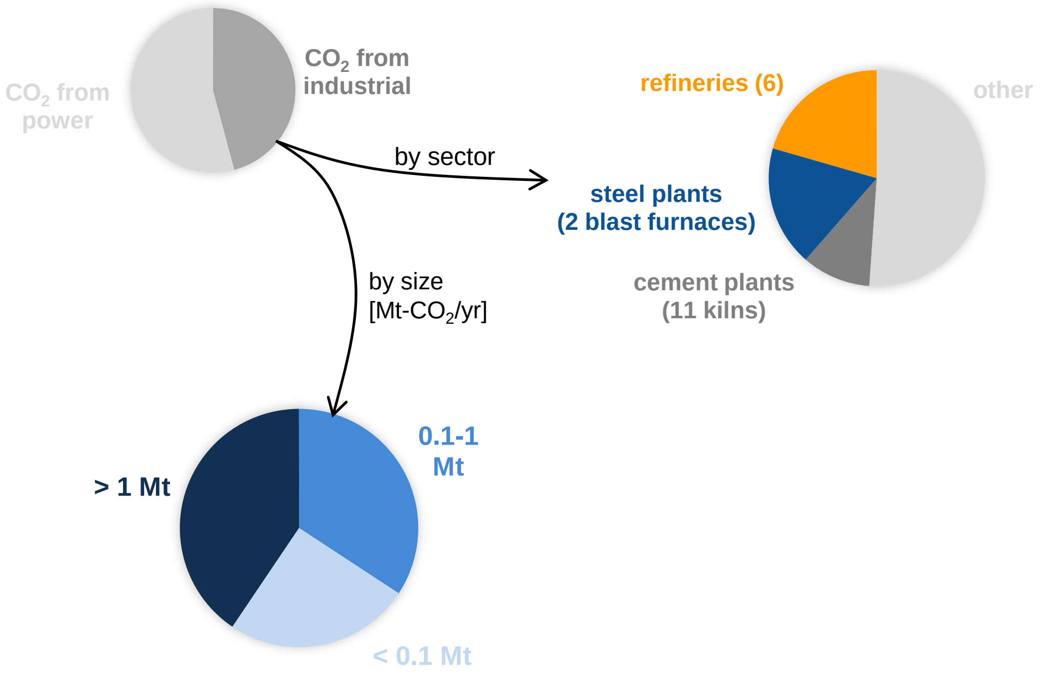
Which options exist for abatement in these industrial sectors?

Which pathways lead to net-zero for power and industry? How much carbon offset is required from power?

Can decarbonisation and domestic production be incentivised using a border tax adjustment?

Which combinations of carbon price and negative emissions credit achieve net zero?

Modelling industrial decarbonisation – UK status quo



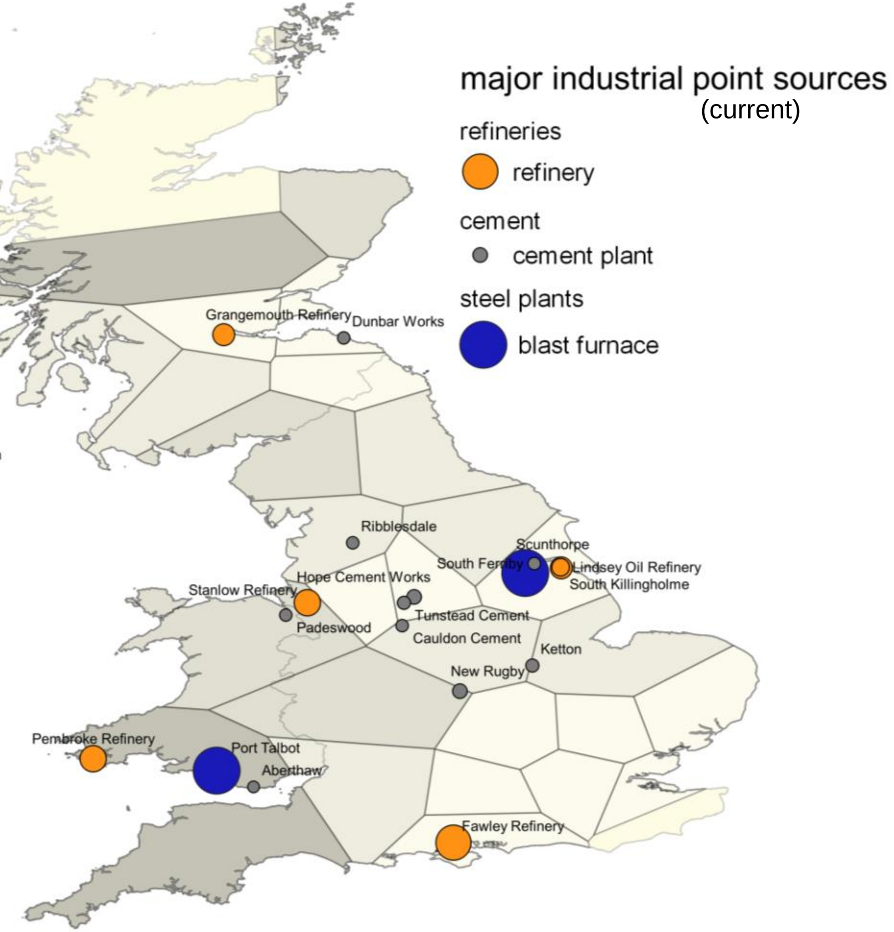
Industrial emissions are spread over a wide range of point source sizes.

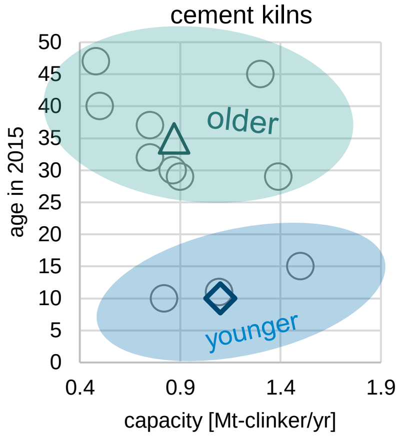
Half of UK industrial emissions stem from 2 steel plants, 6 refineries and 11 cement plants. These were chosen for modelling.

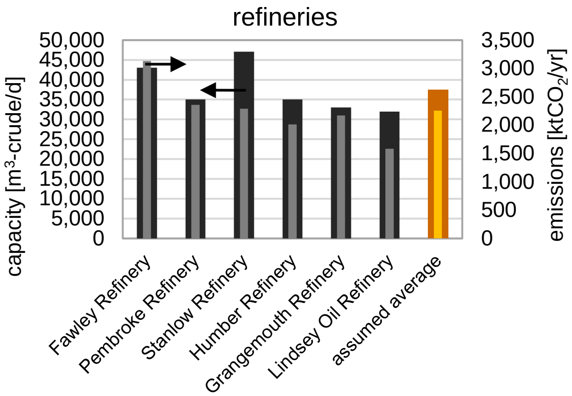
At least a quarter of UK industrial emissions are too small and distributed for carbon capture – underscoring the need for negative emissions in light of the 2050 net zero target.

[14]

Modelling industrial decarbonisation – UK status quo





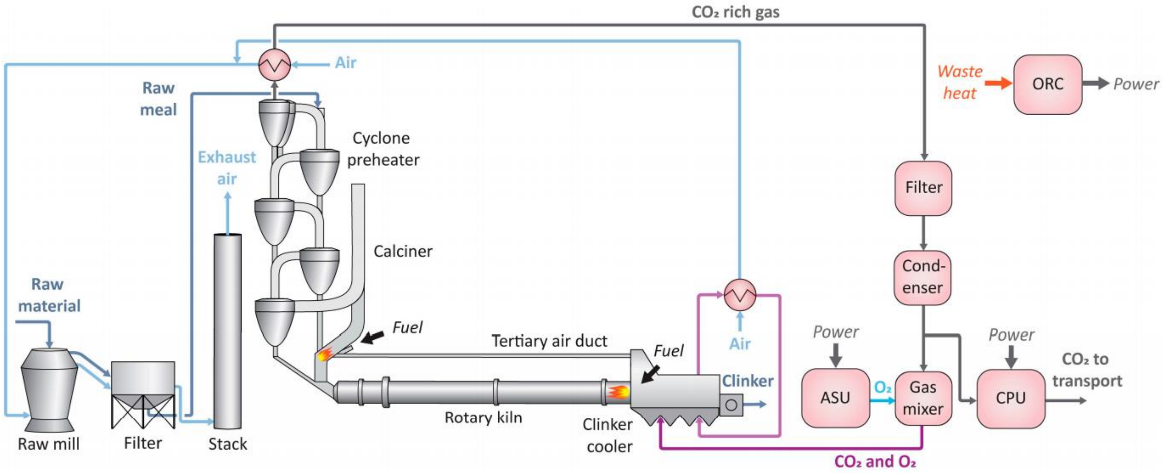


UK point sources were analysed with regard to capacity, emissions and age. Values were grouped and averaged appropriately.

[14][18][19][23][24][27]

Modelling industrial decarbonisation - cement

cement production with oxy-combustion (Voldsund et al., *Energies*, 2019.)

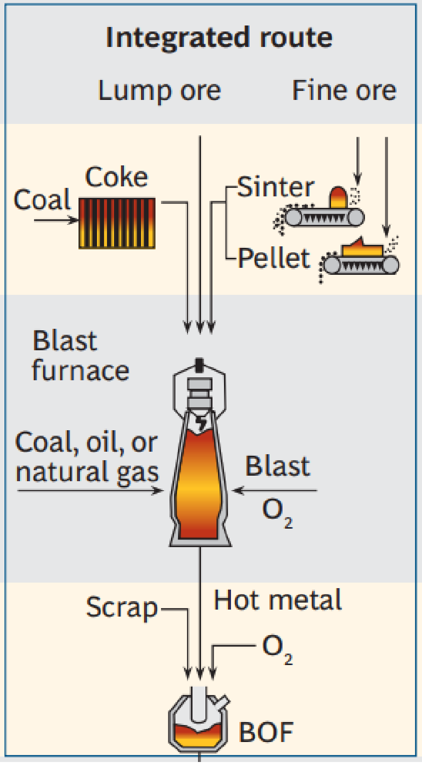


Cement production from limestone ($CaCO_3$) causes process emissions combined with combustion emissions. Every abatement option requires carbon transport and sequestration.

The model includes
- oxy-combustion
- post-combustion capture (PCC)
- calcium looping (CaL), integrated and tail-end
- Membrane-assisted liquefaction (MAL)

Modelling industrial decarbonisation – iron & steel

BF-BOF-Steelmaking



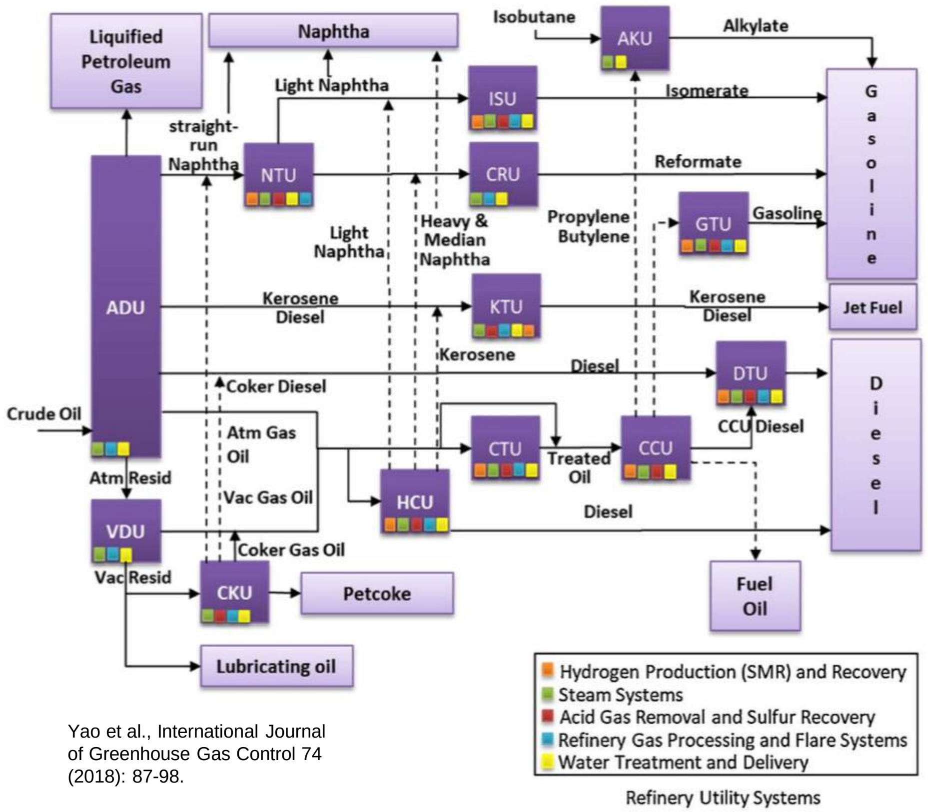
Wörtler et al., BCG & Steel Institute VDEh. 2013.

Part of the substantial CO_2 emissions from reducing iron ore with coke can be captured via PCC. Hydrogen can be used as reducing agent instead, resulting in potentially zero-carbon steel-making.

Steel-making from scrap via electric arc furnaces is limited by the availability of scrap.

Biochar substituting coal combined with CCS leads to carbon-negative steel.

Modelling industrial decarbonisation – refineries



Yao et al., International Journal of Greenhouse Gas Control 74 (2018): 87-98.

Refineries are collections of point sources of varying CO_2 concentration, flue gas flow rate and accessibility – complicating PCC.

Process flow and plant layout vary by individual refinery; generalising is difficult.

PCC for refineries in the model includes two options, based on a case study:

- 63% emissions reduction, more costly
- 22% emissions reduction, less costly

Data for industrial abatement technologies is often unknown or uncertain.

[12]-[14], [30]-[34]

Key assumptions

Net-zero carbon target in 2050 with a **linear** trajectory.
No carbon price (CP) or negative emissions credit (NEC) unless otherwise stated.

Biomass has embodied emissions of 0.25 tCO_2/t caused by the supply chain, which are counted toward the carbon target and penalised by the carbon price.

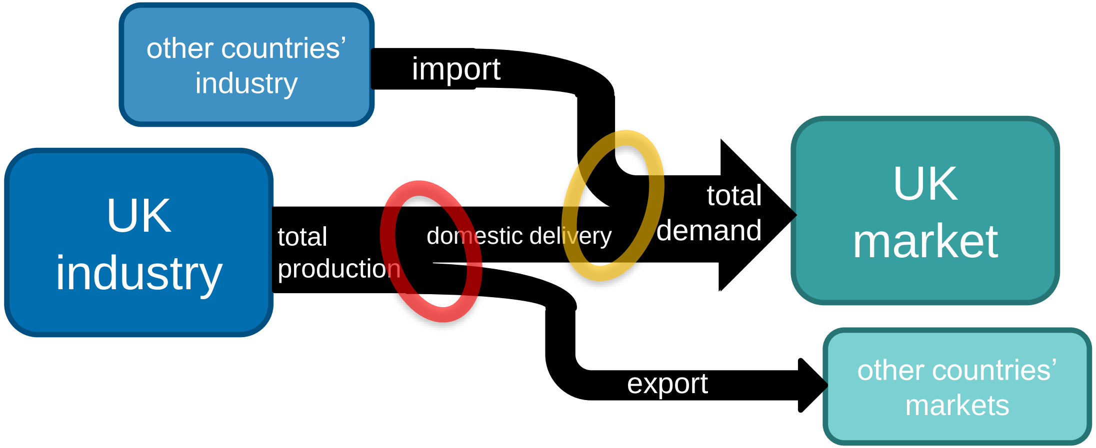
Build rates (BR) are constrained based on historical data and increased by a factor when needed.

~50% of **transport** and **heat** are **electrified**. The shape and magnitude of the power demand curve consequently change.

Electricity consumption of industrial plants is added to the demand in the power sector.

The 50% of **industrial emitters** which are not explicitly modelled require offsets in 2050.

Modelling industrial decarbonisation – demand, import, export



$$\text{ImportRatio} = \frac{\text{Import}}{\text{Total Demand}}$$

$$\text{ExportRatio} = \frac{\text{Export}}{\text{Total Production}}$$

[15][17][18][26][35][36]

Industrial CCS scenarios – overview

	abatement technologies	import ratio	export ratio
BAU & offset		fixed	fixed
Abate & offset	available	fixed	fixed
Import & offshore		increasing	fixed
Abate & export	available	fixed	increasing

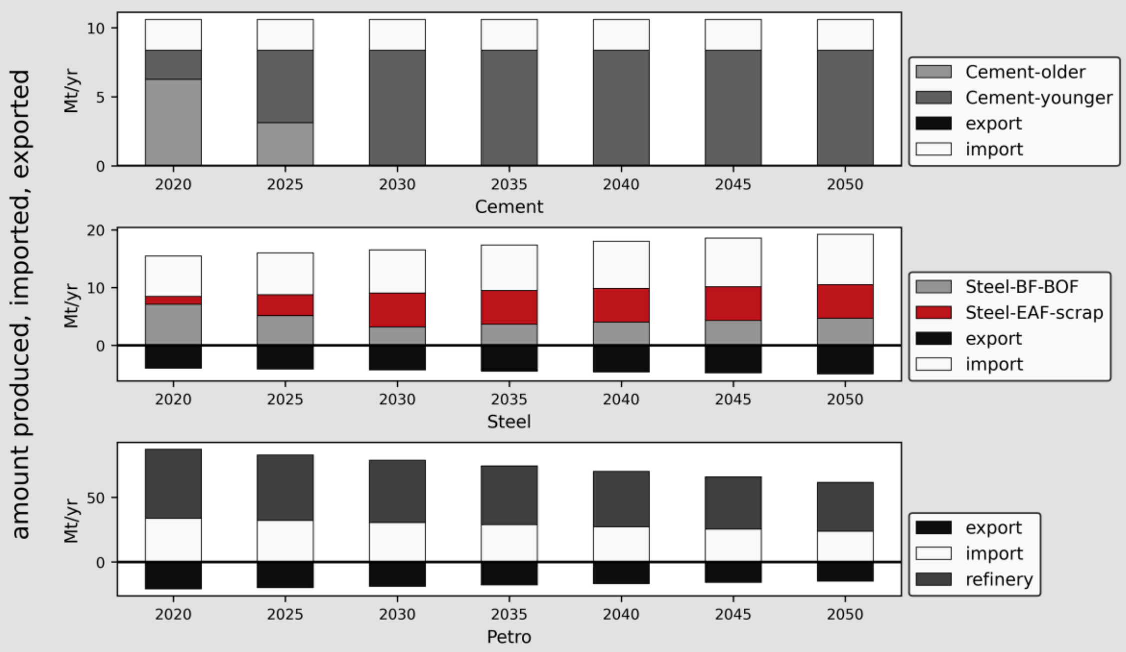
Import and export ratios are fixed to preserve the market structure.

Deployment of technologies depends on

- when they become available to the system
- the retirement time of old capacity
- their relative abatement cost

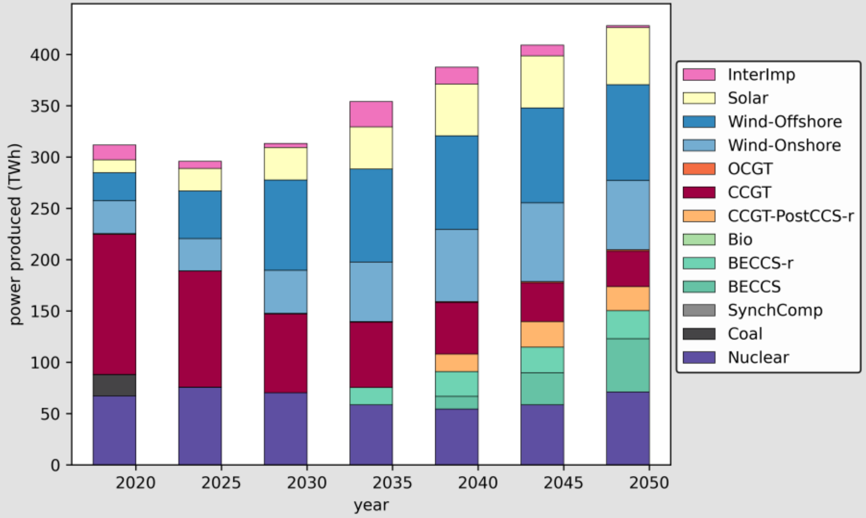
Many of these parameters are *unknown* or *uncertain*.

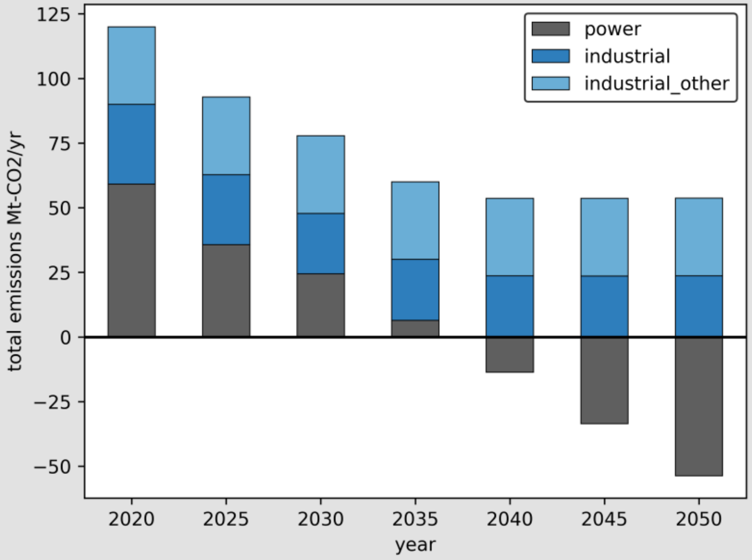
Results – BAU and offset



Retiring capacity is replaced with new-built high-carbon plants.
Low-carbon secondary steelmaking from scrap via electric arc furnaces is expanded, adding electricity demand to the power sector.

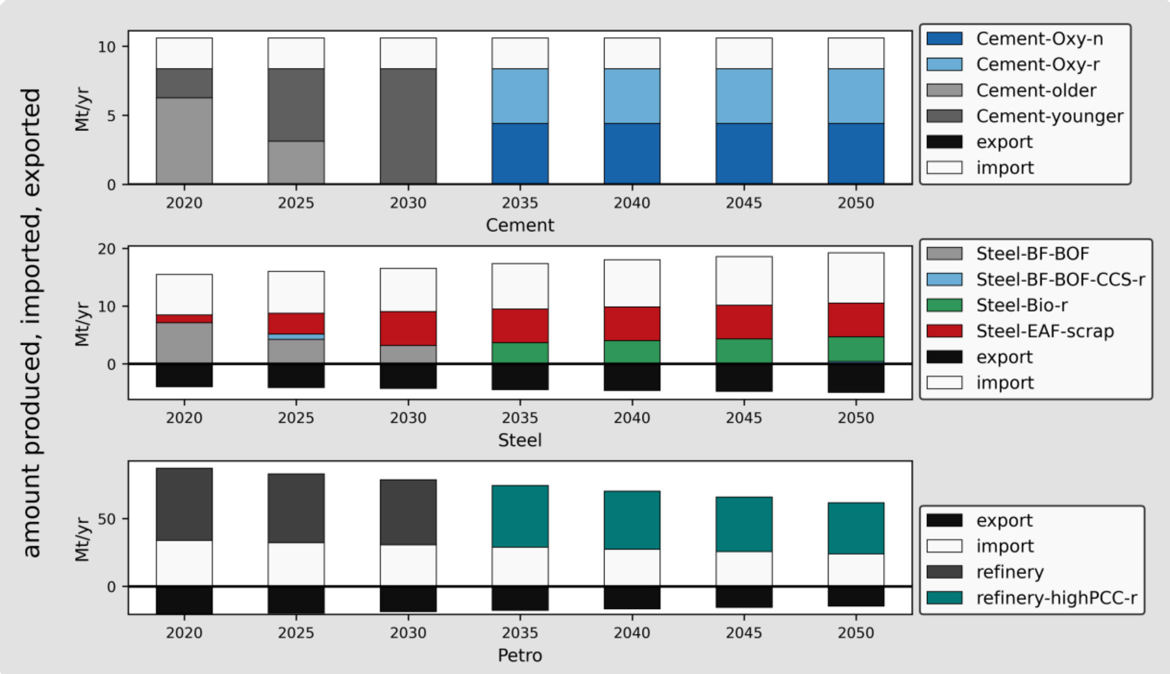
Results – BAU and offset





13 GW of **BECCS** are delivering **66 Mt-CO_2/yr of negative emissions in 2050**.
12 Mt-CO_2/yr offset emissions from CCGT-CCS and CCGT, 54 Mt-CO_2/yr are offsets for steel, cement, refineries and other industrial sectors.

Results – abate and offset



Abatement is preferred over BECCS carbon offsets.

Cement: Oxy-combustion is the clear favourite for retrofit and new-built.

Steel: Secondary steelmaking is expanded. Existing capacity is retrofitted with bio-CCS.

Refineries: Higher amount of PCC with higher cost and higher emissions reduction is selected.

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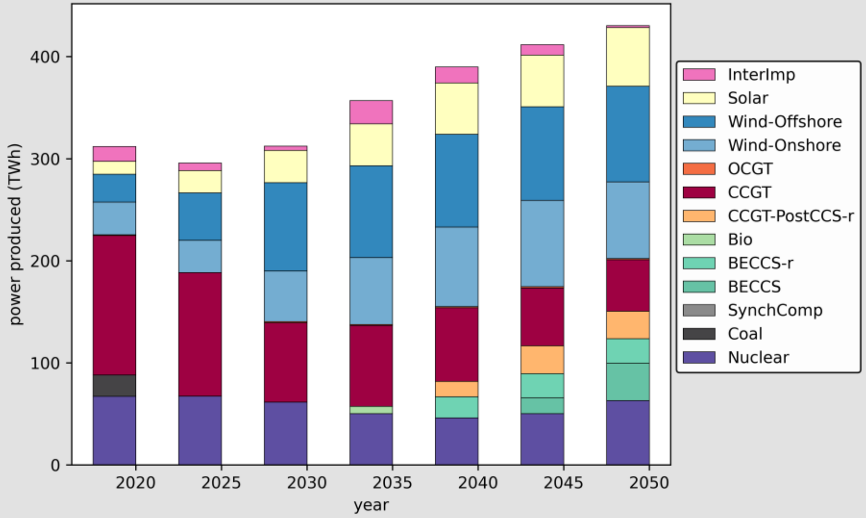
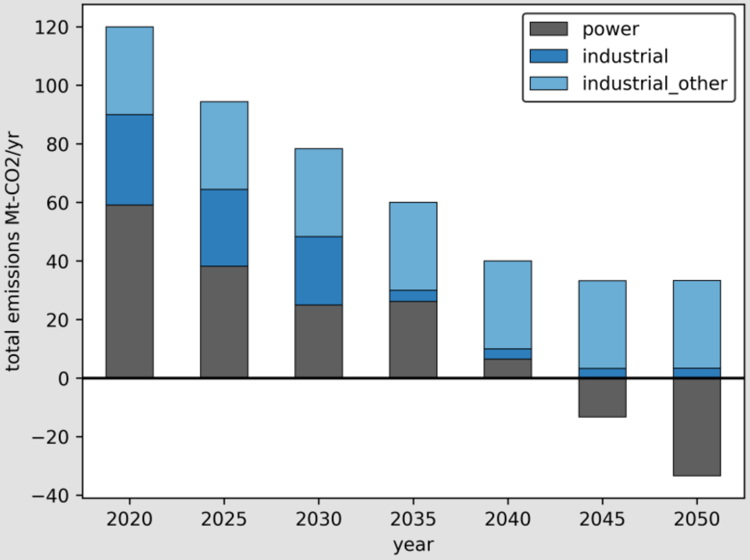
Results – abate and offset





10 GW of **BECCS** are delivering **50 Mt-CO_2/yr of negative emissions in 2050**.
17 Mt-CO_2/yr offset emissions from CCGT-CCS and CCGT, 33 Mt-CO_2/yr are offsets for steel, cement, refineries and other industrial sectors

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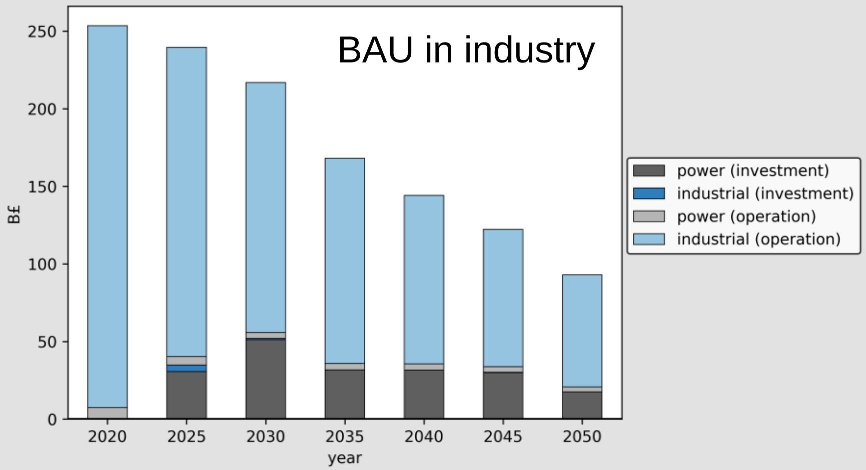
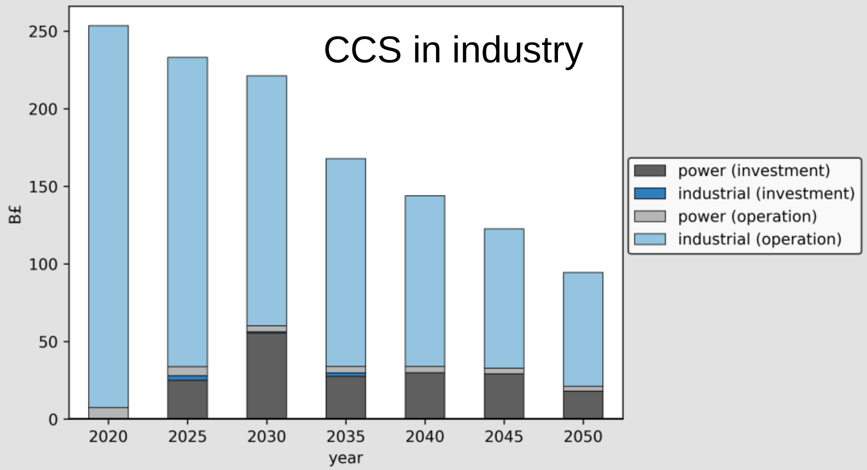
Results – BAU vs. abatement in industry





Assuming import prices at current technology OPEX, costs are the same within the margin of error.

When a carbon price is applied to industrial emissions, CCS in industry becomes significantly less costly than BAU.

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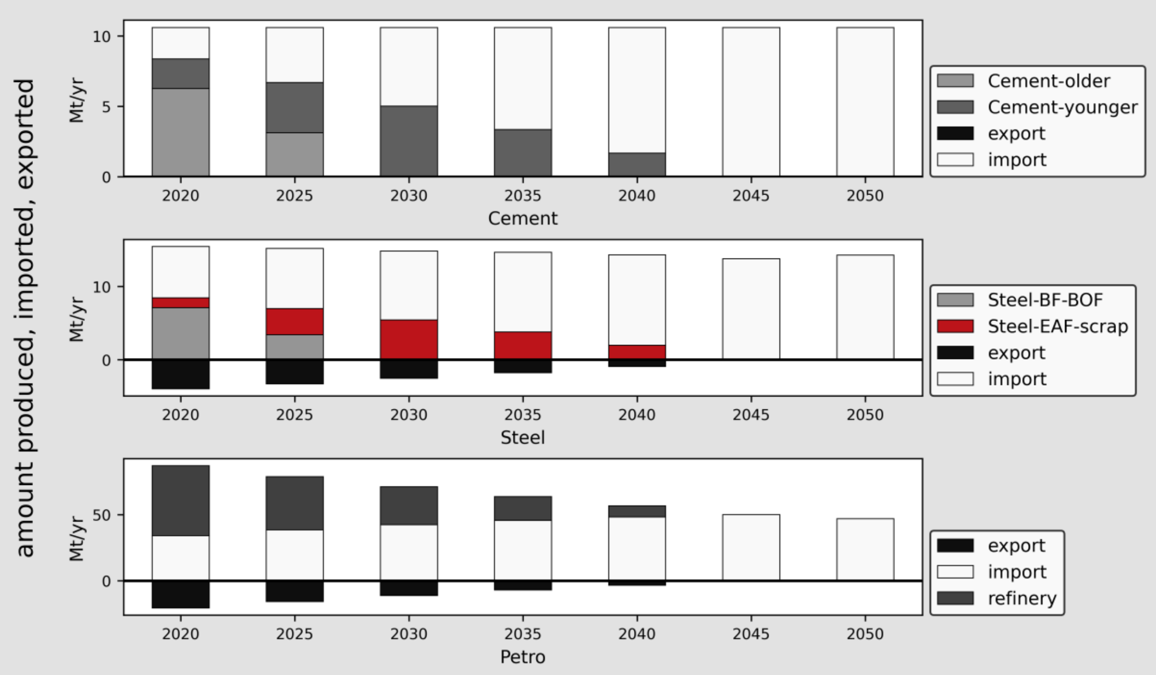
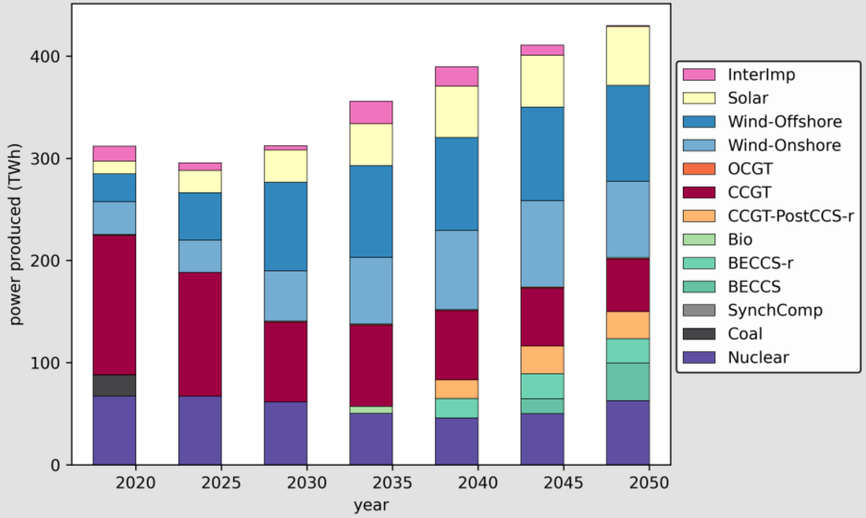
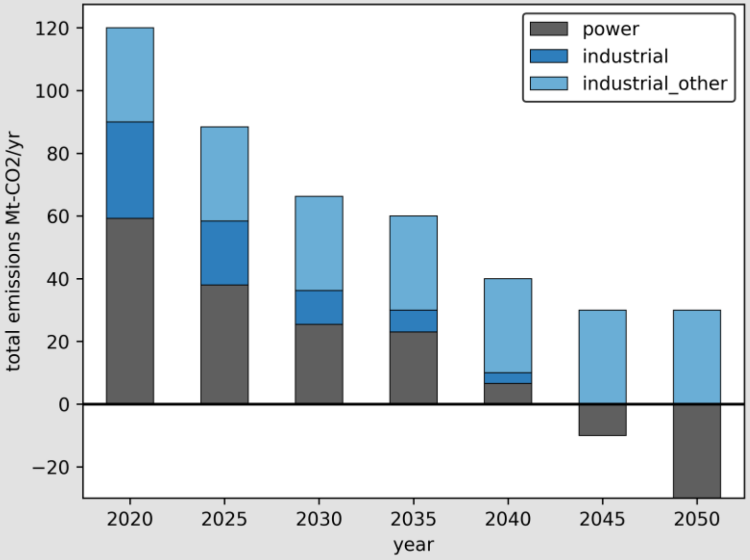
Results – import and offshore



Exiting capacity is retired at the end of its lifetime or shut down and replaced with imports.

Results – import and offshore





9.5 GW of **BECCS** are delivering **48 Mt-CO_2/yr of negative emissions in 2050**.
18 Mt-CO_2/yr offset emissions from CCGT-CCS and CCGT, 30 Mt-CO_2/yr are offsets for other industrial sectors.

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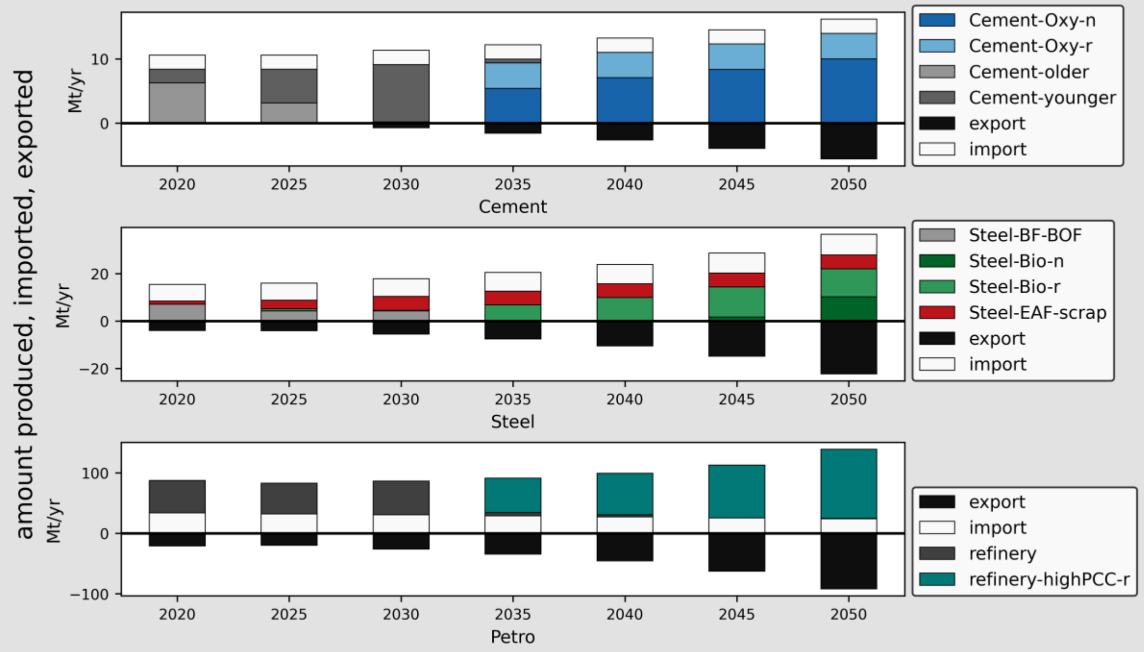
Results – abate and export



Cement: Oxy-combustion for existing and new plants is optimal.

Steel: Secondary steelmaking is expanded. Existing capacity is retrofitted with bio-CCS. New-build bio-CCS steel is added.

Refineries: Higher amount of PCC with higher cost and higher emissions reduction is selected.

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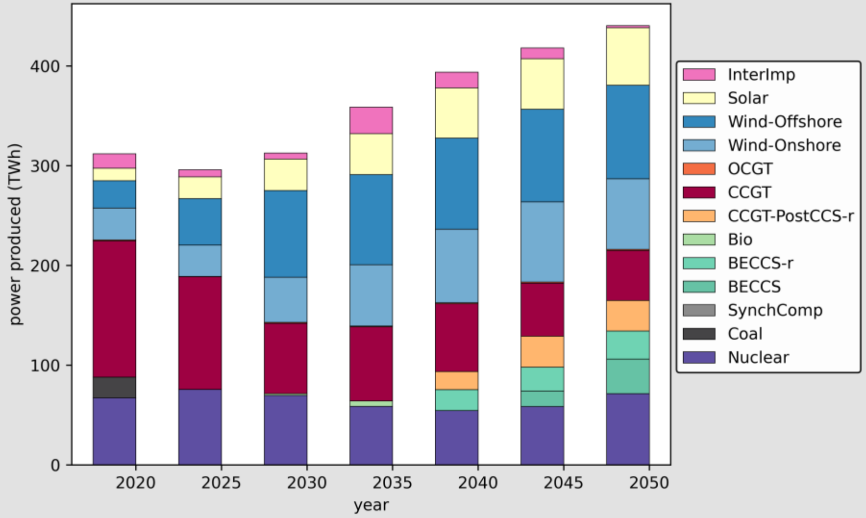
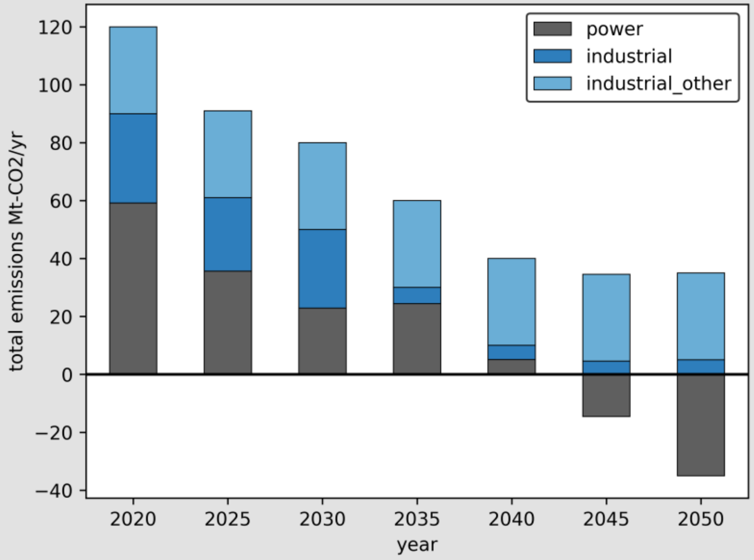
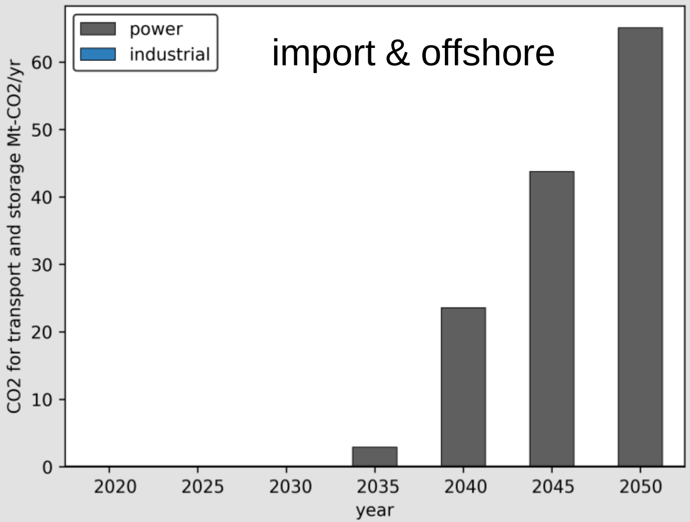
Results – abate and export

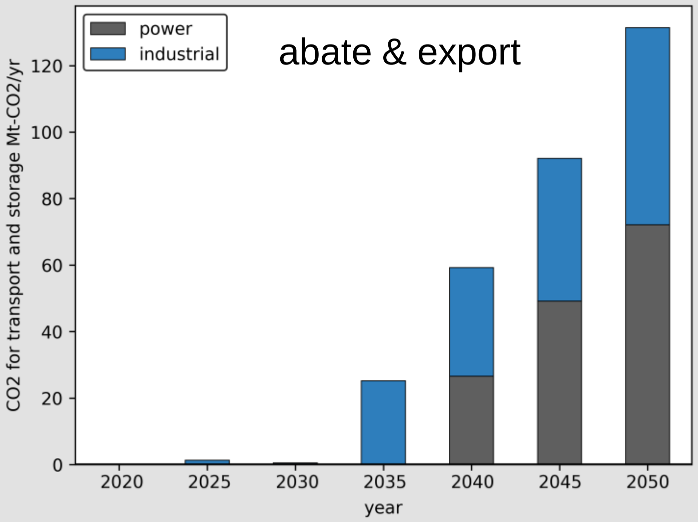




10 GW of **BECCS** are delivering **52 Mt-CO_2/yr of negative emissions in 2050**.
17 Mt-CO_2/yr offset emissions from CCGT-CCS and CCGT, 35 Mt-CO_2/yr are offsets for steel, cement, refineries and other industrial sectors

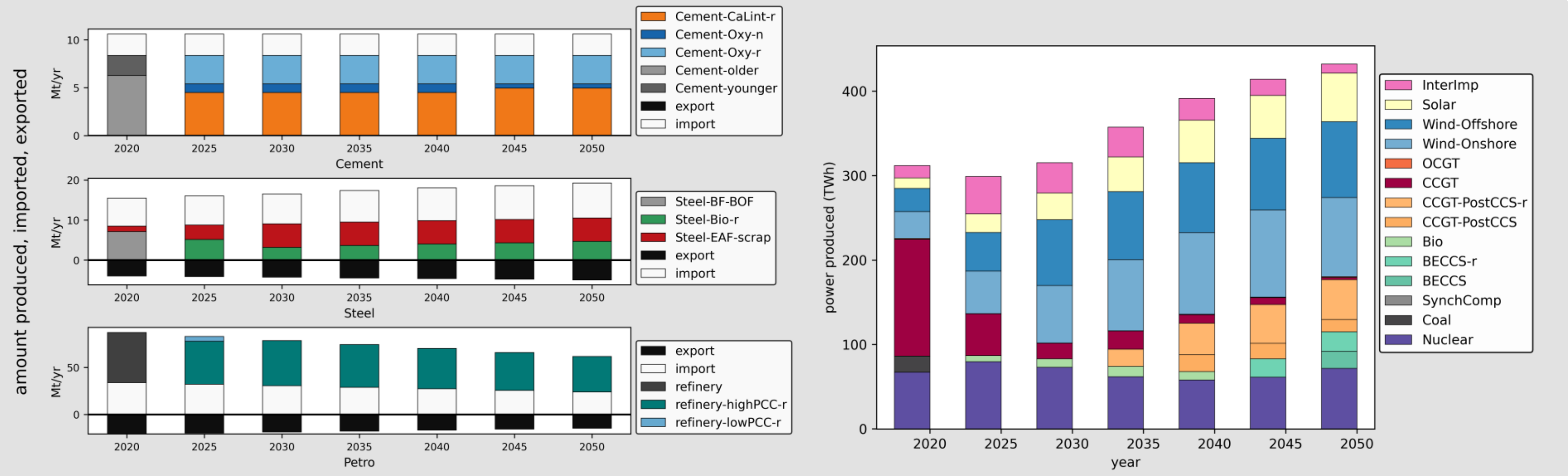
Results – CO_2 for transport & storage





Ca. **65 $MtCO_2$/yr** require transport and storage if industrial emissions from cement, steel, refineries are offshored.
If industrial emissions are abated, this number rises to ca. **85 $MtCO_2$/yr**.
In our “abate & export” scenario, **130 $MtCO_2$/yr** require transport & storage.

Abate & offset with carbon price



Industrial CCS is deployed 10 years sooner. CCGT-CCS is deployed sooner and in greater quantity to replace CCGT. BECCS is added later as fewer offsets are required.

Border tax adjustment (BTA)

border tax adjustment [£/tCO_2] × import carbon intensity [tCO_2/Mt] = penalty [£/Mt]

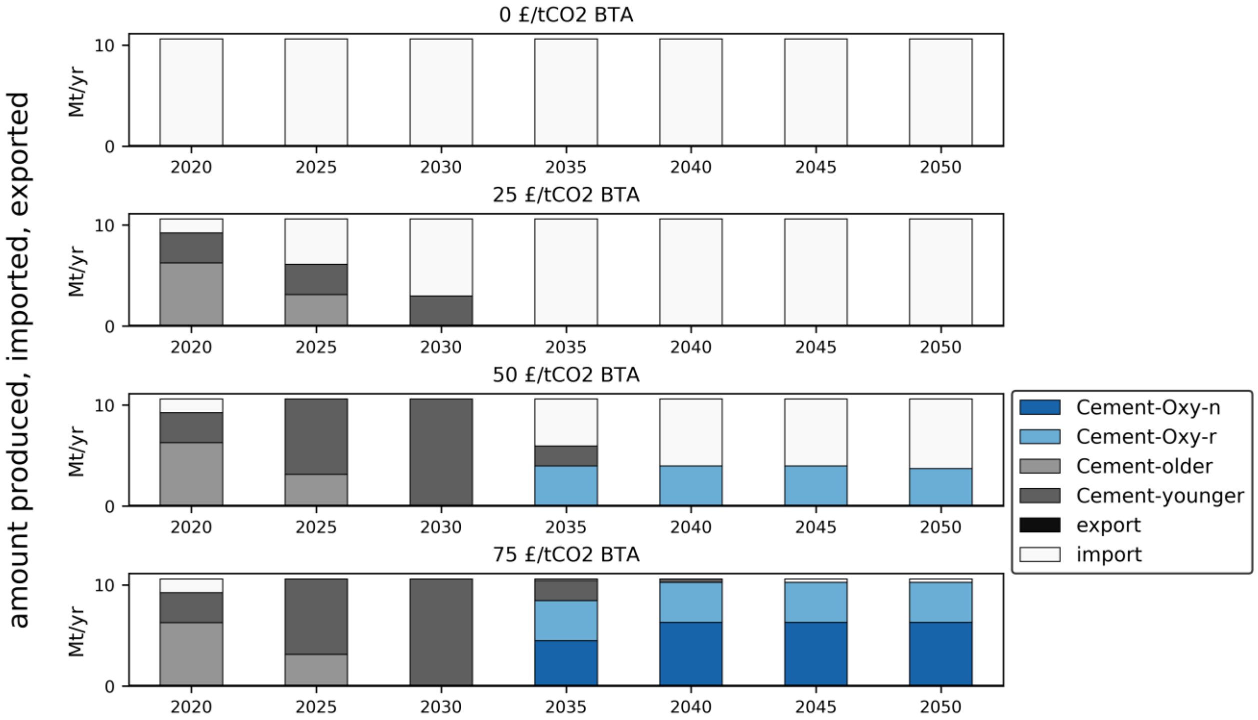
Import price = OPEX of conventional technology
Import carbon intensity = carbon intensity of conventional technology
BTA assumed constant over time

baseline production cost
(+ CCS cost)
(+ carbon tax)
+ carbon offset cost

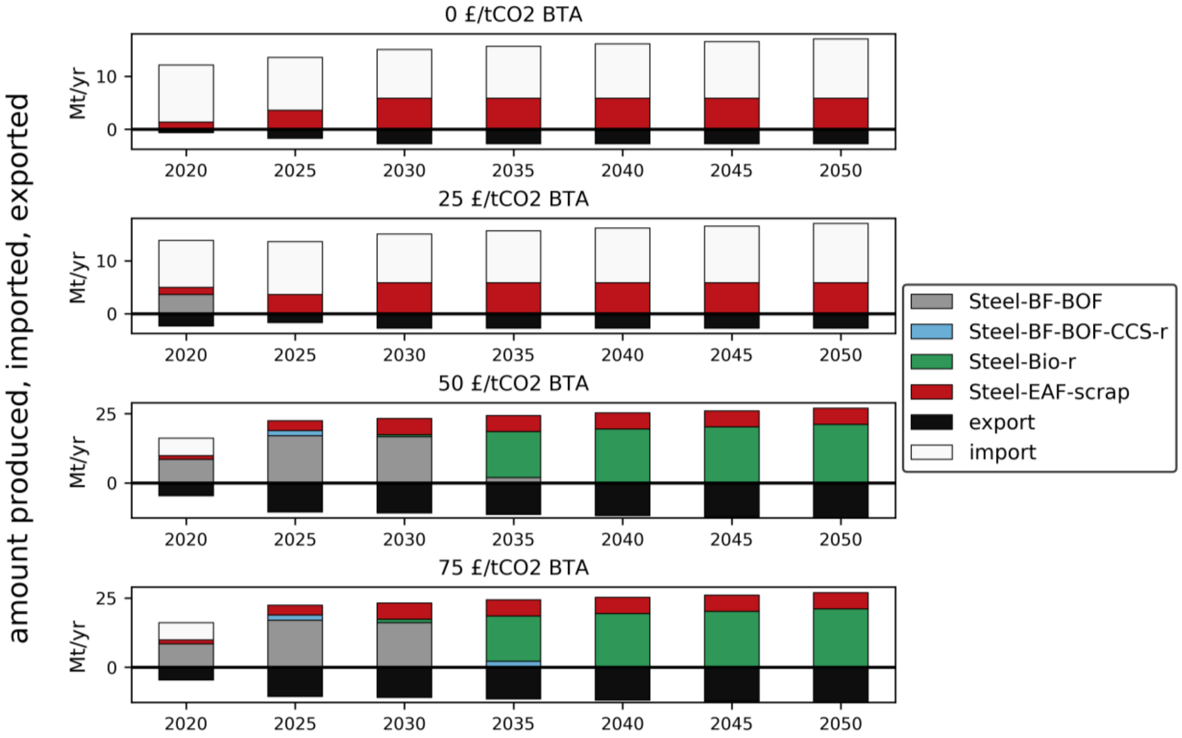
vs.

Import cost
+ border tax adjustment

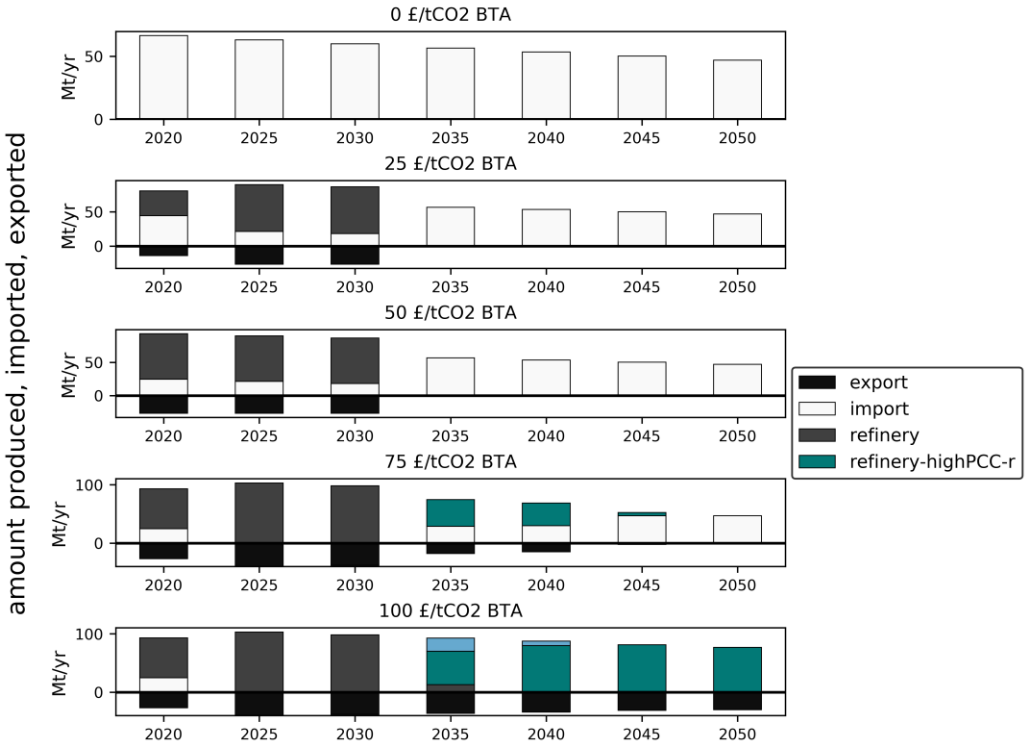
BTA – cement


0 £/tCO2 BTA
25 £/tCO2 BTA
50 £/tCO2 BTA
75 £/tCO2 BTA
amount produced, imported, exported
Mt/yr
0
10
2020
2025
2030
2035
2040
2045
2050
Cement-Oxy-n
Cement-Oxy-r
Cement-older
Cement-younger
export
import

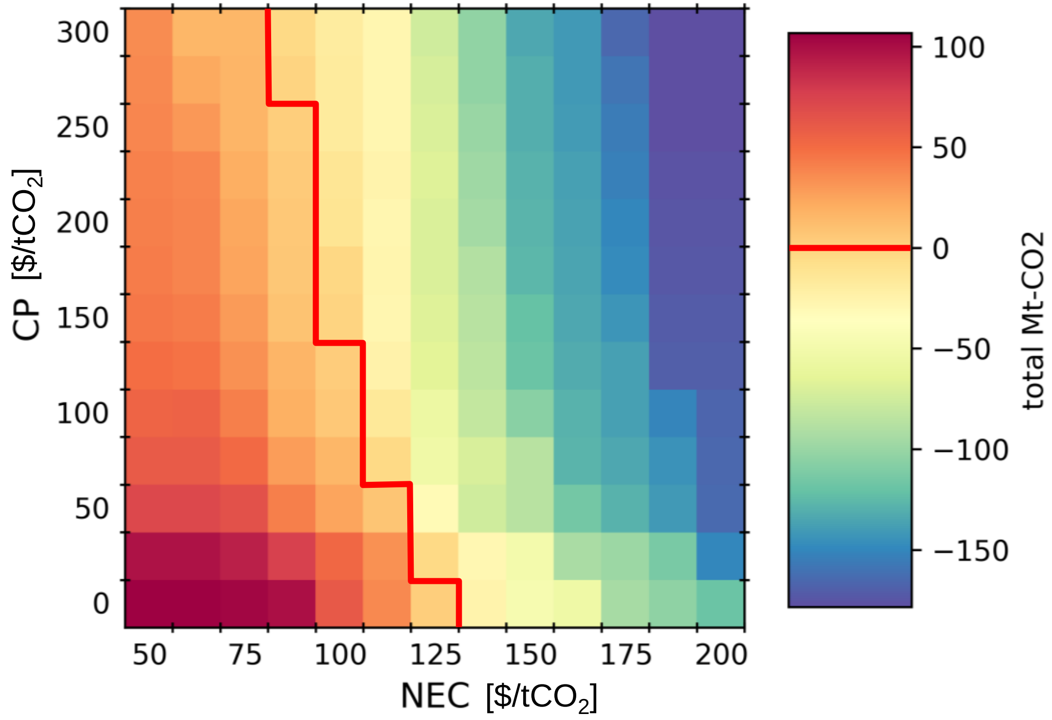
BTA – steel


0 £/tCO2 BTA
25 £/tCO2 BTA
50 £/tCO2 BTA
75 £/tCO2 BTA
amount produced, imported, exported
Mt/yr
10
0
25
2020
2025
2030
2035
2040
2045
2050
Steel-BF-BOF
Steel-BF-BOF-CCS-r
Steel-Bio-r
Steel-EAF-scrap
export
import

BTA – refineries



How to achieve net zero using CP & NEC



A NEC above 138 £/t-CO_2 achieves net zero for power and industry in our model without a CP.

A NEC between 88-138 £/t-CO_2 achieves net zero in combination with a CP.

Sharp increases in CP achieve only marginal reductions in total emissions; emissions are more sensitive to NEC than CP.

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Conclusions

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Emissions from UK cement plants, steel plants and refineries can be reduced by 90% while maintaining production in the UK.

Optimal technology choices according to our model all involve CCS.

Abate & offset incurs similar costs to BAU & offset but leaves room for BECCS to offset other sectors.

Exporting zero-carbon cement, steel and petrochemicals is possible by deploying low-carbon production technologies in the UK – a potential economic boost.

CCS is deployed first in industry. Power overtakes after 2045.

A high enough BTA can force the system from offshoring emissions to domestic production.

A NEC is more effective than a CP in achieving net zero. A combination may be optimal from a public spending perspective.

TOTAL

Future work

We are constantly improving our cross-sector model, modifying model constraints, assumptions, and numbers.
Scenarios change as we optimise the way we describe the UK energy system.

Where are synergies in the decarbonisation of power and industry with regard to industrial clusters?

How do both benefit from shared infrastructure?

What is the effect of other policy instruments for incentivising low-carbon UK industry, such as
- carbon takeback obligation for imports
- subsidies for local production

What is the impact of the pathways for UK industry on employment and GDP?

Which combination of CP and NEC is optimal in achieving net zero from a public spending perspective.

25th February 2021

Decarbonisation of power and industry in the UK and the role of CCS

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