RAF134/2223 Energy Innovation Needs Assessments

Technical Methodology Report

June 2025

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Acronyms and abbreviations

Abbreviation	Definition
BECCS	Biomass energy with carbon capture and storage
CAES	Compressed air energy storage
CCGT	Closed cycle gas turbine
CCS	Carbon capture and storage
CB7	Carbon Budget 7
COP	Coefficient of performance
DACCS	Direct air carbon capture and storage
DDM	Dynamic Dispatch Model
DESNZ	Department for Energy Security and Net Zero
EINA	Energy Innovation Needs Assessments
ETSAP	Energy Technology Systems Analysis Program
EU	The European Union
FES	Future Energy Scenarios
GAMS	General Algebraic Modelling System
GHG	Greenhouse gas
GSHP	Ground Source Heat Pump
GVA	Gross Value Added
HD	High Diversification
HH	High Hydrogen
HTGR	High Temperature Gas Reactor
IEA	International Energy Agency
MC	Minimally Constrained
NSTA	North Sea Transition Authority
O&M	Operations and maintenance
OCGT	Open cycle gas turbine
ONS	Office for National Statistics
RoW	Rest of World
SMR	Small Module Reactor
SOEC	Solid-Oxide Electrolyser Cells
SW	Sizewell C
SW	Shannon-Weiner
SWN	Shannon-Weiner-Neumann

Glossary

Term	Definition
Annual deployment	The average amount of capacity added per year over a given 5-year period.
Capacity factor	The ratio of actual energy output over a period to the maximum possible output if the energy system operated continuously at full capacity.
CAPEX	The initial capital expenditure required to construct, manufacture, design and install the components associated with a particular technology.
Component	A constituent part of a technology which accounts for a share of its total levelised cost e.g. in offshore wind, components include foundations, turbines and OPEX.
Cost category	A cost category is an aggregated cost grouping which is higher than the component level and lower than the technology level. Typical cost categories are CAPEX, OPEX and decommissioning.
Cumulative deployment	The total amount of capacity in operation at a given point in time.
Decommissioning	The phase after the end of an asset's useful economic lifetime where it is dismantled and removed.
Direct jobs	A direct job is a job that is supported as a direct result of a specific economic activity or investment.
GVA multiplier	The share of turnover that represents gross value added (GVA).
Innovation Level (IL)	In the systems modelling results that are used to provide deployment inputs for certain technologies, there is variation across scenarios according to the assumed level of innovation: Low, Medium and High (see Models section for more information on the systems modelling used to model these scenarios)
Indirect jobs	An indirect job is a job that exists to produce the intermediate goods and services used as inputs to the direct (primary) activity.
Levelised technology costs	The discounted stream of CAPEX, OPEX, decommissioning costs and any other costs associated with the deployment of a technology.
OPEX	The ongoing expenditures required for maintaining and operating an asset during its useful economic lifetime.
PRODCOM	A system for categorising products produced by manufacturers. There are approximately 3,800 products as defined in the PRODCOM list, and each product is identified by an 8-digit PRODCOM code.
Productivity multiplier	A ratio of the typical GVA supported per worker per year in providing a good or undertaking an activity
RoW	The rest of the world - the global market excluding the UK market.

Turnover	The total revenue supported from the sale of a good or from undertaking an activity.
Type I multiplier	The type I employment multiplier is the ratio of direct plus indirect employment changes to the direct employment change.
UK export market share	The share of gross global exports of a certain good or activity which is met by UK-based exporters.
UK market share	The share of total activity in a given market related to the production of a certain good or the fulfilment of a certain activity which is met by UK-based entities.
UK-captured turnover	The total revenue supported by the sale of a good or service, both domestically and as an export activity that flows to UK-based entities.
Useful economic lifetime	The period during which an asset is expected to be economically viable before replacement or retirement is justified.

Introduction, scope and limitations

Achieving the UK's ambitious Net Zero target requires the accelerated scaling and deployment of innovative clean energy technologies. The UK government has a central role to play in supporting the research, development and deployment of these innovations to achieve global and national climate objectives. The decisions made now in the prioritisation and investment of crucial clean energy technologies will be pivotal to enable progress in the coming years and decades.

The Energy Innovation Needs Assessments (EINAs) have been developed and updated to identify key innovation needs across the UK's energy system, to provide an evidence base for the prioritisation of investment and support for clean energy innovation. The 2025 publications reflect an update on the 2019 exercise, accounting for the significant changes and progress both in the clean energy sector and in the wider economy. To complement and build on the UK's Net Zero Research and Innovation Framework, the updated EINAs will inform key decisions on clean energy innovation funding through a structured evidence base that quantifies and assesses the role and scale of opportunities. The evidence enables comparison across technologies and takes account of wider factors that may impact deployment and scale up.

To develop this evidence, the following analysis (outlined in Figure 1), has been implemented:

- Prioritisation of technologies for consideration in the EINAs according to key DESNZ criteria.
- An assessment of the prioritised technology's innovation needs, costs and barriers to deployment.
- Use of UK TIMES and HighRES models to explore the implications of innovation investments on the UK energy system across hypothetical net zero scenarios.
- Economic analysis, including Gross Value Added (GVA) and employment, of the deployment of the technologies.

The scope of the EINAs project spans the UK energy system. Technologies considered are limited to those that provide clean energy supply, reduce demand for energy or reduce emissions. While transport energy use and requirements were included within modelling, this sector was out of scope for innovation assessments. There are eight separate technology themes reports, providing more detail on the innovation needs, deployment and economic opportunities of the prioritised EINAs sub-themes. This report provides details of the EINAs methodology.

The 2025 EINAs publications have been commissioned by DESNZ and produced by a consortium led by Carbon Trust, with Mott MacDonald, UCL and Pengwern Associates.

Scope and Limitations of the EINAs:

The EINAs project is a research exercise to evaluate the potential impact of technological innovations on the UK energy system and Net Zero targets and help inform decisions on clean energy innovation funding.

A number of technologies were included as part of the prioritization but were not included in the systems modelling due to limitations of the models used for the EINAs, data availability and resource constraints. The three hypothetical scenarios developed to represent potential routes to Net Zero were selected due to their differing constraints which provide a more diverse set of outputs and insights.

The technologies and scenarios selected do not represent UK Government policy.

Initial technology prioritisation

1. Initial longlist based on published scenarios, DESNZ priorities and engagement activities, and technical expert input.
2. Longlist prioritised according to 4 DESNZ criteria: known Net Zero priority, UK relevance, energy security and TRL.
3. Shortlist further prioritised based on modelling capability and data availability.

Data gathering and updated model

1. Development of three UK energy system scenarios: Minimally Constrained, High Hydrogen and High Diversification.
2. Data gathering across the priority EINAs technologies at three innovation levels.

Energy systems modelling of EINA

1. Modelled scenarios and analysis of innovation opportunities.
2. Innovation values for each EINAs technology area.
3. Cost and deployment for EINAs technologies to 2050.

Economic calculators and analysis

1. Updated economic calculators from the previous EINAs.
2. Updated economic data inputs.
3. Analysis of economic opportunities, including jobs and GVA, for the EINA technologies.

Selected EINAs Sectors

1. Offshore Renewables
2. Nuclear Fission
3. Heating and Buildings
4. Carbon Management
5. Hydrogen
6. Energy storage
7. Networks
8. Industrial Decarbonisation

Final outputs

1. Updated systems models, UK TIMES and highRES, and modelling scenarios
2. Cost savings, deployment and cost modelling outputs across three scenarios
3. Tables of innovation needs
4. Economic opportunity calculators for each EINA
5. Eight sub-theme EINA reports assessing the innovation opportunities
6. An overview EINA report
7. A Technical Methodology EINA report

Figure 1: Overview of the EINAs approach

Technology prioritisation

An initial longlist of priority Net Zero technologies was developed based on the previous EINAs work, published national and global scenarios, input from DESNZ expert engagement, and input from technical experts from across the EINAs consortium. This longlist was then further prioritised according to the following criteria:

- **Known Net Zero priority:** Areas where there is clear government direction or expert consensus. Additionally, areas where a technology might not have a high potential for innovation, be necessary for energy security considerations or align with current UK capabilities, but net zero cannot be achieved without it and still requires government intervention, the analysis considered its inclusion.
- **Energy security:** Technologies necessary for system resilience (grid/import shocks). Some technologies may not provide high levels of decarbonisation or economic benefit but are essential in guaranteeing or improving UK energy security and resilience to international disruptions. Where relevant to innovation, such technologies have been considered.
- **UK relevance:** Areas where the UK is likely to have an impact on the development or deployment of the technology. Some technologies/components may provide high economic and decarbonisation opportunities in principle but may not be adequate for UK specific circumstances (e.g. require scales of production the UK cannot match relative to larger countries). In such cases narrower component-level opportunities may still be considered as relevant. Additionally, some technologies with high potential are already receiving extensive attention from industry with significant sums dedicated to R&D. In such cases public R&D funding is of lower priority.
- **Technology Readiness Level (TRL):** Technologies or sub-technologies / components, that are close to commercialisation, approximately TRLs 7-9, and technologies which have limited likelihood of being commercially viable by 2040, even if promising in the longer term, were generally not considered priorities for the EINAs analysis. The definitions for TRL ratings used were aligned with the definitions used by UKRI.[1]

The shortlisted technologies were then taken forward for an in-depth qualitative analysis of innovation needs, costs and barriers to deployment via a literature review.[2] Additionally, systems modelling and economic analysis was conducted on the selected technologies (methodology presented below).[3]

[1] UKRI (Accessed: 2025) Eligibility of technology readiness levels (TRL)
[2] The networks sub-theme technologies were assessed through stakeholder engagement with support from IUK.
[3] Data for the industrial decarbonisation technologies which informed the economic analysis were sourced from recent DESNZ analysis due to limitations of the system modelling.

System modelling methodology

Introduction

Two models were used to explore the implications of innovation investments on the UK energy system. UK TIMES is an energy system model that covers the whole UK energy system and all UK greenhouse gas (GHG) producer emissions, including those from sources outside the energy system. HighRES is a high-resolution electricity system investment and planning model.

This section describes the key methodological choices that underpin the EINAs system modelling outputs. As the two models were run together, with the aim of combining their outputs to assess the value of innovation, each is described together. The following aspects are examined:

- UK TIMES and HighRES model descriptions
- Model calibration and modifications for EINAs
- Modelling output metrics
- Scenario design and implementation in each model

Models

UK TIMES

UK TIMES is used to identify the most cost-effective pathway to reducing emissions while meeting the UK's energy demands. UK TIMES uses the TIMES framework from the Energy Technology Systems Analysis Program (ETSAP); one of the longest running Technology Collaboration Programmes of the International Energy Agency (IEA)[4]. The model minimises economy-wide discounted system cost over the model time horizon (2010–2060) while adhering to constraints such as the 2050 net-zero GHG emissions target. UK TIMES is an established model, previously used to inform the setting of Carbon Budgets 5 and 6 (and planned for the 7th budget), and many other projects across academia[5] and industry[6].

UK TIMES represents the key demands of the economy, including industry, transport, buildings, and agriculture[7]. It also covers supply sectors such as resource extraction and trade, electricity generation, and fuels processing (including biofuels and hydrogen supply chains), as

[4]The TIMES model code can be found on GitHub. Documentation can be found on the IEA-ETSAP website.
[5] Barrett, J., et al. (2022). "Energy demand reduction options for meeting national zero-emission targets in the United Kingdom." Nature Energy **7**(8): 726-735.
[6] https://ukerc.ac.uk/news/national-grid-uses-uk-times-scenarios/.
[7] Detailed documentation of UK TIMES is available from https://low-energy.creds.ac.uk/7-appendix/.

well as the transport, transmission, and distribution of these energy commodities throughout the energy system. While UK TIMES lacks the granularity of sector-specific models, its system-wide scope enables the analysis of cross-sectoral interactions and supply-demand dynamics that individual sector models cannot capture. This makes it ideally suited for assessing the potential economy-wide value of innovation across 20 technology families, modelling their individual and combined impact under three different potential future developments for the UK energy system.

HighRES

HighRES is a high temporal and spatial resolution power systems model used to design cost-effective, flexible and weather resilient electricity systems for Great Britain and Europe. The implementation of HighRES used for the EINA analysis is based on that used previously in Price et al. (2023)[8], which covers the UK disaggregated into 9 zones, and a further 27 European countries aggregated into an additional 9 zones. HighRES[9] is a least-cost optimisation model of the power system which simultaneously optimises spatially-explicit annualised investment costs in each of the 18 zones, and hourly dispatch, for a whole year of operation. It represents transmission and interconnection between these zones, and cost-optimal bidirectional trade between countries. In addition, HighRES also schedules the provision of hourly frequency response and operating reserve by thermal generators and storage technologies, accounting for technology restrictions such as ramping and unit commitment if required. It is specifically designed to analyse the effects of high shares of variable renewables and explore integration and flexibility options. It uses data for onshore wind, offshore wind, and photovoltaic radiation, to inform capacity deployment of variable renewables.

Model calibration and modifications

UK TIMES

A new version of the UK TIMES model was developed for the EINA analysis, which involved a carefully managed integration of recent model versions evolved from multiple projects across UCL and DESNZ. This version is similar to UK TIMES v1.5 but included a range of additional DESNZ data assumptions and constraints. This rigorous merging process ensured the model reflected the most recent model developments and available data. Additionally, several model-wide calibrations, updates to existing cost and efficiency data, and the incorporation of new technologies were implemented specifically for the EINA analysis, as detailed below.

[8] Price, J., I. Keppo, and P.E. Dodds, “The role of new nuclear power in the UK's net-zero emissions energy system.” Energy, 2023. **262**: p. 125450.
[9] HighRES formulation model is available at https://doi.org/10.1016/j.softx.2022.101003

Calibration and base assumptions

UK TIMES models a time horizon from 2010 to 2060. To increase the applicability of the scenarios, the model was calibrated to align with historical data up to 2020 where possible. This included (but was not limited to) calibrating:

- The production, imports and exports of fossil fuel (oil, natural gas and coal) for their use across the energy system, including for electricity generation.
- All existing electricity generation and storage (i.e., short-term storage batteries and pumped hydro) capacities.
- Deployment of heat pumps for buildings.
- Deployment of battery electric vehicles for road transport.
- Use of oil products in non-domestic buildings.

Additionally, the analysis reflected maximum and minimum deployment levels allowed in the future for certain technologies to align with the UK government's expectations up to July 2024, which differed from the results generated by least-cost optimisation in UK TIMES. This included (but not limited to):

- Building a minimum level of nuclear reactors to match the "lower electrification" scenario Dynamic Dispatch Model (DDM), including a minimum new nuclear capacity build in 2030 (Hinkley Point C), 2035 (Sizewell C and others) and in 2045.
- Building a minimum amount of onshore wind from 2030 and onwards, at least meeting the levels in the DDM's "lower electrification" scenario.
- Limiting biomethane produced from anaerobic digestion to a maximum level of 10 TWh in 2030, then setting a 1.5 TWh maximum annual growth in 2030-2035.
- Excluding hydrogen for heating in new residential houses.
- Limiting the level of heat networks deployed for domestic and non-domestic buildings across the modelled time horizon. In 2030, deployment is capped at 12 TWh for domestic buildings and 13 TWh for non-domestic buildings. From 2035 onwards, a minimum deployment level of 25 TWh is imposed for non-domestic buildings. In addition, maximum deployment levels for all buildings are set at 40 TWh in 2035, 54 TWh in 2040, 69 TWh in 2045, and 81 TWh in 2050.
- Limiting the deployment of blue hydrogen in 2025 to 50% of total hydrogen production then lowered this limit over time to 40% in 2050.

Data for existing technologies were updated to the latest available figures, where applicable, including capital costs and coefficient of performance (COP) for air-source heat pumps, costs for conservation measures (such as wall, loft, and floor insulation), and data for existing pressurised water nuclear reactors.

Additions and modifications to the base model for the EINA analysis

Several technologies were introduced into UK TIMES as part of the EINA analysis and were implemented using the low innovation level assumptions from the EINA dataset. These technologies are:

- Floating offshore wind.
- Nuclear Gen 4 High Temperature Gas-Cooled reactors (HTGR).
- Nuclear Small Modular Reactors (SMR).
- 4-hour duration lithium-ion batteries for electricity storage.
- Solid-Oxide Electrolyser Cells (SOEC) for hydrogen production.
- Ground Source Heat Pump (GSHP) for heat networks for different housing archetypes.

Additionally, a new set of technologies for low-carbon fuels and chemicals production, sourced from Kim et al., (2024)[10], was integrated into the core UK TIMES model version. This includes pathways to produce synthetic jet fuels, diesel, and feedstocks for the chemicals sector, derived from biomass pellets, municipal solid waste, or hydrogen with captured CO2. Bio-based pathways have the option to be built with or without CCS units. The biomass-to-fuels process with CCS from this recent integration is included in the “BECCS” EINA technology family as the BECCS-fuel technology. As a large proportion of the capital costs and efficiency losses for BECCS for hydrogen and BECCS for fuels production technologies are associated with gasification units, the techno-economics and plant scale for these two technologies were appropriately proportioned to ensure modelling consistency.

Several versions of some technologies are defined in UK TIMES. These often include an assumed level of innovation in the future that reduces costs (e.g., four different type of DAC technologies). Some of these technologies were included in the EINAs analysis. However, there was concern that those not covered by an EINA might be unintentionally deployed if they are low-TRL technologies and are assumed in the base version of UK TIMES to have a higher rate of innovation in the future than would be consistent with a low innovation scenario. To address this, several UK TIMES technologies were disabled. This included DAC technologies, which were reduced from four to two, as well as some short- and medium-term electricity storage technologies, that were not examined in the EINAs analysis.

Some EINA innovation assumptions would affect technologies that were not analysed in the EINAs, so steps were taken to ensure the data assumptions were consistent where necessary. For example, the cost and performance assumptions for retrofit BECCS-electricity and retrofit natural gas reforming for hydrogen production technologies were updated to align with their counterparts without retrofits that used EINA data.

[10] Kim, S., et al. (2024). "Technoeconomic characterisation of low-carbon liquid hydrocarbons production." Energy 294: 130810.

UK TIMES represents thousands of existing and future technologies across the economy. It was not feasible to exhaustively review the assumed innovation level for every technology not covered by the EINA analysis. While reasonable steps were taken to align innovation levels for EINA technologies and closely related alternatives, some residual risk remains that the overall technology mix across the modelled time horizon could be influenced by assumptions that could not be fully harmonised. In practice, these risks exist for all models covering the wider economy, given their scale and complexity.

HighRES

Calibration with UK TIMES scenarios

HighRES was calibrated to represent the Minimally Constrained and High Diversification scenarios modelled in UK TIMES. For each scenario, HighRES was run for the years 2035 and 2050. The data in Table 1 was extracted from each UK TIMES scenario to represent the respective scenarios in UK TIMES, for the years 2035 and 2050, and implemented in HighRES as constraints or data assumptions.

Table 1: UK TIMES inputs and outputs used in HighRES

UK TIMES data (Inputs or Results)	Included in HighRES as:
Inputs: Cost assumptions for generation and storage technologies	Input cost assumptions. Investment costs in HighRES are annualised.
Results: Electrification of service demands	Included in HighRES as exogenous annual electricity demands.
Results: Electricity grid carbon intensity	Included in HighRES as electricity grid carbon intensity maximum bound.
Results: Capacity of generation technologies	Included in HighRES as minimum bounds for total generation technologies.
Results: Marginal values for commodities	Included in HighRES as commodity costs.
Results: Hydrogen use in the electricity sector for each scenario	Included in HighRES as an upper bound for hydrogen use in standalone hydrogen CCGT and OCGT generation technologies

Load profiles

Electricity demands for HighRES for each scenario and modelled year were obtained from UK TIMES, as shown in Table 1. Hourly annual demands were based on the method detailed in Price et al. (2023)[11], where 2012 profiles are obtained from metered data from Open Power System Data[12], and disaggregated into temperature dependent and independent portions. The

[11] Price, J., I. Keppo, and P.E. Dodds, The role of new nuclear power in the UK's net-zero emissions energy system. Energy, 2023. 262: p. 125450.
[12] Open Power System Data. 2020. *Data Package Time series*. Version 2020-10-06 https://doi.org/10.25832/time_series/2020-10-06

weather-independent profiles were then augmented with an assessment of hourly electrified heat, ensuring that the weather profile driving variable renewables supply and heat demand were consistent.[13] They were then augmented by electrified transport demands, based on optimised profile shapes from the Flexibility in Great Britain project[14], which assumed 85% of vehicles can shift their demand away from peak times or into times of high renewables output, with, in 2050, 25% also capable of discharging into the grid.

Modelled technologies and existing capacities

The version of HighRES used in this project represents 17 generation technologies, 6 storage technologies and synchronous condensers. Table 2 shows the generation and storage technologies modelled in HighRES. UK TIMES generation technologies were grouped into HighRES generation technologies and minimum capacities of each technology were imposed, as shown in Table 1. Storage technology capacities were left unbounded for the model to optimise, except for pumped hydro storage, for which power and energy capacities were fixed using assumptions provided by DESNZ.

Table 2: Generation and storage technologies modelled in HighRES.

Generation technologies	Storage technologies
Hydrogen CCGT	H2-Salt-OCGT: Long-term storage technology representing a PEM electrolyser, salt cavern storage, and a hydrogen OCGT, modelled as a unit.
Hydrogen OCGT	H2-Salt-CCGT: Long-term storage technology representing a PEM electrolyser, salt cavern storage, and a hydrogen CCGT, modelled as a unit.
Natural gas CCGT with CCS	Li-ion-1: 1-hour storage Li-Ion battery
Natural gas CCGT	Li-ion-4: 4-hour storage Li-Ion battery
Natural gas OCGT	Pumped Hydro storage
Biomass	CAES: 24 hour compressed air energy storage.
Biomass with CCS	
Solar	
Tidal	
Wind offshore	
Wind onshore	
Hydro run-of-river	
Hydro reservoir	
Nuclear EPR – Nuclear PWR representing Hinkley Point C	
Nuclear SW – Nuclear PWR representing Sizewell C	
Nuclear HTGR	
Nuclear SMR	

In addition to nodal renewable capacity constraints detailed in Representation of nuclear generation section, two further feasibility constraints informed by DESNZ were added in

[13] Price, J., I. Keppo, and P.E. Dodds, The role of new nuclear power in the UK's net-zero emissions energy system. Energy, 2023. 262: p. 125450.
[14] Flexibility in Great Britain | The Carbon Trust

HighRES for all scenarios in 2035. First, total CAES storage power capacity could not exceed 5 GW. CAES cavern storage for up to 24 hours at full power was assumed. Second, the sum over all hydrogen-to-power capacities could not exceed 7.5 GW. These technologies included both standalone hydrogen OCGT/CCGT and the long-term storage units H2-Salt-OCGT/OCGT.

Standalone hydrogen OCGT and CCGT generation was constrained in HighRES so that the available hydrogen could not exceed what was consumed by the electricity sector in each UK TIMES scenario (Table 1). Any additional hydrogen use needed to be produced within HighRES through the long-term storage deployment options which included PEM electrolyser capacity, salt cavern storage, and hydrogen OCGT/CCGT capacities.

Representation of nuclear generation

HighRES has the option of defining existing capacities of technologies. Their CAPEX is then not included into the objective function. Nuclear EPR, nuclear SW, and pumped hydro (see Table 2) were represented as existing capacities so their CAPEX was not included in the objective function. Locations and capacities for nuclear EPR and nuclear SW were fixed and informed by DESNZ. Additionally, for each UK TIMES scenario, all remaining capacities in 2035 and 2050 of old technologies – those already operating in 2010 – were included as existing capacities in HighRES.

Nuclear HTGR and Nuclear SMR are considered as new capacities and are added into the objective function. Locations for SMR and HTGR capacities were implemented according to DESNZ provisional expectations at the time of analysis (‘nodes’ are described in the section below):

- For 2035, the model is free to allocate SMR capacities into nodes 7 and 8. It always chooses node 7.
- For 2050, SMR capacity from 2035 is fixed into node 7, and the model is left free to allocate new SMR capacity between nodes 4, 5, and 8.
- The model is free to allocate nuclear HTGR in nodes 4, 5, 6, 7, and 8.

Nodal capacity constraints for variable renewables in HighRES

To account for feasibility constraints for renewable deployment in HighRES, data from NESO’s Future Energy Scenarios (FES) 2024[15] was incorporated as nodal constraints in HighRES.

For solar, onshore wind and offshore wind, renewable capacities from FES’s Counterfactual Scenario in 2030 were used as HighRES minimum capacities per node in 2035. For 2050, HighRES 2035 results were imposed as nodal renewable minimums. For maximum capacities per node, FES maximum nodal wind/PV capacities across all scenarios in 2050 were used to

[15] FES 2024 Data workbook, available at https://www.neso.energy/publications/future-energy-scenarios-fes

limit HighRES in both 2035 and 2050. Figure 2 shows FES areas, HighRES areas, and an overlay of both.

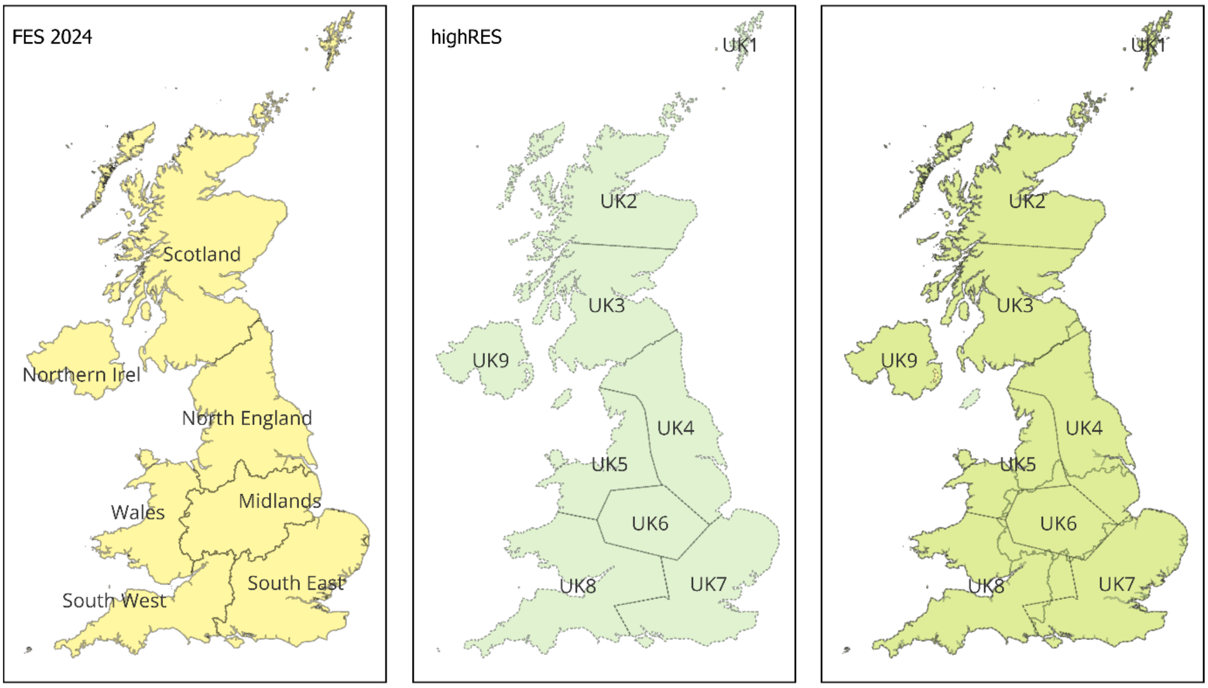

Figure 2: FES 2024 areas, HighRES areas, and overlapped areas

Because the areas in FES and HighRES do not exactly match, the assumptions presented in Table 3 were made for constraining minimum and maximum HighRES generation capacities using FES data.

Table 3: Assumptions for matching FES and HighRES areas

HighRES area	FES areas used for HighRES minimum capacity constraints	FES areas used for HighRES maximum capacity constraints	Detail
UK1	-	-	-
UK2 **UK3**	Scotland	Scotland	The sum of UK2 and UK3 in HighRES is equivalent to Scotland in FES. Scotland data in FES is used for min/max capacity constraints.
UK4 **UK5**	North England	North England + Wales + Midlands	UK4 and UK5 in HighRES spread over North England, a part of the Midlands, and a part of Wales. North England's FES data is used as minimum capacity for UK4+UK5, and the sum of North England, Wales, and Midlands is used as the maximum capacity.

UK6	0.5 Midlands[16]	Midlands	UK6 falls within what in FES is the Midlands. FES Midlands data is used as maximums, and half of the Midlands's capacity in FES is used as minimums.
UK7	South East	South East	UK7 is very similar to the South East in FES. The South East in FES is used for min/max capacity constraints for UK7.
UK8	South West	South West + Wales	UK8 in HighRES spreads over the South West and half of Wales in FES. South West capacities are used for minimums, and South West + Wales are used to constrain the maximum capacities.
UK9	-	-	-

This approach yields the following capacity bounds for HighRES nodes:

Table 4:HighRES nodal minimum and maximum wind and solar capacities

HighRES areas	Minimum capacities [GW]			Maximum capacities [GW]		
	PV	Onshore Wind	Offshore wind	PV	Onshore Wind	Offshore wind
UK2+UK3	1.2	15.8	5.6	8.9	23.7	43.3
UK4+UK5	4.0	2.0	12.1	53.9	16.9	33.4
UK46			0.4			
UK6	2.6	0.3		24.8	2.8	1.4
UK7	4.3	0.6	8.5	23.1	1.8	18.0
UK8	5.5	0.4	0.0	30.4	8.5	12.9
Total	17.6	19.2	26.7	141.1	53.6	109.0

Transition from 2035 to 2050

The EINA scenarios that were developed using UK TIMES were represented in HighRES using the input assumptions listed in Table 1. In addition to using generation technologies' capacities obtained from UK TIMES as minimum capacity constraints for HighRES in 2035 and 2050, the transition between 2035 and 2050 in HighRES was represented by specifying minimum bounds for technologies in 2050 based on investments in the HighRES 2035 runs. These included nodal renewable capacities obtained in HighRES in 2035, as explained in the Load profiles section above, and transmission capacities. Transmission capacities per technology between nodes were obtained for each HighRES 2035 run and used as minimum transmission capacities between nodes in 2050.

[16] UK6 in HighRES is landlocked. Midlands's offshore wind capacity was assigned to UK4.

Modelling output metrics

UK TIMES outputs

The analysis included 20 EINA technology families, each with three innovation levels. Data for each innovation level was collected and prepared using the most recent literature available on the target technologies at the time of analysis.

The innovation levels were broadly defined as follows:

- Low innovation: represented the lower bounds of expected performance improvements and cost reductions over time for the technologies considered. Innovation was still assumed where supported by literature and sector experts from the EINA consortium. In specific cases, limits were applied to technologies to reflect expectations under a state of low innovation (e.g. a maximum of 18 Mt of CO2 capture via DAC in 2050). These instances were noted in the system benefits sections of the relevant EINA technology theme reports.
- Medium Innovation: reflected an increase in performance improvement and cost reductions over time compared to the low innovation level. These estimates generally aligned with central projections found in the literature and were selected based on sector expert judgement. Technology-specific limits applied under low innovation were removed or replaced.
- High innovation: represented higher levels of expected performance improvements and cost reductions, as reported in the literature. Sector expert judgement was used to ensure feasibility within the UK context. Outlier estimates were excluded; therefore, this level does not necessary correspond to the highest levels of performance improvement and cost reduction projections found in the literature.

The "all low innovation" scenario assumed low innovation for all families. The impact of innovation was assessed for each family individually at medium and high innovation levels, as well as two additional runs examining the collective impact of innovation across all families at these levels. This resulted in 40 runs for individual technology families and 3 combined runs across innovation levels, repeated for three core scenarios, amounting to 129 UK TIMES sensitivity runs.

Due to the large number of runs, the process of generating input scenario files, running UK TIMES scenarios, processing outputs, and summarising the important output metrics was automated. Table 5 shows the output metrics extracted or produced through post-processing for the EINA analysis.

Table 5: UK TIMES output metrics

Output metric	Description	Units
Technology deployment	Technology-specific generation	TWh for all technologies, except DACCS and geological storage, which are in Mt.

Output metric	Description	Units
	Technology-specific capacity	GW for electricity and hydrogen generation technologies (including all BECCS), Mt for DACCS and geological storage, and TWh for all other technologies.
	Combined generation of technology family	TWh for all technologies, except DACCS and geological storage, which are in Mt.
	Combined capacity of technology family	GW for electricity and hydrogen generation technologies (including all BECCS), Mt for DACCS and geological storage, and TWh for all other technologies.
Technology levelised cost	Levelised costs of producing a unit (output unit) of product	£ (2022)/MWh for all technologies, except DACCS and geological storage, which are in £(2022)/t.
Innovation value	The differences in the total undiscounted annualised costs by period (2025, 2030, 2035, 2040, 2045 and 2050) against the counterfactual, or the reference scenario in which all EINA technologies assume low innovation. Additionally, the discounted and the undiscounted cumulative reduction in the total system costs (2025-2050). For the latter, using an economy-wide discount rate of 3.5% per year.	£ billion (2022)
Greenhouse gas emissions price (or the carbon price)	These prices reflect the change in the undiscounted total system cost caused by either emitting or avoiding one unit of greenhouse gas.	£/t CO2e

HighRES outputs

Table 6 shows the output metrics produced for each HighRES run.

Table 6: HighRES output metrics

Metric family	Metric description	Units
UK system metrics	Total UK annualised system cost	£m2010
Zonal technology costs	CAPEX per technology and node	£m2010
	OPEX per technology and node	£m2010
Deployment	Existing/New/Total generation capacity per technology per node	GW
	Existing/New/Total storage power capacity per technology per node	GW
	Existing/New/Total storage energy capacity per technology per node	GWh
	Total transmission capacity between nodes	GW
Generation and capacity factor	Annual generation and capacity factor per technology per node	GWh and fraction
System inertia	Average inertia provided per technology per zone	GWs per Hz
	Maximum inertia provided per technology per zone	GWs per Hz
	Minimum inertia provided per technology per zone	GWs per Hz
System frequency response	Average hourly frequency response provided per technology per zone	GW
	Maximum hourly frequency response provided per technology per zone	GW
System reserve	Average hourly system reserve provided per technology per zone	GW
	Maximum hourly system reserve provided per technology per zone	GW

Scenario design and implementation in each model

To examine the sensitivity of the EINA technology family innovation values to the future development pathway of the UK's energy system, three plausible net-zero scenarios were developed:

- Minimally Constrained (MC)
- High Hydrogen (HH)
- High Diversification (HD)

As mentioned earlier, a range of DESNZ data assumptions and constraints were used in all scenarios. All three scenarios were developed in UK TIMES as described in 'Model calibration and modifications' sections. The implementation in HighRES is described in the same section.

Minimally Constrained scenario

The Minimally Constrained scenario was designed to show the largest potential impacts from innovation investments by minimising the number of constraints on the energy system.

UK TIMES was free to cost-optimise the conversion of existing homes[17] to use hydrogen for heating. Even where the gas network was repurposed to use hydrogen, households were not required to fit hydrogen heating devices. For example, it was cost-optimal for some households to adopt hydrogen heating during the gas repurposing programme in the 2030s but then to change to electric heating in the period 2050–2060. Hydrogen use for heating non-domestic buildings was excluded to further differentiate this scenario from the High Hydrogen scenario, introduced below.

High-temperature gas-cooled reactors (HTGR) were assumed to be unavailable in all low innovation scenarios in this analysis.

Future domestic oil and gas extraction aligned with estimates from the North Sea Transition Authority (NSTA),[18] which indicate a long-term production decline.

High Hydrogen scenario

The High Hydrogen scenario is based on the Minimally Constrained scenario, with a range of constraints added to force hydrogen use across the economy. These constraints were based on estimates of H2 demand ranges in the DESNZ hydrogen transport and storage networks pathway policy paper published in 2023,[19] further adjusted based on the hydrogen production cost estimates available as of late 2024. Table 7 shows the maximum hydrogen consumption

[17] Those built before 2010, which is the first modelled year in UK TIMES. Homes built from 2011 were assumed to not use hydrogen.
[18] https://www.nstauthority.co.uk/data-and-insights/insights-and-analysis/production-and-expenditure-projections/
[19] https://www.gov.uk/government/publications/hydrogen-transport-and-storage-networks-pathway

in each sector and a minimum overall level of consumption that were applied in each year from 2035 to 2050.

Table 7: Constraints on hydrogen consumption and electricity generation capacity in the High Hydrogen scenario

	TWh					GW		
	2030	2035	2040	2045	2050	2030	2035	2050
Industry maximum	N/A	15	30	45	60			
Electricity generation maximum	1	8	25	50	70	1	7	55
Heat maximum	0	5	30	48	60			
Of which non-domestic maximum	0	1	5	8	10			
Transport maximum	4	14	24	42	71			
All sectors minimum	N/A	35	90	170	235			

High Diversification scenario

The High Diversification scenario is based on the Minimally Constrained scenario. The scenario aims to have a high level of energy security through two approaches:

- Limiting imports of key commodities to reduce UK reliance on overseas resources.
- Diversifying resource and technology use across the economy to limit the impacts of any supply interruptions, price rises or technology failures.

Net imports of oil, natural gas and coal were limited as a function of consumption. Electricity imports were limited as a function of exports. Total imports were limited as a function of total primary energy production. These limits used in the High Diversification scenario, imposed for the period 2030 to 2050, are listed in Table 8. Coal imports are not restricted but the use of coal in the economy is limited to current levels for the future. Electricity imports are restricted to be the same or lower than electricity exports to both continental Europe and the Republic of Ireland.

Table 8: Constraints on imports in the High Diversification scenario

	2030	2035	2040	2050	% descriptor
Total imports must not exceed	80%	40%	20%	20%	of total primary energy production (treating uranium for nuclear power as domestic)

Net imported oil must not exceed	75%	75%	60%	50%	of total oil refinery consumption
Net imported gas must not exceed	80%	60%	40%	40%	of total gas consumption
Net imported coal must not exceed	100%	100%	100%	100%	of total coal consumption
Electricity imports from continental Europe must be less than	100%	100%	100%	100%	of ELC exports to Europe
Electricity imports from the Republic of Ireland must be less than	100%	100%	100%	100%	of ELC exports to the Republic of Ireland

Electricity is expected to power most end-use technologies in the future so the approach to diversification focuses on electricity generation. In contrast to the import limits, diversification is based on generation capacities rather than commodity flows, as the availability of spare capacity would minimise the impacts of interruptions to any part of the generation portfolio. Commodity flow limits would be more appropriate if the focus were potential long-term high feedstock prices.

As several renewable generation technologies have low capacity factors, total electricity generation capacity is likely to increase in the future. For this reason, the capacities in the diversification constraints were derated to reflect their expected available capacity at the peak generation period – so for example, only around half the capacity of offshore wind is considered available at peak times in the constraint. Table 9 shows the maximum "peak" capacities for each group of electricity generation technologies in the High Diversification scenario, as a function of total electricity generation peak capacity.

Table 9: Fraction of capacity of each technology assumed to contribute to peak generation

Capacity limits	2030	2040	2050
Natural gas	40%	25%	25%
Solid biomass, excluding waste	25%	25%	25%
Coal	10%	10%	10%
Oil	10%	10%	10%
Manufactured fuels	10%	10%	10%
Renewables (wind, solar, wave, geothermal and hydro)	75%	75%	75%
Wind	50%	50%	50%
Nuclear	25%	25%	25%
Hydrogen	50%	35%	25%

To align with DESNZ feasibility expectations, the High Diversification scenario has a maximum cumulative capacity constraint of 24 GW for nuclear by 2050 and a maximum cumulative capacity for solar of 10% higher than the Minimally Constrained scenario capacity. Deployment of new coal- and oil-based electricity generation are not permitted in this scenario.

To prevent the model from building excessive capacity in other technologies due to the constraints in the High Diversification scenario, a minimum availability factor is set: 25% for CCGT and 4% for all other existing and new power plants. Geothermal electricity is assumed to become available from 2035 as no current projects are in development.

As in the Minimally Constrained scenario, hydrogen heating for non-domestic buildings is excluded in the High Diversification scenario.

HighRES implementation

The Minimally Constrained and High Diversification scenarios were implemented in HighRES for all electricity technologies at low, medium and high innovation levels. The general procedure for implementing each scenario was:

- Obtaining the data in Table 1 from UK TIMES for 2035 and 2050.
- Generating load curves for 2035 and 2050, assuming 2012 as the weather year.
- Implementing the constraints specified in the HighRES section, for both 2035 and 2050.

As the Minimally Constrained scenarios in UK TIMES have no hydrogen used in the electricity sector, deployment of standalone hydrogen OCGT and CCGT capacities were fixed to zero for all Minimally Constrained scenarios in HighRES. For the High Diversification scenarios in HighRES, the use of hydrogen for electricity generation in standalone OCGT/CCGT was constrained by UK TIMES hydrogen production for the electricity sector in each run.

For the four EINA storage technologies (Li-Ion-4, CAES, H2-Salt-OCGT and H2-Salt-CCGT), individual runs for each innovation level were implemented, for 2035 and 2050, for both the Minimally Constrained and High Diversification scenarios. These individual runs considered all technologies at low innovation levels, except for the individual EINA storage technology which was varied across Medium and High Innovation levels. These runs were used to inform the innovation value of individual storage technologies compared to the respective base scenario with all technologies at low innovation levels. It is important to note that for the individual runs, the only element that was varied was the cost data for the individual technology. Load curves, weather data, and data extracted from UK TIMES were kept constant at the base scenario values.

Finally, the whole procedure was repeated for a “bad weather” year that had high demand in winter at the same time as low renewable generation (2010). The weather year influences the temperature-dependent parts of the load curves (see HighRES section) and the weather data used to estimate hourly renewable capacity factors.

Business opportunities methodology

Introduction

To distinguish from the methodology used in the 2019 EINAs, this section will refer to the previous methodology as EINAs 1.0, and this iteration as EINAs 2.0.

The EINAs 2.0 business opportunities calculators aim to provide insights on the gross value added (GVA) and jobs that might be supported by key innovative energy technologies expected to help deliver the UK's commitment to net zero.

For each technology covered in EINAs 2.0, scenarios for domestic deployment and technology costs (typically from UK TIMES)[20] are combined to generate an estimate of the size of that technology's market in the UK. Where reliable estimates are available, the calculators also estimate the potential size of global markets for the same technology, based on estimates of deployment and technology costs sourced from literature.

UK-based firms are unlikely to service the entirety of its domestic market and will only service a portion of the global export market. To account for this, estimates of UK-based firms' market shares in each market are used to determine the size of the markets that UK-based firms are expected to access. The total market size multiplied by the UK's expected market share determines how much UK-based turnover might be supported because of the deployment of the technology in the UK and overseas.

Drawing from these turnover estimates, the primary outputs of the calculators are GVA, direct jobs and indirect jobs. The estimates for the number of direct jobs supported are also broken down by occupation (by SOC code).

Estimating the future economic impact of innovative energy technologies, many of which have little or no current deployment, is an exercise which comes with a high degree of inherent uncertainty. As a result, this methodology should not be interpreted as a forecasting exercise. Instead, it is an attempt to help inform UK government decision making by providing an illustrative, but evidence-based, indication of the scale of the opportunities for UK businesses that could be associated with certain illustrative energy system scenarios. In addition to whether or not the future of the UK and global energy system will evolve in a manner consistent with the scenarios used, a crucial source of uncertainty concerns the ability of UK firms to achieve the assumed market share of domestic and global markets. This will depend on a wide range of factors including the competitiveness of UK firms, the pace of technological innovation, government policy support, and international market dynamics. Continued investment in skills, infrastructure, and research will be essential to enhance the UK's ability to capture these potential opportunities.

[20] The data for the energy storage technologies are derived from the highRES model, and the industrial decarbonisation data is derived from recent DESNZ analysis at the time the current EINAs were being developed..

The findings do not reflect UK government policy or ambition.

The calculators cover the time horizon from 2020 to 2050 and, unless otherwise specified, monetary values refer to 2022 GBP.

This methodology sets out step by step explanations of inputs, outputs and calculations for a typical EINAs 2.0 technology.

Calculator schema

The calculator schema displays how data inputs and assumptions are combined to calculate 'calculated variables' (intermediate outputs) and, eventually, the calculators' primary and secondary outputs related to jobs and GVA.

Inputs

The calculators have four sets of inputs:

- Technology deployment scenarios – Deployment and technology cost series
- Cost component breakdown – the breakdown of the technology costs into constituent components and the definition of these components
- Data – Economic, trade and technical data
- Assumptions – Modelling and technical assumptions

Technology deployment scenarios

As discussed above, the calculators typically consider two markets, the UK market and the RoW market. For both markets, the calculators rely on scenarios for the future deployment and costs of each technology to determine the size of a technology's potential market.

The units of these deployment and cost series vary across technologies. For example, for an electricity generation technology like offshore wind, deployment is in GW and costs in terms of £/MWh. For direct air carbon capture and storage (DACCS) on the other hand, deployment is in MT of carbon capture capacity and costs on a £/tonne CO2 captured basis.

The sources of the deployment and cost series used in the first iteration of the EINAs 2.0 calculators are set out below. However, the calculators have been designed so that these inputs can be easily replaced by alternative deployment and cost scenarios.

UK deployment scenarios

Scenarios for future UK deployment of the EINAs 2.0 technologies are typically informed by systems modelling results (principally UK TIMES). For a typical EINAs 2.0 technology, the systems modelling estimates deployment and technology costs in 9 illustrative scenarios. These scenarios are combinations of energy system scenarios with different assumed levels of technological innovation. The 9 scenario combinations are set out below:

Minimally constrained:

- Low innovation
- Medium innovation
- High innovation

High hydrogen:

- Low innovation
- Medium innovation
- High innovation

High diversification:

- Low innovation
- Medium innovation
- High innovation

The System modelling methodology section above provides more information on the approach used to model the illustrative energy system scenarios used in the calculators.

International deployment

For international deployment and costs, only one scenario per technology was used throughout. The scenario used varies slightly between technologies as a result of data availability but, typically, is drawn from scenarios that the scenario developer considers to be consistent with the temperature goals of the Paris Agreement.

For most technologies, data for future costs and deployment could be taken directly from the literature but, for certain more novel technologies in EINAs 2.0, it was necessary to apply additional assumptions or adjustments.

See Appendix for the sources of the estimates of future international deployment and costs and explanations of any data manipulations required.

Cost component breakdown

The aggregated costs associated with a technology are made up of a number of cost components. These components reflect the different activities associated with the CAPEX, OPEX and decommissioning phases of a typical asset for that technology. Each activity (cost component) will have different characteristics in terms of, for example, productivity, the market share of UK firms, or employment intensity. The breakdown of the cost categories for each technology was based on the insight of sector experts and the availability of cost data.[21]

The first way in which different characteristics were assigned to each cost component was by matching each cost component to the 6-digit HS trade code judged to be most relevant for that component and, through the use of statistical correspondence tables, to an associated 4-digit SIC industry code. The allocated 6-digit HS code informs the calculation of the UK's current market share (See Appendix 2); the 4-digit SIC code is used to estimate the ratio of GVA to turnover and the number of jobs per £ of GVA. See Appendix 6 for the full list of HS and SIC code matches.

In addition, each cost component is a) assigned a cost category and b) determined to be an energy component or not. The assignment of a cost category (CAPEX, O&M, decommissioning or other) is necessary as the economic activity associated with that cost category will take place at different times over an asset's life: CAPEX costs are typically

[21] The breakdown was only done to the level of disaggregation for which it was possible to identify a corresponding cost breakdown in the literature.

incurred in the 5-to-10-year period prior to deployment, O&M costs are incurred from the point of deployment until the end of the asset's useful economic life and decommissioning costs (if relevant) are met in the 5 to 10 year period following the end of the asset's economic lifetime. Energy component identification allowed these cost components to be excluded from the EINA's 2.0 calculators. They were excluded for two reasons:

- To avoid double counting. The electricity and hydrogen inputs used by some EINAs 2.0 technologies could be the outputs of other EINAs 2.0 technologies. For example, some of the electricity expected to be used to produce hydrogen through electrolysis will be produced by offshore wind, tidal stream, nuclear generation technologies for which the calculators provide job and GVA estimates. Likewise, some of the hydrogen expected to be used in hydrogen turbines will be produced by electrolysers, BECCS (H2) and autothermal reforming. Counting the jobs and GVA supported by electricity and hydrogen production when it is both being generated and used could mean counting that economic activity twice. By excluding energy inputs within the use technology, analysts are able to sum the number of jobs/GVA supported across the EINAs 2.0 without risk of double counting.
- In this version of the business opportunities calculators, only one cost breakdown (percentage of costs by component) can be applied per technology over time. The volatility of many energy prices makes the assumption that the cost breakdown is constant over time difficult to justify. The exclusion of energy costs removes this concern.

The energy inputs whose costs are excluded across the calculators are hydrogen, electricity, biomass and natural gas.

Data

Economic and trade data

The economic and trade data housed in the calculator's data sheets is, typically, sourced from the ONS and COMTRADE. The particular series and the relevant URLs are set out in the table below.

Table 10: Summary of economic and trade data

Variable	Identifier	Units	Latest year(s)	Source[22]
Turnover	4-digit SIC	£ millions	2018-2022	ONS: Annual Business Survey, Non-financial business economy, UK: Sections A to S
GVA	4-digit SIC	£ millions	2018-2022	

[22] For jobs by SIC by SOC, the URL provided here is for the latest version of this data publicly available (Jul-23 to Jun-24). For calculator development, ONS provided a bespoke data set covering the calendar year of 2023.

Employment	4-digit SIC	# of Jobs	2018-2022	ONS: Business Register and Employment Survey
Value of imports by market	6-digit HS	$ millions	2021-2023	COMTRADE: Trade data
Jobs by SIC by SOC	4-digit SIC	# of jobs	2023	ONS: 4-digit occupational coding (SOC) by age, highest qualification, sex, 4-digit industry (SIC), and ITL3 region, UK
Type I employment multiplier	2- to 4-digit SIC	N/A	2019-2020	ONS: Employment multipliers and effects in the UK

Technical data

The technical data for each technology are sourced from reviews of the academic and grey literature. More established technologies, with a denser literature, tend to have more robust assumptions and data.

The technical assumptions and data points used in a typical EINAs 2.0 calculator are set out below.

Table 11: Summary of technical data requirements

Variable	Granularity	Units	Time horizon
Useful economic lifetime	Technology	Years	Static
CAPEX & decommissioning periods[23]	Technology	Years	Static
Capacity factor series	Technology	%	2000 - 2050
Breakdown of technology costs by cost component	Component	%	Static
The UK's market share of domestic and international markets[24]	Component	%	2000 - 2050

[23] The number of years over which CAPEX and decommissioning costs are spread respectively for a typical asset under this technology classification.

[24] See Appendix 2 for more information on market share assumptions.

Technology-specific discount rate[25]	Technology	%	Static

Assumptions

There are two broad categories of assumptions made in the calculators; those used to fill data gaps and those used made for modelling purposes. Assumptions can be made at the calculator, technology or cost component level.

- An assumption made at the calculator level applies to all technologies in the calculator.
- An assumption made at the technology level applies to all cost components of the technology.
- An assumption made at the cost component level applies only to that cost component.

The sets of assumptions made for each calculator have been logged separately. The logs provide a description of each assumption as well as an explanation of where it fits into the calculator. It also provides a rating of the quality and impact of the assumption made and explanations of how these ratings were determined. In combination, the assessments of quality and impact are used to determine the degree of risk which the assumption poses to the reliability of the calculator's estimations. Low quality assumptions with high impacts on the calculation are marked as requiring improvement at the earliest opportunity.

The set of standardised (core) modelling assumptions used across the calculators are set out in Appendix 3.

Calculations

For each typical technology, there are 7 calculation steps. These steps combine the technology deployment scenarios, data inputs and assumptions to determine intermediate outputs and, ultimately, the GVA and jobs and associated breakdowns associated with the technology's deployment.

Deployment

The first step in the calculation is to convert the technology deployment series which report cumulative deployment over time (typically at 5-year intervals) to series of average annual additional deployment.

[25] In UK TIMES, each technology has its own discount rate which reflects the perceived risk associated with the deployment of the technology. In line with this, each technology in the EINAs 2.0 calculators is assigned a technology-specific discount rate.

$$Average\ annual\ additional\ capacity_t = \frac{Cumulative\ capacity_t - Cumulative\ capacity_{t-1}}{5}$$

Annual additional capacity only includes ‘new’ capacity which is in addition to that which was installed previously. Assets have a useful economic lifetime after which they will need to be replaced and so, to get the full picture of the economic activity associated with a technology at a given point in time, it is also necessary to consider how much capacity needs to be replaced and when. Accordingly, total annual added capacity = annual additional capacity + annual replacement capacity where annual replacement capacity in year x is calculated to be the annual additional capacity in year x - y where y is the useful economic life of the technology.

Cost phasing

The calculator’s estimation of the market size associated with a given technology is, in simplified terms, the product of technology deployment (units) and technology costs (£/unit). However, as discussed in the Cost component breakdown section, the costs of different components are incurred at different points in an asset’s life. In the calculators, this is accounted for through a cost phasing step.

The inputs used in this step are:

1. The total amounts of capacity added per 5-year period by market.
2. The technology cost series (see the Technology deployment scenarios section).
3. A technology-specific cost profile table which determines how costs are split between cost categories and how they are profiled over time. These time profiles rely on technical assumptions of useful economic lifetime, cost breakdown by component, typical construction and decommissioning periods and technology-specific discount rates (See Table 11).

When combined, these three inputs can be used to determine how the costs associated with each tranche of capacity addition are spread over time. Where a ‘tranche’ refers to the capacity added over a 5-year period. This is done separately for each cost category (CAPEX, OPEX, decommissioning, etc) relevant to the technology in question and for each market.

The calculation first determines the total spend on each cost category over each 5-year period and then annualises this value (by dividing by 5) to get the average annual cost for the 5-year period.

The calculation works as follows:

- **Step 1:** The total levelised lifetime cost associated with the total amount of capacity added in each 5-year period in each market, is calculated. Total levelised lifetime cost of deployment in 5-year period x = total deployment in 5-year period x * levelised cost per unit of capacity deployed in 5-year period x.

- **Step 2:** The total levelised lifetime cost associated with the total amount of capacity in each 5-year period, in each market, is distributed across cost categories on the basis of how the technology's costs are broken down by component.
- **Step 3:** The breakdowns of total levelised lifetime costs for each tranche (5-year period) by cost category are then profiled over time. This profiling is done on the basis of cost phasing, relative to the year of deployment.
- **Step 4:** The stream of costs for each tranche (5-year period) are divided by 5 to get the average costs per year by cost category over time.

Illustrative example:

10 GW of tidal stream capacity is deployed between 2021 and 2025 (2 GW per year), with a levelised lifetime cost of 4 billion GBP per GW, with an economic lifetime of 25 years and where CAPEX is 60% of the levelised cost, OPEX is 30% and decommissioning is 10%. This 'tranche' of capacity addition would have the following phased costs:

Total levelised lifetime cost associated with deployment between 2021-2025: 10 GW * 4 billion GBP per GW = 40 billion GBP.

CAPEX: 40 billion GBP * 60% = 24 billion GBP total in 5-year period leading to 2025. 24 billion GBP / 5 = 4.8 billion GBP per year in 2025.

OPEX: Using a 5% discount rate[26], 30% PV of OPEX costs implies a cost stream of 11.8% of the levelised cost over each 5-year period of the asset's lifetime[27]. 40 billion GBP * 11.8% = 4.8 billion GBP total per 5-year period. 4.8 billion GBP / 5 = 1.0 billion GBP per year across the asset's lifetime.

Decommissioning: Using a 5% discount rate, 10% PV of decommissioning costs implies a future cost of 24.2% of the levelised cost in the 5-year period following the end of asset's lifetime. 40 billion GBP * 24.2% = 9.7 billion GBP total in 5-year period leading to 2055. 9.7 billion GBP / 5 = 2.4 billion GBP per year in 2055.

Market size

To determine the total market size associated with each cost category at a given point in time, the phased costs for each tranche of deployment need to be aggregated by year. This aggregation gives the total amount spent per year per cost category by market.

[26] In UK TIMES, each technology has its own discount rate which reflects the perceived risk associated with the technologies deployment. In line with this, each technology in the EINAs 2.0 calculators is assigned a technology-specific discount rate.

[27] See Appendix 4 for explanation of time profiling of costs.

The annual costs per cost category by market can then be converted into costs per cost component by market using the distribution of costs by component for each cost category (see Table 11).

The result of this step is the average annual gross turnover assigned to a certain cost component over the relevant 5-year period. As an illustrative example, a value of £1,000,000 for installation in 2025 in the UK means that, across the period 2021-2025, the average annual turnover derived from installation of the deployed assets over that 5 year period is £1,000,000.

UK's market share

The next step in the calculation is to adjust the total market size by market for the share of those markets which UK entities will be able to capture. The total annual market size by component by market is combined with assumptions for UK's market share (Appendix 2).

The output from this step is the total annual turnover captured by the UK by component and by market over time as a result of technology deployment.

GVA

GVA is estimated by applying the component-specific GVA to turnover ratios, sourced from the ONS, to the estimates of the amount of turnover captured by the UK by component calculated in the UK's market share sheet (See Table 10 for data source).[28]

The output from this step is the total annual GVA associated with UK entities by component and by market over time as a result of technology deployment.

Jobs supported

The calculator estimates the number of direct and indirect jobs associated with the EINAs 2.0 technologies. To estimate the number of direct jobs, the component-specific GVA per worker ratios, sourced from the ONS, are applied to the estimates of the amount of GVA supported in the UK by component (See Table 10 for data source). Indirect jobs are estimated by applying the component-specific Type I employment multipliers, sourced from the ONS, to the estimates of the numbers of direct jobs (See Table 10 for data source). The total number of jobs is the sum of direct and indirect jobs.

The outputs from this step are the total numbers of direct, indirect and total jobs supported in the UK by component and by market over time as a result of technology deployment.

Job breakdown

The occupation breakdown is estimated by applying the component-specific occupation distribution, sourced from the ONS, to the number of total direct jobs supported by that

[28] See Appendix 3 for more on modelling assumptions related to this methodology.

component (See Table 10).[29] The calculation determines, for each component, in each market, how many direct jobs might fall under each of 15 occupation categories over time (See Appendix 5 for more information on the 15 occupation categories).

Outputs

Headline results

The calculators provide headline results on the following metrics:

- **Annual deployment in the UK.** This is the estimated amount of capacity installed that year in the UK where capacity installed = capacity added + capacity replaced. The units of deployment vary by technology.
- **Turnover (£ million).** This is the estimated amount of revenue captured by UK-based firms that year as a result of the technology's deployment and operation in the UK and internationally.
- **GVA (£ million).** This is the estimated amount of GVA supported in the UK that year as a result of the technology's deployment and operation in the UK and internationally.
- **Direct, indirect and total jobs (jobs).** This is the estimated number of direct, indirect and total (direct + indirect) jobs supported in the UK that year as a result of the technology's deployment and operation in the UK and internationally.

Note that even in years where there is no deployment of capacity in the UK, there may be estimated economic activity i.e. GVA and direct, indirect and total jobs supported by the operation of existing assets and/or as a result of exports.

Results breakdowns

The calculator also provides the following breakdowns of the GVA and jobs estimates:

- **GVA by market (£ million).** This is a breakdown of the estimated GVA supported in the UK that year as a result of the technology's deployment and operation in the UK and internationally. The breakdown shows an estimation of how much of this GVA is driven by the domestic market and how much will be driven by exports.
- **Jobs by market (jobs).** This is a breakdown of the estimated number of direct and indirect jobs supported in the UK that year as a result of the technology's deployment and operation in the UK and internationally. The breakdown shows an estimation of how many of these jobs are driven by the domestic market and how many will be driven by exports.

[29] See Appendix 3 for more on modelling assumptions related to this methodology.

- **Jobs by occupation (jobs).** This is the estimated number of direct jobs supported in the UK that year as a result of the technology's deployment and operation in the UK and internationally broken down across different occupation types.

Appendix 1: International deployment

The tables below set out the sources and any relevant manipulations required to estimate international deployment and technology costs for the EINAs 2.0 technologies. Networks and industry technologies are excluded from these tables as, due to a lack of data availability, it was not possible to estimate international deployment of the technologies in these calculators.

Table 12: Sources and data manipulations for international deployment series

Technology	Calculator	Source(s)	Manipulation(s)
Offshore wind (fixed)	Offshore wind	4C Offshore	N/A
Offshore wind (floating)	Offshore wind	4C Offshore	N/A
Tidal stream	Tidal	OEE (2021) ETIPOCEAN (2021)	ETIPOCEAN (2021), Page 6 & Figure 8 presents cumulative deployment from 2010 to 2020. For 2030 onwards, Figure 11 of OEE (2021) presents cumulative deployment. For 2025, data is interpolated.
Small modular reactors (SMR)	Nuclear	IEA (2021) DESNZ (2024)	IEA (2021) provides a forecast for total global nuclear capacity. In absence of SMR-specific data, it is assumed the share of global nuclear capacity which is SMR is the same as is forecast for the UK. The share of total nuclear capacity which is SMR in the UK is estimated by combining the systems modelling results for SMR with the total deployment of nuclear forecast for the UK in DESNZ (2024).
High-Temperature Gas Reactors (HTGRs) / Gen IV	Nuclear	IEA (2021) DESNZ (2024)	IEA (2021) provides a forecast for total global nuclear capacity. In absence of HTGR-specific data, it is assumed the share of global nuclear capacity which is SMR is the same as is forecast for the UK. The share of total nuclear capacity which is HTGR in the UK is estimated by combining the systems modelling results for HTGR with the total deployment of nuclear forecast for the UK in DESNZ (2024).
Air-source heat pumps (ASHPs)	Heating and buildings	IEA (2021) Eurostat (2025)	IEA (2021) forecasts deployment of heat pumps over time. The IEA also forecast that roughly 70% of buildings energy

			demand is residential and this analysis assumes that this proportion also holds true for buildings energy demand from heat pumps. Combining these two forecasts, and assuming that the global distribution of heat pump technologies matches that seen in the EU (Eurostat, 2025), and that this distribution remains the same over time, leads to an estimate of international capacity of residential ASHPs.
Ground-source heat pumps (GSHPs)	Heating and buildings	IEA (2021) Eurostat (2025)	IEA (2021) forecasts deployment of heat pumps over time. The IEA also forecast that roughly 70% of buildings energy demand is residential and this analysis assumes that this proportion also holds true for buildings energy demand from heat pumps. Combining these two forecasts, and assuming that the global distribution of heat pump technologies matches that seen in the EU (Eurostat, 2025), and that this distribution remains the same over time, leads to an estimate of international capacity of residential GSHPs.
Water-source heat pumps (WSHPs)	Heating and buildings	IEA (2021) Eurostat (2025)	IEA (2021) forecasts deployment of heat pumps over time. The IEA also forecast that roughly 70% of buildings energy demand is residential and this analysis assumes that this proportion also holds true for buildings energy demand from heat pumps. Combining these two forecasts, and assuming that the global distribution of heat pump technologies matches that seen in the EU (Eurostat, 2025), and that this distribution remains the same over time, leads to an estimate of international capacity of residential WSHPs.
Roof insulation	Heating and buildings	Dataintelo (2025)	CAGR between 2023 and 2032 extrapolated to 2050.
Wall insulation	Heating and buildings	Dataintelo (2025)	CAGR between 2023 and 2032 extrapolated to 2050.

Floor insulation	Heating and buildings	Dataintelo (2025)	CAGR between 2023 and 2032 extrapolated to 2050.
Carbon capture and storage (CCS) (Power)	CCS & GGR	IEA (2023)	N/A
BECCS (Electricity)	CCS & GGR	IEA (2023)	N/A
BECCS (Hydrogen)	Hydrogen	IEA (2023) CCC (2020)	IEA (2023) forecasts global hydrogen consumption. The CCC (2020) forecast that, in the UK, biomass will power 13% of hydrogen production by 2050. In absence of better data, it is assumed that the British share is representative of the sector globally.
BECCS (Fischer-Tropsch)	Biomass	IEA (2023) IEA (2019) Sustainable Aviation (2020)	IEA (2023) forecast that global aviation fuel use will reach 15,000 PJ by 2050 in a Net Zero 2050 scenario and EINA (2019) forecast that, of this, around 28% will be sustainable aviation fuel (SAF) in 2050 (extrapolating between 2040 and 2050). Of this 28%, Sustainable Aviation (2020) forecast that Fischer Tropsch synthesis will account for around 5.5% all SAFs produced.
Direct air carbon capture and storage (DACCS)	CCS & GGR	IEA (2023)	N/A
Geological storage	CCS & GGR	IEA (2022)	N/A
Electrolysis	Hydrogen	DNV (2022)	N/A
Autothermal reforming (AR)	Hydrogen	DNV (2022) DNV (2023)	DNV (2023) forecasts hydrogen production through fossil fuels + CCS. DNV (2022) forecasts the share of this hydrogen production through fossil fuels + CCS will be methane reforming.
Hydrogen transmission & transport	Hydrogen	It was not possible to identify forecasts of international deployment for this technology.	
Hydrogen Turbine (OCGT & CCGT)	Hydrogen	IEA (2023)	N/A
Batteries (4hrs)	Storage	IEA (2024) NESO (2023)	IEA (2024) forecasts global deployment of battery storage capacity. To estimate

			the share of that total battery storage which is 'medium term' battery storage (4hr), the National Energy System Operator's (NESO's) Future Energy Scenario (FES) 2023 estimate for the proportion of total short and medium term storage (liquid air, compressed air and battery storage) which is expected to be medium term in the 'leading the way' scenario is used as a proxy.
Compressed air energy storage	Storage	IEA (2024)	IEA (2024) forecasts the global deployment of 'other storage' capacity. It is assumed that this is representative of the level of CAES deployment by 2030. It is assumed that global deployment grows to 50GW by 2050. In absence of published forecasts for deployment post-2030, the 2050 estimate relies on the judgement of sectoral experts.
Long term hydrogen storage (Depleted gas fields & salt caverns)	Storage	IEA (2023) Hydrogen UK (2022)	IEA (2023) forecasts the capacity of underground hydrogen storage. Hydrogen UK (2022) estimates that, of the theoretical underground hydrogen storage capacity in the UK, approximately 85% is in the form of salt caverns and depleted gas fields. In absence of better data, it is assumed that this distribution can also be applied to global underground hydrogen storage.

Forecasts for international technology costs were more challenging to identify in the literature and so for many EINAs 2.0 technologies, it was necessary to use technology costs in the UK (as estimated by the systems modelling) as a proxy for international costs as well. Table 13 below reports the sources for all the technologies where data was identified in the literature.

Table 13: Sources and data manipulations for international technology cost series

Technology	Calculator	Source(s)	Manipulation(s)
Offshore wind (fixed)	Offshore wind	NREL (2024) Trinomics (2018)	Data for 2005 to 2020 is sourced from Trinomics (2018) - Figure 1-8 using averages for China, Japan & USA. 2018 EUR are converted to 2018 USD and inflated to 2022 USD using the World Bank's GDP deflator series. Data for 2025 to 2050 are sourced from NREL (2024) - moderate scenario. In

			absence of data, LCOE in 2000 & 2005 is set equal to that in 2010.
Offshore wind (floating)	Offshore wind	NREL (2024)	Data for 2030 to 2050 are sourced from NREL (2024) - moderate scenario. In absence of data, pre-2030 LCOE is assumed to be at the level of 2030.
Tidal stream	Tidal	OES (2023) Coles et al. (2021)	Data for 2025 onwards is sourced from OES (2023) - Figure 2.2. For the period 2010 to 2020, data is backcast using learning rates for tidal stream in the UK in figure 6 of Coles et al. (2021).
Direct air carbon capture and storage (DACCS)	CCS & GGR	IEAGHG (2021)	Short term (2030) and long term (2050) costs sourced from Page 15 & 16 of IEAGHG (2021). The intervening years are interpolated. Electric 100kt used for 2030 and electric 1Mt absorbent used for 2050. Solid NOAK in both cases. Excluding energy and T&S costs.
Electrolysis	Hydrogen	DNV (2022) IEA (2023) IEA (2022)	Costs per kg H2 produced by electrolyser type are sourced from Figure 5.4 of DNV (2022). Figure 3.7 in IEA (2023) provides an estimate for the distribution of electrolysers types in 2030. It is assumed this is constant over time. Combining these series provides a weighted average cost per kg H2 over time. Intervening years are interpolated. Total costs are adjusted to remove energy costs (in line with approach to UK TIMES modelling outputs) using page 93 of IEA (2022) - share of total costs which are energy for European offshore wind powered electrolysis. (3/4.4 = 68%). This share is assumed to be constant over time.
Autothermal reforming (AR)	Hydrogen	DNV (2022) Hydrogen Europe (2024)	Costs per kg H2 produced is sourced from Figure 5.4 of DNV (2022) - methane reforming with CCS. Intervening years are interpolated. Total costs are adjusted to remove energy costs (in line with approach to UK TIMES modelling outputs) using page Figure 2.4 of Hydrogen Europe (2024) - share of total costs which are energy + feedstock (2.5/4 = 63%). This share is assumed to be constant over time.

Appendix 2: Market share assumptions

The share of future EINAs 2.0 technology markets which will be captured by UK-based firms is challenging to forecast with a high degree of certainty. In the EINAs calculators, estimates relied on the best available evidence at the time of the analysis. However, the calculators are designed such that this input can be replaced should better evidence become available in the future. There are two principal methodologies used for developing market share assumptions for most technologies.

Ricardo (2024) methodology

For most technologies, the methodology used for this adjustment is anchored by outputs from the Ricardo 2024 report “Research to quantify the economic opportunities for the UK as a result of the global energy transition” commissioned by DESNZ.

The technology groups which apply the Ricardo methodology are offshore wind, tidal, storage, heat pumps, biomass, hydrogen and CCS & GGR.

In these cases, the Ricardo report sets out calculator level projections for UK share of a) its domestic market and b) the global market. These calculator level projections are combined with component-level trade data and, where necessary, additional assumptions to generate component-level projections for UK market share.

For most technologies, where no alternative evidence is available, it is assumed that 100% of operations, maintenance and installation activities are conducted by domestic firms.

Alternative methodology

Export market

For technologies not covered by the Ricardo (2024) report, a few adjustments to the central methodology are applied. The principal difference is that the calculation needs to make an additional adjustment which is the conversion of the UK’s export market share (based on trade data) to the UK’s share of the global market. This conversion necessitates an assumption to be made around the percentage of a given market which is traded (as opposed to being serviced by domestic firms).

% of market traded[30]: The data on global deployment used as an input to the calculators refers to the total deployment, with no consideration for how much of the economic activity associated with that deployment will be imported. Where the estimates sourced from the literature (or trade data) are shares of the export market as opposed to the share of the total global market, an adjustment needs to be made to account for the fact that only a portion of the

[30] In EINAs 1.0 this assumption was referred to as 'tradability'.

total market will be traded. For example, the deployment of 10 GW of a power generation technology in China might be associated with a turnover of £10 billion. However, if Chinese firms service 50% of this market, then, only £5 billion of that market will actually be captured in trade data. The estimate of the UK's share of the export market is their share of this £5 billion turnover as opposed to the £10 billion turnover.

In most cases where there are no Ricardo (2024) estimates, the methodology for estimating market share relies on current trade data. This trade data provides an estimate for the UK's share of the export market and so, the adjustment from total market size to the UK's share of the market is as follows:

1. Total market size (£) * % traded (%) = Size of traded market (£)
2. Size of traded market (£) * UK's market share (%) = Market captured by the UK (£)

In the few instances where the % of market traded assumption is required in EINAs 2.0, the values used are those from EINAs 1.0. EINAs 1.0 assumptions on how the UK's current market share (as determined by trade data) will develop over time are also applied.

Technology groups which use this approach to export market shares are nuclear and insulation technologies.

Domestic market

For technologies where there is no Ricardo estimate for UK firms' share of the domestic market two approaches were taken to fill this data gap.

For nuclear and insulation technologies, the classification of the technologies in these was deemed sufficiently similar to that in EINAs 1.0 such that the approach taken to domestic market shares in EINAs 1.0 could be applied again. In these cases, market share is largely based on sector expert opinion and historical trends.

For networks and industry technologies, an estimate of UK firms' share of the relevant domestic market was estimated by combining ONS PRODCOM data on UK firms' production with COMTRADE trade data on imports and exports. This approach was used because it was deemed that there was no evidence from EINAs 1.0 which could be used for these technology

groups given that networks is a new area in EINAs 2.0 and the classification of industry technologies is substantially different in EINAs 2.0 relative to EINAs 1.0.

$$UK\ firms'market\ share = \frac{Domestic\ production - exports}{Domestic\ production + imports - exports}$$

Technology level market shares

Outcomes of the two methodologies for developing market share assumptions are set out in the table below. The table displays this analysis' assumptions of UK firms' market share of the domestic and global markets at the technology level for all technologies included in the business opportunities calculators in 2025, 2035 and 2050. For network and industry technologies, it was not possible to estimate the size of the global market and so no global market share assumptions were made.

Technology	Domestic market share (%)			Global market share (%)		
	2025	**2035**	**2050**	**2025**	**2035**	**2050**
Fixed offshore wind	46%	46%	46%	3.6%	3.6%	3.6%
Floating offshore wind	42%	42%	42%	3.6%	3.6%	3.6%
Tidal stream	70%	72%	75%	1.5%	1.2%	0.8%
High-Temperature Gas Reactors	75%	79%	86%	0.7%	0.9%	1.2%
Small Modular Reactors	75%	79%	86%	0.7%	0.9%	1.2%
CCS (Power)	78%	75%	72%	0.9%	0.9%	0.9%
BECCS (electricity)	78%	75%	72%	0.9%	0.9%	0.9%
DACCS	82%	80%	77%	0.7%	0.7%	0.7%
Geological storage	65%	60%	55%	1.4%	1.4%	1.4%
Insulation - Roof	89%	89%	89%	0.9%	1.0%	1.0%
Insulation - Wall	89%	89%	89%	0.9%	1.0%	1.0%
Insulation - Floor	89%	89%	89%	0.9%	1.0%	1.0%
ASHP	85%	84%	84%	0.2%	0.2%	0.2%
GSHP	87%	85%	85%	0.2%	0.2%	0.2%
WSHP	88%	87%	87%	0.2%	0.2%	0.2%
Electrolysis	48%	58%	70%	0.1%	0.1%	0.1%
Autothermal reforming	64%	71%	79%	0.1%	0.1%	0.1%
BECCS (hydrogen)	52%	55%	60%	0.1%	0.1%	0.1%
Hydrogen transmission/transport	51%	64%	80%	0.2%	0.1%	0.1%
Hydrogen turbine (OCGT & CCGT)	43%	47%	52%	0.1%	0.1%	0.1%
BECCS (Fischer-Tropsch)	68%	79%	93%	0.1%	0.1%	0.1%
Battery (4hrs)	27%	27%	27%	0.1%	0.1%	0.1%
CAES (24hrs)	24%	24%	24%	0.1%	0.1%	0.1%
Hydrogen storage (DGFS & salt caverns)	67%	73%	80%	0.1%	0.0%	0.0%
Dynamic Line Rating	70%	70%	70%			
High-Temperature Superconducting cables	90%	90%	90%			
D-suite solutions	85%	85%	85%			
Furnaces and kilns CCS (industry)	62%	62%	62%			
Furnaces and kilns Greenfield (industry)	59%	59%	59%			
Furnaces and kilns Retrofit (industry)	59%	59%	59%			
Steam production and distribution Boiler (industry)	54%	54%	54%			

Technology	Domestic market share (%)			Global market share (%)		
Steam production and distribution CHP (industry)	69%	69%	69%			
Steam production and distribution Heat Pump (industry)	16%	16%	16%			
Steam production and distribution Retrofit (industry)	55%	55%	55%			
Waste heat recovery and/or re-use (industry)	48%	48%	48%			
Bioprocessing and catalysts (industry)	92%	92%	92%			
Food processing machinery (industry)	70%	70%	70%			
Industrial control equipment (industry)	63%	63%	63%			
Machinery for processing stones, ceramics, cement (industry)	52%	52%	52%			
Paper-making machinery (industry)	57%	57%	57%			
Pumps, compressors, motors (industry)	68%	68%	68%			
Drying (industry)	68%	68%	68%			
Cracking (industry)	78%	78%	78%			
Miscellaneous (industry)	63%	63%	63%			
Hydrogen Production (industry)	70%	70%	70%			

Appendix 3: Core GVA/job modelling assumptions

Assumption	Explanation
Productivity growth is assumed to be captured in reduced unit costs rather than through an increase in GVA per worker. GVA per worker is assumed to be constant over time.	Some degree of productivity growth is captured in the assumptions around labour costs used to determine the forecasts of unit costs and so, including an increase in GVA per worker as well risks double counting.
The GVA to turnover ratio, GVA per worker, ratio of direct to indirect jobs and distribution of jobs by occupation for the 4-digit SIC code matched with the cost component is representative of the activities which make up the cost component.	There aren't data on these variables for the cost components which make up the technologies covered in this analysis. In the absence of this data, the SIC-code matching approach is deemed as a pragmatic approach which takes data from sectors of the UK economy which are as comparable with the activities in question as possible.
It is assumed that the useful economic lifetime of each technology is constant over time.	There isn't a sufficiently strong evidence base to forecast how useful economic lifetimes will evolve by 2050 and so this simplifying assumption was made.
Within a given SIC code, the proportion of jobs accounted for by different occupations is assumed to be constant over time.	This is a simplifying assumption in absence of forecasts for this distribution.
The GVA/turnover ratio is assumed to be constant over time.	This is a simplifying assumption in absence of forecasts for this measure.
Cost reductions from innovation are shared pro-rata across cost components (this implies that the breakdown of costs by cost component is constant over time).	This is a simplifying assumption in absence of cost-component-specific cost forecasts.
Only one SIC-code and one HS-code are matched to each cost component.	Using multiple SIC or HS codes per component could help ensure that a broader range of activities related to a given cost component are captured. However, this approach also risks including activities that are not directly relevant. To enhance transparency, it was considered preferable to use only the single SIC and HS code (where applicable) deemed most relevant to each cost component.

Appendix 4: Discounted present values

Each technology has a cost profile which sets out how the aggregate technology costs are phased over time relative to the year of deployment. CAPEX costs are typically met in the 5-year period leading up to deployment, OPEX costs are met from the point of deployment until the end of the asset's useful economic life and then decommissioning costs (where relevant) are typically met in the 5-year period following the end of the asset's economic lifetime.

The cost per unit series used as an input to the calculators are levelised costs. They represent the discounted stream of CAPEX, OPEX, decommissioning costs and any other costs associated with the deployment of a technology. However, the calculator aims to understand the undiscounted economic activity, and the associated supported employment, in the year that those activities are taking place. For example, it seeks to understand the economic activity - and hence supported employment - with asset decommissioning in the years that this decommissioning happens; this cannot be computed directly from the discounted value of decommissioning costs measured at the point that the asset is deployed.

To address this, the levelised costs are converted into an undiscounted value in the year in which the cost is borne (relative to the deployment year) and spread across the periods of time for which these costs will be incurred. This adjustment uses the technology-specific discount rate.

As an illustrative example, for a technology with a 5% discount rate, a 25-year useful economic lifetime and where 30% of the levelised costs are OPEX costs, the undiscounted OPEX costs in the years in which they are borne would be calculated as follows:

- The modelling periods in the calculators are 5-year intervals and so, a 5% discount rate over a 5-year period is equivalent to a compounded rate of (1.05^5 – 1) = 28% per 5-year interval.
- OPEX can be characterised as an annuity and the formula for the present value of an annuity is:
- $PV = Annuity[\left(1 - \left[\frac{1}{(1+r)^n}\right]\right) * r^{-1}]$ where PV is the present value, annuity is the value of the annuity, r is the discount rate and n is the number of periods.
- Rearranged this gives $Annuity = \frac{(PV*r)}{(1-[1/(1+r)^n])}$. Applying this formula to the example; $Annuity = \frac{(30\%*0.28)}{(1-[1/(1.28)^5])} = 11.8\%$.

Appendix 5: Occupation categories

There are 412 4-digit SOC codes in the SOCC 2022 framework (available here). These 412 codes were aggregated to 15 bespoke SOC groupings for this analysis. The 15 SOC groupings are a mix of SOC 1-digit, 2-digit and 3-digit codes. 3-digit (more granular) codes are used for more relevant occupations to the EINAs calculators and 1-digit (more aggregated) codes are used for less relevant occupations.

In the language of the SOC 2022 framework, the major, sub-major and minor SOC code groups covered by the 15 bespoke aggregated groupings are set out in the table below.

Table 14: Occupation categories

Heading	Major / sub-major group	Sub-major/minor groups included
Managers, directors and senior officials	1	All
Science, research, engineering and technology professionals	21	All
Other professional occupations	2x	22, 23, 24
Science, engineering and technology associate professionals	31	All
Other associate professional occupations	3x	32, 33, 34, 35
Administrative and secretarial occupations	4	All
Skilled metal trades	52xi	521, 522
Skilled electrical and electronic trades	52xii	524, 525
Skilled construction and building trades	53	All
Other skilled trade occupations	5x	51, 54, 523
Caring, leisure and other service occupations	6	All
Sales and customer service occupations	7	All
Process, plant and machine operatives	81	All
Transport and mobile machine drivers and operatives	82	All
Elementary occupations	9	All

Appendix 6: Component to SIC and HS code matches

Each of the cost components which is defined as making up a technology included in this analysis is assigned a 4-digit SIC code. HS codes are only assigned to components which are defined as ‘goods-based’ components (i.e. manufacturing) as trade data by HS codes is only available for products and not services. Service-based components (i.e. installation) are not assigned HS codes.

Technology	Component	4-digit SIC-code	HS-code
Fixed offshore wind	Turbine	2811	850231
	Foundations	2511	730820
	Installation	7112	
	Balance of system	2712	853720
	Decommissioning	7112	
	Operations and maintenance	3511	
Floating offshore wind	Turbine	2811	850231
	Foundations, moorings & anchors	2511	730820
	Installation	7112	
	Balance of system	2712	853720
	Decommissioning	7112	
	Operations and maintenance	3511	
Tidal stream	Turbine	2811	8410
	Foundations and moorings	2511	730820
	Connection	2711	850423
	Installation	7112	
	Operations and maintenance	3511	
High-Temperature Gas Reactors	Front end fuel cycle	2440	8401
	CAPEX Construction	4220	8401
	CAPEX Component Manufacturing	2530	8401
	CAPEX Materials	2300	2845
	O&M	3511	
	Decommissioning	3900	
	Waste management	3900	
Small Modular Reactors	Front end fuel cycle	2440	8401
	CAPEX Construction	4220	8401
	CAPEX Component Manufacturing	2530	8401
	CAPEX Materials	2300	2845
	O&M	3511	
	Decommissioning	3900	
	Waste management	3900	
CCS (Power)	Capex: Owner's costs	7112	
	Capex: Equipment & Construction	4220	841490
	O&M non-fuel	7112	
	Decommissioning	7112	
BECCS (electricity)	Capex: Owner's costs	7112	
	Capex: Equipment & Construction	4220	841490
	O&M non-fuel	7112	

	Decommissioning	7112	
DACCS	Capex	4220	841490
	O&M non-fuel	7112	
	Decommissioning	7112	
Geological storage	Site development (characterisation, permitting, licensing)	910	
	Capex (drilling/re-use wells)	2420	730640
	Leakage liability/insurance	6500	
	O&M (during injection incl. MMV)	910	
	O&M (post closure incl. MMV)	910	
Insulation - Roof	Survey and design	7112	
	Installation (labour)	4320	
	Materials	2399	6806
	Project management (labour)	4320	
	Certification, legal and insurance	6900	
	Repair remedial/ancillary works	7112	
Insulation - Wall	Survey and design	7112	
	Installation (labour)	4320	
	Materials	2399	6806
	Project management (labour)	4320	
	Certification, legal and insurance	6900	
	Repair remedial/ancillary works	7112	
Insulation - Floor	Survey and design	7112	
	Installation (labour)	4320	
	Materials	2399	6806
	Project management (labour)	4320	
	Certification, legal and insurance	6900	
	Repair remedial/ancillary works	7112	
ASHP	Enabling works for retrofit applications	7112	
	Unit cost of heat pump	2825	841861
	External plantroom/ Acoustic attenuation	2825	841861
	Pipework and Ancillary systems	2825	841861
	Installation and Commissioning Cost	4322	
	O&M maintenance	4322	
GSHP	Enabling works for retrofit applications	7112	
	Permitting costs/ Abstraction charges/ Site Testing	7112	
	Unit cost of heat pump	2825	841861
	Pipework and Anciliary systems	2825	841861
	Collector system	2420	841861
	Filtration for open loop	2825	841861
	Installation and Commissioning Cost	4322	
	O&M maintenance	4322	
WSHP	Enabling works for retrofit applications	7112	
	Permitting costs/ Abstraction charges/ Site Testing	7112	
	Unit cost of heat pump	2825	841861
	Pipework and Anciliary systems	2825	841861

	Boreholes (for vertical drilling), ground works / trenching (horizontal closed loop) (excluding contamination)	4312	
	Installation and Commissioning Cost	4322	
	O&M maintenance	4322	
Electrolysis	Capex - Stack	2790	841490
	Capex - balance of power	2712	853720
	O&M non-fuel	7112	
	Decommissioning	7112	
Autothermal reforming	Capex equipment	2530	841490
	Capex construction	4220	
	O&M non-fuel	7112	
	Decommissioning	7112	
BECCS (hydrogen)	Capex: Owner's costs	7112	
	Capex: Equipment and construction	4220	841490
	O&M (Non-fuel)	7112	
	Decommissioning	7112	
Hydrogen transmission/transport	Capex equipment - pipeline	2420	730640
	Capex equipment - compressor	2813	841490
	Capex construction	4220	
	O&M non-fuel	7112	
	Decommissioning	7112	
Hydrogen turbine (OCGT & CCGT)	Capex equipment	2811	850239
	Capex construction	4220	
	O&M non-fuel	7112	
	Decommissioning	7112	
BECCS (Fischer-Tropsch)	Capex: Owner's costs	7112	
	Capex: Equipment and construction	4220	841490
	O&M (Non-fuel)	7112	
	Decommissioning	7112	
Battery (4hrs)	Storage block	2720	850760
	Balance of system	2712	853720
	Power equipment and systems integration	2712	853720
	EPC	7112	
	Grid integration	3510	
	Project development	7112	
	O&M	7112	
	Decommissioning	7112	
CAES (24hrs)	Storage block	2790	731100
	Turbine, Compressor, Balance of Plant & EPC management	2813	841490
	O&M	7112	
Hydrogen storage (DGFS & salt caverns)	Capex equipment - Wells / piping	2420	730640
	Capex equipment - Gas conditioning	2813	841490
	Site preparation	910	
	O&M non-fuel	7112	
	Decommissioning	7112	
Dynamic Line Rating	CAPEX - Hardware	2651	90303

	CAPEX - Installation	7112	
	CAPEX - Software & IT	6310	
	OPEX	7112	
High-Temperature Superconducting cables	CAPEX	2732	854460
	OPEX	7112	
D-suite solutions	CAPEX	2651	90303
	OPEX	6310	
Furnaces and kilns CCS (industry)	CAPEX	2813	841490
	OPEX - Non energy	7112	
Furnaces and kilns Greenfield (industry)	CAPEX	2821	8514
	OPEX - Non energy	7112	
Furnaces and kilns Retrofit (industry)	CAPEX	2821	8514
	OPEX - Non energy	7112	
Steam production and distribution Boiler (industry)	CAPEX	2530	8402
	OPEX - Non energy	7112	
Steam production and distribution CHP (industry)	CAPEX	2530	8402
	OPEX - Non energy	7112	
Steam production and distribution Heat Pump (industry)	Enabling works for retrofit applications	7112	
	Unit cost of heat pump	2825	841861
	External plantroom/ Acoustic attenuation	2825	841861
	Pipework and Ancillary systems	2825	841861
	Installation and Commissioning Cost	4322	
	OPEX - Maintenance	4322	
Steam production and distribution Retrofit (industry)	CAPEX	2530	8402
	OPEX	7112	
Waste heat recovery and/or re-use (industry)	Direct costs (CAPEX)	2825	841950
	Indirect costs (CAPEX)	7112	
	OPEX	7112	
Bioprocessing and catalysts (industry)	CAPEX	2651	9027
	OPEX	7112	
Food processing machinery (industry)	CAPEX	2893	8438
	OPEX	7112	
Industrial control equipment (industry)	CAPEX	2651	9032
	OPEX	7112	
Machinery for processing stones, ceramics, cement (industry)	CAPEX	2849	8464
	OPEX	7112	
Paper-making machinery (industry)	CAPEX	2895	8439
	OPEX	7112	
Pumps, compressors, motors (industry)	CAPEX	2813	841490
	OPEX	7112	
Drying (industry)	CAPEX	2821	8419
	OPEX	7112	
Cracking (industry)	CAPEX	2821	8514
	OPEX	7112	
Miscellaneous (industry)	CAPEX	2800	9032
	OPEX	7112	

Hydrogen Production (industry)	CAPEX	2829	841989
	OPEX	7112	

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