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Consequences of selecting technology pathways on cumulative carbon dioxide emissions for the United Kingdom

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HIGHLIGHTS

- We dynamically model energy demand for the UK's fifth carbon budget.
- We model fastest feasible growth of nuclear and offshore wind capacity for the UK.
- Deploying offshore wind early gives lower cumulative CO_2 emissions.
- Our model supports national policy discussion of energy infrastructure investments.
- We model effects of infrastructure investment on employment.

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ABSTRACT

The UK has an ambitious target of an 80% reduction in carbon dioxide emissions by 2050, to be reached using a series of 'carbon budgets' to aid policy development. Current energy systems modelling methods do not explore, or are unable to account for, physical (thermodynamic) limits to the rate of change of infrastructure. The power generation sector has a variety of technological options for this low-carbon transition. We compare physically constrained scenarios that accentuate either carbon capture and storage, fastest plausible nuclear new build, or fastest plausible build rate of offshore wind. We set these in the context of the UK's legislated fifth carbon budget, which has a comprehensive range of carbon reduction measures with respect to business-as-usual. The framework for our scenario comparison uses our novel system dynamics model to substantiate the policy's ability to meet 2035 emissions targets while maintaining financial productivity and socially expected employment levels. For an ambitious nuclear new build programme we find that even if it stays on track it is more expensive than offshore wind generation and delays emissions reductions. This affects the cumulative emissions and impacts on the UK's ability to contribute to international climate change targets. If delays or cancellation occur to the deployment programmes of carbon capture and storage technologies or nuclear new build, we suggest the electricity and decarbonisation targets can by met by a fast growth of offshore wind generation with no change to financial and employment levels.

1. Introduction and background

International deliberations ranging from the United Nations' Conference of the Parties to the World Economic Forum highlight significant global challenges for energy use and climate change (and some solutions), left then for individual countries to embrace and implement. The outcomes are frequently muted and inevitably delayed. The 2015 Paris Climate Change Agreement [1] committed all countries to constraining temperature increase within one action plan, while emphasising the plight faced by developing and vulnerable countries. In the World Economic Forum's Risks Report [2] two of the five most important interconnected risks were 'unemployment and under-employment leading to social instability' and 'failure of climate change mitigation and adaptation'. Energy policy and science are broadening to

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Nomenclature

Software and Data availability

Name of software	7see-GB
Contact	Dr. Simon H. Roberts (corresponding author)
Programming environment	Vensim
Availability	Freely available as a Vensim Reader version. The full model is also freely available from the corresponding author.
Data	All data sources used in this paper are included in the downloadable version of this model.
Download URL	http://dx.doi.org/10.7488/ds/2252
Year first available	2017
Hardware required	2.0 GHz processor with 2 Gb memory
Software required	Windows (XP/Vista/7/8/8.1) or Macintosh OSX (10.4+)
Program size	10 Mb

Acronyms

5CB	scenario of the fifth carbon budget of the Committee on Climate Change
AFC	actual final consumption
BAU	business as usual
CCS	carbon capture and storage
CCT	combined cycle turbine (for gas generation)
FC	fixed capital
FCF	fixed capital formation
FNNB	scenario of fastest nuclear new build
FOfW	scenario of fastest offshore wind generation growth
GFCF	gross fixed capital formation
LCOE	levelised cost of electricity
NPISH	non-profit institutions serving household
PHEV	plug-in hybrid electric vehicle

Nomenclature, model variables and suffices

b_n	beginning year for construction of nuclear power station n
BAU	business as usual
c_n	completion year for construction of nuclear power station n
CCSI	CCS increase (a flow)
CE	carbon emissions (a flow)
CE′	carbon emissions net of measures (a flow)
CGC	construction of generating capacity (a flow)
CO_2_capture	emissions of CO_2 captured by CCS (a flow)
consump_factor	consumption factor implementing reduction in AFC in order to meet demand for FCF_{meas}
DN	dwelling number (a stock)
DNI	dwelling number increase (a flow)
EDN	energy efficient dwelling number (a stock)
EDNI	energy efficient dwelling number increase (a flow)
elec_dmd	demand for electricity from industry, dwellings or transport (a flow)
elec_dmd′	demand for electricity from industry, dwellings or transport net of measures (a flow)
elec_sup	supply of electricity by power generation (a flow)
elec_sup′	supply of electricity by power generation net of measures (a flow)
EVN	energy efficient vehicle number (a stock)
EVNI	energy efficient vehicle number increase (a flow)
FC	fixed capital (a stock)
FCF	fixed capital formation (a flow)
fuel_dmd	demand for fuel from power generation, industry or dwellings (a flow)
gas_dmd	demand for gas from industry, dwellings or transport (a flow)
gas_dmd′	demand for gas from industry, dwellings or transport net of measures (a flow)
GC	generating capacity (a stock)
GCD	generating capacity decrease (a flow)
GCI	generating capacity increase (a flow)
GCUC	generating capacity under construction (a stock)
GFCF	gross fixed capital formation (a flow)
HPN	heat pump number in dwellings (a stock)
HPNI	heat pump number increase (a flow)
inv_final_dmd′	final demand for investment (GFCF) net of measures (a flow)
k	numbering of industries as consumers of inputs
meas	policy measures
n	numbering of individual new build nuclear power stations
p	production by industry, as classified by industry, at basic prices (a flow)
pet-prod_dmd	demand for petroleum products from industry, dwellings or transport (a flow)
PVN	PHEV vehicle number (a stock)
PVNI	PHEV vehicle number increase (a flow)
t	time, in years
veh_travel	travel of vehicles in units of vehicle-km per year (a flow)
VN	vehicle number (a stock)
VNI	vehicle number increase (a flow)

Nomenclature, time-dependent exogenous coefficients

CC(t)	fuel consumption coefficient for travel
CF(t)	CO_2 capture factor
CIC(t)	CO_2 intensity coefficient
ECoE(t)	extra cost of energy efficient vehicle as a coefficient
ECoP(t)	extra cost of PHEV vehicle as a coefficient
EF(t)	efficiency factor
EIC(t)	electricity increase coefficient
FRC(t)	fuel reduction coefficient
GtFC(t)	GCI-to-FCF coefficient
HRC(t)	heating reduction coefficient
OC(t)	output coefficient
OLF(t)	output loss factor
PC(t)	production coefficient
pGFCF(t)	coefficient for proportion of GFCF provided by final products from either of manufacturing, construction or services (less rental)
RBO(t)	rate of biofuel output
TC(t)	travel coefficient
UC(t)	utility coefficient